S. HRG. 113–749

NATURAL RESOURCE ADAPTATION: PROTECTING ECOSYSTEMS AND ECONOMIES

HEARING

BEFORE THE

SUBCOMMITTEE ON OVERSIGHT

OF THE

COMMITTEE ON
ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

FEBRUARY 25, 2014

Printed for the use of the Committee on Environment and Public Works

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NATURAL RESOURCE ADAPTATION: PROTECTING ECOSYSTEMS AND ECONOMIES

TUESDAY, FEBRUARY 25, 2014

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON OVERSIGHT,
Washington, DC.

The subcommittee met, pursuant to notice, at 2:30 p.m. in room 406, Dirksen Senate Building, Hon. Sheldon Whitehouse (chairman of the subcommittee) presiding.

Present: Senators Whitehouse, Markey, Inhofe, Vitter, Sessions.

OPENING STATEMENT OF HON. SHELDON WHITEHOUSE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator WHITEHOUSE. The distinguished ranking member is on his way, so I will open with my opening statement.

First of all, we will call the hearing to order and I will open with my opening statement. Then when Senator Inhofe arrives, if he is here at the conclusion of my opening remarks, he can give his. If not, I will interrupt the witness and allow whoever is speaking at the time to yield to my distinguished ranking member.

We are here today for the committee to discuss the benefits that our American natural resources provide to us and the need for adaptation planning to protect these American resources in the face of climate change. I have been proud to work on this issue in recent years with former Senator Max Baucus. While Max is no longer here in the Senate, I am glad that this committee is meeting today to carry on this important work. From the beaches of Rhode Island to the glaciers of Montana, nature's bounty provides us with life's essentials: clean air and water, crops and timber, recreation and our outdoor heritage. Climate change threatens to rob us of these essentials.

I have gone to the Senate floor now nearly 60 times to urge my colleagues to wake up to the facts of carbon pollution. But the fact of the matter is that even if we stop carbon pollution today, we still face decades of change in our air and water and temperatures and in extreme weather.

So while we must take up the challenge to reduce greenhouse gas emissions, we must also begin to prepare and adapt and secure our natural resources against the changes that we cannot avoid. Status quo management and planning will not be good enough. A GAO report on the topic, citing several sources, says "Natural resource management has historically been based on the idea of maintaining current environmental conditions, or restoring species and habitats to some desired former condition. As the climate continues to change," GAO concludes, "this approach will become increasingly more difficult, if not impossible to maintain."

But adaptation to warming air and ocean temperatures to catastrophic weather events, even to full ecosystem shifts, isn't easy work. And the Federal, State and local leaders we entrust to protect our property and our ecosystems are often constrained by outdated laws and regulations.

That is why Senator Baucus and I introduced the Safeguard America's Future and the Environment Act, the SAFE Act, for short. It puts all climate adaptation tools and approaches on the table and would engage local stakeholders as well. As a first step, the SAFE Act requires adaptation planning and management efforts by Federal natural resources agencies, those that manage nearly 30 percent of land in the United States, as well as our marine resources, like fisheries, and our exclusive economic zone that extends 200 miles from our shore.

The Administration is already doing what it can on this front. The President's climate action plan includes steps to prepare us for the effects of climate change. And he further focused the Administration's adaptation efforts in an executive order he issued in November. John Holdren, the Director of the White House Office of Science and Technology Policy, is here to update us on these efforts, as well as the science behind what we are seeing and why strategic adaptation planning is so necessary in the face of climate change.

The executive order builds on the first national fish, wildlife and plants adaptation strategy which Congress requested in 2009 and the Administration released last March. I look forward to hearing from Fish and Wildlife Service Director Dan Ashe about implementation plans for the strategy as well as other adaptation measures being championed by the Service.

I would also like to thank the witnesses on our second panel who will provide much-needed perspective on what is happening outside of Washington. In particular, I want to recognize Chris Brown, President of the Rhode Island Commercial Fishermen's Association. Chris's livelihood depends on the oceans. Sadly, our oceans are becoming ground zero for damage from carbon pollution. The oceans are warming. That is a measurement, not a theory. Sea level is rising. That is another measurement. Oceans are becoming more acidic. Again, a measurement, not a theory.

These changes are already affecting marine life. Some species are moving northward and southward toward the colder water of the poles, as quickly as 10 to 45 miles per decade. Events that are timed for spring or summer, like egg-laying or migration, are happening several days earlier each decade. More acidic waters caused a 70 to 80 percent loss of oyster larvae at a hatchery in Oregon and crashed wildstocks in Washington State.

In Rhode Island, Narragansett Bay has seen an overall increase in annual water temperature of between 3 and 4 degrees since 1960. According to Christopher Deacutis, the previous chief scientist of the Narragansett Bay estuary program, "Fish species in Narragansett Bay are shifting, seemingly in step with increased temperatures." UI Professor Jeremy Colley and others have shown that coldwater marine species such as the winter flounder, which used to be the dominant fish species in the Bay, are radically decreasing in numbers. Meanwhile, warmer water species such as summer flounder, scup and butterfish seem to be increasing. As fish species shift, either farther north or farther offshore, our fisheries management strategies are going to have to keep up and so is our science. We need to understand how environmental conditions are changing to better predict how species will react and how to manage them for the benefit of our fishermen.

I am grateful that Chris is here to remind us that in addition to our national parks, forests and land species, our oceans and coasts and fisheries and the economies they support are also jeopardized by climate change. We must prepare for the changes that are coming and as well do everything we can to prevent future changes from carbon pollution.

I look forward to today's discussion, and before we turn to the witnesses, let me turn to our distinguished ranking member.

[The prepared statement of Senator Whitehouse follows:]

STATEMENT OF HON. SHELDON WHITEHOUSE, U.S SENATOR FROM THE STATE OF RHODE ISLAND

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I've gone to the Senate floor now nearly 60 times to plead with my colleagues to wake up to the facts of carbon pollution. The fact of the matter is that even if we stop carbon pollution today, we still face decades of changes in air and ocean temperatures and extreme weather. So while we must take up the challenge to reduce greenhouse gas emissions, we must also begin to adapt, and secure our natural resources against the changes we cannot avoid.

Status quo management and planning will not be good enough. A GAO report on the topic, citing several sources, says, "natural resource management has historically been based on the idea of maintaining current environmental conditions or restoring species and habitats to some desired former condition. As the climate continues to change, this approach will become increasingly more difficult if not impossible to maintain. "

But adaptation—to warming air and ocean temperatures, to catastrophic weather events, even to full ecosystem shifts—isn't easy work, and the Federal, State and local leaders we entrust to protect our property and our ecosystems are often constrained by outdated laws and regulations. That's why Senator Baucus and I introduced the Safeguarding America's Future and the Environment Act. The SAFE Act, for short, puts all climate adaptation tools and approaches on the table, and would engage local stakeholders as well.

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"Fish species in Narragansett Bay are . . . shifting, seemingly in step with increased temperatures. [URI Professor] Jeremy Collie and others have shown that cold-water marine species such as the winter flounder, which used to be the dominant fish species in the bay, are radically decreasing in numbers. Meanwhile, warmer-water species such as summer flounder, scup and butterfish seem to be increasing."

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I look forward to today's discussion.

OPENING STATEMENT OF HON. JAMES M. INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Senator INHOFE. Thank you, Mr. Chairman. I don't agree, but let's——

Senator WHITEHOUSE. You weren't expected to.

[Laughter.]

Senator INHOFE. Last month during the hearing on the climate action plan, I spent the bulk of my time raising concerns about the Environmental Protection Agency's rollout of its greenhouse gas regulations, which I found to be alarmingly hypocritical. On the one hand, the Administration says these regulations are urgently needed. On the other hand, the EPA intentionally delayed the rule's publication to prevent it from being implemented prior to the mid-term elections this fall. This is kind of reminiscent of the last elections that we had.

Does anyone other than me care that fewer, and I understand, and I say to my good friend, and we are good friends, that while I don't agree on this, neither do the majority of the people in the U.S. Senate or in the House. Because they can't get more than 35 votes, is all you can get today, a bill to legislatively allow the EPA to regulate greenhouse gases. We know this is true, we have been there before. So now they are trying to do what they couldn't do with legislation through regulation. And the cost of these is pretty alarming.

Now, what is more concerning is that there is similar behavior taking place across the government, including the Fish and Wildlife

Service, the bald eagle, the Golden Eagle Protection Act passed in 1940, and it protects our national bird from hunting, poaching and other activities that could harm it. The Act states that without a permit, it is illegal to take, possess or sell or purchase any bald eagle. Wind turbines, with their massive blades, kill an estimated 1.4 million birds a year as the turbines spin through the air. Some of these casualties have been protected birds like the bald eagle.

Federal law stipulates that the illegal killing of bald eagles be punished with fines and/or jail sentences. But this won't be the case for the wind industry. On December 6th of 2013, the Administration said that it would begin granting waivers to wind farm operators so that they would be able to kill bald eagles for a period of 30 years without fear of any retribution. That is pretty shocking.

While I am not particularly bothered by the fact that permits are being offered, I am extremely concerned by the systematic practices of this Administration to use its powers to help its friends in renewable energy, while punishing its enemies developing traditional fossil fuels. Other species receive similar protections to the bald eagle under the Endangered Species Act. One covered species is the American burrowing beetle, many of which are located in eastern Oklahoma. For the past 2 years, eastern Oklahoma has been without a general conservation plan making it illegal to engage in nearly all activities that could disturb the ABB.

Despite repeated attempts by my office, the State of Oklahoma and dozens of private entities, we have not managed to get anything out of the Service. This is a big deal, because many companies are planning to build new neighborhoods, develop new oil and gas wells and construct new pipelines, but because of the GCP, its effect is not final, they can't do it. When this is compared to the new permits the Service may offer the wind industry, I can't think but that this is a startling double standard.

Justice is supposed to be blind. Treatment of different industries is supposed to be equal under the law, including the energy industry. And while the President says that he has an all of the above energy strategy, evidence shows whether the EPA or the Fish and Wildlife Service, that its real strategy is focused primarily on restricting traditional fossil fuels while assisting the development of renewables.

This favoritism also extends to the way the government thinks about the adaptability of our Nation to changing circumstances. Renewable energy requires massive amounts of land to make very small quantities of power. But the government seems to ignore this fact. One recently constructed solar farm takes up five square miles but only makes enough electricity to power 140,000 homes. By contrast, a typical natural gas powered plant may in total take up only half of a square mile, but can generate enough power to support over a million homes.

So despite the true impacts of renewables on the environment, the Administration continues to turn a blind eye to them. It is my hope that during this hearing we will be able to uncover some of the facts and provide a better framework for comparing the relative benefits and costs of the different forms of energy.

Again, I would just repeat what I said earlier, ever since the Kyoto Treaty, I say to our Chairman, we have gone through this thing. I can recall the first bill to be introduced was not really a Democrat bill, it was the McCain-Lieberman bill. It was soundly defeated, and this was 12 years ago. There have been several others, one by a new member of this committee that I am sure will be here, my very good friend from Massachusetts. And they have not been able to get enough votes to even get a third of the vote out of the Senate and less than a third in the House.

So there is something wrong with the system, I say to my chairman, that we are able to go ahead and do through regulation what they have tried over and over again for 12 years to get through legislation unsuccessfully.

Thank you, Mr. Chairman.

[The prepared statement of Senator Inhofe follows:]

STATEMENT OF HON. JAMES M. INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Mr. Chairman, thank you for holding this hearing today. It is important for us to conduct oversight on all aspects of the President's Climate Action Plan to uncover the impact it will have on our Nation.

Last month, during a hearing on the Climate Action Plan, I spent the bulk of my time raising concerns with the Environmental Protection Agency's rollout of its greenhouse gas regulations, which I found to be alarmingly hypocritical. On the one hand, the Administration says these regulations are urgently needed; on the other, the EPA intentionally delayed the rule's publication to prevent it from being implemented prior to the midterm elections this fall.

And does anyone other than me care that fewer than 35 percent of the members of either the House or the Senate would even vote in favor of legislation granting EPA the authority to regulate greenhouse gases? And yet we continue to spend countless time debating the issue.

This is alarming, but what's more concerning is that I see similar behavior taking place across the government, including at the Fish and Wildlife Service.

The Bald Eagle and Golden Eagle Protection Act, passed in 1940, protects our national bird from hunting, poaching, and other activities that could harm it. The act states that without a permit, it is illegal to "take, possess, sell, [or] purchase" any bald eagle.

Wind turbines, with their massive blades, kill an estimated 1.4 million birds per year as their turbines spin through the air. Some of these casualties have been protected birds like the bald eagle.

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Other species receive similar protections to the Bald Eagle under the Endangered Species Act. One covered species is the American Burying Beetle (ABB), many of which are located in Eastern Oklahoma.

For the past 2 years, Eastern Oklahoma has been without a General Conservation Plan, making it illegal to engage in nearly all activities that could disturb the ABB.

Despite repeated attempts by my office, the State of Oklahoma, and dozens of private entities, we have not managed to get anything out of the Service. This is a big deal because many companies are planning to build new neighborhoods, develop new oil and gas wells, and construct new pipelines, but because the GCP is not final, they cannot do it.

When this is compared to the new permits the Service may offer wind industry, I can't help but think this is a startling double standard.

Justice is supposed to be blind. Treatment of different industries is supposed to be equal under the law, including the energy industry. And while the President says that he has an all-of-the-above energy strategy, evidence shows—whether at EPA or the Fish and Wildlife Service—that his real strategy is focused primarily on restricting traditional fossil fuels while assisting the development of renewables.

This favoritism also extends to the way the government thinks about the adaptability of our nation to changing circumstances. Renewable energy requires massive amounts of land to make very small quantities of power, but the government seems to ignore this fact. One recently constructed solar farm takes up 5 square miles but only makes enough electricity to power 140,000 homes. By contrast, a typical natural gas power plant may, in total, take up only a half square mile but can generate enough power to support over one million homes.

Despite the true impacts of renewables on the environment, the Administration continues to turn a blind eye to them. It's my hope that during this hearing, we'll be able to uncover some of these facts and provide a better framework for comparing the relative benefits and costs of different forms of energy.

Senator WHITEHOUSE. Always glad to hear from the ranking member. Some would say that the problem is the problem with Congress. That is one that elections will cure, with any luck.

Senator INHOFE. I do agree with that.

Senator WHITEHOUSE. Now we have Dr. Holdren, who is the Assistant to the President for Science and Technology and the Director of the White House Office of Science and Technology Policy. He is also the co-chair of the President's Council of Advisors on Science and Technology.

He has served previously as a member of the President's Council of Advisors on Science and Technology during the Clinton administration and also chaired studies for President Clinton on preventing theft of nuclear materials, disposition of surplus weapon plutonium, the prospects of fusion energy, U.S. energy R&D strategy and international cooperation on energy technology innovation. He holds advanced degrees in aerospace engineering and theoretical plasma physics—hurts my head just to say that—from MIT and Stanford.

Dr. Holdren, welcome and thank you. Then we will turn to Mr. Ashe.

STATEMENT OF HON. JOHN P. HOLDREN, PH.D., DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT

Mr. HOLDREN. Thank you, Chairman Whitehouse, Ranking Member Inhofe. I am certainly pleased to be here today to discuss with you the Federal Government's ongoing work to inform and support climate change preparedness and resilience in communities across America.

Few environmental factors affect our Nation's economy, communities and ecosystems more than weather and climate. Severe weather and climate change poses important risks to human health, safety, livelihoods and property. In 2012 alone, the National Oceanic and Atmospheric Administration's National Climate Data Center identified 11 weather-related events in the United States that each resulted in losses exceeding a billion dollars, totaling $110 billion in damages and 377 deaths across the entire year.

And we are all acutely aware that the severe drought currently afflicting California and other areas of the southwest is having important impacts on agriculture, ranching, water resource management and other critical sectors of the region's economy.

Scientifically, one cannot say that any single episode of extreme weather, no storm, no flood, no drought, was caused by climate change. What scientists can say is that global climate has been so extensively impacted by the human-caused buildup of greenhouse gases that many such events are being influenced by climate change. Any effective effort to boost climate preparedness will require anticipating and planning for changes in the frequency, intensity and locations of some kinds of extreme weather and climate events as well as for other changes, such as the continuing rise of sea level.

Strengthening America's climate resilience also requires a full understanding of how climate change is affecting the health of our environment and natural resources and what can be done to plan and prepared for such changes. As you pointed out in your opening statement, Senator Whitehouse, ecosystems provide a range of important benefits to people, including protection of coastal areas, clean drinking water and opportunities for commerce, tourism and recreation.

Some of the Nation's ecosystems have been depleted or degraded due to non-climatic factors, pollution, over-harvesting, changes in land use, that have reduced the ability of these systems to provide benefits to people. But these benefits are further threatened by climate change, the impacts of which include widespread changes in the Nation's habitats and ecosystems. Certain commercial fish species are moving northward along the east coast as waters warm. The timing of some biological events, such as flowering and migration, is shifting in regions across the Country. Decreases in rainfall and snow pack in the west are reducing the health and productivity of forests and agricultural systems alike.

The President's climate action plan, released last June, provides a roadmap for Federal action to meet the pressing challenges that come with climate change, including concrete actions that can be taken to boost the resilience and preparedness of American communities. These actions build on work already completed or underway, including a number of Federal interagency climate adaptation strategies related to freshwater resources, fish, wildlife and plants and marine resources.

The plan also recognizes the need to ensure that the best science, research, data, tools and technologies are brought to bear in implementing all climate preparedness and resilience efforts. The White House Office of Science and Technology Policy is working with partners within and outside government to meet this challenge and to meet the growing demand among decisionmakers on the ground for accessible and actionable information to inform their efforts to plan and prepare for climate change.

I thank the committee for its support and interest in this issue, and I look forward to continuing to work with you. I will be pleased to take any questions that you may have.

[The prepared statement of Dr. Holdren follows:]

Statement of Dr. John P. Holdren
Director, Office of Science and Technology Policy
Executive Office of the President of the United States
to the
Oversight Subcommittee
of the
Committee on Environment and Public Works
United States Senate
on
February 25, 2014

Chairman Whitehouse, Ranking Member Inhofe, and Members of the Subcommittee, I am pleased to be here with you today to discuss the efforts of the Federal Government to inform and support climate preparedness and resilience across the Nation.

Few environmental factors affect our economy, livelihoods, and ecosystems more than weather and climate. Severe weather, climatic extremes, and climate change pose risks to human health, safety, and property. In 2012, the National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center identified eleven weather or climate events that each resulted in losses exceeding $1 billion in the U.S., totaling $110 billion in damages and 377 deaths across the entire year. The damage caused by Hurricane/Post-tropical Cyclone Sandy (Sandy) alone was estimated at over $65 billion, and damages from drought in 2012 totaled approximately $30 billion. The severe drought currently affecting California and other areas of the Southwest is impacting critical economic sectors, such as agriculture, ranching, and water resource management.

People and property have always been vulnerable to extreme events, but recent trends are making many of those vulnerabilities worse. Sea-level rise is increasing the height of storm surge that hits coastal communities during hurricanes. More frequent episodes of extreme heat are leading to increased vulnerability to heat stroke and deaths; the very young, the very old, the sick, and the poor are particularly vulnerable. Disruption and failure of critical transportation, energy, and telecommunications infrastructure is occurring due to extreme heat and severe storms. Wildfires in the American West, while subject to much year-to-year variability, are on a long-term upward trend, imperiling homes, businesses, and forests already weakened by drought and outbreaks of pine bark beetles that also are related to climate.

Scientifically, one cannot say that any single episode of extreme weather—no storm, no flood, no drought—was caused by climate change; but the global climate has been so extensively impacted by the human-caused buildup of greenhouse gases that many such events are being influenced by climate change. Effective climate-preparedness efforts will require anticipating and planning for changes in the frequency, intensity, and locations of some kinds of extreme events, as well as for more gradual changes such as the continuing rise of sea level and movement of the geographic ranges of pests and pathogens.

The health of the U.S. economy rests on many pillars, and one of those pillars—of particular relevance to the jurisdiction of the Committee—is the health of our natural environment and the resources it provides. Ecosystems provide many benefits to people, including coastal protection, clean water, and opportunities for commerce, tourism, and recreation. Resilient ecosystems have the ability to enhance resilience of communities to extreme weather and climate. For example, salt marshes, sand dunes, and barrier islands can serve as "nature's defenses," helping to shield adjacent homes and businesses from storm surge and coastal flooding. Many ecosystems have already been depleted or degraded due to non-climatic factors, such as pollution, overharvesting, and changes in land use, reducing the ability of these systems to provide benefits to people.

These benefits are further threatened by the impacts of climate change, which are leading to widespread changes in the nation's habitats and ecosystems. Certain commercial fish species are moving northward along the East Coast as waters warm. Acidifying ocean waters threaten the viability of shellfish aquaculture operations in the Pacific Northwest. The timing of biological events, such as flowering and migration, is shifting in regions across the country. Warming spring seasons in Alaska have affected the location and availability of plant species that caribou feed on. Decreases in rainfall and snowpack in the West are reducing the health and productivity of forests and agricultural systems and threatening the survival of endangered salmon runs. Climate change presents an additional challenge that natural resource managers must address to ensure the health of ecosystems for centuries to come.

Climate Preparedness and Resilience Efforts

Responding to climate change is an urgent public health, safety, national security, and environmental imperative. The President's Climate Action Plan, released in June 2013, provides a roadmap for Federal action to meet the pressing challenges of a changing climate through cutting carbon pollution, preparing the United States for the impacts of climate change, and leading international efforts to address global climate change. The Plan acknowledges the reality that even as we work to avoid dangerous climate change, we must strengthen America's resilience to the climate impacts we are already experiencing – and those that can no longer be avoided. Today, I will focus primarily on the Federal Government's efforts to advance climate preparedness and resilience across the nation.

In November 2013, the President signed Executive Order 13653, *Preparing the United States for the Impacts of Climate Change*, directing agencies to help American communities strengthen their resilience to extreme weather and prepare for other impacts. Specifically, this Executive Order directs agencies to: modernize Federal programs to better support local preparedness for climate change impacts; enhance the resilience of the Nation's valuable infrastructure and natural resources; and develop information, data, and tools to help decision makers on the ground. The Executive Order established a new interagency Council on Climate Preparedness and Resilience, chaired by the Office of Science & Technology Policy, the Council of Environmental Quality, and the National Security Council. Executive Order 13653 also created a State, Local and Tribal Leaders Task Force, composed of 26 elected officials from across the country. The Council and Task Force have already begun working to identify how the Federal Government can: remove barriers to climate-resilient investments; modernize Federal programs, grant, and loans to better support local efforts; and develop the tools necessary to help communities prepare for climate change and to sustain healthy ecosystems.

Federal agencies are examining how a changing climate will impact their missions and operations. In February 2013, some agencies released their first-ever climate change adaptation plans, outlining strategies to reduce their vulnerability to the impacts of climate change. Agencies are being asked to continue advancing development and implementation of their adaptation planning efforts, as well as to identify existing barriers to enhancing preparedness. We are already beginning to see leadership and action emerging across the agencies – and these efforts are making a difference on the ground. For example, the Department of Transportation (DOT), in partnership with states and communities, is advancing integration of climate information to minimize the effects of extreme weather and climate change on critical transportation infrastructure. In 2010 and 2011, DOT's Federal Highway Administration (FHWA) supported state Departments of Transportation and Metropolitan Planning Organizations' efforts to pilot approaches for conducting climate change vulnerability and risk assessments. FHWA helped to support projects in San Francisco Bay, coastal and central New Jersey, Hampton Roads, Virginia, the State of Washington, and the Island of Oahu, Hawaii. Informed by these pilot efforts, DOT is now supporting 19 Climate Resilience Pilots across the country. These on-the-ground projects will advance understanding of current and future vulnerabilities – and will inform actions to improve transportation safety and minimize the disruptions that affect communities on a daily basis. Similarly, FHWA is conducting a study of climate vulnerability for transportation facilities in Mobile, AL, and developing tools to help transportation authorities across the nation identify risks and develop adaptation strategies.

The Administration is focused on ensuring the nation's infrastructure is resilient to the increased impacts of climate change and extreme weather. For example, the Department of Health and Human Services is working to create sustainable and resilient hospitals in the face of climate change. Through a public-private partnership with the healthcare industry, it will identify best practices and provide guidance on affordable measures to ensure that our medical system is resilient to climate impacts. It will also collaborate with partner agencies to share best practices among Federal health facilities.

Agencies are analyzing the impacts of climate change on key sectors of our economy and are developing strategies to address them. Last summer, the Department of Energy (DOE) released a report outlining the impacts of climate change on the energy sector, including power-plant disruptions due to drought and the disruption of fuel supplies during severe storms. The report also pinpoints potential opportunities that would make our energy infrastructure more resilient to these risks. In September 2013, sixty-three experts from Federal, academic, and nongovernmental organizations released a report documenting the effects of climate change on oceans and marine resources. This study reviewed how climate variability and change are affecting ocean physical, chemical, and biological systems – and how these changes are already having societal impacts by affecting fisheries and other ocean industries. Additional reports on climate impacts on critical economic sectors will be released within the next year.

In November 2013, the Administration launched the National Drought Resilience Partnership (NDRP) to help communities better prepare for droughts and to reduce impacts on families and businesses. The NDRP is coordinating Federal efforts across the country and working closely with State and local governments and other partners to improve community preparedness and resilience to drought. With the severe drought in California, the NDRP is also playing a critical role in response, helping to connect communities to the Federal assistance they need. For example, in California, NOAA, the Environmental Protection Agency (EPA), the Bureau of Reclamation (BOR), and the U.S. Fish and Wildlife Service (USFWS) are working daily with their State counterparts to maximize operational flexibilities related to water delivery, while maintaining important environmental safeguards.

The Climate Action Plan and Executive Order 13653 are also advancing actions to increase the climate resilience of natural resources. The Executive order charged the Department of the Interior (DOI), the U.S. Department of Agriculture (USDA), NOAA, the EPA, the Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers (USACE), among others, to identify additional opportunities for enhancing the resilience of the Nation's watersheds, natural resources, and ecosystems in the face of climate change through potential changes to their land- and water-related policies and programs. Agencies are building on efforts already completed or underway, as outlined in agencies' climate change adaptation plans, as well as recent interagency climate adaptation strategies, such as the National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate; the National Fish, Wildlife, and Plants Climate Adaptation Strategy; and the resilience efforts outlined in the National Ocean Policy Implementation Plan. Collectively, these efforts will help to safeguard the nation's valuable natural resources in a changing climate.

The President's Climate Action plan directs Federal agencies to "update their flood-risk reduction standards for federally funded projects." This effort builds on the work done by the Hurricane Sandy Rebuilding Task Force which announced in April 2013 that all federally funded Sandy-related building projects must meet a consistent flood risk management standard. We are actively working to create a flood risk management standard for major Federal investment that will provide a minimum level of risk reduction against flood hazards and rely on the best available, actionable science on both current and future risk.

Improving integration of science into preparedness decisions

Climate preparedness efforts depend on access to timely and relevant scientific information. The Office of Science and Technology Policy (OSTP) is responsible for ensuring that the best science, research, data, tools, and technologies are brought to bear in implementing U.S. climate preparedness and resilience efforts. The Climate Action Plan and Executive Order 13653 provide an opportunity to advance understanding of climate impacts and to inform preparedness and response options. One of the themes of the Climate Action Plan is "using sound science to manage climate impacts," through developing actionable climate science, assessing climate change impacts in the United States, launching a Climate Data Initiative, and providing a toolkit for climate resilience.

Many leaders around the country have requested scientific and technical support from the Federal Government to inform the development and prioritization of preparedness efforts. The Administration has learned, through conversations with decision makers, including the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience, that simply providing scientific information is often not enough to support decision making. Science needs to be made accessible, understandable, and usable. We are working across the Federal family and in close communication with non-Federal partners to meet the growing demand for this "actionable" information. The U.S. Global Change Research Program (USGCRP), which coordinates and integrates global change research across 13 agencies, has a new strategic focus on "informing decisions." Efforts to advance science in support of climate preparedness are emerging across agency initiatives and programs. Federal agencies are working to respond to the planning needs of communities on the ground. For example, in the immediate aftermath of Sandy, NOAA, in partnership with FEMA, the USACE, and the USGCRP, created a set of map services to help communities, residents, and other stakeholders consider risks from future sea-level rise in planning for reconstruction. These map services integrate the best-available FEMA flood-hazard data for each location with information on future sea-level rise, highlighting areas that will be at risk in the future.

Later this year, the Administration will release the Third National Climate Assessment (NCA). The NCA, required by the Global Change Research Act of 1990, is an important resource for understanding and communicating climate science and impacts in the United States. The NCA informs the nation about already-observed changes, the current status of the climate, and anticipated trends for the future. The Third NCA, written by over 240 authors from universities, local, state, tribal, and Federal governments, non-governmental organizations, and the private sector, will present a comprehensive picture of climate impacts on U.S. regions and sectors. The information in the NCA will help decision makers and citizens throughout the country prepare for climate change. The NCA includes climate impacts and projections and assesses progress in the nation's responses to climate change. The NCA has built partnerships inside and outside of the government to support this effort – and has engaged thousands of individuals in the development and review of the report. To improve accessibility of information and findings for citizens and scientists, the Third NCA will be deployed as an interactive, online report, including access to underlying data and resources.

As part of the Climate Action Plan, and consistent with President Obama's May 2013 Executive Order on open data, the Administration is also launching a new Climate Data Initiative and the creation of an open-source Climate Resilience Toolkit. These resources will enhance the availability of government data and information to fuel entrepreneurship, innovation, scientific discovery, and public benefits. The

Climate Data Initiative will leverage Federal, state, and local datasets to stimulate private-sector innovation around preparedness for, and resilience to, climate change. In the coming months, the Administration will launch a pilot of the Climate Data Initiative initially focused on sea-level rise and other coastal hazards. Additional pilots (*e.g.*, food security, human health) will be launched over the coming months. The Climate Resilience Toolkit will complement the Climate Data Initiative by providing science-based and data-driven tools to help local, state, tribal, and regional planners better understand the impacts of climate change in their own communities.

We look forward to working with leaders from the public and private sectors to ensure that scientific information developed by the Federal Government is available and useful for informing actions that make communities, economies, infrastructure, and natural resources more resilient to extreme weather and climate change.

The President believes that the Federal Government must do more to help communities across the country become more resilient to the effects of climate change. Recent events have reinforced our knowledge that our communities and economy remain vulnerable to extreme weather, natural hazards, and climate change. For that reason, two weeks ago in Fresno, the President announced that the 2015 Budget will include a new $1 billion Climate Resilience Fund. The President proposes to use this Fund to: invest in research and unlock data and information to improve understanding and projections of the impacts of climate change; help communities plan and prepare for the impacts of climate change and encourage local measures to reduce future risk; and fund breakthrough technologies and infrastructure that will make us more resilient in the face of changing climate.

I thank the Committee for its support and interest in this issue, and I look forward to continuing to work with you. I will be pleased to take any questions Members may have.

Environment and Public Works Committee
Hearing
February 25, 2014

Follow-Up Questions for Written Submission

Questions for Holdren

Questions from: **Senator David Vitter**

1. Both yourself and a former colleague of yours, the late Stephen Schneider, made claims that global cooling was a looming disaster. Dr. Schneider once stated "On the one hand, as scientists we are ethically bound to the scientific method, on the other hand, we are not just scientists, but human beings as well. And like most people, we'd like to see the world a better place, which in this context translates into our working to reduce the risk of potentially disastrous climatic change. To do that, we need to get some broad-based support, to capture the public's imagination. That, of course, entails getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of the doubts we might have. Each of us has to decide what the right balance is between being effective and being honest."

Do you agree that it is appropriate as a scientist to offer up embellished scenarios with simplified dramatic statements regardless of whether or not those statements are wholly accurate?

A: The question misstates what the late Dr. Schneider and I were saying about global climate change in the early 1970s. It also misrepresents Dr. Schneider's views about scientific honesty by reproducing a misleadingly incomplete version of an observation Dr. Schneider made in an interview with Discover magazine in 1989.

On global cooling: From around 1940 into the early 1970s, the average surface temperature of the Earth had been falling. In that period, a combination of factors—including (a) natural cooling influences arising from variations in the Earth's orbit and tilt and (b) the cooling effect of increased atmospheric concentrations of particulate matter arising largely from human activities --was outweighing the warming effect of the buildup of atmospheric carbon dioxide, also caused primarily by human activities. It was unclear at the time whether the cooling influences would continue to prevail, leading ultimately to a new ice age, or whether continuation of the carbon-dioxide buildup would eventually overwhelm those cooling influences and push the Earth into a long-term warming trend. This uncertainty about which direction human influences would ultimately take the global climate was clearly expressed in the highly regarded MIT summer studies of 1970 (The Study of Critical Environmental Problems) and 1971 (The Study of Man's Impact on Climate) and was the basis of the balanced statements on the topic that Dr. Schneider and I were making at the time. By the late 1970s, it was becoming apparent that the warming influences of carbon dioxide were starting to prevail, and, of course, the dominance of

warming influences over cooling ones has become ever more obvious in the decades since. My position, along with Dr. Schneider's, evolved along with the evidence. That is what scientists are supposed to do: we change our views when relevant new evidence materializes and survives the critical scrutiny of the expert community.

On scientific integrity: The false assertion that Dr. Schneider advocated scientific dishonesty arose a quarter of a century ago when his critics elected to quote selectively from a passage in an interview with him that was published in the October 1989 issue of Discover. One conspicuous forum for this assertion was an editorial in The Detroit News from November 22 of that year. The incomplete Schneider quotation provided there was missing the same key elaborations as the quotation in the Senator's question, above. Those elaborations change the meaning completely. The response that Dr. Schneider provided to The Detroit News is germane here (http://stephenschneider.stanford.edu/Publications/PDF_Papers/DetroitNews.pdf):

> **Since the News devoted several column inches in its editorial to partially quote that Discover Magazine reported I had said, The News must feel this is important. Therefore, let me set the record straight by quoting the entire paragraph from Discover, since the absence of what The News left out (in italics below) seriously misrepresents the totality of my views:**
>
> **"On the one hand, as scientists we are ethically bound to the scientific method, *in effect promising to tell the truth, the whole truth, and nothing but – which means that we must include all doubts, the caveats, the ifs, ands and buts.* On the other hand, we are not just scientists but human beings as well. And like most people we'd like to see the world a better place, which in this context translates into our working to reduce the risk of potentially disastrous climate change. To do that we need to get some broad based support, to capture the public's imagination. That, of course, means getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have. *This "double ethical bind" we frequently find ourselves in cannot be solved by any formula.* Each of us has to decide what the right balance is between being effective and being honest. *I hope that means being both.*"**
>
> **It is strange that The News should accuse me of trying to hide scientific uncertainty through this quote, when by the very nature of explaining the dilemma I am being unusually forthright in trying to show how all scientists face a bind when forced to communicate in short sound bites in the media what the essence of a controversial complex problem is. It is hard to imagine how this constitutes hiding the truth when it's plainly stated. Obviously, the absence of the last sentence of the Discover magazine quote in the editorial totally misrepresents my views.**

Dr. Schneider made the mistake of including, in a somewhat rambling interview response, a sentence that lent itself to being taken out of context. I would state the relevant principle more succinctly: It is desirable to be effective; it is essential to be honest.

2. Do you completely disavow the material, population projections and legislative proposals you made with Paul Ehrlich in your 1977 book *EcoScience?* In particular, do you still believe

that "Indeed, it has been concluded that compulsory population-control laws, even including laws requiring compulsory abortion, could be sustained under the existing Constitution if the population crisis became sufficiently severe to endanger the society"?

A: **The quote you cite from 1977 is a quote from a chapter that is a compilation of ideas and concepts that had been discussed in the literature. It was identified as such. This summary of views from the literature appears in a large, comprehensive book in which I was mainly responsible for the chapters on geochemical cycles, on energy, and on materials. The authors' statement at the end of the chapter says clearly, "We do not advocate these measures."**

3. Are you aware of a Freedom of Information Act request for your work-related emails on the email account you used at Woods Hole Research Center, an environmental group where you were employed, which you are alleged to have continued using while working as an advisor to the president? (OSTP FOIA # 14-02) It seems some of this correspondence turned up in the "Richard Windsor" email lawsuit.

A: **My staff has made me aware of the receipt of FOIA # 14-02.**

4. Although EPA is producing hundreds of emails from agency officials that have come from non- official accounts for government-related correspondence, OSTP has told FOIA requesters that your emails will not be produced. OSTP claims that, the email exists only on the Woods Hole Research Center computer server and was never copied to OSTP as required by law. Therefore, OSTP claims they are outside of FOIA's reach.

Did anyone at OSTP ask you to search that account and produce work-related emails? If so, did you search the account or did you refuse to do so? If not, would you be willing to search that account?

A: According to my staff, OSTP has not told the FOIA requestor that my emails will not be produced. Nor have my staff asserted that the email exists only on the Woods Hole Research Center's computer server. Rather, my staff responded to the requester in a letter that reads in relevant part:

> **[Y]ou sent the Office of Science and Technology Policy (OSTP) a request under the Freedom of Information Act....**
>
> **OSTP sent you a letter on February 4, 2014, [explaining that]...OSTP understood your request to be one that sought a search of the jholdren@whrc.org account, and not a search of any OSTP email accounts. Accordingly, our February letter explained that your request was unperfected and offered you an opportunity to perfect your request.**
>
> **On February 18, 2014, you sent OSTP a letter clarifying that you are requesting a search of Dr. John Holdren's OSTP email account for**

records to and from jholdren@whrc.org. OSTP has conducted a search of Dr. Holdren's OSTP email account and will produce responsive records to you on a rolling basis...

5. On May 10, 2010, you drafted a memo with the subject line: "Reminder: Compliance with the Federal Records Act and the President's Ethics Pledge." This was written after one of your employees at OSTP had been shown to be using a private email account for work-related email.

The memo included the phrase:

> "OSTP has long had an excellent record of complying with legal and ethical standards. We should all be proud of that record, and we all need to be vigilant in maintaining it. This memo describes how one of our employees recently fell short in this regard, inadvertently implicating two important standards that govern our activities as Federal employees: the Federal Records Act and the President's Ethics Pledge. The information below serves as a reminder of what these standards require from all of us and what you must do to ensure compliance...
>
> If you receive communications relating to your work at OSTP on any personal email account, you must promptly forward any such emails to your OSTP account, even if you do not reply to such email. Any replies should be made from your OSTP account. In this way, all correspondence related to government business- both incoming and outgoing- will be captured automatically in compliance with the FRA. In order to minimize the need to forward emails from personal accounts, please advise email senders to correspond with you regarding OSTP-related business on your OSTP account only...."

The dates on the emails which emerged in the Richard Windsor lawsuit show that, at the time of this memo, you still were using a private email account for work-related emails. Because OSTP failed to copy those emails as required by law, it is possible that federal records are under the sole control of that outside group and are not available to FOIA requesters, the media, or congressional oversight requests.

How does such an activity comport with your compliance email?

A: I am unfamiliar with the specific emails to which you refer. Consistent with the memo I authored, I endeavor to ensure any work-related emails sent to or from a private email account are preserved on OSTP's system.

6. In your testimony you state: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Who defines "full scientific certainty?" Who decides what constitutes "irreversible damage?"

A: As part of the efforts of the Federal Government to inform and support climate

preparedness and resilience across the Nation, including efforts to reduce the risks and costs of future disasters, Federal policies, programs, and practices are being thoroughly examined for potential adjustments to reduce risks and existing vulnerabilities where science-based information is sufficient to support that adjustment. This effort includes identifying risks and related vulnerabilities that if left unattended, may lead to serious or irreversible damage. Concepts and common interpretation of relevant terms are part of that effort as well. Ideally, these terms would be defined and applied consistently across the Federal government, and measures to prevent environmental degradation would be formulated through cooperation of the Executive and Legislative branches, based on full consideration of the costs and risks of both action and inaction.

7. What is the current rate of sea level rise per year from empirical evidence, not models?

A: The average rate of sea-level rise observed by satellites over 1993-2010 is 3.2 millimeters a year. The rate between 1901 and 2010 was 1.7 millimeters a year. (Source: IPCC Working Group 1 5th Assessment Report, 2013.)

8. What decade was the worst decade for drought in the United States?

A: Drought can be measured physically in terms of precipitation deficit, soil dryness, or lack of river flow. In addition, drought can be measured in terms of socioeconomic impacts. Which period is "the worst" will likely depend on which measure is selected. Using tree growth (which reflects soil moisture) as a measure, geological data indicate prolonged and severe droughts in areas of the United States during the Middle Ages. It is difficult to pinpoint a specific decade, but some analyses suggest that the period 1550 – 1600 was the driest in the last 500 or so years, at least in the Western United States. (Source: NOAA http://www.ncdc.noaa.gov/paleo/drought/drght_500years.html)

During the 20th century, using the Palmer Drought Severity Index as a measure, the 1930s had the most severe and prolonged drought in the United States as a whole. The drought that has afflicted much of the Western United States since 2000 is by some accounts the worst in that region in the last 800 years. (Source: Christopher R. Schwalm et al., Reduction of carbon uptake during turn of the century drought in western North America, *Nature Geoscience*, vol. 5, August 2012, pp 551–556). The three-year continuing drought in California is the worst in the 118 years of good records and may have been the worst in the last 500 years. (Source: UC Berkeley Professor of Earth and Planetary Sciences Lynn Ingram at http://newscenter.berkeley.edu/2014/01/21/states-water-woes/).

9. During the 1930s, 2.5 million residents of the plains states fled due to many years of extreme heat and drought. When you say that the US climate is becoming more severe are you referring to droughts?

A: Trends across hazards indicate exacerbation of impacts attributable in part to

changes in global climate. Trends in drought vary from region-to-region, and these trends have diverse causes. In the Southwest, for example, observations show an overall increase in area affected by drought during the 20th century. (*Source:* Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* Island Press: Washington, DC.) See also the answers to questions 8 and 10.

10. You recently stated "We've always had droughts in the American West, of course, but now the severe ones are getting more frequent, they're getting longer, and they're getting dryer."

Professor Roger Pielke Jr. and the University of Colorado has provided evidence that claims of droughts worsening due to global warming directly contradict scientific reports.

The Intergovernmental Panel on Climate Change found that there is "not enough evidence at present to suggest more than low confidence in a global-scale observed trend in drought." Dr. Pielke Jr. has added that even a report from the U.S. government said that "droughts have, for the most part, become shorter, less frequent and cover a smaller portion of the US over the last century." A 2012 paper published in the journal Nature found "[I]ittle change in global drought over the past 60 years."

What science are you using when you claim that "severe" droughts are "more frequent," "longer," and "dryer?"

A: Trends in drought vary from region to region. Also, whether a trend exists or not may depend upon which type of drought (meteorological, agricultural, or hydrological) is being considered.

My comments to reporters on February 13, to which Dr. Pielke referred, were provided just ahead of President Obama's visit to the drought-stricken California Central Valley and were explicitly about the drought situation in California and elsewhere in the West.

That being so, any reference to the "report from the US government" (CCSP 2008) should include not just the sentence highlighted in Dr. Pielke's testimony but also the sentence that follows immediately in the relevant passage from that document and which relates specifically to the American West. Here are the two sentences in their entirety (http://downloads.globalchange.gov/sap/sap3- 3/Brochure-CCSP-3-3.pdf):

> ***Similarly, long-term trends (1925–2003) of hydrologic droughts based on model derived soil moisture and runoff show that droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the U.S. over the last century (Andreadis and Lettenmaier, 2006). The main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends (Groisman et al., 2004; Andreadis and Lettenmaier, 2006).***

In my recent comments about observed and projected increases in drought in the American West, I mentioned four relatively well-understood mechanisms by which climate change can play a role in drought.

These are:

1. In a warming world, a larger fraction of total precipitation falls in downpours, which means a larger fraction is lost to storm runoff (as opposed to being absorbed in soil).

2. In mountain regions that are warming, as most are, a larger fraction of precipitation falls as rain rather than as snow, which means lower stream flows in spring and summer.

3. What snowpack there is melts earlier in a warming world, further reducing flows later in the year.

4. Where temperatures are higher, losses of water from soil and reservoirs due to evaporation are likewise higher than they would otherwise be.

Regarding the first mechanism, the 2013 report of the IPCC's Working Group I, *The Science Basis* (http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf, p 110), deems it "likely" (probability greater than 66%) that an increase in heavy precipitation events is already detectable in observational records since 1950 for more land areas than not. In the U.S. specifically, findings of an observed, increasing trend in extreme precipitation date from at least 1998 (Karl and Wright, 1998 *Bulletin Amer. Meteor. Soc.*) and are confirmed in a recent review (Janssen et al, 2014. *Earth's Future*). The second, third, and fourth mechanisms reflect elementary physics and are hardly subject to dispute; furthermore, they are supported by peer-reviewed observational studies, some of which are cited below.

Concern over climate change and drought is not confined to the academic community. Here is what the California Department of Water Resources says about climate change and drought: "Climate change is having a profound impact on California water resources, as evidenced by changes in snowpack, sea level, and river flows." (From the California Department of Water Resources: "Climate change is having a profound impact on California water resources, as evidenced by changes in snowpack, sea level, and river flows" (Source: http://www.water.ca.gov/climatechange/)

Additional References (with particularly relevant direct quotes in italics):

Christopher R. Schwalm et al., Reduction of carbon uptake during turn of the century drought in western North America, *Nature Geoscience*, vol. 5, August 2012, pp 551–556.

> ***The severity and incidence of climatic extremes, including drought, have increased as a result of climate warming. ... The turn of the century drought in western North America was the most severe drought over the past 800 years, significantly reducing the modest carbon sink normally present in this region. Projections indicate that***

drought events of this length and severity will be commonplace through the end of the twenty-first century.

Gregory T. Pederson et al. , The unusual nature of recent snowpack declines in the North American Cordillera, *Science*, vol. 333, 15 July 2011, pp 332–335.

Over the past millennium, late 20th century snowpack reductions are almost unprecedented in magnitude across the northern Rocky Mountains and in their north-south synchrony across the cordillera. Both the snowpack declines and their synchrony result from unparalleled springtime warming that is due to positive reinforcement of the anthropogenic warming by decadal variability. The increasing role of warming on large-scale snowpack variability and trends foreshadows fundamental impacts on streamflow and water supplies across the western United States.

Gregory T. Pederson et al., Regional patterns and proximal causes of the recent snowpack decline in the Rocky Mountains, US, *Geophysical Research Letters*, vol. 40, 16 May 2013, pp 1811–1816.

The post–1980 synchronous snow decline reduced snow cover at low to middle elevations by ~20% and partly explains earlier and reduced streamflow and both longer and more active fire seasons. Climatologies of Rocky Mountain snowpack are shown to be seasonally and regionally complex, with Pacific decadal variability positively reinforcing the anthropogenic warming trend.

Michael Wehner et al., Projections of future drought in the continental United States and Mexico,*Journal of Hydrometeorology*, vol. 12, December 2011, pp 1359–1377.

All models, regardless of their ability to simulate the base-period drought statistics, project significant future increases in drought frequency, severity, and extent over the course of the 21 st century under the SRES A1B emissions scenario. Using all 19 models, the average state in the last decade of the twenty-first century is projected under the SRES A1B forcing scenario to be conditions currently considered severe drought (PDSI<–3) over much of the continental United States and extreme drought (PDSI<–4) over much of Mexico.

D. R. Cayan et al ., Future dryness in the southwest US and the hydrology of the early 21 st century drought, *Proceedings of the National Academy of Sciences*, vol. 107, December 14, 2010, pp 21271–21276.

Although the recent drought may have significant contributions from natural variability, it is notable that hydrological changes in the region over the last 50 years cannot be fully explained by natural variability, and instead show the signature of anthropogenic climate change.

E. P. Maurer et al. , Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada, *Journal of Geophysical Research*, vol. 112, 2007, doi:10.1029/2006JD08088.

> ***The warming experienced in recent decades has caused measurable shifts toward earlier streamflow timing in California. Under future warming, further shifts in streamflow timing are projected for the rivers draining the western Sierra Nevada, including the four considered in this study. These shifts and their projected increases through the end of the 21st century will have dramatic impacts on California's managed water system.***

H. G. Hidalgo et al ., Detection and attribution of streamflow timing changes to climate change in the western United States, *Journal of Climate*, vol. 22, issue 13, 2009, pp 3838–3855, doi: 10.1175/2009JCLI2740.1.

> ***The advance in streamflow timing in the western United States appears to arise, to some measure, from anthropogenic warming. Thus the observed changes appear to be the early phase of changes expected under climate change. This finding presages grave consequences for the water supply, water management, and ecology of the region. In particular, more winter and spring flooding and drier summers are expected as well as less winter snow (more rain) and earlier snowmelt.***

Barnett, T.P. et al., "Human-Induced Changes in the Hydrology of the Western United States" Science 22 February, 2008. pp 1080-1083.

> ***"Our results are not good news for those living in the western United States. The scenario for how western hydrology will continue to change... foretells water shortages, lack of storage capacity,... and other critical impacts."***

11. Empirical evidence suggests that the last five years have brought the fewest US hurricane landfalls of any five year period in recent history. Since President Obama took office in 2009, there have been three US hurricane landfalls. By contrast, during Grover Cleveland's presidency the US was hit by 26 hurricanes, many of which were major hurricanes. When you claim that the US climate is becoming more severe are you referring to hurricane activity?

A: The Intergovernmental Panel on Climate Change (IPCC) finds that it is "virtually certain" that tropical cyclone activity in the North Atlantic (the ocean basin that threatens the US Gulf and east coasts) has increased since 1970.
(<u>Source</u>: IPCC Working Group 1 5th Assessment Report, 2013.)

12. Was Hurricane Sandy or the Great Colonial Hurricane of 1635 the most severe to hit New England?

A: By some estimates, the hurricane of 1635 was the most severe hurricane to make

landfall in U.S. history. Since the climate system has historically been shaped by natural variability, and more recently by human influences imposed on top of that natural variability, isolated episodes of extreme weather in the historical record do not negate the scientific consensus that anthropogenic climate change may increase the probability of extreme events occurring or may worsen the consequences of a specific extreme weather event (*e.g.,* more damage from a given storm surge because of sea-level rise), even if the event itself cannot be shown to have been caused by climate change.

13. How many coal fired power plants were in operation in the year 1635?

A: **There were none.**

14. Not discounting the fact that we did see some severe tornadoes over the past two years, empirical evidence suggests that the last two years were the quietest years on record for US tornadoes. Is your claim that the climate is becoming more severe based on tornado activity?

A: In 2007, the IPCC concluded that "There is insufficient evidence to determine whether trends exist in . . . small-scale phenomena such as tornadoes, hail, lighting, and dust storms."
(Source: IPCC 4th Assessment Report: Synthesis Report. 2007).

15. In 2009 you claimed "if you lose the summer sea ice, there are phenomena that could lead you not so very long thereafter to lose the winter sea ice as well. And if you lose that sea ice year round, it's going to mean drastic climatic change all over the hemisphere." In terms of our historical records of the Arctic and Antarctic what is the exact status today of the amount of sea ice at both locations?

A: As of mid-March 2014, the extent of sea ice in the Arctic and Antarctic are approximately 15 million and 4 million square kilometers, respectively. (Source: National Snow and Ice Data Center.)

Since 1979, Arctic sea ice extent has decreased during March (when the ice reaches a maximum) by 2.6% per decade and in September (annual minimum) by 13.7% per decade. The seven record-low Arctic ice extents were 2007-2013. (Source: NOAA, *Arctic Report Card: Update for 2013* (http://www.arctic.noaa.gov/reportcard/sea_ice.html.)

Recent analysis of Nimbus I satellite data showed that there was substantially more Antarctic sea ice in 1964 than any time since 1972. Nonetheless, sea ice currently is not diminishing as rapidly in Antarctica as in the Arctic despite an overall warming of the planet. The slower response of Antarctic sea ice to warming is an area of active research.

By what year do you expect temperatures in the winter in both the Arctic and Antarctic to average above freezing?

A: When this might occur depends on what measures are taken to mitigate future climate change.

16. There are reports that temperatures are so cold at the Arctic right now that new ice is forming at the rate of one Manhattan every minute and a half, and in areas that were previously ice free. Is that accurate?

A: Sea ice forms in the Arctic Ocean when a combination of conditions is met: air temperatures are well below freezing, there is minimal solar heating, and currents are not bringing warm water to the region. At times, there is rapid freezing of the surface over large areas. That ice, however, is much thinner than it was in the first half of the last century. In fact, in 2013, the volume of Arctic sea ice was less than half of what it was in 1979.

At this time of year (March), the extent of Arctic sea ice begins to decrease, as summer approaches. Over this past winter, the extent of Arctic sea ice was less than the 1981-2010 average. Since the start of satellite monitoring of sea ice around 1980, the extent of Arctic sea ice has decreased by roughly a million square km or more, depending on month and year. (Source: National Snow and Ice Data Center, e.g. http://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/)

17. In earth's geologic history have more species extinctions been associated with a warming climate or a freezing climate?

A: Extinctions are believed to be associated not with warming or cooling *per se*, but rather with high rates of climate change that outpace the ability of species and ecosystems to adapt. Projections indicate "potential 21st-century global warming that is comparable in magnitude to that of the largest global changes in the past 65 million years but is orders of magnitude more rapid," creating "daunting challenges for species."
(Source: Diffenbaugh and Field. 2013. *Science* Vol. 341 no. 6145 pp. 486-492).

18. Why does NOAA never publicly mention nor utilize its monthly and yearly *State of the Climate* reports? The reports include temperature numbers derived from the state of the art Climate Reference Network, completed in 2008, with the "...express purpose of detecting the national signal of climate change."

They were designed to be free of the effects of urbanization/UHI and any need for adjustments. "The stations are placed in pristine environments expected to be free of development for many decades. Stations are monitored and maintained to high standards, and are calibrated on an annual basis."

Millions of dollars were spent on this new climate network, yet the public never sees it utilized in any public climate report, and the old network which is fraught with problems is still used for these reports instead of the new one. There's no mention of it even for comparison purposes.

Why is that?

A: NOAA publicly releases its monthly US and global climate reports via websites, emails to media, constituents and Congressional staff, and over social media. In addition, NOAA Office of Legislative and Intergovernmental Affairs (OLIA) sends out the monthly US and global reports to staff of NOAA's authorizing and appropriations Committees as well as staff members who have attended its briefings in the past. All of this information is available on NCDC's website (see http://www.ncdc.noaa.gov/sotc/), but if you or your staff wish to receive it in email form please contact NOAA OLIA by emailing mackenzie.tepel@noaa.gov.

The U.S. Climate Reference Network (USCRN) and the U.S. Historic Climate Network (USHCN) data are publicly available on NOAA's National Climatic Data Center's (NCDC's) website to compare our nation's temperature changes. As part of NOAA's mission, NOAA's NCDC provides graphical comparisons of U.S. average maximum and minimum temperature computed from both USCRN and USHCN. These graphs are updated monthly and are available at http://www.ncdc.noaa.gov/temp-and-precip/national-temperature-index/.

Given that USHCN has a much longer period of record going back to the 19th century (versus 9 years for USCRN) NCDC uses this data set for long-term monitoring and in its reports. The length of the dataset is one of the reasons why the USHCN remains important in monitoring climate.

The USCRN began to be fielded in 2000, parts of the network were commissioned starting in 2004 and it remains the gold standard of climate monitoring. The longer the system is in operation, the more useful it will continue to be to monitor long-term climate trends. Already it is used to validate USHCN national trends over the recent decade. The fact that U.S. temperature trends between USCRN and USHCN are in close agreement since USCRN has been operation validates our corrections applied to the full USHCN record are valid for national temperature trend monitoring (see the Appendix).

Additionally, while USCRN was established for the purposes of national monitoring, we still rely on the USHCN's much denser network of stations that are more effective for measuring trends on smaller space scales then compared the USCRN. This is another reason why the USHCN's denser network of corrected data is especially useful to precisely monitor small area trends.

Additional background on USCRN and USHCN is discussed in the attached Appendix.

19. Are there known social and economic benefits to increased C02?

A: The effects of CO_2 are dependent on the inherent physical and chemical properties of this molecule, and how these properties directly and indirectly affect physical, biological,

and social systems. Without CO_2 in the atmosphere acting as a blanket to keep the Earth warm, Earth would be icebound. Increases in atmospheric CO_2 concentration, mostly from human-related activities, above the pre-industrial (circa 1750) level, however, are leading to rising global-average surface temperature and associated changes to climatic patterns to which current human societies and ecosystems are adapted. Changes to our climate and natural systems, in turn, affect our economic and social wellbeing in a variety of ways. Increased atmospheric CO_2 concentration increases plant growth, up to a point, if other nutrients are not limiting and if the climatic consequences of the CO_2 increase do not offset the CO_2 fertilization effect. The USDA finds that, in the real world, a net benefit for food crops from increasing CO_2 is unlikely (see the answer to question 20). And, although there is an economic benefit of a warming climate in reducing heating expenses and potentially cold weather-related mortality, this effect has been evaluated and found to be less than the countervailing impact of the rise in air conditioning expenses and potential heat-related mortality. This spectrum of competing benefits and costs of actions associated with greenhouse gas emissions is routinely evaluated in Federal decision-making under Executive Orders, and incorporated in the Social Cost of Carbon documentation.

20. Is there science that shows that agriculture harvest increases with an increase in C02?

A: **According to the U.S. Department of Agriculture (USDA), "Plant response to climate change is dictated by a complex set of interactions to CO_2, temperature, solar radiation, and precipitation. . . Increasing CO_2 in the atmosphere is a positive for plant growth, and controlled experiments have documented that elevated CO_2 concentrations can increase plant growth while decreasing soil water-use rates. The effects of elevated CO_2 on grain and fruit yield and quality, however, are mixed; reduced nitrogen and protein content observed in some nitrogen-fixing plants causes a reduction in grain and forage quality. This effect reduces the ability of pasture and rangeland to support grazing livestock. The magnitude of the growth stimulation effect of elevated CO_2 concentrations under field conditions, in conjunction with changing water and nutrient constraints, is uncertain. Because elevated CO_2 concentrations disproportionately stimulate growth of weed species, they are likely to contribute to increased risk of crop loss from weed pressure... Increases in temperature coupled with more variable precipitation will reduce productivity of crops, and these effects will outweigh the benefits of increasing carbon dioxide."**
(Source: Walthall et al. 2012. Climate change and agriculture in the United States: effects and adaptation. USDA Technical Bulletin 1935. Washington, DC. 186 pages).

21. Is there science that shows plant life can have greater drought resistance and require less water with increased C02?

A: According to USDA, "The effects of elevated CO_2 on water-use efficiency may be an advantage for areas with limited precipitation. Other changing climate conditions may either offset or complement such effects. Warming temperatures, for instance, will act to increase crop water demand, increasing the rate of water use by crops. Crops grown on soils with a limiting soil water-holding capacity are likely to experience an increased risk of drought and potential crop failure as a result of temperature-induced increases in crop water demand, even with improved water-use efficiencies. Conversely, declining trends of

near-surface winds over the last several decades and projections for future declines of winds may decrease evapotranspiration of cropping regions. Crops and forage plants will continue to be subjected to increasing temperatures, increasing CO_2, and more variable water availability caused by changing precipitation patterns. These factors interact in their effect on plant growth and yield. A balanced understanding of the consequences of management actions and genetic responses to these factors will form the basis for more resilient production systems to climate change."
(Source: Walthall et al. 2012. Climate change and agriculture in the United States: effects and adaptation. USDA Technical Bulletin 1935. Washington, DC. 186 pages.)

22. Which benefits were incorporated into developing the Social Cost of Carbon?

A: The Social Cost of Carbon (SCC) is meant to be a comprehensive estimate of the monetized value of the net effects (both negative and positive) of global climate change, including, but not limited to, changes in net agricultural productivity, human health, and property damages from increased flood risk. The interagency group developed the range of SCC estimates using three well-known peer-reviewed integrated assessment models (IAMs) -- DICE, PAGE, FUND -- a range of socioeconomic and emissions scenarios, three discount rates, and a probability distribution for climate sensitivity. (Details of these can be found in the 2010 and 2013 Federal SCC technical support documents and on the author websites and publications for each of these individual models.) A variety of anticipated climate change-related impacts were incorporated by the authors of the three IAMs, including potential benefits associated with carbon dioxide emissions. For example, the FUND model incorporates increases in agricultural and forestry productivity at certain levels of warming. The model also incorporates the benefits of reductions in energy expenditures due to reduced demand for space heating and the reduction in cardio-vascular and respiratory mortality and morbidity associated with extreme cold. When all impacts are considered, at levels of warming consistent with current emissions trajectories, the long-term projected damages associated with those carbon emissions significantly exceed the projected benefits from the carbon emissions in the models. The SCC estimates reflect that net social cost.

It should be noted that, given current modeling and data limitations, current SCC estimates do not include all important damages. As noted by the IPCC Fourth Assessment Report, it is "very likely that [SCC] underestimates" the damages. The IAMs do not currently include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature because of a lack of precise information on the nature of damages and because the science incorporated into these models naturally lags behind the most recent research. Nonetheless, the SCC is a useful measure to assess the benefits of CO_2 reductions. (Source: http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf)

23. Why does the National Academy of Engineers consider electrification the greatest engineering achievement of the 20th Century?

A: In 2003, the National Academy of Engineering (NAE) published *A Century of Innovation: Twenty Engineering Achievements that Transformed our Lives*. At the top of the NAE's list of engineering achievements of the 20th century was electrification. As the NAE noted, more than half of the other "Top 20" engineering achievements (such as electronics, computers, the Internet, and household appliances) would not have been possible without electrification. Abundant and available electric power helped spur America's economic development and distributed the benefits of that economic development widely, from cities to farms. Electricity also continues to be a major focus of scientific and engineering endeavor. As the NAE notes:

"New engineering challenges have continued to arise, among them how to transmit electricity at higher and higher voltages for maximum efficiency. Improvements in both materials and systems have brought transmission voltages up from the 220 volts of the 1880s to the 765,000 volts of today. And still the search goes on for new and better ways to harness energy from sources that now include everything from nuclear reactors to the wind, the Sun, and even the geothermal energy of Earth itself. Wind farms, with scores of sleek, narrow-bladed, computer-controlled wind turbines, have become increasingly productive; improvements in efficiency have brought the cost of wind-produced electricity down significantly in the past 15 years. [Investor-owned utilities] are also devoting more research dollars to improving solar power. Photovoltaic cells that generate electricity directly are becoming more efficient, but engineers are also working on other innovative approaches, including a technique known as solar thermal, in which arrays of mirrored parabola-shaped collectors focus sunbeams to heat oil to as high as 750°F to drive steam turbines."

The Administration, through its programs of research and innovation in energy, and through its support of fiscal incentives such as tax credits and loan guarantees, continues to assist in ensuring that the United States has a balanced and affordable future supply of electricity that will meet the needs of the 21st century.

24. You state in your testimony that "the global climate has been so extensively impacted by the human-caused buildup of greenhouse gases."

Please provide evidence of each climate parameter that has been extensively impacted by human-caused buildup of greenhouse gases, aside from the levels of greenhouse gases themselves.

A: On the global scale, according to the IPCC, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." The height of the "tropopause," the boundary between the lowest layer of the atmosphere and the stratosphere, as well as the moisture content of the lower atmosphere, have also increased. The stratosphere has cooled. In some regions, other climate parameters have also been affected. These include river flows, extremes in temperature and precipitation, tropical cyclone activity, and extreme high sea levels. (Source: IPCC Working Group I 5th Assessment Report. 2013)

Appendix to Question 18
from the National Oceanic and Atmospheric Administration (NOAA)

The U.S. Climate Reference Network (USCRN) establishes the highest standards for climate monitoring. USCRN is fully operational and plays a significant role in determining the Nation's climate profile, in conjunction with the older networks like the U.S. Historical Climatology Network (USHCN). Data from USCRN, along with other information concerning the system, are freely available online at http://www.ncdc.noaa.gov/crn.

USCRN adheres to the highest global climate monitoring principles endorsed by the U.S. National Academy of Science, and provides the U.S. with the greatest confidence in national temperature and precipitation trends. Since 2005, the network's 114 stations in the continental U.S. have provided sufficient coverage to enable the calculation of a high-quality national temperature average. This gives us more than eight years of high-quality temperature data for the lower 48 states. We also have 2 stations in Hawaii, and have installed 13 of 29 planned network stations in Alaska.

While NOAA's National Climatic Data Center (NCDC) designed USCRN to provide the highest quality climate observations, the network's length of record is currently too short to provide longer-term multi-decadal and century-scale perspectives on the nation's climate. However, NCDC has also worked for decades to build a reliable climate record provided by stations in other networks, including the USHCN. The great advantage of continuing the USHCN monitoring is that data from many of its stations date back to the early 20th Century. From a climate perspective, such long-term data is of great value. Therefore, NCDC continues to employ the USHCN in conjunction with the USCRN to build a robust climate record for the future while continuing to provide verification for older observational methods.

Since its implementation, USCRN has not only improved our monitoring of today's climate, but has also increased confidence in the older USHCN stations. One of USCRN's missions is to provide verification for national temperatures computed from USHCN during the two networks' common period of operation from 2005-13. As part of this mission, NCDC provides graphical comparisons of U.S. average maximum and minimum temperature computed from both USCRN and USHCN. These graphs are updated monthly and are available at http://www.ncdc.noaa.gov/national-temperature-index/.

Figure 1, below, shows the annual average temperature anomalies for both networks from 2005-2012. As you will see, the graph shows very close agreement – the correlation in national average temperature computed from the two networks is greater than 99%. Therefore, continuing to monitor USHCN, as verified by USCRN, allows us access to a valuable temperature record dating to 1900 (**Figure 2**).

For further information please see:

Diamond, H.J., T.R. Karl, M.A. Palecki, C.B. Baker, J.E. Bell, R.D. Leeper, D.R. Easterling, J.H. Lawrimore, T.P. Meyers, M.R. Helfert, G. Goodge, and P.W. Thorne, 2103: U.S. Climate Reference Network after one decade of operations: Status and assessment. *Bulletin of the American Meteorological Society*, **94**, 485–498, doi:10.1175/BAMS-D-12-00170

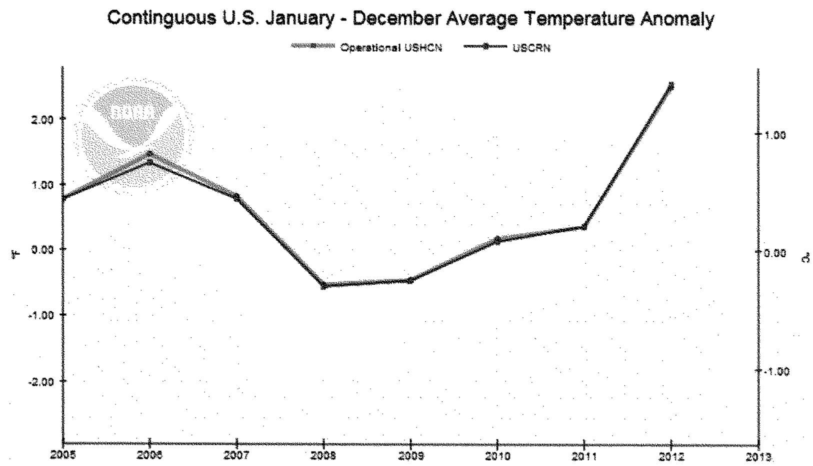

Figure 1. USHCN (red) and USCRN (blue) national annual temperature anomalies, 2005-2012.

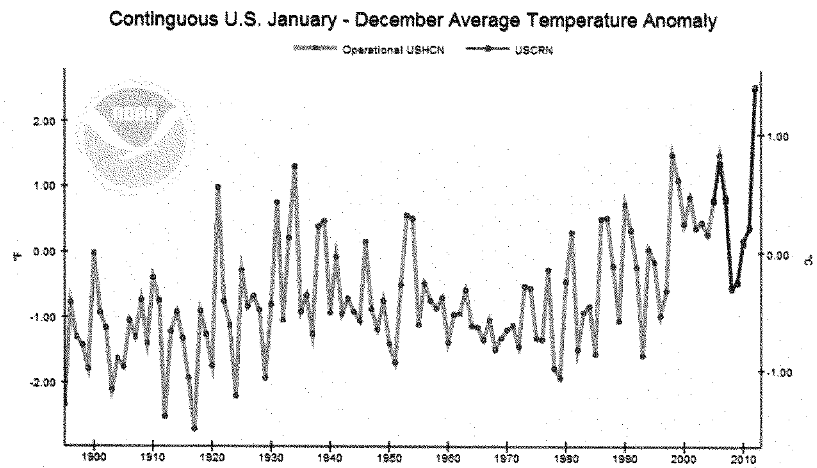

Figure 2. USHCN (red) and USCRN (blue) national temperature anomalies, 1895-2012. USCRN observations validate USHCN observations, but the historical run of USHCN is very important.

Senator WHITEHOUSE. Thank you, Dr. Holdren. And as is custom in this committee, your longer statement that was provided will be put into the record. We appreciate that you were able to summarize in the appropriate amount of time.

Mr. Ashe, welcome. Actually, let me do my proper introduction to you. Daniel Ashe was confirmed on June 30th, 2011 as the 16th Director of the U.S. Fish and Wildlife Service. Prior to his appointment, Mr. Ashe served as the Fish and Wildlife Service Deputy Director for Policy, beginning in 2009.

Mr. Ashe is a career member of the Fish and Wildlife Service, having served in a great variety of capacities, and formerly was a professional staff member of the former House Committee on Merchant Marine and Fisheries. He is also a legacy, his father served in the Fish and Wildlife Service for 37 years. Mr. Ashe brings to us a B.S. in biological science degree from Florida State University and a masters in marine affairs from the University of Washington.

Please proceed, Mr. Ashe.

STATEMENT OF THE HON. DANIEL M. ASHE, DIRECTOR, UNITED STATES FISH AND WILDLIFE SERVICE

Mr. ASHE. Thank you, Mr. Chairman, Senator Inhofe. It is a pleasure to be here again.

If we think about this issue of adaptation and response to climate change, I think what I would say is, climate change affects every aspect of the enterprise of wildlife conservation. But it is not just climate change, it is climate change on top of and turbo-charging the cumulative effects of other factors driving wildlife populations, things like habitat loss and fragmentation, wildlife diseases like white nose syndrome in bats and Kitrick fungus in amphibians, species invasions, wildfire. So it is climate change on top of all of these things. We see these effects, these cumulative, accelerating effects, everywhere we look.

Chairman Whitehouse, in your region of the Country, consider Atlantic salmon conservation. For nearly 40 years, the U.S. Fish and Wildlife Service has worked with many partners, State, tribal, local, to try to achieve Atlantic salmon conservation in the Connecticut River. We have put forth great effort with great partnerships. But what we find is now with the accelerating effects of climate change, driving warming of the water and changing of the chemical and physical characteristics of the Connecticut River, that that is acting synergistically with other factors, like the presence of predators that never existed in the Connecticut River, like smallmouth bass and human-based pollution of the water, and barriers to migration like dams and other barriers in the Connecticut River and tributaries.

So climate change now acting cumulatively and synergistically with those effects are telling us that we can't achieve Atlantic salmon conservation in the Connecticut River. So if we are going to achieve that, we need to look elsewhere within the historic range of the species.

Mr. Inhofe, as you know, we are seeing the same things in the range of the Lesser prairie chicken. Certainly habitat loss and alteration changes are being accelerated and exacerbated by changes in soil moisture and other things that seem to be driving the Lesser prairie chicken toward potential extinction. We have made great efforts working with the State to put in place a range-wide plan, working on a candidate conservation agreement to drive conservation, habitat conservation for this species. But the one missing ingredient there is rain, and will we get rain, and will the presence or absence of rain, is that a phenomenon of weather, or is that a phenomenon of climate. Does it really matter. What we need to do is, we need to better understand what is driving the fate of these creatures that we are responsible for.

And as I was thinking about this, I am going to borrow from a book called The Legacy, by David Suzuki. He talks about the human enterprise and he talks about the fact that we are not an impressive species in size and speed and strength or sensory alacrity. But the key to our success as a species is this two-kilogram organ encased in our skull. The human brain has more than compensated for our lack of physical or sensory abilities. We observe, we learn, we remember. We recognize causal relationships and we come up with innovative solutions to problems.

So throughout history, drawing on our experience and knowledge, we have dreamed of our place in the world and imagined the future into being. By inventing a future, we could look ahead, we could see where dangers and opportunities lay and recognized that our actions would have consequence in that future. Foresight gave us a leg up and brought us into a position of dominance in the world. I think now we are at that position of time where foresight is especially important. As we look at all of these things that are influencing not only the future of the wildlife that is the mission and responsibility of my agency, but our life, it seems like it is an especially important time for us to exercise that special human ingredient and characteristic of foresight.

Thank you.

[The prepared statement of Mr. Ashe follows:]

TESTIMONY OF DAN ASHE, DIRECTOR
U.S. FISH AND WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR
BEFORE THE
SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
SUBCOMMITTEE ON OVERSIGHT
REGARDING
NATURAL RESOURCE ADAPTATION: PROTECTING ECOSYSTEMS AND ECONOMIES

February 25, 2014

Chairman Whitehouse and Members of the Committee, thank you for the opportunity to testify before you today on the role and efforts of the U.S. Fish and Wildlife Service (Service), in partnership with other Department of the Interior (Department) bureaus and stakeholders at all levels, to protect ecosystems and other natural resources in the face of climate change impacts.

This hearing comes at a time when the nation's living resources are being impacted by forces acting upon large landscapes and ecosystems such as habitat fragmentation or loss due to land use changes; invasive species; fish and wildlife disease; wildfire, floods, and drought – all exacerbated by climate change. The nation's natural resources, including water, fish and wildlife, and forests, are among our most valuable economic assets. Our natural heritage, including hunting, fishing, and outdoor recreation are being threatened by these impacts at landscape and watershed scales that cross multiple Federal, State, Tribal, and local management jurisdictions.

Impacts of Climate Change on Natural Resources

The Earth's average surface temperature is increasing due to human emissions of greenhouse gases, and this has and will likely continue to erode habitat quality and sustainability for fish and wildlife species and, in some cases, cause abrupt changes to entire ecosystems. From the Arctic to the Everglades to our territories in the Pacific Ocean, these impacts are already affecting local, State, Tribal, regional, national and international economies and cultures.

According to the U.S. Global Change Research Program significant changes in the U.S. climate over the past 50 years have occurred, including increases in average temperatures, shifts in rainfall and storm patterns, increases in wildfires, more frequent water shortages, rising sea levels, loss of Arctic sea ice, ocean acidification, changing precipitation patterns, and coastal flooding and erosion. This has the potential to gradually erode habitat quality and sustainability for fish and wildlife species, and in some cases cause abrupt changes to entire ecosystems. These working landscapes to wilderness areas far from human habitation, impacts can be seen from the Arctic to the Everglades, and across the nation to our territories in the Pacific Ocean, and are already affecting local, State, Tribal, regional, national and international economies and cultures.
As the climate continues to change over the next century, so too will the effects on species, ecosystems, and their functions.

Climate change is now among the greatest challenges facing the conservation of our native species, and it is contributing to dramatic changes in the habitats they need for breeding, migrating, and wintering. Over time, climate change is impacting the dynamics of wildlife disease, increasing the threat to biodiversity. As the Earth warms, ecosystems adapted to cooler climates are altered in important ways, creating new habitat for some species and reduced habitat for others. Species distribution shifts in response to climate change can lead to a number of new challenges for natural resource managers, such as the arrival of new pests, the disruption of ecological communities and interspecies relationships, and the loss of particularly valued species from some areas. Warmer temperatures, be they in the Spring, Summer, Fall, or Winter cause change to plant communities and shorten insect life cycles. This leads to the annual appearance of these important food sources to being out of sync with bird migration and breeding cycles; this means less opportunities for bird watchers and hunters to enjoy our natural heritage.

National Wildlife Refuges along our nation's coasts are losing habitat to sea level rise. A host of species, from birds to mammals to fish and reptiles, are losing their homes. Dramatic and measurable loss of sea ice is impacting wildlife in the northern latitudes, where the impacts of climate change are most profound. Areas of the nation are experiencing extreme drought, which, while not entirely due to climate change, starkly illustrates the linkage between climate water availability and the sustainability of fish and wildlife.

Climate adaptation is defined by the Intergovernmental Panel on Climate Change (IPCC) as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Most simply, climate adaptation means helping people and natural systems prepare for and cope with the effects of a changing climate. Integrating and coordinating adaptation planning efforts among government and nongovernment sectors can help decrease the risks and impacts of climate change on our natural resources, communities, and economies.

Coordinated Action to Address the Need for Adaptation

Over the past decade, there have been an increasing numbers of calls for action by government and nongovernmental entities to better understand, prepare for, and cooperatively address the impacts of climate change on natural resources and the communities that depend on those resources. For example, in 2007 the U.S. Government Accountability Office released a study entitled: *Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources*, recommending that guidance and tools be developed to help Federal natural resource managers incorporate and address climate change into their resource management efforts. In 2008, the U.S. Global Change Research Program released the report: *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*, which called for and identified a variety of new approaches to natural resource management to increase resilience and adaptation of ecosystems and resources.

More recently, the President's Climate Action Plan (Plan) released in June 2013 serves as a blueprint for responsible national and international action to slow the effects of climate change using existing authorities. Building on efforts underway in States and local communities across the country, the Plan describes the regulatory activities aimed at reducing carbon pollution while helping the nation prepare for, and reduce, future impacts. The Plan's recognition of the importance of protecting natural resources and promoting resilience in fish and wildlife and their habitats is an integral part of our nation's comprehensive response to climate change. Given the disruption that a changing climate implies for our mission, the Service is committed to meet the goals of this important Plan by continuing to reduce our carbon emissions, implement adaptation measures, and engage our key stakeholders and constituencies. On November 1, 2013 the Administration released Executive Order (EO) 13653: Preparing the United States for the Impacts of Climate Change. In response, the Department is now working to update its Climate Change Adaptation Plan and assess how policies, programs, and regulations need to change to become more resilient to climate change, among other activities.

Adaptation forms the core of the Service's response to climate change and means strategic, science-based management actions, including regulatory and policy changes that will help reduce the impacts of climate change on fish, wildlife, and their habitats. It is also the centerpiece of Department's Secretarial Order 3289.

Department of the Interior Secretarial Order 3289

In 2009, then Secretary of the Interior Ken Salazar signed Secretarial Order 3289, which established a Departmental Climate Change Response Council (Council) to "execute a Department-wide strategy to increase scientific understanding of and development of effective adaptation management tools to address the impacts of climate change on cultural and natural resources." Composed of the Secretary, the Deputy Secretary, Counselor to the Secretary, Assistant Secretaries, and the Solicitor, the Council was assembled to coordinate the climate change adaptation response efforts of its agencies and Bureaus, and the Secretarial Order commits the Department to working with other, relevant Federal agencies. The Secretarial Order also requires the Departments agencies and bureaus to consider and analyze climate change impacts when engaged in long-term planning, setting priorities for scientific research, or making major decisions about the use of Departmental resources. Specifically regarding adaptation to climate change, the Secretarial Order requires Department decisions with regard to climate change adaptation be informed by science, and it directs the establishment of the Landscape Conservation Cooperatives (LCCs) and regional Climate Response Centers, which have become the Department's Climate Science Centers, managed by the U.S. Geological Survey (USGS).

The Department's climate change adaptation policy was issued in the Department Manual in December of 2012 (523 DM 1). The policy provides guidance for addressing climate change impacts upon the Department's mission, programs, operations, and personnel. The Service is currently working to step down this policy into bureau-level guidance on climate change, and has completed an initial policy (056 FW 1) designating responsibilities and expectations related to climate adaptation.

National Fish, Wildlife and Plants Climate Adaptation Strategy

In March of 2013, the National Fish, Wildlife, and Plants Climate Adaptation Strategy (the Strategy) was released. As the accompanying Federal Register notice (April 1, 2013) states: "This Strategy presents a unified approach—reflecting shared principles and science- based practices—for reducing the negative impacts of climate change on fish, wildlife, plants, our natural resource heritage, and the communities and economies that depend on them. The Strategy provides a basis for sensible actions that can be taken now, in spite of the uncertainties that exist about the precise impacts of climate change."

Development of the Strategy was co-led by the Service, the National Oceanic and Atmospheric Administration (NOAA), and the New York State Department of Environmental Conservation, representing state fish and wildlife agencies. It was developed in response to a request in the Conference Report for the FY 2010 Interior, Environment and Related Agencies Appropriations Act (House Report 111–316, pages 76–77) for the White House Council on Environmental Quality (CEQ) and the Department of the Interior to: ''develop a national, government-wide strategy to address climate impacts on fish, wildlife, plants, and associated ecological processes'' and ''provide that there is integration, coordination, and public accountability to ensure efficiency and avoid duplication.'' In addition, CEQ's Interagency Climate Change Adaptation Task Force supported this request and called for the development of a climate adaptation strategy for fish, wildlife, and plants in its 2010 Progress Report to the President.

The Strategy was developed in coordination with other Federal adaptation efforts such as the National Ocean Policy Implementation Plan and the National Freshwater Action Plan (Priorities for Managing Freshwater Resources in a Changing Climate) , and it draws from existing adaptation efforts by States, Federal agencies and others. Its premise is that no single entity or level of government can safeguard wildlife and society against the effects of climate change. It does not prescribe any mandatory or regulatory requirements, but is designed to coordinate government-wide fish and wildlife climate change adaptation efforts and to build on growing efforts outside the Federal and State fish and wildlife governments to understand, track, and reduce impacts of a changing climate on the nation's valuable fish, wildlife, and plants. It outlines a roadmap of key steps needed to help safeguard the nation's natural resources in the face of these challenges. This Strategy is a key component of the growing effort by Federal, State and Tribal governments and non-governmental entities to reduce the risks and impacts of climate change.

The Strategy was developed with input from a wide variety of sources, with multiple opportunities for public input, and was shaped by comments from more than 55,000 Americans. In addition to describing the impacts of climate change on fish and wildlife, the Strategy identifies seven key steps, or goals, to help safeguard the nation's fish, wildlife, and plants in a changing climate. These seven goals are

- Goal 1: Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.
- Goal 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.
- Goal 3: Enhance capacity for effective management in a changing climate.
- Goal 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.
- Goal 5: Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate.
- Goal 6: Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate.
- Goal 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

The Strategy also describes opportunities for numerous sectors to address these challenges and then describes how its goals and strategies may be implemented with coordination across the Federal government, States, and other entities. It provides guidance about what further actions are most likely to promote natural resource adaptation to climate change, and describes mechanisms that will foster collaboration for effective action among all levels of government, conservation organizations, and private landowners.

The Service is now co-leading a Joint Implementation Working Group (JIWG) to promote implementation of the Strategy. Our partners are NOAA and the Association of Fish and Wildlife Agencies (AFWA). The White House Council on Environmental Quality is also supporting this effort. The JIWG includes representation from most of the agencies that participated in development of the Strategy (15 Federal, 5 State, and one inter-Tribal commission) and will be responsible for reporting on implementation and for future revisions of the Strategy. The Service will continue its dual role of implementing the Strategy within its own programs, and also working with the many other agencies that need to be involved in Strategy implementation through the JIWG.

Strategic Habitat Conservation and Landscape Conservation Cooperative Network

Complex and persistent challenges, like climate change, have led the Service to re-assess how best to meet our goals under our mission, which is *"working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people."* The agency's traditional focus has been to conserve fish and wildlife resources in the face of anthropogenic activities that threaten their sustainability. In modern times, the threats to the sustainability of fish and wildlife populations are much more diffuse and, in many cases, result from cumulative impacts caused by stressors such as habitat loss and climate change.

The Service's response to this has included the adoption of Strategic Habitat Conservation as our core conservation approach for sustaining populations of fish and wildlife. This is in the context of landscape and system sustainability, and led to the establishment of the Landscape Conservation Cooperative (LCC) Network to apply public-private partnerships that can support conservation planning, implementation, and evaluation at landscape scales. With the signing of Secretarial Order 3289, the Department launched the LCC Network to better integrate science and management to address climate change and other landscape scale issues. Holistic, collaborative, adaptive, and grounded in science, LCCs are working to ensure the sustainability of our, land, water, wildlife, and cultural resources. Twenty-two LCCs across the nation, working within their respective landscapes and collaborating across their geographic boundaries, collectively form an integrated network of resource managers and scientists who share a common need for scientific information to achieve their individual and shared goals of conserving our nation's natural heritage.

Taken together, and working within the larger conservation community, Strategic Habitat Conservation and the LCC Network will improve the necessary collaboration that enables private, State, Tribal, and Federal conservation infrastructure to operate as a networked, leveraged system.

Landscape Conservation Cooperatives

Habitat loss and fragmentation through land conversion, fire, floods and drought, invasive species, and other watershed and landscape-level threats to fish and wildlife is being exacerbated by global climate change. This has made it necessary for the Service to make an important and really historic shift in our approach to conservation from a single species, parcel-by-parcel, threat-by-threat management agency toward collaborative, cross-jurisdictional work through LCCs and other partnerships. These broader, more inclusive approaches help us better understand and then meaningfully and strategically reduce widespread threats at the landscape level. The traditional jurisdictions of local, State, Tribal and Federal agencies over land and wildlife can fragment conservation efforts. With limited funding and resources, the cost of securing and applying the necessary science to understand how these many stressors are affecting natural resources and what can be done to help them adapt must be pooled among government agencies and leveraged with non-government funds where possible.

The LCCs are self-directed, applied science conservation partnerships that build a shared view of landscape conservation science needs across Federal, State, Tribal, and local agencies and nongovernmental organizations. The LCC forum supports collaborative conservation partnerships that define, share and acquire science and management tools, including research, monitoring, and conservation planning and design, and decision-support tools. The resulting data, information, knowledge, and tools can be applied by resource or land management agencies and private landowners to build resilience to climate change impacts and other landscape-level threats. Resource management entities using these products can then monitor, re-evaluate and adapt them to better fit changing resource needs, landscape conditions, or just to improve their application. Partners in the LCCs bring resources to the projects selected by the LCCs, thereby leveraging the Federal investment and ensuring meaningful partner investment in this collaborative approach. With the size of conservation challenges presented by climate change and other forces on the landscape, no one agency or land manager can fully conserve our natural resources and their benefits to our economy alone. We cannot afford to act in isolation, risking wasteful redundancies and significant gaps in the science and the applied management that must consider the larger threats to ecosystems that threaten our valuable living and cultural assets. By focusing multiple management agencies and private efforts on the highest priority conservation issues, the Department expects to be able, in the long term, to demonstrate new efficiencies in the management of natural resources through the LCCs.

The work of LCCs is informed by the Department's Climate Science Centers (CSCs) and many other scientific institutions. These 22 forums are unique in the conservation world and directly address congressional mandates to improve efficiency, reduce duplication, and coordinate among the diverse set of agency programs operating at multiple levels. LCCs do not duplicate other regional, cooperative conservation partnerships, like the Joint Ventures for Migratory Birds or the National Fish Habitat Partnerships, which are comprised of entities that determine conservation priorities and implement them on the ground. Rather, LCCs provide a forum for these conservation partnerships and other management entities to determine the higher-level science needs to inform their work and to help their applications adapt as new information is collected and applied to their efforts.

Examples of the work of LCCs include the development of a critical tool for understanding how climate change will affect protected areas and native island species by the Pacific Islands Climate Change Cooperative. This vulnerability assessment measures the risk that climate change poses to more than 1000 plant species native to Hawaii, helping State and Federal managers with native plant conservation by revealing which plant species are at highest risk from climate change, which areas to protect as future habitat, which protected areas will lose species, and which species will benefit most from stronger management in the present. In addition, the Upper Midwest and Great Lakes Landscape Conservation Cooperative, along with other partners, has identified opportunities to optimize connectivity in the Great Lakes Basin to restore native fish migrations, while controlling invasive species. This project has resulted in identification of more than 270,000 potential barriers and an initial optimization model that identifies those barriers in which removal would provide connectivity to the most tributary distance given a certain budget.

Like many LCCs, the North Atlantic LCC is fully supporting implementation of the National Fish, Wildlife and Plant Climate Adaptation Strategy. Because effective adaptation begins with understanding how the landscape is changing, the LCC is developing information and tools that assess the combined impacts of climate change (temperature, precipitation, sea level rise, floods) and urban growth on natural resources in the Northeast. In addition, the LCC is working with Northeast Region States to develop habitat classifications and maps, regional species and habitat vulnerability assessments, frameworks for modeling landscape change, assessments of regional species of concern and other decision-making tools. These tools collectively will create a landscape conservation design "blueprint" for the region that provides broader context for State and local conservation decisions and actions. The LCC is now putting these tools into action through a comprehensive landscape design effort with North Atlantic LCC partners in the Connecticut River watershed – about 400 miles long and 7.5 million acres – to conserve, connect and restore habitats and natural systems that sustain fish, wildlife and people. What we achieve and learn with our partners in this pilot geography will be refined and applied in landscapes throughout the Northeast. The information and tools being developed through the LCC are providing regional context for updating State Wildlife Action Plans so that States can understand (and reflect in their updated plans) their best contribution to regional conservation as well as their best response to the challenge of climate change.

The Inter-LCC Greater Sage Grouse Initiative in partnership with the Western Association of Fish and Wildlife Agencies has led to many important developments, including an enhanced working relationship with the western States. This multi-LCC project is characterized by: collaboration among management entities at range-wide and LCC scales; coordination of planning, implementation, and evaluation to increase efficiency and reduce redundancy; development of science-based decision support tools; and shared access to sage-grouse data through a common data portal which allows State and Federal managers to work from the same information for interpretation of current and future habitat and population conditions.

The Great Northern LCC (GNLCC) is working with cooperators to assess and develop wildlife corridors at the regional, ecosystem, and local scales. For example, they support the Western Governors' Association (WGA) Crucial Habitats and Corridors Landscape Integrity and Connectivity analysis across 18 western states; provide funding for the Washington Wildlife Habitat Connectivity Working Group to complete wildlife corridor analyses for 16 focal species throughout Washington and in the Columbia Plateau region across Oregon and Washington; support the Crown Managers' Partnerships in analyzing and mapping connectivity in the Crown of the Continent; collaborate with the America's Great Outdoors Crown Demonstration Landscape Team to improve connectivity across roads in the Crown; and support a collaborative Land and Water Conservation Fund Proposal in the Idaho-Montana Divide area to improve wildlife connectivity between Yellowstone Park and the Central Idaho Wilderness. Species that stand to benefit from this work include grizzly and black bears, elk, wolverine, mule deer, cutthroat trout, bull trout, and many others. The Great Northern LCC has, in collaboration with the USGS, also developed LC-MAP, a virtual database and shared collaborative workspace that allows partners to share, access, and analyze common datasets and information to further coordinated research, management, and resource conservation. The GNLCC recently received a grant to integrate LC-MAP with the WGA Crucial Habitat Assessment Tool (CHAT) system. This LCC, which covers portions of Montana, Idaho, Oregon, Washington, and Wyoming, has 25 partner organizations on the Steering Committee and over 50 organizations participating in regional conservation forums.

South Atlantic LCC staff are working closely with a multitude of resource organizations and several interdisciplinary teams to complete a shared conservation blueprint for the multi-State LCC geographic area, due in 2014. This will provide an actionable and spatially-explicit map depicting the places and actions needed to sustain ecosystems of the southeastern US in the face of future change.

The self-directed working group model presented by the LCCs is an effective and efficient approach to testing, adapting, and delivering the science and conservation tools necessary to meet modern conservation challenges with the biggest value for the use of public and private funds contributed to their work.

Agency Implementation of Cooperative Adaptation Approaches

Sea Level Rise: At Alligator River National Wildlife Refuge on the North Carolina coast, the North Carolina chapter of The Nature Conservancy (TNC) and the Service have forged a partnership to evaluate the effects of different adaptation strategies on areas impacted (or likely to be impacted) by sea level rise. This project is also supported by a $1 million donation from Duke Energy, a $250,000 private donation, a Southeast Aquatic Resources Partnership Community-based Restoration Program grant, a NOAA Community-based Restoration Program grant, and several other smaller donations. The project managers have engaged with local communities, fishermen, NGOs, State and Federal agencies, and the general public to educate them on the project through public meetings, volunteer involvement, and other outreach activities.

This refuge encompasses about 154,000 acres on the Albemarle Peninsula in North Carolina, where sea level rise is the primary climate change impact of concern. This vulnerability is exacerbated by human alterations to the system, including an extensive network of drainage ditches used for agriculture and forestry. Sea level rise will in turn intensify other problems such as shoreline erosion, saltwater intrusion, and biodiversity loss. The strategies this partnership is testing include constructing oyster reefs to buffer shorelines from waves and storm surges, restoring the natural hydrologic regime and associated wetland systems, and planting salt- and flood-tolerant species. Successes would include reductions in the rates of ecosystem change, shoreline erosion, saltwater intrusion, and land subsidence, and an increase in the growth and survivability of salt- and flood-tolerant plant and tree species.

The Blackwater Climate Adaptation Project is a partnership between The Conservation Fund, Audubon Maryland/DC, and the U.S. Fish and Wildlife Service supported by a grant from the Town Creek Foundation. Our objective is to ensure the long-term persistence of high tidal marsh habitat in Dorchester County, MD, together with its full assemblage of associated bird species, as well as Chesapeake Bay fisheries that depend on these wetlands for shelter and food. Rapid sea level rise threatens the survival of this ecosystem during the current century. This Assessment is the first step toward developing a sea level rise adaptation strategy and corresponding actions to conserve the tidal marshes of Blackwater for the long term.

Northeast Biological Toolbox: In collaboration with Federal and State partners as well as non-governmental conservation organizations, the Service is developing and implementing tools to predict the effects of climate change and inform future management plans. In the Northeast, this includes a vulnerability assessment for shorebird habitat, created in partnership with the Manomet Center for Conservation Sciences and designed for refuge managers to determine the vulnerability of their sites to climate change and consider what options are available to best maintain shorebird habitat. The assessment is being implemented currently at Monomoy (Massachusetts), Chincoteague (Virginia), and E.B. Forsythe (New Jersey) National Wildlife Refuges.

Conclusion

The Service's responsibilities cover a wide range of natural resources that are to be preserved, protected, managed, and made available for public use through Federal statutes. Many of these resources are managed for public use because of their importance to the national economy. In fact, it could be said that the abundance of natural resources in the United States has contributed to our global economic leadership. We recognize the importance of these resources to a range of economic sectors, and we know that climate change is already and will continue to impact their availability for current and future generations of Americans.

With Congressional support, the Department created strong networks to deliver the science and adaptive conservation actions needed to protect our native ecosystems, living resources, and their economic benefits to a wide range of commercial and public interests. In closing, I would like to thank the Sub-Committee and Senators Whitehouse and Baucus for their leadership in designing and promoting both the need and the necessary approaches to accomplish this important task.

Senator WHITEHOUSE. Thank you, Director Ashe.

How would the capacity of our human brain exercise its God-given quality of foresight be influenced in your world, in protecting our natural resources, if we fail to acknowledge the reality of climate change?

Mr. ASHE. It cannot be, if we do not acknowledge the reality of climate change. I think in what we are doing in the Fish and Wildlife Service, you acknowledged, one, the National Fish, Wildlife and Plants Climate Change Adaptation Strategy. We are working with our State partners, with our tribal partners, with local partners to think about the future and to plan for that. Some of the steps are simple, that we need to learn more, we need to understand more about the effect of a changing climate on populations. We need to be able to anticipate more. We are developing a national and international network of landscape conservation cooperatives, a partner-driven, partner-managed scientific enterprise. We are working to conserve and connect large landscapes, to build a representative, resilient and redundant conservation network. And we are doing that not just with environmental community partners like the Nature Conservancy or Defenders of Wildlife, we are doing that with energy industry partners. So simple common sense steps to make a difference.

Senator WHITEHOUSE. As was the case with Mr. Holdren, Director Ashe, your full statement will be made a matter of record here. You State in it, according to the U.S. Global Change Research Program, significant changes in the U.S. climate over the past 50 years have occurred, including increases in average temperatures, shifts in rainfall and storm patterns, increases in wildfires, more frequent water shortages, rising sea levels, loss of arctic sea ice, ocean acidification, changing precipitation patterns and coastal flooding and erosion.

Is that a matter of theory or is that at this point a matter of observation?

Mr. ASHE. Those are all matters of observation, sir.

Senator WHITEHOUSE. Dr. Holdren, the President recently announced plans for a billion dollar climate resilience fund that is meant to help communities deal with harms from extreme events due to climate change. Can you talk a little bit about how these resilience measures, completed before or in the recovery phase of a natural disaster, actually save money in the future? We have lived through this question with Sandy in New England and I would like to have your comment on that.

Mr. HOLDREN. First of all, we know of course that events like Sandy are immensely expensive. We also know from both experience and analysis that prevention of damage is almost always considerably less expensive than rebuilding after the damage or otherwise trying to repair it.

In the natural resource context that is the particular focus of this hearing, we know that community resilience, the resilience of human communities, depends in many respects on ecosystem resilience. The declines in benefits provided by ecosystems, including as a result of climate change, have direct and indirect impacts on livelihoods and the economy of communities. Loss of coral reefs due to bleaching and disease means losses of revenue for the tourism industry as well as declines in reef-dependent fish species that have commercial value.

Again, almost invariably, when you count up the cost of allowing this damage to continue unabated versus the cost of intervening to reduce the damage or increase resilience to protect against it, you find that these investments are a bargain. That is why the President has proposed his billion dollar climate resilience fund. It will be a bargain.

Senator WHITEHOUSE. Thank you very much.

I will yield back my time to our distinguished ranking member.

Senator INHOFE. Thank you, Mr. Chairman.

Mr. Ashe, I said in my opening statement I have been concerned that the Service has been giving preferential treatment under the Endangered Species Act to renewable energy producers when compared to those of traditional fuels. I know we have talked about this before. But this is particularly problematic in Oklahoma with the American burrowing beetle. You and I both know that the oil and gas industry is the source of most economic activity there. But because there isn't a general conservation plan in place, most of this new activity has been curtailed. It is my understanding that a new general conservation plan is under development.

You are a good friend of Richard Hatcher in our State of Oklahoma and you have visited extensively with each other. He is our director of the Oklahoma Department of Wildlife Conservation. And he asked if it would be possible to allow modified conservation practices until a new GCP is completed, which is expected to be later this year. What would be your answer to that? Would that be possible?

Mr. ASHE. Thank you, Mr. Inhofe. Mr. Hatcher is a great American and a great friend. I think we are working on an interim plan for the American burrowing beetle. In fact, people are meeting today, I am told, in Oklahoma with the State and with representatives from the energy industry to try to find a solution while we work on the larger general conservation plan.

So Senator, we are committed to trying to find a solution. It is surprisingly vexing, I have to admit. But we are working to try to find an interim solution, and conversations are literally going on as we speak. I am hopeful that by the spring we will have identified a solution.

Senator INHOFE. The question, though, that he asked was, would it be possible to go ahead and address this thing, possible to allow maybe a modified conservation practices until the new plan is completed. I think as you just now said, it is expected to be completed soon. It is very close right now. So in the interim period, that is the concern he was asking about.

Mr. ASHE. I would have to talk to Richard specifically about his ideas. I have not had a chance to do that.

Senator INHOFE. OK, that would be good. That is fair enough, you would do that.

I think most of our conversation has been around the Lesser prairie chicken. This is something that has been of great concern in the State of Oklahoma and about a four-State area, New Mexico, Kansas and Texas and Oklahoma. From what I understand, we are in the very final stages of giving final approval to the oil and gas

CCAA and acres are being enrolled in the State-based range-wide plan.

I recently wrote you a letter asking if you would allow enrollment in the CCAAs beyond a listing decision. This is important because we are about a month away from the deadline. It often takes several weeks to complete the enrollment process. Enrollment can't be done until the CCAA is finalized. Would you allow a post-position enrollment?

Mr. ASHE. I cannot do that. Our expectation, Senator, is that the Candidate Conservation agreement will be completed this week, by Friday of this week. So we will have a completed instrument and sign-ups can begin.

If we were to list the Lesser prairie chicken, then it would no longer be a candidate. So it would not be appropriate for people to sign——

Senator INHOFE. So you are saying you cannot do it, even if you are willing to do that?

Mr. ASHE. We cannot do it.

Senator INHOFE. If we were to find that you can do it, then would you reconsider that? Because we are right down now to the deadline. The time is on us now.

By the way, I have to say this, for this committee, how much I appreciate the fact that you in your confirmation made an agreement to come out, talk to our people about the cooperative plans that we have, the partnership plans that we have in Oklahoma.

Mr. ASHE. Thank you, sir.

Senator INHOFE. You did it not only once, but twice. So I thank you very much for that.

So far to my understanding, several hundred thousand acres have been enrolled in the RWP, 4 million are in the queue. And between 5 million and 6 six million acres will be enrolled in the CCAA in the first week following its approval. Are you encouraged by what you have seen, are seeing from the conservation standpoint with the range-wide plan and the CCAAs?

Mr. ASHE. I am greatly encouraged, sir.

Senator INHOFE. Now, there isn' time, my time has expired, but let me just take a little bit, because there is a new critter coming I wasn't even familiar with, and that of course is the northern long-eared bat. I figured beetles and Lesser prairie chickens would be enough, and now we are concerned with this. Apparently this affects some 39 States.

It has come to our attention that the Service issued guidance requiring Section 7 conferencing reviews for the projects proposed to take place in the species range which is, as I said, affects now 39 States, is that right? About 39 States. This has occurred despite the fact that the species has only been proposed as an endangered species. That determination has not yet been made. It is also my understanding that these Section 7 reviews are only allowed prior to a listing when a project is going to jeopardize the existence of the species across the entire range. Can you explain to me why the Service is doing this, and isn't it getting ahead of itself? By the way, of the 39 States, everyone at this table here is one of the 39 States.

Mr. ASHE. Senator, I will have to get back to you on the details related to the long-eared bat. I am not intimately familiar. I would say we cannot, or we do not and cannot require consultation prior to a listing. Consultation is a formal, statutorily required commitment on the part of the Federal agency once a species is listed.

We sometimes do what we call conferencing on a candidate species, which is a voluntary process to provide advice and guidance. With regard to the lesser prairie chicken, for instance, we have done a conference with the Natural Resource Conservation Service, which has allowed us to provide certainty to landowners that sign up and implement best conservation practices for lesser prairie chicken. We have done the same thing for sage grouse. So sometimes we do conferencing informally to encourage investment in conservation before a species is listed, but we can't require consultation.

Senator INHOFE. Yes. I know my time is expired, but when you talk about the burrowing beetle and the lesser prairie chicken, it really is only in a smaller number of States. This apparently affects a large number of States.

I also want to take advantage of the opportunity to welcome my good friend Senator Markey from Massachusetts. He and I have gone around and around in debates for the last 12 years. We have always maintained a very good relationship and friendship. I appreciate your adding your expertise to this committee, Senator Markey.

Senator WHITEHOUSE. And indeed, it is Senator Markey's turn, so I recognize him for his first appearance in this committee. We will miss Senator Baucus, but he has certainly been replaced by a very prominent figure in the environmental cause. I am delighted to have Ed Markey with us. The floor is yours, Senator.

Senator MARKEY. Thank you, Mr. Chairman, very much. I am looking forward to learning a lot about these issues. I am familiar with many of them, after 37 years on these committees. Senator Inhofe and I, we started back in 1987 having these conversations, when we joined the House of Representatives. So we are 27 years now into our conversation.

Senator INHOFE. But neither one of us has moved yet.

Senator MARKEY. My father always said that when two people agree upon absolutely everything, you don't need one of those people. So we are both needed here. We are needed for this conversation. We have to just continue to have it, and I thank you, my friend, Jim Inhofe, for all these years.

Chairman Whitehouse, thank you for all your leadership on the issues. I am looking forward to working with you and Chairman Boxer and all the members of the committee to work on these issues that are so central to the health of our economy and the health of the citizens of our Nation, whether it is rebuilding roads or reducing the impact of what comes out of the tailpipes of the cars that drive on them, the work of this committee is crucial to driving the United States economy.

Today's hearing is examining one of the major risks to America's environmental and economic health climate change. It is having tangible impacts in Massachusetts right now. My State loses land to rising sea levels every year. Our iconic cod have been moving north as ocean temperatures warm and are contributing to the extreme economic challenges facing Massachusetts fishermen and the coastal communities that depend upon them.

Thankfully we already have many of the tools needed to prepare for the impact of climate change and reduce the risk in the future. Building upon natural coastal defenses will not only help protect infrastructure on land but also provide benefits for the fishing and tourism industries. Increasing the efficiency of our energy and water use can help respond to climate change and lower utility bills for our homeowners at the same time. Addressing climate change means capitalizing on the trillion dollar clean energy opportunity that exists. Cleaning up and fortifying our aging, polluting energy infrastructure could be the job creation engine of our time. Eighty thousand Americans are already employed in the wind sector in our Country. That is about the same number of people that mine coal in our Country today.

Solar is one of the fastest-growing sectors of our economy, 142,000 Americans are employee in solar, 24,000 new solar jobs added to our economy last year. These are high-wage jobs, $23 an hour on average. These are International Brotherhood of Electrical Workers jobs, these are roofer jobs, these are jobs that our soldiers are learning how to do when they return home. It has been clear for years that we need to invest in America's resilience to climate change and our clean energy economy. Building climate-smart infrastructure and more wind and solar capacity will create jobs that are good for saving creation at the same time.

Now, Dr. Holdren, let's start with a basic analogy. If the current State of scientific understanding of human beings' influence on climate change is like a jigsaw puzzle, are most of the pieces still in the box or have scientists put enough together to establish what the picture is?

Mr. HOLDREN. I would say that most of the major pieces are in place. We have an increasingly clear picture of how human activities are influencing the global climate. That picture has been reflected in not only the reports every several years of the Intergovernmental Panel on Climate Change, contributed to by hundreds of climate scientists from around the world, but regular reports by our National Academies of Science, the academies of science of every other major country that has an academy of science. And the basic picture is that we know without question that the climate of the earth is changing in ways that stand out sharply against the backdrop of natural variations that have operated over millennia. We know with very high confidence that the principal driver of these recent changes has been human activities, above all, the emission of heat-trapping substances, carbon dioxide, methane, nitrous oxide, black soot and others.

And we know with high confidence that those changes in climate are already causing harm to human well-being in many forms and many places. A number of them have been referred to already. There are uncertainties surrounding the quantitative details in many cases. Climate scientists are well aware of the importance of measuring and quantifying uncertainty and working to reduce it over time. But the uncertainties and the details that are not yet well understood do not obscure, do not implicate those fundamental understandings which I just summarized.

Of course, we also work hard to try to create where we are headed as well as where we have been. And that is harder. As often has been said, predictions are difficult, particularly about the future.

Senator MARKEY. Yogi Berra.

Mr. HOLDREN. Yogi Berra. The uncertainties are greater looking forward than in trying to match our understanding with what has happened in the past. But we can have high confidence that as long as the buildup of greenhouses gases continues that the kinds of disruption of global climate that we have seen already will only grow. And the dimensions of the damage to human well-being associated with that will grow apace.

Senator MARKEY. And I agree with you, the impacts are going go become more severe, the solutions are going to be more costly. We have to basically accept the fact that the pieces of the puzzle are in place.

I thank you, Mr. Chairman.

Senator WHITEHOUSE. Senator Vitter.

Senator VITTER. Thank you, Mr. Chairman. I would just ask unanimous consent that my opening statement be in the record.

Senator WHITEHOUSE. Without objection.

Senator VITTER. Thank you. And thank you, gentlemen, for being here, and for your work.

Director Ashe, I wanted to ask you, is your agency currently engaged in consultation related to the EPA's proposed New Source Performance Standards for power plants?

Mr. ASHE. We are engaged in consultation with EPA over their proposed rules under Section 316(b), the Clean Water Act, yes.

Senator VITTER. And how would you describe that level of consultation? Is it the formal consultation process?

Mr. ASHE. It is a formal consultation process, yes, sir.

Senator VITTER. And how extensive has that been specifically with regard to New Source Performance Standards for power plants?

Mr. ASHE. I am not certain how to answer your question. I am not sure what you are looking for. We have been engaged in conversation with EPA.

Senator VITTER. Let me back up, because I think we are talking about two different things. I am talking about New Source Performance Standards for power plants, which is separate from 316(b). So with regard to endangered species, are you engaged in consultation with EPA on New Source Performance Standards?

Mr. ASHE. I do not believe that we are, sir. I will have to check and make sure of that, but I do not believe that we are.

Senator VITTER. If you can check and submit that follow—up for the record. Assuming you are correct, and you are not, why aren't you? You don't think this has any potential impact on endangered species?

Mr. ASHE. The obligation for consultation, Senator, is on the action agency. So EPA would determine whether a consultation was necessary and they would provide us with a biological assessment, which then would be the basis for a biological opinion. So your question is appropriately directed to the action agency.

Senator VITTER. OK, I will direct it to them. But I would point out that, for instance, in contrast to that, you are definitely involved in Section 7 consultation, for instance, in the cooling water intake rule of EPA.

Mr. ASHE. Correct, 316(b).

Senator VITTER. Was that initiated by EPA?

Mr. ASHE. It was.

Senator VITTER. OK. Now, I would also point out, in that scenario, they are considering alternatives, all of which, both of which, I think there are two big alternatives, have a beneficial impact on endangered species. The discussion is more or less how big the beneficial impact is, is that correct?

Mr. ASHE. No, sir, the discussion is that permit framework under Section 316(b) would authorize the use of cooling waters, which will have a significant effect on threatened and endangered species. So the discussion is about minimizing and avoiding those potential impacts and reasonable and prudent measures that the EPA and State-delegated programs could take.

Senator VITTER. The point is, all the alternatives being considered are benefits compared to the status quo on endangered species.

Mr. ASHE. That is the purpose of a consultation, is to determine and to determine what measures can be taken by EPA within its Clean Water Act authorities to avoid and minimize the take of endangered species. Probably, sir, since the 1970's and the passage of the great environmental laws in the 1970's, everything the government does makes life better under the Clean Water Act, under the National Forest Management Act, under the Clean Air Act. The question is not whether it is one increment better. The question is, can EPA within its discretion undertake reasonable and prudent measures to improve the likelihood that species will be recovered.

Senator VITTER. Let's go back to that standard with New Source Performance Standards. Because New Source Performance Standards fundamentally are going to shift power supply sources for energy. And to the extent it shifts it, for instance, to wind, it takes up a whole lot more land footprint than existing sources. Is that not likely to have a major potential impact on endangered species?

Mr. ASHE. Again, sir, it is not for me to determine. It is for the action agency to determine in looking at their action. You are asking me a completely hypothetical question.

Senator VITTER. It is not hypothetical. It is going on, and you are the top lead actor in the Federal Government who is supposed to be concerned about endangered species essentially, correct?

Mr. ASHE. I am concerned about them.

Senator VITTER. OK. So it is not hypothetical. The question is, if we are shifting power supply to things that take up a whole lot more land, could that have an impact on endangered species?

Mr. ASHE. It could, theoretically, have an impact on endangered species. It could.

Senator VITTER. Therefore, would it be appropriate in your opinion, I understand you don't initiate this legally, but therefore, as the person who is charged with thinking about endangered species in the Federal Government, would it be appropriate to think about that through a formal consultation process?

Mr. ASHE. It is appropriate any time an action agency is taking an action for them to consider the effect of their action on endangered species. In fact, they have an obligation to do so under the Endangered Species Act. But it is their call.

Senator VITTER. It is the legal responsibility, it is their call. I am asking the question, are they making the right call by not initiating any consultation process with you on the matter?

Mr. ASHE. That is not for me to say, sir.

Senator VITTER. OK. If I could just wrap up, I think it is collectively for us to say, and I think clearly, clearly this major rulemaking has a broad potential impact on endangered species. I think clearly the lack of any consultation is completely inappropriate.

Senator WHITEHOUSE. Senator Sessions.

Senator SESSIONS. Thank you, Mr. Chairman. I appreciate the opportunity to be with the subcommittee.

Thank you both for being here today. Dr. Holdren, you are the Director of the Office fo Science and Technology Policy, called the President's top science advisor, commonly, and it is an important office for sure. I would say you feel a responsibility to accurately tell the American people the challenges and facts dealing with science and technology in America.

Mr. HOLDREN. That is one of my responsibilities. But my first responsibility is giving the President accurate information about science and technology, bearing on his decisions.

Senator SESSIONS. I understand that. On February 14th, during a press conference at the White House, about the President's trip to California, where he was promoting or talking about a new $1 billion drought climate change fund, you stated, a, weather practically everywhere is being caused by climate change.

Mr. HOLDREN. That is not quite what I said, sir, but we will come back to that.

Senator SESSIONS. You said more than that. Then you said "We really understand a number of reasons that global climate change is increasing the intensity and frequency and life of drought and drought-prone regions." Then you talked about "the connection between the increasing frequency and intensity of droughts and climate change." You also asserted that severe droughts are "getting more frequent, they are getting longer, they are getting drier," and that "we have seen droughts and drought-prone regions becoming more frequent and more severe and longer."

Will you stand by that?

Mr. HOLDREN. The one part I don't stand by is the initial quotation, because I said weather practically everywhere is being influenced by climate change, not caused by climate change. And I explained that as well in my opening statement here. What we have done, we have warmed the surface of the earth, we have warmed the surface of the oceans. That is influence climate and is influencing weather everywhere.

Senator SESSIONS. The weather changes, we all know that, it has since time immemorial. But do you stand by your statements that droughts are getting more frequent, and getting longer and they are getting drier and the other comments I made? And if so, cite for us a scientific report or data that supports that.

Mr. HOLDREN. I would be happy to do that. My statement was that droughts are getting more severe in some regions. That is supported by the report of the Intergovernmental Panel on Climate Change 2013. Its science basis supported by the National Climate Assessment——

Senator SESSIONS. No, no, no. What you said, sir, you said, and I am quoting here, the first quote I mentioned did mention drought-prone regions. But you talked about the connection between increasing "frequency and intensity of drought and climate change" and you asserted that severe droughts are "getting more frequent, they are getting longer and they are getting drier."

Mr. HOLDREN. In some regions, and I would be happy to provide you the scientific references. There is a long list of them.

Senator SESSIONS. Well, what about the United States of America?

Mr. HOLDREN. In the United States of America, droughts are getting more severe in the American west and in the Colorado River basin. We are experiencing in the Colorado River basin what looks like probably the most severe drought in a thousand years. California is heading for what looks like one of the most severe drought in 500 years. And the data show that we are experiencing in the western United States, we are experiencing one of the most——

Senator SESSIONS. Well, let me tell you what Dr. Pilkey said, who sat in that chair you are sitting in today just a few months ago, he is a climate impact expert, and he agrees that warming is partly caused by human emissions. But he testified "It is misleading and just plain incorrect to claim that disasters associated with hurricanes, tornadoes, floods or droughts have increased on climate change time scales either in the United States or globally." Dr. Roy Spencer at the University of Alabama testified "There is little or no observational evidence that severe weather of any type has worsened over the last 30, 50 or 100 years." The American Enterprise Institute evaluated the data and the National Oceanic and Atmospheric Administration Palmer Drought Severity Index, are you familiar with that?

Mr. HOLDREN. I am.

Senator SESSIONS. And they concluded "The Palmer Drought Severity Index shows no trend over the record period beginning in 1895 in terms of drought. More areas in the United States have experienced an increase in soil moisture than a decline." And the IPCC of April of last year admitted their previous reports had been in error, stating "Based on updated studies, conclusions regarding global increasing trends in drought since the 1970's were probably overstated." And the congressional Research Service, our own group here, likewise finds that droughts haven't been increasing.

Mr. HOLDREN. On your last point about global drought, of course we know that in a warming world with evaporation increasing, precipitation also increases. More places are getting wetter than are getting drier.

Senator SESSIONS. Oh, so we don't have any drought?

Mr. HOLDREN. So when you say global drought, if I may finish, when you say global drought, you are averaging out the places that are getting drier and the places that are getting wetter. What I am talking about is what has been happening in drought-prone regions. The first few people you quoted are not representative of the mainstream scientific opinion on this point. And again, I will be happy to submit for the record recent articles from Nature, Nature GeoScience, Nature Climate Change, Science and others showing that in drought-prone regions droughts are becoming more intense.

Senator WHITEHOUSE. The record will remain open for 2 weeks after this hearing.

Senator SESSIONS. Mr. Chairman, I thank you and I thank the witness. We expect that a taxpayer paid government official should be very accurate and not advance a political agenda but tell us the absolute facts.

Mr. HOLDREN. That is what I have been doing.

Senator SESSIONS. I look forward to getting that additional information.

Mr. HOLDREN. Happy to provide it.

Senator WHITEHOUSE. Thank you very much, Dr. Holdren. Thank you very much, Director Ashe.

We are pressed for time, because we have a vote at 3:30, so let's see how quickly we can get the next panel on, and I will urge them to be particularly diligent about confining their remarks to the allotted period of time, and we will see if we can get some questions in.

Let's swing right into action. I think you all heard the concerns that I have about our timeframe. We have been squeezed up against a vote that has been scheduled for 3:30. So we are going to have to try to fit in what we can.

Let me start with Mr. Matson, who is the Vice President for Climate Adaptation, at Defenders of Wildlife. He directs Defenders' efforts to create and implement policies and strategies to safeguard wildlife and habitat from the effects of climate change. He has a BS in biology and geology from the University of Rochester, masters in environmental management from the Yale School of Forestry and Environmental Studies, and his masters research focused on biodiversity and management of the National Elk Refuge in Wyoming. Mr. Matson, please proceed. Your full statement will be made a matter of record.

STATEMENT OF NOAH MATSON, VICE PRESIDENT FOR CLIMATE ADAPTATION, DEFENDERS OF WILDLIFE

Mr. MATSON. Thank you, Mr. Chairman, Ranking Member Inhofe. Again, my name is Noah Matson. I am the Vice President for Climate Change Adaptation for Defenders of Wildlife, a national non-profit conservation organization. Thank you for the opportunity to provide input into this important hearing.

Asking your indulgement for a moment, imagine a country where a single storm could kill almost 2,000 citizens and level over $100 billion worth of damage. Imagine a country where the majority of its fruits and vegetables and crops are threatened because of a prolonged drought. Imagine a country where whole villages have to be relocated and escape an eroding coast.

I am not talking about the Philippines, Namibia or the Maldives. All these things have happened or are happening right here in America, where Hurricane Katrina pummeled the Gulf Coast, California's 3-year long drought is shriveling crops and the Alaskan

Native village of Newtok is making plans to move as its coast washes away.

We are woefully unprepared for "natural disasters." Even less prepared as these and other disasters are magnified by a changing climate. Preparing for responding and adapting to the impacts of climate change is a moral and economic issue. Taking reasonable steps now to prepare for the future will save lives, save jobs, save money, save our communities and the nature that supports us.

In preparing for the future we need to look to nature to provide many of the protective services we all need. We can reduce the risk of flooding by restoring flood plains that naturally absorb and slow flood waters. We can reduce the risk of water shortages and water quality degradation by maintaining and restoring watersheds. We can reduce the risk of wildlife by restoring forests near residential areas to more fire-adaptive ecosystems.

Although nature can provide all these benefits to help protect our communities, wildlife and ecosystems are also being negatively impacted by climate change. Dr. Holdren and Dr. Ashe listed many of these impacts, so I won't repeat them. However, I personally have seen the impacts on habitat first-hand in a number of national wildlife refuges, including Prime Hook National Wildlife Refuge in Delaware. In 2009, a storm punched and breached the coastal dunes at the refuge, spraying saltwater into the refuge's freshwater marshes, critical migratory stopover for tens of thousands of ducks, gees and other migratory birds. The saltwater killed the marsh, 4,000 acres in the span of a couple of years, as freshwater marsh grasses were converted to open water, limiting the ability of the refuge to provide for the migratory birds that depends on that habitat.

The good news is the Federal Government, many State and local communities are beginning to plan for the future, a future unlike the past. The Obama administration is taking this issue seriously. Not only is the Administration tackling the causes of climate change head-on, limiting greenhouse gas emissions, the President has also issued an executive order on preparing for climate change.

As described by Director Ashe, the Administration also released the National Fish, Wildlife and Plants Climate Adaptation Strategy. Since wildlife don't know when they have crossed jurisdictional boundaries, the intergovernmental approach is critical if we are going to have any chance of helping species respond to climate change, especially as they attempt to shift their ranges across the landscape.

Despite these important advances, more needs to be done. Specifically, I urge the Congress to enact the Secure America's Future Environment Act. Mr. Chairman, your SAFE Act would protect American communities, wildlife and natural habitat from the increasingly destructive effects of climate change.

Two, providing funding. Congress should provide adequate funding to maintain and expand key Federal programs supporting adaptation efforts and natural resources conservation. Three, we need to prepare better for disasters. Protecting and restoring natural systems is often the least expensive method of buffering communities against disasters, and therefore must be considered in disaster preparation and recovery. Finally, I urge you to protect large connected landscapes to facilitate species movements.

On behalf of Defenders of Wildlife, I thank you for the opportunity to provide this input and I would be happy to take any questions. Thank you.

[The prepared statement of Mr. Matson follows:]

Written Statement of
Noah Matson
Vice President for Climate Adaptation, Defenders of Wildlife

Before the
Oversight Subcommittee
Senate Environment and Public Works Committee
February 25, 2014

Mister Chairman and members of the subcommittee, my name is Noah Matson and I am the Vice President for Climate Adaptation for Defenders of Wildlife. Thank you for the opportunity to provide input to the Committee on "Natural Resources Adaptation: Protecting ecosystems and economies."

My organization was founded in 1947 and is a national non-profit organization with more than 1 million members and supporters dedicated to the protection and restoration of all wild animals and plants in their natural communities. I come before you today to express our profound concern that we stand at a crucial moment in our history when we must act, and act now, if we desire to protect this natural heritage – the nation's diverse fish and wildlife resources.

This hearing couldn't come at a more important time. As a nation we are unprepared for extreme weather events, "natural disasters", and the growing impacts of climate change. Luckily, the federal government, states, and local communities are beginning to take important steps to address this critical issue, but much more needs to be done.

CLIMATE AND EXTREME WEATHER EVENTS ARE ALREADY IMPACTING SOCIETY

Hurricane Katrina sent a wall of water almost 30 feet high crashing into the Gulf Coast, pushing its storm surge 12 miles inland, with disastrous consequences. It was one of our deadliest and costliest storms, responsible for taking almost 2,000 lives and leveling over $100 billion in economic damages. This damage was magnified by overheated ocean temperatures, rising sea levels, and degraded coastal ecosystems that were less able to absorb the powerful storm surge than in the past, not to mention years of ignoring New Orleans and other nearby communities' vulnerabilities to such a storm event. And just last year, Hurricane Sandy inflicted damages almost as great in the Northeast, damaging over 650,000 structures and displacing thousands of residents, many for over a year.

Prolonged drought is crippling the nation's agriculture sector. Drought in 2011 and 2012 cost Oklahoma $2 billion in agricultural losses. The President recently visited California to survey the damage and commit federal resources to addressing the state's historic drought threatening a large proportion of the nation's fruit and vegetable crops. 2013 was the state's driest year on record, a third straight year of drought, and agricultural losses for 2014 are projected to reach $5 billion.

These impacts are only the "tip of the melting iceberg" of extreme events, from massive flooding to massive wildfires, the nation has recently experienced. In 2011, no fewer than 14 extreme-weather-related events—each one causing damages in the billion-dollar range—hit the United States, smashing the previous record of nine in 2008. These are disasters in large part because we have not developed appropriate systems and policies to deal with them, especially disasters that are outside historic average conditions.

ECOSYSTEMS CAN HELP US BE BETTER PREPARED FOR CLIMATE IMPACTS

We need to be better prepared for these and other climate-driven impacts and adapt to the new reality of more extreme weather and the other equally daunting challenges of a warming planet. One response to these impacts is technological – we can build bigger levees, higher dams and stronger seawalls. These might protect some areas from larger rains and floods, but could also put other communities at risk. Higher levees, for instance, funnel more water downstream, resulting in greater flooding there, as well as catastrophic consequences should a levee fail. Moreover, in an era of declining budgets at all levels of government, massive investments in "hard infrastructure" may not be forthcoming even in the face of serious climate threats.

By preserving and rebuilding our "green" infrastructure—floodplains, wetlands, forests and other natural components of our ecosystems that work together as a whole to provide "ecosystem services" such as flood control and water filtration—we can harness nature to help provide protection from extreme events.[1]

Harnessing the power of nature we can:

- Reduce the risk of flooding by restoring floodplains that naturally absorb and slow flood waters.
- Reduce the risk of water shortages and water quality degradation by maintaining and restoring water-system watersheds.

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[1] For more information and detailed case studies of the use of ecosystems for building climate resilience, see Delach, Aimee. Harnessing Nature: The Ecosystem Approach to Climate Change Preparedness. 2012. Defenders of Wildlife. Available at http://www.defenders.org/sites/default/files/publications/harnessing-nature-the-ecosystem-approach-to-climate-change-preparedness.pdf

- Reduce the risk of heat stress associated with heat waves by planting shade trees, replacing impervious surfaces with green spaces and restoring forests near built-up areas to lessen the "heat island" effect.
- Reduce the risk of wildfire by restoring forests near residential areas to more natural fire-adapted ecosystems.
- Reduce the risk of sea level rise and storm surge by maintaining and restoring coastal wetlands and developing "living shorelines" instead of hard seawalls.

Natural ecosystems provide countless benefits and services to the nation, largely unnoticed. According to the Outdoor Industry Association, outdoor recreation alone, enjoyed in natural areas, supports over 6 million jobs and is a $646 billion industry, double the spending on pharmaceuticals ($331 billion).[2] Natural resources conservation supports over 660,000 jobs and stimulates $93 billion in direct economic activity.[3]

Nature matters. We pit jobs and industry versus the environment at our own peril. We directly depend on the environment for our survival, our quality of life, and our economy. We need to take a holistic view when planning for and responding to the impacts of climate change and increased risks of natural disasters.

<u>WILDLIFE AND ECOSYSTEMS ARE FEELING THE IMPACTS OF CLIMATE CHANGE</u>

Nature is also in trouble. Some of the first signs of our changing planet are apparent through changes we are seeing in wildlife populations. It is no exaggeration to say that all of the work that is being done to conserve wildlife and its habitat, in North America and around the globe, is put at risk by the potential consequences to wildlife of climate change.

Species are the proverbial canaries in the coal mine. And it is not just polar bears that are losing ground. For example, moose populations from Maine to Minnesota have plummeted – driven down by warm winters that have allowed ticks and other parasites to thrive.

The impacts on species are often complex. Exotic, introduced mosquitoes in Hawaii are finding more favorable conditions further upslope of Hawaii's volcanic mountains, spreading deadly avian malaria to many of Hawaii's endangered birds. Plants are blooming earlier, like Washington's cherry blossoms, but species that depend on certain flowers aren't always emerging from the winter at the same time causing mismatches in timing of these important life cycle events. Snowshoe hares turn white in the late fall and brown in the spring in response to light, but with winters coming later and snow melting earlier than in the past, researchers are finding white hares on brown earth, making them easy prey.

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[2] Outdoor Industry Association. The Outdoor Recreation Economy. 2012. Available at http://www.outdoorindustry.org/advocacy/recreation/resources.php

[3] Southwick Associations. The Conservation Economy: Direct investments and contributions. 2013. Prepared for the National Fish and Wildlife Foundation. Available at http://www.avcrp.org/wp-content/uploads/2013/04/NFWF-Conservation-Economy-Rpt-Southwick-3-11-2013.pdf

Commercially important species are also in trouble. Oyster farms in the Pacific Northwest saw a 60 percent drop in 2008 and crashed by 80 percent in 2009 as oyster shells were dissolved in the acidic waters created by too much CO2 in the atmosphere. In the Norwest Atlantic Ocean, two thirds of the commercially important fish stocks shifted their latitude and depth significantly between 1968-2007 in response to increased sea temperatures, forcing fishing fleets to shift along with them at great costs.[4]

Habitat is also being lost. In 2009, a storm punched a breach through coastal dunes at Primehook National Wildlife Refuge in Delaware, spilling saltwater into the refuge's freshwater marshes, critical migratory stopover for tens of thousands of ducks, geese and other migratory birds. The saltwater killed the marsh - 4,000 acres of freshwater marsh grasses were converted to open water - limiting the ability of the refuge to provide for the migratory birds dependent on that habitat.

The impacts of climate change on species include:

- Direct effects of higher temperatures
- Sea and land ice and snowpack meltdowns
- Habitat shifts
- Heightened risks from invasive species and disease
- Rising sea levels
- Longer droughts
- Greater extremes in precipitation and/or flooding patterns
- Disruptions to the timing and patterns of seasonal cycles and migrations
- Excess carbon dioxide and ocean acidification
- Changes in ocean circulation patterns

Land and fish and wildlife managers need more resources to be able to detect and plan for these types of changes and clear policy direction to implement necessary protective measures.

<u>GROWING AWARENESS OF THE NEED FOR VIGOROUS POLICY RESPONSE</u>

The good news is that the federal government, and many states and local communities are already taking action.

The Obama administration is taking this issue seriously. Not only is the administration tackling the causes of climate change head on, limiting greenhouse emissions from power plants and vehicles and improving energy efficiency, the President has also issued an executive order (E.O. 13653) on preparing for climate impacts. This important policy statement requires federal agencies to integrate climate change preparedness into their programs, to evaluate and reduce the risks of climate change on their missions and local communities, to coordinate their actions, and to support state, local,

[4] Nye JA, Link JS, Hare JA, and Overholtz WJ. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Mar Ecol-Prog Ser 393: 111–29.

tribal and private-sector efforts to improve climate preparedness and resilience. The executive order recognizes the importance of "natural infrastructure," safeguarding natural resources, and managing lands and waters for climate resilience. Too many of our federal lands and water projects have not assessed or planned for the impacts of climate change, and this executive order is a critical first step in addressing this deficiency.

The administration also released the National Fish, Wildlife and Plants Climate Adaptation Strategy. This unprecedented effort was led by a steering committee of over 16 federal agencies, 5 states fish and wildlife agencies, and 2 tribal conservation commissions making it the first national-level intergovernmental climate adaptation strategy in the country. Since wildlife don't know when they have crossed jurisdictional boundaries, this intergovernmental approach is critical if we are going to have any chance of helping species respond to climate change, especially as they attempt to shift their ranges across the landscape. For too long, individual land and fish and wildlife managers have been struggling with responding to the real-time impacts of climate change on their own. This strategy is the beginning of an effort to develop, coordinate, and implement shared approaches to dealing with climate change impacts. In addition to calling for integrating climate change into land and species management, one of the critical components of the strategy is to accelerate the conservation of an interconnected network of conservation lands, including increasing habitat connectivity for species that are on the move. The administration now needs to put leadership and resources behind implementing this important national strategy.

Congress has also taken some important steps that will help make our wildlife and ecosystems more resilient to the impacts of climate change and extreme events.

Last year, Congress recognized the importance of planning and preparing for future conditions in The Hurricane Sandy Disaster Relief Supplemental Appropriations Act of 2013. Thanks to strong bipartisan support, particularly evident in the House, the measure included $360 million to Department of the Interior programs to "increase the resiliency and capacity of coastal habitat and infrastructure to withstand future storms and reduce the amount of damage caused by such storms." The Interior Department is now busy restoring wetlands, marshes, beaches and other coastal areas from Virginia to Rhode Island to Maine that will help buffer communities from future storms.

The Hurricane Sandy supplemental appropriation gave $2.9 billion to the Army Corps of Engineers for planning and constructing flood-reducing projects that support the long-term sustainability of coastal ecosystems. It also set down some new ground rules: the bill requires the Army Corps of Engineers to reconsider projects that were authorized before Hurricane Sandy and other extreme weather events. These and all future project plans must take current scientific projections of climate-related risks into account. This is a big step towards making climate planning a part of all building decisions, and will help ensure the success of future projects.

And thanks to congressional direction and funding, the National Climate Change and Wildlife Science Center has been established within the U.S. Geological Survey to help provide ongoing critical scientific and technical information to land and wildlife managers in order to understand and plan for the impacts of climate change.

At the state level, many fish and wildlife agencies have conducted climate vulnerability assessments of the wildlife in their states and have amended their State Wildlife Action Plans and other species management plans to address climate adaptation. More broadly, state, county and city governments have developed over 100 climate adaptation plans to reduce the risks of climate change.

MOVING FORWARD TO A MORE RESILIENT FUTURE

We are already experiencing the impacts of climate change.[5] We absolutely need to reduce the levels of greenhouse gas emissions that cause global warming. Even if the human-induced emissions of greenhouse gases are stabilized in the very near future, however, our nation will continue to feel effects for centuries to come due to the timescales associated with climate processes and feedbacks. Simply put, we need to radically change our approach to natural resources, disaster mitigation and recovery, infrastructure, and other types of long-term planning to account for an ever changing climate.

Despite the important legislative developments noted above, Congress must do more to ensure an effective response to this ongoing challenge. Additional actions by Congress should include:

- **Enact the Securing America's Future and Environment (SAFE) Act.** Introduced by Senator Sheldon Whitehouse (RI) and former Senator Max Baucus (MT), the SAFE Act, S. 1202, is designed to protect American communities, wildlife and natural habitat from the increasingly destructive effects of climate change. This non-regulatory bill, supported by Defenders of Wildlife and sportsmen, conservation and recreation organizations, recognizes the countless benefits that healthy natural resources provide to our country's health, safety, economy and well-being, underscores the urgent need to help them adapt to a more rapidly changing climate and provides a road map to do so. The SAFE Act codifies the National Fish, Wildlife and Plants Climate Adaptation Strategy into law and encourages full agency implementation. The bill legislatively authorizes the National Climate Change and Wildlife Science Center, within the U.S. Geological Survey. The bill also provides context for directing any future resources Congress may choose to allocate to the states to help with addressing climate adaptation challenges, and ensures continuity of natural resources climate adaptation programs through changing administrations.
- **Provide funding.** Congress should provide adequate funding to maintain and expand key federal programs supporting adaptation efforts and natural resources conservation. Federal, state, and tribal agencies are starving for critically needed funds for both basic operations and for assessing, planning for, and implementing future-oriented adaptive actions.

[5] IPCC 2013. Summary for Policy Makers. Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis. Found that warming of the climate system is ***unequivocal*** and that it is ***extremely likely*** that human influence has been the dominant cause of the observed warming since the mid-20th century.

- **Prepare for Disasters**. Protecting and restoring natural systems is often the least expensive method of buffering human communities against disaster and therefore must be considered in disaster preparation and recovery. Preparing for extreme climate impacts will save lives, property and tax dollars. Congress should build on the foundation laid by the Hurricane Sandy emergency supplemental appropriations and ensure federal natural disaster-related programs account for and mitigate climate risks. Federal disaster programs should anticipate future climate changes and build them into disaster planning, mitigation and recovery projects.
- **Integrate climate change into all relevant programs and activities**. In addition to disaster response programs, climate change places great risk to the achievement of many agency missions and programs. Even though the administration has released high-level adaptation policies, many federal agencies still aren't accounting for climate change when planning their programs.
- **Protect large, connected landscapes**. Climate change is highlighting the value of protecting and reconnecting large landscapes that serve as critical watersheds, carbon storage banks, and wildlife habitat. Climate change forces species to move, but movement is restricted unless we protect a network of conservation areas connected by wildlife habitat corridors that allow species to respond to climate impacts. These natural areas will in turn provide us with clean water, flood protection, replenishment of our groundwater, open space and recreation.

On behalf of Defenders of Wildlife, thank you for the opportunity to share our perspective on this critical issue. We look forward to working with this subcommittee and others in Congress to develop effective measures to help our wildlife and ecosystems adjust to the impacts of climate change and buffer our communities from climate risks.

Senator WHITEHOUSE. Thank you very much, Mr. Matson.

Our next witness is David Houghton. He is the President of the National Wildlife Refuge Association. The National Wildlife Refuge Association works with the National Wildlife Refuge System in engaging other conservation non-profits, private landowners, and refuge friends groups in safeguarding wildlife. Mr. Houghton has worked for and in partnership with the U.S. Fish and Wildlife Service for more than 25 years, including a stint at the Rhode Island Refuge Complex years ago, where he served as deputy refuge manager.

We are delighted to have him here, and please, Mr. Houghton, proceed with your testimony.

STATEMENT OF DAVID HOUGHTON, PRESIDENT, NATIONAL WILDLIFE REFUGE ASSOCIATION

Mr. HOUGHTON. Senator Whitehouse, thank you very much. It is an honor and a pleasure to be here today to talk about these important issues.

Again, I am David Houghton. I am President of the National Wildlife Refuge Association. The Association has worked since 1975 to champion the integrity and the stature of the 150-million acre national wildlife refuge system. Many do not know that the refuge system is almost twice as large as the national park system. It annually receives 46.5 million visitors and has an economic output of $2.4 billion into the American economy. There is a national wildlife refuge in every State and territory of this great Country.

A growing body of evidence has linked climate change and effects on wildlife populations. Migration timing, age, structure, as well as condition with wildlife has been affected. This has also been affecting the National Wildlife Refuge System around the Country.

I would like to talk about some of these effects and then I would like to talk about what the United States Fish and Wildlife Service is doing and how this has positive effects on the economy.

During Hurricane Sandy, which hit in October 2012, 35 national wildlife refuges were affected at a cost of $64 million. That is equivalent to 15 percent of the annual appropriation to national wildlife refuges. In Rhode Island, at Trustom Pond and John Chafee National Wildlife Refuges, the barrier beaches were eroded and the coastal marshes were impacted.

What was clear about Hurricane Sandy, though, was that the natural systems on these refuges did far better than the manmade systems. But our managers at Trustom Pond National Wildlife Refuge, who have been managing threatened and endangered species of piping plovers and least terns, had never seen a storm with this kind of impact. This storm also affected the New Jersey coast, leaving a 22 mile trail of debris over fragile marshes and woodlands at Edwin B. Forsythe National Wildlife Refuge.

We also see the storm effects outside of the northeast. For example, Button Island National Wildlife Refuge in Louisiana, which was one of the first established national wildlife refuges in 1904 by Teddy Roosevelt was initially 18,000 acres in total. Now, after hurricane after hurricane, it is only 2,000 acres. Passage Key in Tampa was a refuge that was established by Teddy Roosevelt. Because of hurricanes, et cetera, it is no longer. It is no longer on the face of the earth. So these storm events have had great impacts to the national wildlife refuge system.

I would also like to talk about wildfires. We have seen increasingly large catastrophic wildfires in the western United States. This means that more resources are devoted toward fighting these catastrophic fires as well as the interface between forest and our urban areas. This has had an effect on national wildlife refuges because prescribed burn is a very important wildlife tool. And the dollars are not there to be able to conduct these fires any more.

So I would also like to talk about refuges as an economic powerhouse. A report that the Fish and Wildlife Service put out called Banking on Nature said that for every dollar that Congress invests into the National Wildlife Refuge system, $4.87 are returned to the American economy. That means that $2.4 billion came into the economy from refuges. So not only does climate change have an effect on wildlife but also on the refuges ability to provide to the American economy.

So what is the Fish and Wildlife Service doing about it? In Rhode Island, we are restoring over 300 acres of marsh, we are rebuilding a road into Sachuest National Wildlife Refuge. In the Everglades, in the State of Florida, we are working on a new type of refuge. This is a large, landscaped refuge that is able to connect various different endangered species to one another. And in the Pacific, we are working on a refuge, Palmyra Atoll National Wildlife Refuge, which is a unique reef system. We are working very hard to make sure that the reef remains.

Thank you very much, sir.

[The prepared statement of Mr. Houghton follows:]

Testimony of
David Houghton
National Wildlife Refuge Association
before the
U.S. Senate Committee on Environment and Public Works
Subcommittee on Oversight

February 25, 2014

Subcommittee Chairman Whitehouse, Ranking Member Inhofe, and distinguished members of the subcommittee, it is honor to be here today to share our views on natural resource adaptation and the importance of healthy ecosystems in protecting communities and supporting economies, and how these ecosystems are tied to fishing, hunting, tourism and outdoor recreation.

I am David Houghton, President of the National Wildlife Refuge Association. The Refuge Association was established in 1975 as a champion for the integrity and stature of the 150 million acres of lands and waters of the National Wildlife Refuge System. The National Wildlife Refuge System is almost twice as large of the National Park System making it the world's largest network of lands and waters protected for wildlife. The Refuge System receives 46.5 million visitors annually and generates $2.4 billion in economic return. There is a National Wildlife Refuge in every state and territory of this wonderful country.

A growing body of evidence has linked accelerating climate change with observed changes in fish and wildlife, their populations, and their habitats in the United States. According to the U.S. Global Change Research Program, average temperatures of coastal and fresh waters are rising, and we are also experiencing rising sea levels, loss of sea ice, ocean acidification, and increased coastal flooding and erosion. Across the continental United States, climate change is affecting the migration cycles and body condition of migratory birds, causing decoupling of the arrival dates of birds on their breeding grounds and the availability of the food they need for successful reproduction.

Fish and wildlife are facing various threats to their habitat including destructive fires, water shortages, invasive species and disease. The National Wildlife Refuge System is developing management and adaptation strategies at an ecosystem level as well at individual refuges. My testimony will highlight how different refuges are increasing resiliency and adapting to a changing climate.

Storms

During Hurricane Sandy, which hit the East Coast in October 2012, coastal wildlife refuges and marshes provided protection and buffering for inland areas. Hurricane Sandy hit 35 wildlife refuges in the northeast region and caused $64 million in damage – the equivalent of 15% of the Refuge System's annual budget. Some of the refuge wetlands and dunes provided natural protection to nearby communities, but we must rebuild these important natural buffers to be more resilient in the future – both for people, wildlife and the economy.

Rhode Island's coastal lagoons and barrier beaches, which are home to waterfowl, fish species such as striped bass, and endangered species like least tern and piping plover, are highly susceptible to rising sea level and erosive forces associated with more frequent and more significant storm events. In the aftermath of Hurricane Sandy, several coastal restoration and refuge projects have been initiated with the Rhode Island Refuge Complex to increase resiliency for future storms. The goal is to enhance the health and condition of existing salt marshes that are threatened by shoreline erosion and high marsh subsidence.

At Prime Hook National Wildlife Refuge on Delaware Bay is a critical stop on the Atlantic flyway of migratory birds, along with other Mid-Atlantic refuges like Chincoteague National Wildlife Refuge, Blackwater National Wildlife Refuge, and Bombay Hook National Wildlife Refuge. Prime Hook National Wildlife Refuge includes a thin barrier island with a sandy beach, and a marsh behind the beach that has been managed through a series of impoundments as fresh water habitat for migratory waterfowl since the 1960s. Sea level rise and recent coastal storms have degraded the freshwater marsh system at Prime Hook and turned it into an open water system that would not support fish and birds that rely on marshes and wetlands. The elimination of marshes and estuaries also exposes refuge lands and resources to future storms.

Natural erosion, increased due to rising sea levels and increased storm surge, have caused the beach at Prime Hook to be breached by the sea many times over the years, causing an influx of salt water into the fresh-water back bay. Hurricane Sandy greatly accelerated the degradation of the refuge and beach. Residents on the barrier island support fixing these breaches because otherwise the water level rises in the bay and the overall barrier island could erode even more, threatening their houses. Hurricane emergency disaster funds totaling $40 million are now being used to restore the marsh ecosystem, improve sediment retention, and repair the dunes. Hydrological models and long-term monitoring have been established to guide the restoration activities. Restoration of the natural hydrology will increase resilience and decrease long-term vulnerability and risk from storm events.

In New Jersey, Hurricane Sandy left behind a 22-mile trail of debris in the fragile tidal marshes and woodlands of Edwin Forsythe National Wildlife Refuge. The U.S. Fish and Wildlife Service is working to finish this spring the initial cleanup of the debris and then start to restore these environmentally sensitive coastal areas. The cleanup at Forsythe refuge has been focused on Brick, Stafford and Eagleswood townships, where the bulk of the debris is located. The debris on the refuge includes large piles that contain roofs, docks, boats, household chemicals and drums. Forsythe National Wildlife Refuge protects more than 47,000 acres of sensitive wetlands, marshes, and coastal habitats along the New Jersey shore. It is one of the most important habitats for migrating waterfowl and shorebirds east of the Mississippi River.

Refuge Manager Virginia Rettig said it best, "Forsythe Refuge's marshes buffered inland areas from the full brunt of Hurricane Sandy. Nature is our best defense against future storms, and we will clean and restore this vibrant and resilient stretch of coast to sustain wildlife and protect the people of New Jersey in the future."

Following the clean-up, the U.S. Fish and Wildlife Service will undertake a series of marsh restoration and enhancement projects designed to protect coastal communities and infrastructure along 60 miles of the New Jersey shore by increasing the amount, longevity and quality of thousands of salt marsh acres and their associated natural-human values such as floodwater storage, storm wave attenuation, water quality, boating and other recreational opportunities, public and commercial fishing, clamming and oyster grounds, and navigation channels. These values greatly enhance tourism, and the projects will support planning, engineering, construction and monitoring jobs. The projects will also create opportunities for environmental education and scientific research regarding coastal green infrastructure resilience. The living shoreline project will combine attributes of natural and engineered habitats to absorb and dissipate erosional forces and serve as a demonstration area to educate the public and scientists in technology that can be used to bolster our coastal knowledge to protect communities and natural resources.

Finally, in the southeast, Breton Island National Wildlife Refuge in Louisiana was established in 1904 by Teddy Roosevelt to provide nesting habitat for thousands of pelicans, terns and skimmers. Increases in storm severity and frequency have dramatically reduced available habitat. As a result of events like Hurricane Katrina, what was once an 18,000-acre Refuge is now less than 2,000-acres of habitat. It is forecasted to completely disappear in the next five to ten years, following places like Passage Key in Tampa Bay, which no longer exists due to damage from severe storms.

Drought

This nation has seen a severe cycle of drought over the past five years, with focus now on the effects in California. The California drought presents a serious challenge for residents and farmers and is putting wildlife refuges at risk. Sacramento National Wildlife Refuge, Delevan National Wildlife Refuge and Colusa National Wildlife Refuge, just north of Sacramento, depend on irrigation in the summer and winter to maintain wetlands and food for migratory birds. These refuges cover 20,000 acres and receive annually at least 25,000 acre-feet of water. Due to the drought, they do not expect to receive their water allocation this summer, and each refuge has half the water than it normally does for this time of year for millions of ducks, geese and shorebirds. Sutter NWR will receive no water at all. Migratory birds are forced to forage elsewhere which could lead to reversing the hard-fought successful restoration efforts won over the last several decades. The lack of water will reduce economic return to local economies and increase conflict between water needs of agriculture, waterfowl and threatened and endangered fish.

Wildfire

Refuges are facing more extreme wildfire seasons. Each year fire budgets are increasingly allocated to fight catastrophic wildfires and protection of the urban-forest interface, leaving dramatically fewer resources for prescribed burning, an extremely important wildlife management tool in Refuges all over the country. Refuges use prescribed burning to reduce wildfire risk and spur regrowth of habitat for species. This is an essential management tool for the southwest and southeast and is integral to the recovery of threatened and endangered species. Last year, the Refuge System had half of the prescribed burning funds as it did in FY10. It is important that more funding is provided for recognized adaptation and mitigation strategies, including prescribed burning and hazardous fuels treatments. This approach can help reduce the costs of large wildfires, promote greater ecological resilience at landscape level, and reduce the impacts to ecosystems services and watersheds.

National Wildlife Refuges – An Economic Powerhouse

In November 2013, the U.S. Fish and Wildlife Service released *Banking On Nature*, a report on the economic benefits to local communities of National Wildlife Refuge visitation. The report states that for every $1 Congress provides in funding to run the National Wildlife Refuge System, $4.87 on average is returned to local communities, making it a good investment of government funds. The *Banking On Nature* report also shows that national wildlife refuges are a good investment for local communities, providing a measurable boost to their economies.

Even during the economic downturn, visitation increased at refuges and supported local communities. From 2006 to 2011, refuge visitation increased by 30 percent and overall economic output from refuges increased by 22 percent, resulting in an annual $2.4 billion returned to local economies every year.

The *Banking On Nature* report shows that the National Wildlife Refuge System:

- Generates $2.4 billion in sales and economic output, a 20% increase since 2006;
- Welcomes 46.5 million visitors annually, a 30% increase since 2006;
- Returns on average $4.87 to a local economy for every $1.00 Congress provides in funding, a 22% increase since 2006;
- Creates 35,000 jobs annually, a 23% increase since 2006;
- Produces $792.7 million in job income for local communities;
- Generates $342.9 million in local, county, state and federal tax revenue
- 77% of refuge-related spending was done by visitors from outside the local area.

Examples of Managing for Adaption and Resiliency
Finally, I'd like to offer a few examples of how Refuges are managing for adaptation and resiliency.

Rhode Island Refuges

The purpose of restoration projects at John Chafee National Wildlife Refuge and Sachuest Point National Wildlife Refuge in Rhode Island is to increase coastal resilience to a changing climate for eight local communities, economies and wildlife that depend on healthy salt marsh ecosystems on over 400 acres in key coastal areas of Rhode Island. These projects will: Restore natural hydrologic flow and functioning to 300 acres of key salt marsh habitat; Enhance and sustain marsh habitat and nesting productivity for federal trust species; Enhance marsh resiliency to sea level rise by improving drainage and increasing marsh elevations; Reduce the frequency of flooding onto local roads, which prevents access to the refuge visitor center and beaches; Reduce the distribution of non-native species and limit infestations in the future; and Prevent coastal erosion while mitigating pollution and volume of storm water runoff.

The USFWS, State of Rhode Island, Save the Bay, the Army Corp of Engineers, University of Rhode Island, the Environmental Protection Agency and others are working together to identify programs and practices to enhance salt marsh stability and resiliency across coastal Rhode Island. This work includes a comprehensive restoration strategy on the John Chafee National Wildlife Refuge in the Narrow River to increase salt marsh shoreline stability, use of beneficial dredge materials to enhance salt marsh elevations, and providing for adequate drainage within salt marshes to allow these areas to keep up with sea level at the maximum rate possible.

Everglades Headwaters National Wildlife Refuge and Conservation Area

This new National Wildlife Refuge and Conservation in central Florida is located in the headwater region of a World Heritage Site: the Everglades. The Refuge and Conservation Area was designed to maintain resiliency and provide adaption opportunities for wildlife by conserving large in-tact lands, maintaining water storage and filtration function in the upper watershed, and creating connected corridors of habitat to allow for nearly 50 threatened and endangered species to adapt and remain resilient to environmental stressors such as climate change.

The Conservation Area was designed to engage many federal, state, and local partners, working together to each play a role in protecting this large landscape. What is also interesting about this new collaborative way of doing business is that in addition to securing the areas that will be most resilient to climate change and offer adaptive qualities for wildlife, the effort is simultaneously safeguarding the water supply for nearly 7 million Americans in South Florida, protecting the

American food supply by conserving some of the largest calf-cow ranches in the United States, and it supplements the buffer zone around air training operations at the Avon Park Military Base, allowing the military to train our men and women of the armed forces in combat flight operations. This Refuge is not only good for conserving ecosystems, it protects American ways of life.

Texas Coastal Refuges

The U.S. Fish and Wildlife Service has made strategic investments in future storm response capability. As a result of hurricane damage, the Service has taken proactive steps to consolidate operations and maintenance facilities at four coastal refuges in Louisiana and Texas. The Winnie, Texas depot was constructed in response to repeated hurricane storm damage and loss of heavy equipment. The USFWS consolidated operations into one depot facility rather than continue to maintain separate and distinct fleets of equipment at four low-lying refuges. The facility is centrally located and above any threat from future flooding and serves as the command center for emergency operations. And, the facility is Leadership in Energy and Environmental Design (LEED)-silver rated. We would like to cite this effort as a good investment in adaptation and a model of how to plan for future needs.

Palmyra Atoll National Wildlife Refuge

This remote Refuge in the Pacific Ocean just north of the equator has the most pristine coral reefs left in the world. The U.S. Fish and Wildlife Service is working to remove human stressors such as shipwrecks that bleed iron that in turn ruins reefs, and to restore forests on remote islands. Reducing man-made stresses on the reef allows the reefs to be more resilient to warming waters protects a treasure chest of life that may provide science with species that have played critical roles in fighting disease and providing other benefits to man besides their inherent value and beauty. Palmyra will act as a last refuge of coral reefs in the Pacific.

<u>Funding</u>

We at the Refuge Association thank this body for an increase in the budget of the National Wildlife Refuge System this year over last year. However, this year's enacted amount is still almost 10% down from the FY10 enacted budget. The 150 million-acre Refuge System receives slightly more than $450 million in operation and maintenance. This compares to the 84 million-acre National Park System that received $2.2 billion, and the Department of Defense marching bands that received $500 million. Refuges are underfunded to carry out their important mission, particularly in a changing world. The Service has a proven track record in Rhode Island, Maryland, Florida, Texas, and all over the nation of developing strategies to adapt and keep these magnificent lands and the wonderful wildlife resilient in a changing world. The Fish and Wildlife Service needs the resources to continue to pump $2.4 billion into the economy each year plus provide $33 billion in ecosystem services to the American public. We respectfully ask for your help and support to protect these national gems like Trustom Pond, Wichita Mountains, Black Bayou, White River and the other 562 Refuges that span from the shores of Maine to the reefs of the Caribbean across our heartland to the wide majestic spaces of Alaska to the exotic atolls of the Pacific.

Thank you again for the opportunity to testify before the subcommittee and I would be pleased to answer any questions Senators may have.

BANKING ON NATURE
National Wildlife Refuge Association
www.refugeassociation.org
The Banking on Nature Report released by the U.S. Fish and Wildlife Service shows that national wildlife refuges are a good investment for American taxpayers and a boost to local economies. The report shows a trend of increased visitation to refuges and increased economic contribution to local communities, even during the height of the worst economic recession since the Great Depression.
561
National Wildlife Refuges
Protection of over
2,170
species of birds, mammals, reptiles, amphibians, and fish
$1 $4.87
For every $1 appropriated to the Refuge System, an average of $4.87 is returned to local economies
BY THE NUMBERS:
46.5 million visitors
35,000 jobs created
$342.9 million in tax revenue
$2.4 billion in economic output

Senator WHITEHOUSE. Thank you very much.

Our next witness, I have a point of personal privilege in recognizing. He is Christopher Brown, the president of the Rhode Island Commercial Fishermen's Association. The Rhode Island Commercial Fishermen's Association was founded in 2000 to protect Rhode Island's first industry from becoming extinct, by maintaining the commercial fishery in the State of Rhode Island as a way of life for present and future generations.

Mr. Brown is the captain of the fishing vessel Proud Mary out of Point Judith, Rhode Island. He built his first boat in 1978 at the age of 20. And he sailed that vessel, the Grandville Davis, for 31 years. He owns Brown Family Seafood, and we are delighted to have him here. Mr. Brown?

STATEMENT OF CHRISTOPHER BROWN, PRESIDENT, RHODE ISLAND COMMERCIAL FISHERMEN'S ASSOCIATION

Mr. BROWN. Thank you, Mr. Chairman and distinguished members of the committee.

Let me begin by thanking you all for letting me share some of the perspectives that I have garnered in over 35 years as a fisherman and 25 years in service to the resource and my industry.

I fish on a much different ocean today than when I first started fishing with my grandfather as a boy in the mid–1960's. When I started out fishing, catching haddock in the waters around Point Judith was commonplace and they were a daily component of our catch. Last year, in 200 days of fishing, I caught only two. They are considered fully rebuilt and are now managed jointly with Canada by virtue of the climate that they have chosen to live in.

In the fall of 2013, in Block Island Sound, I caught 1,800 pounds of spot in a single set of my net. These are fish that are indigenous to the Carolinas, not southern New England. I had never seen a single one until the late 1990's. Although not greatly abundant, regularly caught now in Rhode Island are the species of croaker, grouper, cobia, drum and tarpon. My grandfather never saw a single one of these in his entire life as a fisherman.

Dogfish were determined to have been over-fished roughly 15 to 20 years ago and were assigned to a rebuilding plan. The plan was driven by incorrect biological assumptions of their reproductive capability and initial abundance. They have now overpopulated the waters of the Atlantic from Hatteras to Nova Scotia to the extent that there is no longer an effective migration. In their current unexploited condition, they stand to significantly hamper the recovery of species that either compete with or serve as a food source. These are the findings of Dr. James Sulowsky, Ph.D., professor at the Unviersity of New England, the foremost authority on dogfish in the United States.

I hope that I have adequately portrayed an ocean that is in flux. In New England, we currently are an industry that is in search of a science-based, regulatory co-existence with the laws that govern our fishery. We are a cold water region that has suffered greatly at the hands of a warming regime. Our inability to successfully rebuild several key stocks is well documented. We have evoked the ire of Magnusson repeatedly, and been put to the lash at the hands of an Act that up until now, reasons that ideology serves as a fair substitute for sound and relevant science.

The Magnusson Act was assembled at a time when the science surrounding our fisheries was in its infancy. As we should anticipate, the scientific perspective of the management of our oceans should evolve. The Act has not. To date, we have failed to articulate those discoveries into actionable policy within our fisheries. Any national policy that remains predicated upon outdated scientific perspectives will do unnecessary economic harm to those whom it serves. It will limit the productivity of what I believe to be our national strategic protein reserves and will to some extent damage our national food security.

Our failure to tease out an edified response to these problems from the larger national debate surrounding climate shift strands the enormous sum that we have invested in science and leaves my region without an effective solution to an ongoing and complex environmental problem. Our fields will lay fallow until we dare fashion a different response.

The framers of Magnusson were wise in their decision to construct a document that was largely conceptual by nature. Given that it is thematic and overarching it is therefore lacking in the granular specificity that is needed to deal with environmental problems that are beyond the realm of what was once known. Magnusson Stevens is a profoundly valuable document that should remain our North Star of fisheries management policy. But in New England, in the face of wholesale systemic change, as a standalone document, it has failed to produce the biological or economic results that have been promised and delivered elsewhere. It is in need of a reasonable complement. I believe that the SAFE Act is that complement. It is one which does not attempt to separate the fish from the surrounding sea. I believe it is worthy of your approval.

The wild-caught fisheries of the Northeast may ultimately prove to be the coal miner's canary for the Nation as we grapple with the issue of climate change. A reconsideration of our strategy is called for, given the enormous chasm between what we have endured and what we have gained in New England. I view the SAFE Act as a sound, reasonable, and measured complement to Magnusson. It represents a new set of eyes on the problem and another tool in the tool box. It respects both sides of the larger debate and a chance to evaluate the potential for new strategies in healing our Nation's most iconic fishery.

I urge you to pass this Bill along for further consideration and discussion. Thank you.

[The prepared statement of Mr. Brown follows:]

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Dogfish were determined to have been over fished roughly 15 years ago and were assigned to a rebuilding plan. The plan was driven by incorrect biological assumptions of their reproductive capability and initial abundance. They have now overpopulated the waters of the Atlantic, from Hatteras to Nova Scotia to an extent that there is no longer an effective migration. In their current unexploited condition, they stand to significantly hamper the recovery of a species that either compete with or serve as a food source. These, the findings of Dr. James Sulowsky PHD, Professor at The University of New England, the foremost authority on dogfish in the U.S.

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The Magnusson act was assembled at a time when the science surrounding our fisheries was in its infancy. As we should anticipate, the scientific perspective of the management of our oceans should evolve. The act has not. To date, we have failed to articulate those discoveries into actionable policy within our fisheries. Any national policy that remains predicated on outdated scientific perspectives will do unnecessary economic harm to those it serves; it will limit the productivity of what I believe, are our national protein reserves and compromise to some extent our national food security. Our failure to tease out an edified response to these problems from the larger national debate surrounding climate shift, strands the enormous sum that we have invested in science and leaves my region without an effective solution to an ongoing and complex environmental problem. Our fields will lay fallow till we dare fashion a different response.

The framers of Magnusson were wise in their decision to construct a document that is largely conceptual by nature. Given that it is thematic and overarching it is there for lacking in the granular specificity that is needed to deal with environmental problems that are beyond the rehelm of what was once known. Magnusson Stevens is a profoundly valuable document that should remain our North Star of fisheries management policy, but In New England, in the face of wholesale systemic change, as a stand-alone, document, it has failed to produce the biological or economic results that have been promised and delivered elsewhere. It is in need of a reasonable compliment, one which is free to consider environmental conditions as a necessary component of its decisionmaking process. One which does not attempt to separate the fish from the surrounding sea. I believe that the "Safe Act" could serve our national transition to ecosystem based management, as is called for in Magnusson's vision of our fishery.

The wild caught fisheries of the Northeast may ultimately prove to be the "coal miner's canary" for this Nation as we grapple with the issue of climate change. A reconsideration of strategy is called for given the enormous chasm between what we have endured and what we have gained.

I view the Safe Act as a sound, reasonable, and measured compliment to Magnusson. It represents a new set of eyes on the problem and another tool in the tool box. It respects both sides of the larger debate and a chance to evaluate the potential for new strategies in healing our Nation's most iconic fishery. I urge you to pass this Bill along for further consideration and discussion.

Senator WHITEHOUSE. Thank you, Captain Brown. I appreciate it.

Our next witness is Dr. Patrick Moore, the Chair and Chief Scientist of Ecosense Environmental in Vancouver, Canada. Dr. Moore is a co-founder and former chair of Greenspirit Strategies, an environmental consulting and communications firm in Vancouver, Canada. He received a bachelor of science in forest biology and a Ph.D. in ecology from the University of British Columbia in Canada. Welcome, and please proceed with your statement.

STATEMENT OF PATRICK MOORE, PH.D., CHAIR AND CHIEF SCIENTIST, ECOSENSE ENVIRONMENTAL

Mr. MOORE. Thank you, Chairman Whitehouse, Ranking Member Inhofe.

In 1971, as a Ph.D. student in ecology, I joined an activist group in a church basement in Vancouver Canada and sailed on a small boat across the Pacific to protest U.S. hydrogen bomb testing in Alaska. We became Greenpeace.

After 15 years in the top committee I had to leave, as Greenpeace began to adopt policies that I could not accept from my scientific perspective. Climate change wasn't really an issue when I abandoned Greenpeace, but it certainly is today.

There is no scientific proof that human emissions of carbon dioxide are the dominant cause of the minor warming of the earth's atmosphere over the past 100 years. If there were such a proof it would be written down for all to see. No actual proof, as it is understood in science, exists. Please see Exhibit 1.

The IPCC states, "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid–20th century." "Extremely likely" is not a scientific term but rather a judgment, as in a court of law. The IPCC defines extremely likely as a 95 to 100 percent probability. Those numbers are not the result of any mathematical calculation or statistical analysis. They have been invented to express the "expert judgment" as determined by the IPCC.

As noted by many observers, including Dr. Freeman Dyson of the Princeton Institute for Advanced Studies, a computer model is not a crystal ball. We may think it sophisticated, but we cannot predict the future with a computer model any more than we can make predictions with crystal balls, throwing bones, or by appealing to the gods. When modern life evolved over 500 million years ago, please see the second exhibit, CO_2 was more than 10 times higher than today, yet life flourished at that time. Then an ice age occurred 450 million years ago when CO_2 was still 10 times higher than today. The fact that there were both higher temperatures and an ice age at a time when CO_2 was 10 times higher than they are today fundamentally contradicts the certainty that CO_2 emissions are the main cause of global warming.

Today we remain locked in what is still the Pleistocene Ice Age, with an average global temperature of 14.5 degrees Celsius. This compares with a low of about 12 degrees Celsius during the periods of maximum glaciation in this ice age to an average of 22 degrees Celsius during the Greenhouse Ages, which occurred over longer time periods prior to the most recent ice age. During the Greenhouse Ages, there was no ice on either pole and all the land was tropical and sub-tropical. As recently as 3 million years ago the Canadian Arctic islands were forested. Today, we live in an unusually cold period in the history of life, note on the graph here 14.5 degrees, an unusually low period in carbon dioxide in the history of life, 400 ppm.

There is ample reason to believe that a sharp cooling of the climate would bring disastrous results for human civilization, where there is no reason to believe that a warmer climate would be anything but beneficial for humans and the majority of other species. Please see Exhibit 3.

The IPCC states that humans are the dominant cause of warming since the mid–20th century, which was 1950. From 1910 to 1940, there was an increase in global average temperature of half a degree Celsius over that 30-year period. Then there was a 30-year pause until 1970. This was followed by an increase of .57 degrees Celsius during the 30-year period from 1970 to 2000. Since then there has been no increase. This in itself tends to negate the validity of the computer models, as CO_2 emissions have continued to accelerate during this time.

The increase in temperature between 1910 and 1940 was virtually identical to the increase between 1970 to 2000. Yet the IPCC does not attribute the increase from 1910 to 1940 to human influence. They are clear in their belief that human emissions impact only increased the temperature since the mid–20th century. Why does the IPCC believe that a virtually identical increase in temperature after 1950 is caused mainly by human influence, when it has no explanation for the nearly identical increase from 1910 to 1940?

It is important to recognize that humans are a tropical species. We evolved at the equator in a climate where freezing temperature did not exist. The only reasons we can survive these cold climates are fire, clothing, and housing. It could be said that frost and ice are the enemies of life, except for those relatively few species that have evolved to adapt to freezing temperatures during the ice age. It is extremely likely that a warmer temperature than today's would be far better than a cooler one.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Moore follows:]

Statement of Patrick Moore, Ph.D.

Before the Senate Environment and Public Works Committee, Subcommittee on Oversight

February 25, 2014

"Natural Resource Adaptation: Protecting ecosystems and economies"

Chairman Whitehouse, Ranking Member Inhofe, and members of the Committee. Thank you for the opportunity to testify at today's hearing.

In 1971, as a PhD student in ecology I joined an activist group in a church basement in Vancouver Canada and sailed on a small boat across the Pacific to protest US Hydrogen bomb testing in Alaska. We became Greenpeace.

After 15 years in the top committee I had to leave as Greenpeace took a sharp turn to the political left, and began to adopt policies that I could not accept from my scientific perspective. Climate change was not an issue when I abandoned Greenpeace, but it certainly is now.

There is no **scientific proof** that human emissions of carbon dioxide (CO_2) are the dominant cause of the minor warming of the Earth's atmosphere over the past 100 years. If there were such a proof it would be written down for all to see. No actual proof, as it is understood in science, exists.

The Intergovernmental Panel on Climate Change (IPCC) states: "It is **extremely likely** that human influence has been the **dominant cause** of the observed warming **since the mid-20th century**." (My emphasis)

"Extremely likely" is not a scientific term but rather a judgment, as in a court of law. The IPCC defines "extremely likely" as a "95-100% probability". But upon further examination it is clear that these numbers are not the result of any mathematical calculation or statistical analysis. They have been "invented" as a construct within the IPCC report to express "expert judgment", as determined by the IPCC contributors.

These judgments are based, almost entirely, on the results of sophisticated computer models designed to predict the future of global climate. As noted by many observers, including Dr. Freeman Dyson of the Princeton Institute for Advanced Studies, a computer model is not a crystal ball. We may think it sophisticated, but we cannot predict the future with a computer model any more than we can make predictions with crystal balls, throwing bones, or by appealing to the Gods.

Perhaps the simplest way to expose the fallacy of "extreme certainty" is to look at the historical record. With the historical record, we do have some degree of certainty compared to predictions of the future. When modern life evolved over 500 million years ago, CO_2 was more than 10 times higher than today, yet life flourished at this time. Then an Ice Age occurred 450 million years ago when CO_2 was 10 times higher than today. There is some correlation, but little evidence, to support a direct causal relationship between CO_2 and global temperature through the millennia. The fact that we had both higher temperatures and an ice age at a time when CO_2 emissions were 10 times higher than they are today fundamentally contradicts the certainty that human-caused CO_2 emissions are the main cause of global warming.

Today we remain locked in what is essentially still the Pleistocene Ice Age, with an average global temperature of 14.5°C. This compares with a low of about 12°C during the periods of maximum glaciation in this Ice Age to an average of 22°C during the Greenhouse Ages, which occurred over longer time periods prior to the most recent Ice Age. During the Greenhouse Ages, there was no ice on either pole and all the land was tropical and sub-tropical, from pole to pole. As recently as 5 million years ago the Canadian Arctic islands were completely forested. Today, we live in an unusually cold period in the history of life on earth and there is no reason to believe that a warmer climate would be anything but beneficial for humans and the majority of other species. There is ample reason to believe that a sharp cooling of the climate would bring disastrous results for human civilization.

Moving closer to the present day, it is instructive to study the record of average global temperature during the past 130 years. The IPCC states that humans are the dominant cause of warming "since the mid-20th century", which is 1950. From 1910 to 1940 there was an increase in global average temperature of 0.5°C over that 30-year period. Then there was a 30-year "pause" until 1970. This was followed by an increase of 0.57°C during the 30-year period from 1970 to 2000. Since then there has been no increase, perhaps a slight decrease, in average global temperature. This in itself tends to negate the validity of the computer models, as CO_2 emissions have continued to accelerate during this time.

The increase in temperature between 1910-1940 was virtually identical to the increase between 1970-2000. Yet the IPCC does not attribute the increase from 1910-1940 to "human influence." They are clear in their belief that human emissions impact only the increase "since the mid-20th century". Why does the IPCC believe that a virtually identical increase in temperature after 1950 is caused mainly by "human influence", when it has no explanation for the nearly identical increase from 1910-1940?

It is important to recognize, in the face of dire predictions about a 2°C rise in global average temperature, that humans are a tropical species. We evolved at the equator in a climate where freezing weather did not exist. The only reasons we can survive these cold climates are fire, clothing, and housing. It could be said that frost and ice are the enemies of life, except for those relatively few species that have evolved to adapt to freezing temperatures during this Pleistocene Ice Age. It is "extremely likely" that a warmer temperature than today's would be far better than a cooler one.

I realize that my comments are contrary to much of the speculation about our climate that is bandied about today. However, I am confident that history will bear me out, both in terms of the futility of relying on computer models to predict the future, and the fact that warmer temperatures are better than colder temperatures for most species.

If we wish to preserve natural biodiversity, wildlife, and human well being, we should simultaneously plan for both warming and cooling, recognizing that cooling would be the most damaging of the two trends. We do not know whether the present pause in temperature will remain for some time, or whether it will go up or down at some time in the near future. What we do know with "extreme certainty" is that the climate is always changing, between pauses, and that we are not capable, with our limited knowledge, of predicting which way it will go next.

Thank you for the opportunity to present my views on this important subject.

Attached please find the chapter on climate change from my book, "Confessions of a Greenpeace Dropout: The Making of a Sensible Environmentalist". I would request it be made part of the record.

Excerpted from:

Confessions of a Greenpeace Dropout: The Making of a Sensible Environmentalist

Patrick Moore, Ph.D. Published 2013

chapter twenty-one

Climate of Fear

If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts he shall end in certainties. —Sir Francis Bacon

The global media tells us plainly and bluntly that the vast majority of the world's scientists believe we are headed for a climate catastrophe that will devastate human civilization and the environment. We have no choice but to act immediately to save ourselves from this apocalypse. The greatest threat is the CO_2 released from burning fossil fuels and cutting forests. Fossil fuel use must be cut by 80 percent or more, and we must stop cutting trees. How should we react to this warning?

The subject of climate change, also referred to as global warming, is perhaps the most complex scientific issue we have ever attempted to re- solve. Hundreds, possibly thousands of factors influence the earth's cli- mate, many in ways we do not fully understand. So, first, let us recognize that the science of climate is not settled. In fact, we are only beginning to understand how the earth's climate works.

It is not correct to use the terms *global warming* and *climate change* as if they were interchangeable. Global warming is a very specific term meaning exactly what it says, that the average temperature of the earth is increasing over time. Climate change is a much more general term that includes many factors. For one thing the climate is always changing, whereas it is not always getting warmer. The old maxim "the only constant is change" fits perfectly here. And as the belief in human-caused global warming has come into doubt the term climate change has been adopted as a substitute, even though it means something completely different.

It is one thing to claim increases in CO_2 cause global warming and quite another to claim increases in CO_2 cause:

- Higher temperatures
- Lower temperatures
- More snow and blizzards
- Drought, fire, and floods
- Rising sea levels
- Disappearing glaciers
- Loss of sea ice at the poles
- Species extinction
- More and stronger storms
- More storm damage
- More volcanic eruptions
- Dying forests
- Death of coral reefs and shellfish
- Shutting down the Gulf Stream
- Fatal heat waves
- More heat-related illness and disease
- Crop failure and food shortages
- Millions of climate change refugees
- Increased cancer, cardiovascular disease, mental illness, and respiratory disease[290]
- And, a devastating effect on the quality of French wines[291] □

The science of climatology is only a few decades old. It is not a single science but rather an interdisciplinary cluster of sciences. These include meteorology (the study of weather), atmospheric chemistry, astrophysics and cosmic rays, geology and other earth sciences, oceanography, carbon cycling through all living species, soil science, geology, climate history through the millennia, ice ages and greenhouse ages, study of the sun, knowledge of earth wobbles, magnetic fields and orbital variations, etc. All of these disciplines are interrelated in complex, dynamic patterns that cannot be reduced to a simple equation. That is why climatologists have built very complicated computer models in the hope of predicting future climatic conditions. □A "climate change community" has evolved over the past 30 years con- sisting of widely divergent groups with sharply differing opinions. The most prominent and formally structured group is the United Nations Intergovernmental Panel on Climate Change (IPCC) and the scientists, □

290. "A Human Health Perspective on Climate Change," National Institute of Environmental Health Sciences, April 2010, http://www.niehs.nih.gov/health/docs/climatereport2010.pdf

□291. "Impact of Climate Change on Wine in France," Greenpeace International, September 2009, http://www.greenpeace.org/raw/content/international/press/reports/impacts-of-climate-change-on-w.pdf scholars, activists, and politicians who associate themselves with this organization. The IPCC was created in 1988 as a partnership between the World Meteorological Organization and the United Nations Environment Program, put simply, meteorologists and environmentalists. Members of this group generally believe humans are causing global warming, that we are changing the climate, and this will generally be negative for civilization and the environment. They claim to represent an "overwhelming consensus among climate scientists."[292]

The IPCC is rather insular, believing its members are the only true climate scientists and that those who disagree with them are either some other kind of scientists, or not really scientists at all. Thus there is a self- defined overwhelming, even unanimous, consensus because they don't recognize the legitimacy of those who disagree with them. In 2007 the IPCC published its *Fourth Assessment Report*, which stated, "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic (human- caused) greenhouse gas concentrations."[293]

At the other end of this spectrum there is a considerable contingent of scientists and scholars, largely schooled in the earth and astronomical sciences, who believe climate is largely influenced by natural forces and cycles. They were not organized into an official body until 2007 when the Nongovernmental International Panel on Climate Change (NIPCC) was formed in Vienna. Led by atmospheric scientist Dr. Fred Singer, the NIPCC published "Climate Change Reconsidered," a comprehensive scientific critique of the IPCC's findings, in 2009.[294] This report was signed by more than 31,000 American scientists and concluded, "there is no convincing scientific evidence that human release of carbon dioxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate."[295] Clearly there is no overwhelming consensus among scientists on the subject of climate.[296] In my opinion the believers and the skeptics of human-caused, catastrophic climate change can be roughly divided between those who see history in very recent terms (years to thousands of years) and those who see history in the long term (thousands to hundreds of millions of years). Both meteorologists and environmentalists tend to think about weather and climate in

292. "Statistical Analysis of Consensus," realclimate.org, December 16, 2004, http://www.realclimate.org/index.php/archives/2004/12/a-statistical-analysis-of-the-consensus/

□293. "Summary for Policymakers," *Fourth Assessment Report*, Intergovernmental Panel on Climate Change, 2007, p. 3, http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf□

294. Craig Idso and S. Fred Singer, "Climate Change Reconsidered," Nongovernmental International Panel on Climate Change, 2009. http://www.heartland.org/publications/NIPCC%20report/PDFs/NIPCC%20Final.pdf□

295. "Climate Change Reconsidered," Center for the Study of Carbon Dioxide and Global Change," 2009, www.nipccreport.org/

296. "More Than 700 International Scientists Dissent Over Man-Made Global Warming Claims: Scientists Continue to Debunk 'Consensus' in 2008 & 2009," U.S. Senate Minority Report, March 16, 2009, http://epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=83947f5d-d84a-4a84-ad5d-6e2d71db52d9

terms of recent human history. Geologists, evolutionary biologists, and astrophysicists tend to think of climate in the context of the 3.5 billion-year history of life and the 4.6 billion-year history of the Earth.

The various camps have invented some names for each other and for themselves. Pretty much everyone involved thinks they are "climate scientists." But people who are convinced we are the main cause of climate change have been dubbed "true believers" and "warmists," highlighting what are seen to be religious and ideological orientations, respectively. People who are undecided, critical, or questioning are called "skeptics." The skeptics are happy with this description as it indicates they have an open mind and as scientists they believe they have a duty to challenge unproven hypotheses. The true believers use the word skeptic as a slur, as in "unbelievers," as if it is unacceptable to question their beliefs. Then there are the "climate deniers," or "denialists," terms invented by the true believers, and characterized by skeptics as associating them with Holocaust deniers. Much of this is just name-calling, but it is useful in the sense that it defines the battleground.

Over the years the media have largely ignored the scientists and organizations that remain skeptical of human-caused global warming and climate change. The public has been inundated with alarmist headlines about catastrophic climate change and many governments have bought into the belief there is a global emergency that must be addressed quickly and decisively. As with fear of chemicals, fear of climate change results in a convergence of interests among activists seeking funding, scientists applying for grants, the media selling advertising, businesses promoting themselves as green, and politicians looking for votes. It may not be a conspiracy, but it is a very powerful alignment that is mutually reinforcing.

In 2007 the IPCC and one of its main champions, Al Gore, were awarded the Nobel Peace Prize for alerting the world to the dire threat of human-caused climate change. One would imagine the public would strongly support this alarmist position, having been exposed to such one- sided media coverage and the news of prestigious awards. Amazingly this is not the case, even in countries such as the United States and England, where the official government positions are sharply accepting of catastrophic human-caused warming.

A Pew Foundation poll conducted in October 2009 found only 36 per- cent of the general public in the United States believes humans are the cause of global warming, whereas 33 percent does not believe the earth is warming and 16 percent believe the earth is warming but that it is due to natural causes. Public opinion was sharply divided along partisan lines: 50 percent of Democrats believe global warming is caused by humans, while 33 percent of independents, and only 18 percent of Republicans agree with this. The trend since 2007 is decidedly downwards with about 10 percent fewer people believing in human-caused global warming in all categories.

Another Pew Foundation poll taken in May 2010 asked Americans to rank priorities for Congress. It found only 32 percent think it is very important for Congress to address climate change in the coming months, including 47 percent of Democrats, 29 percent of independents, and 17 percent of Republicans.[297]

The partisan spread mirrors the poll on belief in human-caused cli- mate change almost perfectly. This is a strong indication that the reason a majority is not concerned about climate change legislation is because it doesn't believe in human-caused climate change in the first place.

A poll taken by Ipsos Mori in June 2008 found 60 percent of Britons believed, "many scientific experts still question if humans are contributing to climate change."[298] Clearly a majority of the British public does not believe there is a scientific certainty on the subject.

A more recent British poll in February 2010, again taken by Ipsos Mori, showed that only 17 percent of Britons put climate change in their top three most important issues facing them and their families.[299]

In one of the most surprising surveys taken, 121 U.S. television weather presenters, all members of the American Meteorological Society, were asked their opinions on climate change in April 2010. Ninety-four percent of those surveyed were accredited meteorologists. When asked about the UN's Intergovernmental Panel on Climate Change's statement, "Most of the warming since 1950 is very likely human-induced," a full 50 percent either disagreed or strongly disagreed. Twenty-five percent were neutral and only 24 percent said they agreed or strongly agreed.[300]

In April 2013 a US Department of Agriculture-funded survey of US Midwest corn farmer's beliefs in climate change was published. 18,800 farmers with an income of US$100,000 or more were polled, of whom 26 percent responded (4,778). Only 8 percent of these farmers, who spend their lives in the weather and the climate, agreed with the statement, "Climate change is occurring and it is caused mostly by human activities." In other words, 92 percent of corn farmers do not believe humans are the main cause of climate change. I say give them all honorary doctorates of science.

297. "Public's Priorities, Financial Regs: Congress's Job Rating—13%," Pew Research Center for People and the Press, May 18, 2010, http://people-press.org/report/615/

□298. "Scientists Exaggerate Climate-Change Fears, Majority of Britons Believe," Mail Online, June 22, 2008, http://www.dailymail.co.uk/news/article-1028425/Scientists-exaggerate-climate-change-fears-majority-Britons-believe.html

299. "Climate Change Omnibus: Great Britain," Ipsos Mori, February 24, 2010, http://www.ipsos-mori.com/researchpublications/researcharchive/poll.aspx?oItemId=2552

300. Edward Maibach et al., "A National Survey of Television Meteorologists About Climate Change: Preliminary Findings," George Mason University Center for Climate Change Communication, March 29, 2010, http://www.climatechangecommunication.org/images/files/TV_Meteorologists_Survey_Findings_(March_2010).pdf

Why is there such a high degree of skepticism among professionals and the public when the mainstream media is so biased toward the IPCC view? It would appear they are reading about skeptical opinions on the Internet, blogs in particular, and talking to one another about the subject in an open-minded manner. Obviously most weather presenters are acutely interested in and aware of the fine points of the debate. The fact they disagree with the IPCC "consensus" by two-to-one speaks volumes about where these weather professionals find credibility on the subject of global warming.

Climate science is a classic case of the necessity to distinguish between historical and present facts on the one hand, and predictions of the future on the other. There are a number of things we can say with relative certainty:

• During the past 500 million years, since modern life forms emerged, the earth's climate has been warmer than it is today most of the time. During these "Greenhouse Ages" the earth's temperature averaged around 22 to 25 degrees Celsius (72 to 77 Fahrenheit).[301] All the land was either tropical or subtropical and the world was generally wetter. The sea level was much higher than today and life flourished on land and in the oceans. These warm periods were punctuated by three Ice Ages during which large ice sheets formed at the poles and in mountainous areas, effectively eliminating most plants and animals in those regions.

• The two Ice Ages that preceded the current one occurred between 460 and 430 million years ago and between 360 and 260 million year ago. From 260 million years ago until quite recently, a Greenhouse Age existed for about 250 million years. Ice started to accumulate in Antarctica beginning 20 million years ago and eventually the cur- rent Ice Age, known as the Pleistocene, began in earnest about 2.5 million years ago.[302] *The Pleistocene, which we are still in today and during which our species evolved to its current state, accounts for only 0.07 percent of the history of life on earth.*

• During the coldest periods of the Pleistocene Ice Age the average temperature of the earth was around 12 degrees Celsius (54 degrees Fahrenheit) and there were large ice sheets on both poles. Before the recent retreat of the glaciers, beginning 18,000 years ago, the ice extended below the U.S./Canada border, over all of Scandinavia, much of northern Europe, and well into northern Russia. The sea was about 122 meters (400 feet) lower than it is today, having risen steadily since then and continuing to do so today.[303] In recent times the sea has risen about 20 centimeters (8 inches) per century. The

301. Christopher R. Scotese, "Climate History," Paleomar Project, April 20, 2002, http://www.scotese.com/climate.htm 302. "Ice Age" Wikipedia, http://en.wikipedia.org/wiki/Ice_age□303. "Sea Level," Wikipedia, http://en.wikipedia.org/wiki/Sea_level

cause of sea level rise is a combination of melting glaciers (ice on land) and rising ocean temperature, as water expands when it gets warmer.

- The earth's climate underwent a general warming trend beginning with the end of the last major glaciation, about 18,000 years ago. This has not been an even warming, as there have been many fluctuations along the way. For example, during the Holocene Thermal Maximum between 9000 and 4000 years ago it was warmer than it is today by as much as 3 degrees Celsius (5.4 degrees Fahrenheit).[304] During this time the present-day Sahara Desert was covered with lakes and vegetation, clearly indicating there was much more rain- fall there than today.[305] We know for a fact this was not caused by humans. Many scientists believe it was caused by variations in the earth's orbit around the sun.

- This historical record highlights the importance of analyzing the starting point and end point of temperature measurements when explaining trends, both up and down. It is warmer today than it was 18,000 years ago. But it is cooler today than it was 5,000 years ago during the Holocene Thermal Optimum. So it could be said we have been in a cooling trend for the past 5000 years even though it is warmer now than it was when the glaciation ended. I will try not to "trick" the reader by cherry-picking timelines that support a particular bias.

- Today the average temperature of the earth is about 14.5 degrees Celsius (58 degrees Fahrenheit), decidedly closer to the Ice Age level than the Greenhouse Age level and only 2.5 degrees above the temperature at the height of the last major glaciation. The fact is we are still in the Pleistocene Ice Age and it is possible another major glaciation may occur sometime in the next 10,000 years, but that is a prediction, not a fact.

- Carbon Dioxide (CO_2) is a greenhouse gas in that it tends to heat the atmosphere and thus raise the temperature of the earth. But water vapor is by far the most important greenhouse gas, contributing at least two thirds of the "greenhouse effect." CO_2 and other minor gases, such as methane and nitrous oxide, make up the other third of the greenhouse effect.[306] It is not possible to prove the exact ratios among the various greenhouse gases as they interact in complex ways. □

304. Chris Caseldine et al., "Holocene Thermal Maximum up to 3oC Warmer Than Today, *Quaternary Science Reviews* 25, no. 17–18 (September 2006): 2025–2446.□

305. "Earth's Climatic History: The Last 10,000 Years," *CO_2Science*, http://www.co2science.org/subject/other/clim_hist_tenthousand.php

□306. J. T. Kiehl and Kevin E. Trenberth, "Earth's Annual Global Mean Energy Budget," *Bulletin of the American Meteorological Society* 78, no. 2 (February 1997): 197-208, www.atmo.arizona.edu/students/courselinks/spring04/atmo451b/pdf/RadiationBudget.pdf

In particular, the balance between water vapor and clouds (made up of condensed water vapor) is impossible to predict accurately.[307]

- We know global levels of CO_2 in the atmosphere have risen steadily from 315 parts per million (ppm) to nearly 390 ppm since scientists began taking regular measurements at Mauna Loa on the big island of Hawaii in 1958.[308] This is a very short time compared to the 3.5 billion years of life on earth. Many scientists assume that human emissions of CO_2 from burning fossil fuels are the main cause of this increase. Some scientists question this assumption. It is a fact that CO_2 levels were much higher than they are today during previ□ous eras. This will be discussed in detail later.

- The average temperature of the earth has fluctuated during the past □100 years, sometimes cooling, sometimes warming, and in balance has increased somewhat, especially during the periods from 1910 to 1940 and from 1980 to 1998. Since 1998 there has been no further warming and apparently a slight cooling. There is a lot of controversy around the accuracy of these trends. In particular there is a concern that many of the weather stations used to determine the global aver- age were originally in the countryside but over the years have been swallowed up by expanding urban development. The "urban heat island effect" refers to the fact that concrete and heat from buildings results in an increase in temperature in urban areas compared to the surrounding countryside,[309] thus the possibility exists that the results have been skewed. □In November 2009 the release of thousands of emails, leaked or hacked, from the Climatic Research Unit of the University of East Anglia in the U.K. shocked the climate change community. It was quite clear from a number of email exchanges that the scientists with this most important source of information had been manipulating data, withholding data, and conspiring to discredit other scientists who did not share their certainty that humans were the main cause of climate change. These revelations were quickly dubbed "Climategate" and have since been hotly debated in climate change circles.[310] [311] [312] It is very difficult to find

□307. "Forecast: Water and Global Warming," ESPERE, http://www.espere.net/Unitedkingdom/water/uk_forecast.html
□308. R. F. Keeling et al., "Atmospheric CO_2 Values (ppmv) Derived from In Situ Air Samples Collected at Mauna Loa, Hawaii, USA," Scripps Institute of Oceanography, September 2009, http://cdiac.ornl.gov/ftp/trends/co2/maunaloa.co2□
309. "Surfacestations Project Reaches 82% of the Network Surveyed," surfacestations.org, July 16, 2009, http://www.surfacestations.org/□
310. "The Tip of the Climate Change Iceberg," *Wall Street Journal*, December 8, 2009, http://online.wsj.com/article/SB10001424052748704342404574576683216723794.html□
311. James Delingpole, "Climategate: The Final Nail in the Coffin of 'Anthropogenic Global Warming'?" *Telegraph*, November 20, 2009, http://blogs.telegraph.co.uk/news/jamesdelingpole/100017393/climategate-the-final-nail-in-the-coffin-of-anthropogenic- global-warming/□
312. Andrew C. Revkin, "Hacked E-Mail Is New Fodder for Climate Dispute," *New York Times*, November 20, 2009, http://www.nytimes.com/2009/11/21/science/earth/21climate.html

a balanced account of this scandal. Commentary is divided sharply, with believers claiming that while the scientists involved behaved badly, this does not change the fact that the science is clear that humans are causing warming, while skeptics claim the revelations demonstrate the books have been cooked, placing the entire hypothesis of global warming in doubt.

In December 2009, after months of promotion and hype, the Copenhagen conference on climate change ended in disaster for the true believers. The delegates at the largest international meeting in history failed to reach a single binding decision to control CO_2 emissions. There does not seem to be any conceivable strategy to achieve international agreement on this subject. The United States will not sign a deal that does not include China, India, Brazil, and the other developing countries. The developing countries will not agree to reduce or restrict their CO_2 emissions so long as the U.S. and other industrialized countries have far higher emissions on a per capita basis. Whereas the U.S. emits nearly 20 tonnes (22 tons) of CO_2 per person, China emits 4.6 tonnes (5.1 tons) and India emits 1.2 tonnes (1.3 tons). There is no possibility this impasse will be resolved in the near future. The U.S. will not agree to reduce its emissions to a lower level while the developing countries increase theirs. The developing countries will not agree to a system in which the U.S. and other industrialized countries are allowed even higher per capita emissions. Despite this obvious impasse, the delegates continue to meet regularly, thousands of people jetting to desirable locations like Bali, Montreal, and Rio de Janeiro at public expense, with no possibility of ever reaching agreement.

We can be fairly certain of the facts listed above, with the qualifications given. While this is very interesting, it is not the known facts but rather the unanswered questions that are most intriguing. Climate change cannot be defined by a single question. It is much like peeling back the layers of an onion, beginning with the science, leading to possible environmental impacts, followed by potential economic and social impacts, and concluding with policy options. Among these questions are:

- Is CO_2, the main cause of global warming, either natural or human-caused?
- Are human-caused CO_2 emissions the principal cause of recent global warming?
- Is the recent warming trend fundamentally different from previous warming and cooling trends?
- If warming continues at the rate experienced in the 20th century into the 21st century will this be positive or negative for human civilization and the environment?
- Is the melting of glaciers and polar ice really a threat to the future of human civilization?

- Will increased CO_2 result in "acidification" of the oceans and kill all the coral reefs and shellfish?
- Is it possible for humans to halt global warming and to control the earth's climate?
- Which would cost more to the economy, an 80 percent reduction in fossil fuel use or adaptation to a warmer world?
- Could the United States and China ever agree to a common policy on reducing CO_2 emissions?
- Is the effort to conclude a binding agreement to control CO_2 emissions among all nations futile? □

These are just some of the many questions we must answer if we are to make intelligent choices about the direction public policy should take on the subject of climate change. □Before going into more detail I will clarify two key points. First, the fact that both CO_2 and temperature are increasing at the same time does not prove one is causing the other. It may be that increased CO_2 is causing some or most of the increased temperature. It may also be that increased temperature causes an increase in atmospheric CO_2. Or it may be they are both caused by some other common factor, or it may be just coincidental they are both rising together and they have nothing to do with one an- other. Correlation does not prove causation. In order to demonstrate one thing causes another, we need among other things, to be able to replicate the same cause-effect sequence over and over again. This is not possible with the earth's climate as we are not in control of all (or any of) the factors that might influence climate. Now, if we had a record of CO_2 and temperature going back many millions of years and it showed that increased temperature always followed increased CO_2, we would be a long way toward proving the point. As we shall see later, the historical record is not so clear on the relationship between CO_2 and temperature. □Second, it is often assumed that the interests of humans and the interests of the environment are one and the same. This may be the case for some factors, such as rainfall, but for others it simply does not apply. Take sea level rise, for example. If the sea level rises relatively rapidly, it will damage a great deal of human infrastructure and a great deal of work and expense will be required either to protect or to replace farms, buildings, wharfs, roadways, etc. But fish and other marine creatures will be perfectly happy with the rising sea level and most land animals will not find it difficult to move a few feet higher. A 1.5 meter (5-foot rise) in sea level may inundate Bangladesh, turning much of it into a salt marsh and displacing millions of people. This would be devastating for humans, but from an environmental perspective there is nothing wrong with a salt marsh. From an ecological point of view, a natural salt marsh represents an improvement over intensive agriculture with monocultures of nonnative food crops.

Fortunately, no credible scientist believes the sea level will rise anywhere near 1.5 meters in the next century.

A Longer View

Our lifetimes are so short compared to the billions of years of life's history on earth that we tend to dwell on the very recent past when considering historical information. Nearly all the discussion of climate change is in the context of the past 100 years, or occasionally the past 1000 years, even though the earth's climate has changed constantly for billions of years. Let's take a look at the history of climate change in this larger context, in particular the past 500 million years since modern life forms evolved.

Temperature

The earth's average temperature has fluctuated widely over the past one bil- lion years (see Figure 1). It is interesting to note that during the Cambrian Period, when most of the modern life forms emerged, the climate was much warmer than it is today, averaging 25 degrees Celsius (77 degrees Fahrenheit). Only at three other times during the past billion years has the temperature been as cold as or colder than it is today. The age of the dinosaurs, the Jurassic and Cretaceous Periods, experienced a warm climate with a moderate cooling spell in the late Jurassic. Following the dinosaur extinction the climate remained warm for 10 million years, spiking to 27 degrees Celsius (80 degrees Fahrenheit), followed by a gradual decline that eventually led to the Pleistocene Ice Age. As the graph below indicates, it is colder today than it has been throughout most of the past billion years.

Humans generally prefer warmer climates to colder ones. When I mention that the global climate was much warmer before this present Ice Age, people often say something like, "But humans were not even around five million years ago, certainly not 50 or 500 million years ago. We have not evolved in a warmer world and will not be able to cope with global warming." The fact is we did evolve in a "warmer world." The human species originated in the tropical regions of Africa, where it was warm even during past glaciations nearer the poles. Humans are a tropical species that has adapted to colder climates as a result of harnessing fire, making clothing, and building shelters. Before these advances occurred, humans could not live outside the tropics. It may come as a surprise to most that a naked human in the outdoors with no fire will die of hypothermia if the temperature goes below 21 degrees Celsius (70 degrees Fahrenheit). Yet as long as we have food, water, and shade we can survive in the hottest climates on earth without fire, clothing, or shelter.[313] The Australian Aborigines survived in

313. Claude A. Piantadosi, *The Biology of Human Survival: Life and Death in Extreme Environments* (Oxford: Oxford University Press, 2003)

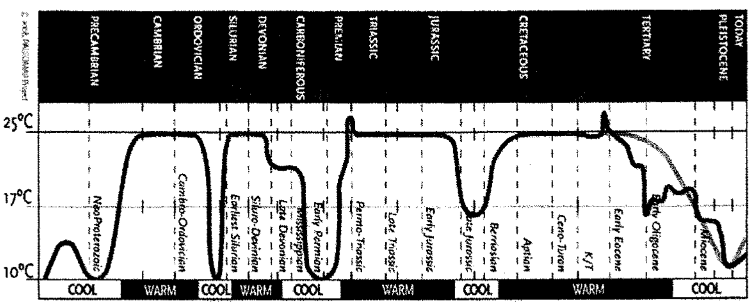


Figure 1. Graph showing global average temperature during the past billion years.[314]

temperatures of over 45 degrees Celsius (113 degrees Fahrenheit) without air conditioning for 50,000 years.

The fact that humans are essentially a tropical species explains why even today there are no permanent residents of Antarctica and only four million people living in the Arctic (0.06 percent of the global population). Most of the Arctic population is engaged in resource extraction and would not choose to live there otherwise. Historically, the very small populations of indigenous people in the Arctic managed to eke out a living by inhabiting ice-shelters, getting food from marine mammals and oil from marine mammals for heating and light. They used sled dogs for transport and protection from polar bears. There is a good reason why there are more than 18 million people in Sao Paulo, Brazil, only 4,429 residents in Barrow, Alaska,[315] and 3,451 inhabitants of Inuvik, Northwest Territory.[316]

Why are there 300 million people in the United States and only 30 million in Canada, which is larger geographically? One word answers this question: cold. About 80 percent of Canadians live within 100 miles of the U.S. border, as it is warmer there (although not by much in many regions) than it is in 90 percent of Canada, which is frozen solid for six or more months of the year.

So clearly, on the basis of temperature alone, it would be fine for humans if the entire earth were tropical and subtropical as it was for millions of years during the Greenhouse Ages. It would also be fine for the vast majority of species in the world today, most of which live in tropical and subtropical regions. But this would not be the case for some other species that have evolved specifically to be able to survive in cold climates.

The polar bear did not exist until the Pleistocene Ice Age froze the Arctic and created the conditions for adaptation to a world of ice. Polar bears are not really

314. Global Temperature Curve by C.R. Scotese, PALEOMAP Project, http://www.scotese.com/climate.htm

315. "City of Barrow – Farthest North American City," http://www.cityofbarrow.org/□316. "Inuvik," http://www.inuvik.ca/tourism/faq.html

a distinct species; they are a variety of the European brown bear, known as the grizzly bear in North America. They are so closely related genetically that brown bears and polar bears can mate success- fully and produce fertile offspring.[317] The white variety of the brown bear evolved as the ice advanced, the white color providing a good camouflage in the snow. Once bears could walk out to sea on the ice floes, it became feasible to hunt seals. It is possible that if the world warmed substantially over the next hundreds of years that the white variety of the brown bear would become reduced in numbers or even die out. This would simply be the reverse of what happened when the world became colder. Some varieties of life that exist today are only here because the world turned colder a few million years ago, following a warmer period that lasted for over 200 million years. If the climate were to return to a Greenhouse Age those varieties might not survive. Many more species would benefit from a warmer world, the human species among them.

The polar bear did not evolve as a separate variety of brown bear until about 150,000 years ago, during the glaciation previous to the most recent one.[318] [319] This is a very recent adaptation to an extreme climatic condition that caused much of the Arctic Ocean to freeze over for most of the past 2.5 million years. The polar bear did manage to survive through the inter- glacial period that preceded the one we are in now even though the earth's average temperature was higher during that interglacial than it is today.[320] So as long as the temperature does not rise more than about 5 degrees Celsius (9 degrees Fahrenheit) above the present level, polar bears will likely survive. But that is a prediction, not a fact.

To listen to climate activists and the media, you would think the polar bear population is already in a steep decline. A little investigation reveals there are actually more polar bears today than there were just 30 years ago. Most subpopulations are either stable or growing. And the main cause of polar bear deaths today is legally sanctioned trophy hunting, not climate change. Of an estimated population of 20,000 to 25,000 bears, more than 700 are shot every year by trophy hunters and native Inuit. One hundred and nine are killed in the Baffin Bay region of Canada alone. And yet activist groups like the World Wildlife Fund use the polar bear as a poster child for global warming, incorrectly alleging that they are being wiped out by climate change.

The population of polar bears was estimated at 6000 in 1960. In 1973 an International Agreement between Canada, the United States, Norway,

317. Katherine Hamon, "Climate Change Likely Caused Polar Bear to Evolve Quickly," *Scientific American*, March 1, 2010, http://www.scientificamerican.com/article.cfm?id=polar-bear-genome-climate□

318. "Polar Bear" Wikipedia, http://en.wikipedia.org/wiki/Polar_bear□

319. Katherine Hamon, "Climate Change Likely Caused Polar Bear to Evolve Quickly," *Scientific American*, March 1, 2010, http://www.scientificamerican.com/article.cfm?id=polar-bear-genome-climate

320. "Interglacial,"Wikipedia,http://en.wikipedia.org/wiki/Interglacial

Russia, and Greenland ended unrestricted hunting and introduced quotas. Since then only native people have been allowed to hunt polar bears, although in Canada the native Inuit often act as guides for non- native hunters. As a result of this restriction on hunting, the population has rebounded to its present level of 20,000 to 25,000. The International Union for the Conservation of Natural Resources Polar Bear Specialist Group reports that of 18 subpopulations of bears, two are increasing, five are stable, five are declining, while for six subpopulations, mainly those in Russia, there is insufficient data.[321] There is no reliable evidence that any bear populations are declining due to climate change and all such claims rely on speculation; they are predictions based on conjecture rather than actual scientific studies.

At the other end of the world in Antarctica, numerous species of pen- guins have evolved over the past 20 million years so that they can live in ice-bound environments. There are also many species of penguins that live in places where there is no ice, such as in Australia, South Africa, Tierra del Fuego, and the Galapagos Islands. It took 20 million years for the Antarctic ice sheet to grow to the extent it has been for the past 2.5 million years, during the Pleistocene Age. Antarctica differs significantly from the Arctic in that most of the ice is on land and at higher elevation. It is very unlikely Antarctica will become ice-free in the near future. It took millions of years for the present ice sheet to develop. In all likelihood the penguins will be able to breathe easily for thousands, possibly millions of years.

Coming closer to the present day, there is good historical evidence that it was warmer than it is today during the days of the Roman Empire 2000 years ago and during the Medieval Warming Period 1,000 years ago.[322][323] We know that during the Medieval Warming Period, the Norse (Vikings) colonized Iceland, Greenland, and Newfoundland. The settlements in Newfoundland and Greenland were then abandoned during the Little Ice Age that lasted from about 1500 to the early 1800s.[324] The Thames River in England froze over regularly during the cold winters of the Little Ice Age. The Thames last froze over in 1814.[325] Since then the climate has been in a gradual warming trend. Given that there were very low levels of CO_2 emissions from human activity in those times, it is not possible that humans caused the Medieval Warming Period or the Little Ice Age. Natural factors had to be instrumental in those changes in climate.

321. "Summary of Polar Pear Population status per 2010," IUCN Polar Bear Specialist Group, http://pbsg.npolar.no/en/status/status-table.html□

322. "Roman Warm Period (Europe – Mediterranean) – Summary," *CO_2 Science*, http://www.co2science.org/subject/r/summaries/rwpeuropemed.php

323. "Medieval Warm Period Project," *CO_2 Science*, http://www.co2science.org/data/mwp/mwpp.php

324. "20th Century Climate Not So Hot," Harvard Smithsonian Center for Astrophysics, March 31, 2003, http://www.cfa.harvard.edu/news/archive/pr0310.html□

325. "The Frozen Thames in London: An Introduction," History and Traditions of England, January 10, 2010, http://www.webhistoryofengland.com/?p=613

Speaking of natural factors, it is clear the climate changes over the past billions of years were not caused by our activities. So how credible is it to claim we have just recently become the main cause of climate change? It's not as if the natural factors that have been causing the climate to change over the millennia have suddenly disappeared and now we are the only significant agent of change. Clearly the natural factors are still at work, even if our population explosion and increasing CO_2 emissions now play a role in climate change. So the real question is, are human impacts over- whelming the natural factors or are they only a minor player in the big picture? We do not know the definitive answer to that question.

Let's go back to the IPCC's *Fourth Assessment Report* in 2007, which stated: "*Most* of the observed increase in global average temperatures *since the mid-20th century* is *very likely* due to the observed increase in anthropogenic (human-caused) greenhouse gas concentrations"[my emphasis]. The first word, *most*, in common usage means more than 50 percent and less than 100 percent, i.e., more than half but not all. That's a pretty big spread, so clearly IPCC members don't have a very precise estimate of how much of the warming they think we are causing. If they are that uncertain, how do they know it's not 25 percent, or 5 percent? They restrict the hu- man influence to "since the mid-20th century," implying humans were not responsible for climate change until about 60 years ago. So the logical question is, What was responsible for the significant climate changes be- fore 60 years ago, the warming between 1910 and 1940, for example? The most problematic term in their statement is "very likely," which certainly provides no indication of scientific proof. The IPCC claims that "very likely" means "greater than 90 percent probability."[326] But the figure 90 is not the result of any calculation or statistical analysis. The footnote entry for the term "very likely" explains, "in this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, *using expert judgement*, [my emphasis] of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%."[327] One expects "judgments" from judges and opinionated journalists. Scientists are expected to provide calculations and observable evidence. I'm not convinced by this loose use of words and numbers.

According to the official records of surface temperatures, 1998 was the warmest year in the past 150 years. Since then the average global temperature remained relatively flat down, completely contrary to the predictions of the IPCC,

326. "Summary for Policymakers," Intergovernmental Panel on Climate Change, 2007, p. 3 http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

327. Ibid.

and in spite of steadily growing CO_2 emissions from countries around the world. This drop in temperature is now attributed to natural factors, something that was downplayed in previous predictions. Mojib Latif, a prominent German meteorologist and oceanographer, explains it this way, "So I really believe in Global Warming. Okay. However, you know, we have to accept that there are these natural fluctuations, and therefore, the temperature may not show additional warming temporarily."[328] The question is, How long is temporarily? At this writing the global temperature has not increased during the past 16 years. The assertion that it will resume warming at some time in the future is a prediction, not a fact. And even if warming does resume, it is possible that this may be due to natural factors. *It is not logical to believe that natural factors are only responsible for cooling and not for warming.*

The situation is complicated further by the revelations of "Climategate" in November 2009, which clearly showed that many of the most influential climate scientists associated with the IPCC have been manipulating data, withholding data, and conspiring to discredit other scientists who do not share their certainty that we are the main cause of global warming.[329] It has also been well documented that the NASA Goddard Institute for Space Science, which is responsible for one of the primary temperature records, has dropped a large number of weather stations, mainly in colder regions, thus likely making it seem warming is occurring even though this may not be the case.[330] The situation is in such a state of flux that it may be several years before an objective process is in place to sort out what is believable and what is not.

Leading up to the 15th Conference of the Parties in the Framework Convention on Climate Change in Copenhagen in December 2009, the IPCC, the European Union, and many other participants warned we must keep global temperatures from rising more than 2 degrees Celsius (3.6 degrees Fahrenheit) or we will face climate catastrophe.[331] Yet the global temperature has been 6 to 8 degrees Celsius (11 to 14 degrees Fahrenheit) warmer than it is today through most of the past 500 million years. It seems clear that the real "climate catastrophes" are the major glaciations that occurred during the Ice Ages, not the warm Greenhouse Ages when life flourished from pole to pole.

328. "Scientist Explains Earth's Warming Plateau," National Public Radio, November 22, 2009 http://www.npr.org/templates/story/story.php?storyId=120668812&ft=1&f=1007

□329. James Delingpole, "Climategate: The Final Nail in the Coffin of 'Anthropogenic Global Warming'?" *Telegraph*, November 20, 2009, http://blogs.telegraph.co.uk/news/jamesdelingpole/100017393/climategate-the-final-nail-in-the-coffin-of- ...□... anthropogenic-global-warming/

□330. Joseph D'Aleo and Anthony Watts, "Surface Temperature Records: Policy-Driven Deception?" Science & Public Policy Institute, June 2, 2010, http://scienceandpublicpolicy.org/images/stories/papers/originals/surface_temp.pdf

□331. James Murray, "IPCC Chief Warns Even Two Degree Rise Spells 'Bad News'," businessgreen.com, March 10, 2009, http://www.businessgreen.com/business-green/news/2238184/ipcc-chief-warns-two-degree

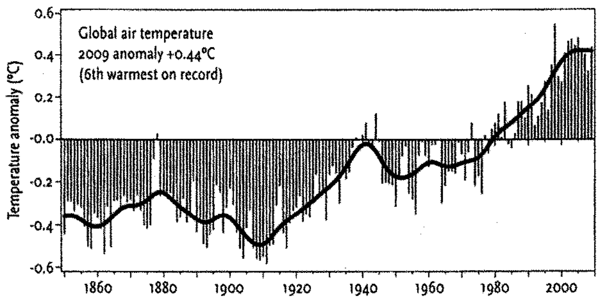


Figure 2. Global temperature trends 1860–2008 according to Phil Jones of the Climatic Research Unit in the U.K.

The graph on this page, Figure 2, is a record of global temperatures from 1850 to 2008, as prepared by the Climatic Research Unit at the University of East Anglia in the U.K.[332] It was authored by Phil Jones, who was at the centre of the "Climategate" scandal. As previously mentioned, the emails he and his colleagues exchanged indicated they withheld data, manipulated data, and attempted to discredit other scientists who held contrary views. Jones was suspended from his post in November 2009, pending an inquiry into the scandal. Therefore the data this graph is based on are not necessarily credible; they need to be rigorously re-examined.[333] But the graph does provide a useful tool for examining a couple of points about recent temperature trends.

The graph indicates global temperature has risen by about 0.8 degrees Celsius (1.4 degrees Fahrenheit) over the past 150 years. But about half of this warming occurred from 1910 to 1940, before the huge increase in CO_2 emissions from fossil fuel that began after the Second World War. What caused this increase? We simply don't know. Then there was a period of cooling from 1940 to 1980, just as CO_2 emissions started to increase dramatically. In the mid-1970s, mainstream magazines and newspapers, including *Time*, *Newsweek*, and the *New York Times*, published articles on the possibility of a coming cold period, perhaps another Ice Age.[334][335] These articles were based on interviews with scientists at the National Academy of Sciences and NASA, among others. Prominent supporters of the global cooling

332. Phil Jones, "Global Temperature Record," Climatic Research Unit, March 2010, http://www.cru.uea.ac.uk/cru/info/warming/

333. Joseph D'Aleo and Anthony Watts, "Surface Temperature Records: Policy-Driven Deception?" Science & Public Policy Institute, June 2, 2010, http://scienceandpublicpolicy.org/images/stories/papers/originals/surface_temp.pdf

334. Mauritzio Marabito, "Same Fears: Different Name?" *Spiked*, December 10, 2009, http://www.spiked-online.com/index.php/site/article/7817/

335. Robert Bradley Jr, "The Global Cooling Scare Revisited ('Ice Age' Holdren Had Plenty of Company)," Master Resource, September 26, 2009, http://www.masterresource.org/2009/09/the-global-cooling-scare-revisited/

theory included present-day global warming supporters such as John Holdren, the Obama administration's science czar[337] and the late Stephen Schneider, a former leading member of the IPCC.[338]

In 1980, global temperatures began a 20-year rise, according to the now questionable records used by the IPCC for its predictions of climate disaster. This is the only period in the 3.5 billion years of life on earth in which the IPCC attributes climate change to human activity. Since 1998 there has been no further increase in global temperature, even according to the IPCC sources. How does one 20-year period of rising temperatures out of the past 150 years prove we are the main cause of global warming?

The alarmists declare that the present warming trend is "unprecedented" because it is happening on a scale of centuries whereas past warming trends have been much slower, giving species time to adapt. This is shown to be false even during the past century. The IPCC does not contend that humans caused the warming from 1910 to 1940; therefore it must have been a natural warming trend. But the warming from 1910 to 1940 was just as large (0.4 degrees Celsius or 0.7 degrees Fahrenheit) and just as rapid over time as the supposed human-caused warming from 1975 to 2000. How can scientists who claim to be on the cutting edge of human knowledge miss this point?

It is a testament to the fickleness of trends in science, public policy, and media communications that such certainty about human-caused climate change came about. That era finally seems to have ended now that more attention is being paid to the proposition that we really don't have all the answers. One hopes this will usher in a more sensible conversation about climate change and a more balanced approach to climate change policy.

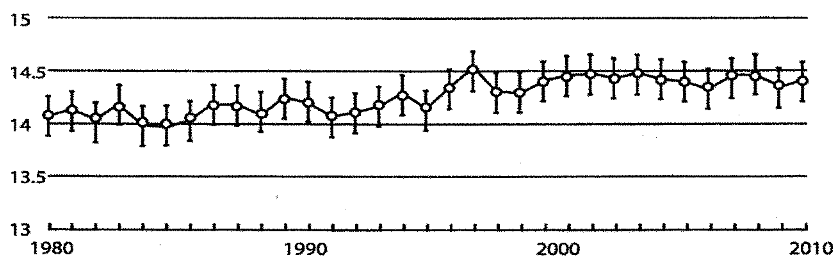


Figure 3. The HadCRUT 3 record of global temperature since 1980. There is no statistically significant increase in temperature since 1997.[336]

336. http://www.thegwpf.org/temperature-standstill-continues-2012-scrapes-top-ten/hadcrut3-2/
337. "John Holdren in 1771: 'New Ice Age Likely'," Zomblog, September 16, 2009, http://www.zombietime.com/zomblog/?p=873
338. John L. Daly, "Stephen Schneider: Greenhouse Superstar," August 2008, http://www.john-daly.com/schneidr.htm

In early 2013 there were three independent announcements by leading believers in human-caused catastrophic climate change that confirmed the standstill in global temperature. James Hansen, Director of the NASA Goddard Institute for Space Studies and senior science advisor to Al Gore, stated "The 5-year running mean of global temperature has been flat for the past decade." In January 2013 The UK Met Office and the Climatic Research Unit of the University of East Anglia released the data for December in their Hadcrut3 and Hadcrut4 global temperature datasets. The data clearly shows that there has been no increase in global temperature for 16 years, since 1997. In an interview with The Australian in February 2013, Rajenda Pachauri, the chair of the Intergovernmental Panel on Climate Change, acknowledged the reality of the post-1997 standstill in global average temperatures.

Carbon Dioxide

The trains carrying coal to power plants are death trains. □*Coal-fired power plants are factories of death.* □—James Hansen, director, NASA Goddard Institute for Space Studies, science advisor to former vice president Al Gore

The entire global warming hypothesis rests on one belief—human emissions of CO_2 are causing rapid global warming that will result in a "catastrophe" if we don't cut emissions drastically, beginning now. Let's look at the history, chemistry, and biology of this much-maligned molecule.

Carbon dioxide (CO_2) and carbon are probably the most talked about substances in the world today. We hear the term "carbon footprint" every day and fossil fuels are now routinely described as "carbon-based energy." True believers speak of CO_2 as if it is the greatest threat we have ever faced. Perhaps our CO_2 emissions will have some negative effects. But in my view CO_2 is one of the most positive chemicals in our world. How can I justify this statement given that the US Environmental Protection Agency has declared CO_2 and other greenhouse gases are "pollutants" that are dangerous to human health and the environment?[339]

What about the undisputed fact that CO_2 is the most important food for all life on earth? Every green plant needs CO_2 in order to produce sugars that are the primary energy source for every plant and animal. To be fair, water is also essential to living things, as are nitrogen, potassium, phosphorus, and many other minor elements. But CO_2 is the most important food, as all life on earth is carbon-based, and the carbon comes from CO_2 in the atmosphere. Without CO_2 life on this planet would not exist. How important is that?

339. "Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act," U.S. Environmental Protection Agency, December 7, 2009, http://www.epa.gov/climatechange/endangerment.html

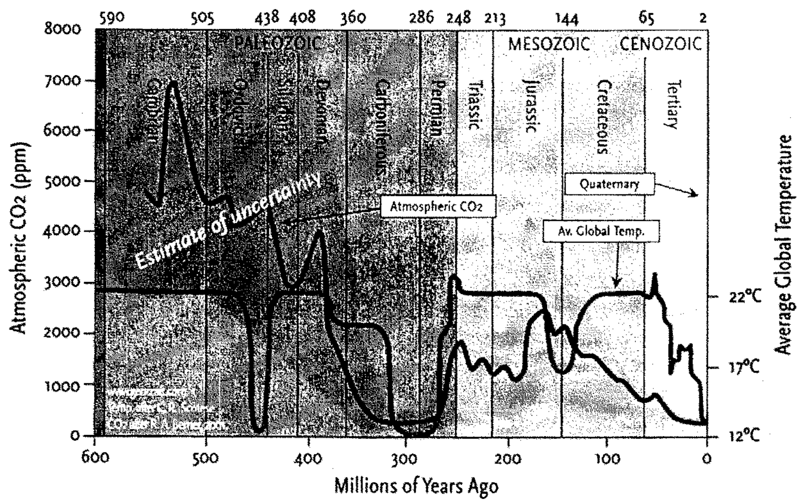


Figure 4. This graph shows global levels of CO2 and the global temperature for the past 600 million years. The correlation between the two parameters is mixed at best, with an Ice Age during a period of high CO2 levels and Greenhouse Ages during a period of relatively low CO2 levels.340

When President Obama appointed Lisa Jackson as head of the EPA, she promised to "ensure EPA's efforts to address the environmental crises of today are rooted in three fundamental values: science-based policies and programs, adherence to the rule of law, and overwhelming transparency." During the EPA's deliberations on the "endangerment" ruling for CO_2, one of its top economic policy experts, Alan Carlin, a 35-year veteran of the agency, presented a 98-page analysis concluding that the science behind man-made global warming is inconclusive at best and that the agency should re-examine its findings. His analysis noted that global temperatures were on a downward trend. It pointed out problems with climate models. It highlighted new research about climate change that contradicts apocalyptic scenarios. "We believe our concerns and reservations are sufficiently important to warrant a serious review of the science by EPA," the report read.

In response to the report Carlin's boss, Al McGartland, emailed him, forbidding him from engaging in "any direct communication" with any- one outside his office about his analysis. In a follow-up email, McGartland wrote, "With the endangerment finding nearly final, you need to move on to other issues and subjects. I don't want you to spend any additional EPA time on climate change.

340. Monte Hieb, "Climate and the Carboniferous Period," Plant Fossils of West Virginia, March 21, 2009, http://www.geocraft.com/WVFossils/Carboniferous_climate.html

No papers, no research, etc., at least until we see what EPA is going to do with Climate."[341] These emails were leaked. So much for transparency, and so much for science.

There is an interesting parallel here with the issue of chlorine, a chemical described by Greenpeace as the "devil's element." There are some chlorine-based chemicals that are very toxic and should be tightly con- trolled and even banned in certain contexts. But as discussed earlier, chlorine is the most important element for public health and medicine, just as carbon is the most important element for life. And yet Greenpeace and its allies give the impression these two building blocks of nature are essentially evil. It is time to bring some balance into this discussion.

Al Gore is fond of reminding us that there is more CO_2 in the atmosphere today than there has been for the past 400,000 years.[342] He may be correct, although some scientists dispute this.[343] But 400,000 years is a blink of an eye in geological history. It is also true to state that CO_2 levels in the atmosphere have rarely been as low as they are today over the entire 3.5 billion years of life on earth, and particularly during the past 500 million years since modern life forms evolved. Figure 4 (previous page) shows the historic levels of CO_2 as well as the global temperature, going back 600 million years

Note the graph shows CO_2 was at least 3000 ppm, and likely around 7000 ppm, at the time of the Cambrian Period, a Greenhouse Age when modern life forms first evolved. This is nearly 20 times the CO_2 concentration today. The Ice Age that peaked 450 million years ago occurred when CO_2 was about 4000 ppm, more than 10 times its present level. If both warm and cold climates can develop when there is far more CO_2 in the atmosphere than today, how can we be certain that CO_2 is determining the climate now?

The graph does show a limited correlation between temperature and CO_2 during the late Carboniferous, and a very weak correlation from then until today. It is true that the most recent Ice Age corresponds with a relatively low CO_2 level in the atmosphere. None of this is intended to make the argument that CO_2 does not influence climate. I am no denier. We know that CO_2 is a greenhouse gas and that it plays a role in warming the earth. The real questions are: How much of a role? and If warming is caused by our CO_2 emissions, does this really harm people and the planet?

Coming closer to the present, one of the best sets of data comes from ice cores at the Russian Vostok station in Antarctica. These cores give

341. Kimberley A. Strassel, "The EPA Silences a Climate Skeptic," *Wall Street Journal*, July 3, 2009, http://online.wsj.com/article/SB124657655235589119.html

342. Dave McArthur, "The Inconvenient Truth About *An Inconvenient Truth*," *Scoop*, July 26, 2006, http://www.scoop.co.nz/stories/HL0607/S00400.htm

343. Ernst-Georg Beck, "180 Years of Atmospheric CO_2 Gas Analysis by Chemical Methods," *Energy and Environment*, 18, no. 2 (2007), http://icecap.us/images/uploads/EE_18-2_Beck.pdf

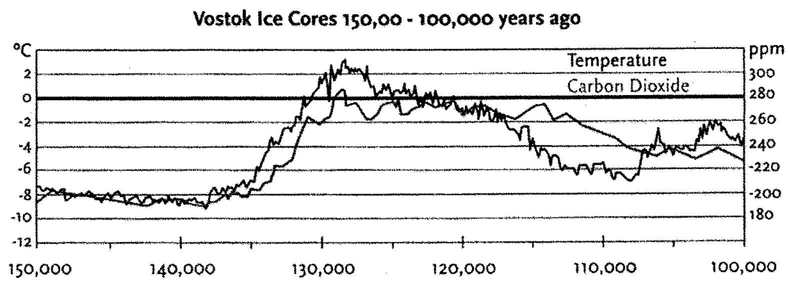


Figure 5. Graph showing temperature and CO_2 levels from 150,000 to 100,000 years ago. Note that temperature rises ahead of a rise in CO_2.

us a picture of both temperature and atmospheric CO_2 levels going back 420,000 years. Al Gore uses this information in his film *An Inconvenient Truth* to assert that it provides evidence that increased CO_2 causes an in- crease in temperature. Closer examination of the data shows that it is the other way around.[344] Through most of this period it is temperature that leads CO_2 as shown for the period 150,000 to 100,000 years ago in Figure 5. When temperature goes up, CO_2 follows and when temperature goes down, CO_2 follows it down.

This does not prove that increases in temperature cause increases in CO_2, it may be that some other common factor is behind both trends. But it most certainly does not indicate rising CO_2 levels cause increases in temperature. It may be that CO_2 causes a tendency for higher temperatures but that this is masked by other, more influential factors such as water vapor, the earth's orbit and wobbles, etc.

The April 2008 edition of *Discover* magazine contains a full-page article about plants, written by Jocelyn Rice, titled, "Leaves at Work." The article begins with this passage, "In the era of global warming, leaves may display an unexpected dark side. As CO_2 concentrations rise, plants can become full. As a result, their stomata—the tiny holes that collect the CO_2...will squeeze shut. When the stomata close, plants not only take less CO_2 from the air but also draw less water from the ground, resulting in a run of water into rivers. The *stomata effect* [my emphasis] has been responsible for the 3 percent increase in river runoff seen over the past century."[345] At this point my BS meter came on. There is no possibility anyone has a data set that could determine a 3 percent increase in global

344. Joanne Nova, "Carbon Follows Temperature in the Vostok Ice Cores," JoNova, 2008–2010, http://joannenova.com.au/global-warming/ice-core-graph/
□345. Jocelyn Rice, "Leaves at Work," *Discover* magazine, April 2008, p. 17
http://www.beattystreetpublishing.com/confessions/references/stomata-effect

river runoff in the past 100 years. The U.K.'s Hadley Centre for Climate Prediction and Research was given as the source of this information. A thorough review of the Hadley Centre website turned up nothing on the subject.[346]

The story goes on to predict that, given present trends in CO_2 emissions, "runoff within the next 100 years could increase by as much as 24 percent above pre-industrial levels... in regions already hit hard by flooding, the stomata effect could make matters much worse." The Great Flood will return and inundate the earth due to trillions of tiny stomata shutting their doors in the face of too much CO_2!

I also knew immediately that the entire article was bogus because I am familiar with the fact that greenhouse growers purposely divert the CO_2 -rich exhaust gases from their wood or gas heaters into their greenhouses in order to greatly increase the CO_2 level for the plants they are growing. I searched the Internet using the phrase "optimum CO_2 level for plant growth." All I needed were the first few results to see plants grow best at a CO_2 concentration of around 1500 ppm, which boosts plant yield by 25 to 65 percent.[347] The present CO level in the global atmosphere is about 390 ppm. In other words, the trees and other plants that grow around the world would benefit from a level of CO_2 about four times higher than it is today. There is solid evidence that trees are already showing increased growth rates due to rising CO levels.[348]

Greenhouse growers are able to obtain growth rates that are 40 to 50 percent higher than the rates plants grow under in today's atmospheric conditions. This makes sense when you consider that CO_2 levels were generally much higher during the time when plant life was evolving than they are today. The fact is, at today's historically low CO_2 concentrations, all the plants on earth are CO_2-deprived. Those plants are starving out there!

Yet believers in catastrophic climate change will not abide by this clear evidence. In May 2010 Science magazine published an article titled, "Carbon Dioxide Enrichment Inhibits Nitrate Assimilation in Wheat and Arabidopsis."[349] The article implied that increased CO levels in the atmos□phere might inhibit the uptake of nitrogen. The popular press interpreted this as evidence that increased CO_2 might not result in increased growth rates, as has been conclusively demonstrated in hundreds of lab and field experiments.[350] This is why greenhouse growers purposely inject CO into their greenhouses. Typically, the *Vancouver Sun* ran with the headline,

346. "Met Office Hadley Centre," Met Office, http://www.metoffice.gov.uk/climatechange/science/hadleycentre/□
347. "Indoor Growing: Using CO_2," Planet Natural, http://www.planetnatural.com/site/xdpy/kb/implementing-co2.html
□348. "Forest are Growing Faster, Climate Change Appears to be Driving Accelerated Growth," Smithsonian Environmental Research Center, February 1, 2010, http://sercblog.si.edu/?p=466□
349. Arnold J. Bloom, "Carbon Dioxide Enrichment Inhibits Nitrate Assimilation in Wheat and Arabidopsis," *Science* 328, no. 5980 (May 14, 2010): 899–903, http://www.sciencemag.org/cgi/content/abstract/328/5980/899
□350. "Plant Growth Database," *CO_2Science*, http://www.co2science.org/data/plant_growth/plantgrowth.php

"Rising Carbon Dioxide Levels May Hinder Crop Growth: Greenhouse Gas Is Not Beneficial to Plants, As Once Thought."[351] The Science article was clever enough not to suggest that CO_2 would "hinder" plant growth, or even to question the proven fact that CO_2 increases plant growth. But by raising a side issue of nitrogen uptake it encouraged the media to make sensationalist claims, apparently debunking the fact that doubling, tripling, or even quadrupling CO_2 results in increased growth, regardless of some point about nitrogen.

It may turn out to be a very good thing that humans discovered fossil fuels and started burning them for energy. By the beginning of the Industrial Revolution CO_2 levels had gradually diminished to about 280 ppm. If this trend, which had been in effect for many millions of years, had continued at the same rate it would have eventually threatened plant life at a global level. At a level of 150 ppm, plants stop growing altogether. If humans had not appeared on the scene, it is possible that the declining trend in CO_2 levels that began 150 million years ago would have continued. If it had continued at the same rate, about 115 ppm per million years, it would have been a little over one million years until plants stopped growing and died. And that would be the end of that!

This is perhaps my most heretical thought: that our CO_2 emissions may be largely beneficial, possibly making the coldest places on earth more habitable and definitely increasing yields of food crops, energy crops, and forests around the entire world. Earlier I referred to my meeting with James Lovelock, the father of the Gaia Hypothesis and one of the world's leading atmospheric scientists. I found it strange he was so pessimistic about the future, and cast our species as a kind of rogue element in the scheme of life.

Whereas the Gaia Hypothesis proposes that all life on earth acts in concert to control the chemistry of the atmosphere in order to make it more suitable for life, Lovelock believes human-caused CO_2 emissions are the enemy of Gaia. But surely humans are as much a part of Gaia as any other species, past or present? How could we know we are the enemy of Gaia rather than an agent of Gaia, as one would expect if "all life is acting in concert"? In other words, is it not plausible that Gaia is using us to pump some of the trillions of tons of carbon, which have been locked in the earth's crust over the past billions of years, back into the atmosphere? Perhaps Gaia would like to avoid another major glaciation, and more importantly avoid the end of nearly all life on earth due to a lack of CO_2. One thing I know for sure is we should be a lot more worried the climate will cool by 2 or 3 degrees Celsius than we should be about it warming by 2

351. Amina Khan, "Rising Greenhouse Gas Levels May Hinder Crop Growth," *Vancouver Sun*, May 15, 2010, http://www.vancouversun.com/health/Rising+carbon+dioxide+levels+hinder+crop+growth/3031640/story.html#ixzz0oFzR7jth

or 3 degrees Celsius. Cooling would definitely threaten our food supply; warming would almost certainly enhance it.

I'm not saying I buy into the entire Gaia Hypothesis hook, line, and sinker. I find some aspects of it very compelling, but it might be a bit of a stretch to believe all life is acting in harmony, like on the planet Pandora in the movie *Avatar*. But that's not my point. What bothers me is the tendency to see all human behavior as negative. Lovelock and his followers seem to need a narrative that supports the idea of original sin, that we have been thrown out of the Garden of Eden, or is it the Garden of Gaia?

The Hockey Stick

No discussion of climate change would be complete without mention of the infamous hockey stick graph of global temperature. The graph, said to depict Northern Hemisphere temperatures over the past 1,000 years, was created by Michael Mann of Pennsylvania State University and his colleagues. It shows a very even temperature until the modern age when there is a steep rise.[352] The surprise for many scientists was that the graph implied the Medieval Warm Period and the Little Ice Age did not exist and that the only significant change in temperature during the past 1000 years was a precipitous rise during the past century. The graph was very controversial in climate science circles. Despite the sharp debate, it was showcased in the 2001 and 2004 reports of the IPCC. [353]

Two Canadians, Steve McIntyre, a retired mining engineer, and Ross McKitrick, an economist, became concerned that the data used to create the hockey stick graph were not objective and the statistical analysis used was not legitimate. They asked Mann and others to provide them with the original data and the statistical methods used to arrive at the hockey stick graph. Mann and his colleagues at the Climatic Research Unit (CRU) at the University of East Anglia refused repeated requests to supply the data. The effort to obtain the data went on for 10 years as the researchers even refused requests under Freedom of Information Act rules. It was not until the release of thousands of emails from the CRU that it became clear information was being withheld illegally and there was a conspiracy of sorts to manipulate the data and discredit opposing opinions.

In 2003 McIntyre and McKitrick published a critique of the hockey stick graph in *Energy & Environment* in which they contended that Mann's paper contained, "collation errors, unjustifiable truncation or

352. Michael E. Mann et al., "Global-Scale Temperature Patterns and Climate Forcing Over the Past Six Centuries," *Nature* 392 (April 23, 1998). http://www.junkscience.com/MSU_Temps/PDF/mann1998.pdf

353. Suzanne Goldenberg, "'Hockey Stick' Graph Creator Michael Mann Cleared of Academic Misconduct," *Guardian*, February 3, 2010, http://www.guardian.co.uk/environment/2010/feb/03/climate-scientist-michael-mann

extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects."[354] As a result of this and other critiques the IPCC did not use the hockey stick graph again in its 2007 report. The continuing debate over this graph highlights the absence of a consensus on the temperature record, never mind whether or not humans are responsible for climate change.

What's So Good About Glaciers, Anyway?

Much has been made of the fact that many glaciers around the world have been retreating in recent years. By many accounts we should be viewing this with alarm. The potential loss of glaciers is portrayed as an ecological catastrophe, as if it were equivalent to a species becoming extinct. In its June 2007 issue the *National Geographic* magazine reported that a certain Peruvian glacier was in a "death spiral," as if it were a living thing.[355] What should we make of this hysterical reaction to melting ice?

It is important to recognize that glaciers have been retreating for about 18,000 years, since the height of the last glaciation. It has not been a steady retreat as there have been times, such as during the Little Ice Age, when the glaciers advanced. But there is no doubt that in balance there has been a major retreat and it appears to be continuing today.

The retreat of the glaciers is largely a result of the climate becoming warmer. It brings us back to the question of whether humans are responsible for the warming or if it is just a continuation of the trend that began 18,000 years ago. Either way, we then must ask whether, in balance, this is a good thing or a bad thing. We know the climate was warmer than it is today during most of the past 500 million years, and that life flourished during these times. We also know there is very little life on, in, or under a glacier. Glaciers are essentially dead zones, proof that ice is the enemy of life.

When a glacier retreats up the valley it carved, the bedrock and gravels are exposed to light and air. Seeds find their way there, on the wind and in bird droppings, and can germinate and grow. Before long the lifeless barrens become a newly developing ecosystem full of lichens, mosses, ferns, flowering plants, and eventually, trees. Isn't it fairly obvious that this is a better environmental condition than a huge blob of frozen water that kills everything beneath it? Glaciers certainly are photogenic, but as we dis-

354. Stephen McIntyre and Ross McKitrick, "Corrections to the Mann et al. (1998) Proxy Data Base and Northern Hemispheric Average Temperature Series," *Energy & Environment* 14, no. 6 (2003): 751–771, http://www.uoguelph.ca/~rmckitri/research/MM03.pdf□355. Tim Appenzeller, "The Big Thaw," *National Geographic*, June 2007, http://ngm.nationalgeographic.com/2007/06/big-thaw/big-thaw-text

cussed in the chapter on forests, you can't judge the health of an ecosystem by the fact that it looks pretty. Sand dunes make for nice scenery too, but they aren't very welcome when they bury a town and kill all the crops.

Much attention has been focused on the Greenland ice cap, virtually one big glacier with many arms to the sea. During the warming that occurred in the 1980s and 1990s it was reported that the Greenland ice cap was melting rapidly. Al Gore predicted the sea might rise by 20 feet in the next century, apparently assuming the entire ice cap might melt in 100 years.[356] This is a physical impossibility. The high elevation and extreme low temperatures dictate that it would take at least thousands of years for the glaciers of Greenland to disappear.

More recently the focus has been on the Himalayan glaciers, the largest ice cap outside the Polar Regions. The story of what has become "Glaciergate" helps to illustrate the present very confused state of climate science and of how important glaciers are, or are not. The 2007 report of the IPCC, its fourth report, stated Himalayan glaciers may be completely gone by 2035, less than 25 years from now.[357] [358] The report warned, "if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate." It was not until the lead-up to the 2009 Kyoto Protocol meeting in Copenhagen that scientists began to question this assertion. The Ministry of the Environment in India published a paper rejecting the 2035 prediction, stating that it would be hundreds of years before the glaciers melted, even if the present warming trend continued.[359] This caused the chairman of the IPCC, Dr. Rajendra Pachauri, who happens to be Indian, to denounce the Environment Ministry's report as "voodoo science."[360]

It was not until after the Copenhagen conference that the IPCC published an admission of error. They stated, "In drafting the paragraph in question, the clear and well-established standards of evidence, required by the IPCC procedures, were not applied properly."[361] Yet Dr. Pachauri refused to apologize for calling the Environment Ministry's report "voodoo science."[362] It was revealed that the 2035 date was based

356. Jeffrey Masters, "Al Gore's *An Inconvenient Truth*," Weather Underground, http://www.wunderground.com/education/gore.asp
357. "The Himalayan Glaciers," Intergovernmental Panel on Climate Change, 2007, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-6-2.html□
358. "IPCC Slips on the Ice with Statement About Himalayan Glaciers," climatesciencewatch.org, January 19, 2010, http://www.climatesciencewatch.org/index.php/csw/details/ipcc_slips_on_the_ice/
359. V. K. Raina, "Himalayan Glaciers," Science & Public Policy Institute, November 12, 2009, http://scienceandpublicpolicy.org/reprint/himalayan_review_of_glacial_studies.html□
360. "Pachauri Calls Indian Govt. Report on Melting Himalayan Glaciers as 'Voodoo Science,'" *Thaindian News*, January 9, 2010, http://www.thaindian.com/newsportal/health/pachauri-calls-indian-govt-report-on-melting-himalayan-glaciers-as-voodoo-science_100301232.html□
361. "Worldwide Glacier Melt a Real Concern; Himalaya Controversy Leaves Questions About IPCC Leadership, climatesciencewatch.org, January 21, 2010, http://www.climatesciencewatch.org/index.php/csw/details/glacier-melt-ipcc-controversy/
□362. "Pachauri Won't Apologies [sic.], Admits IPCC's Credibility Damaged," *India Post*, February 3, 2010, http://www.indiapost.com/international-news/6964-Pachauri-wont-apologies-admits-IPCCs-credibility-damaged.html

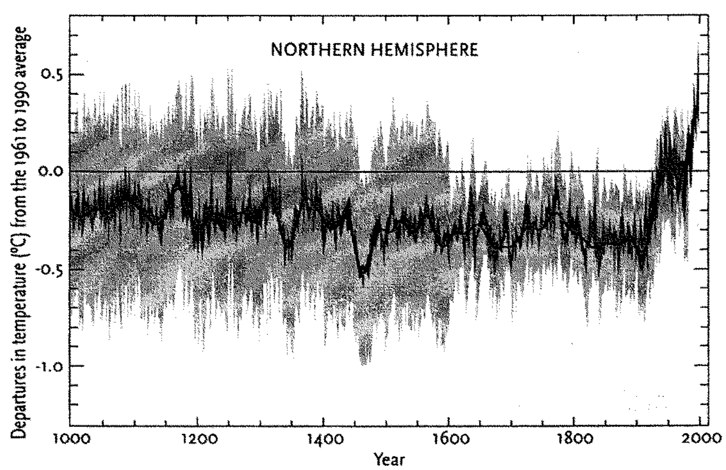


Figure 6. The Michael Mann Hockey Stick Graph as it appeared in the 2001 Assessment Report of the Intergovernmental Panel on Climate Change. 363

on an interview by *New Scientist* magazine of a single Indian scientist, who subsequently admitted his statement was "speculative."[364] The *New Scientist* article was then referred to in a 2005 WWF report on glaciers, which was cited as the only reference in support of the 2035 date.[365]

This has caused something of a crisis of credibility for the IPCC, which had insisted all its predictions were based on peer-reviewed science. As it turns out, the most credible scientists who specialize in the subject of Himalayan glaciers believe it would take at least 300 years for them to melt completely, even if it continues to get warmer. Other indefensible statements in the IPCC report then emerged regarding the disappearance of the Amazon rain forest[366] and the collapse of agricultural production in Africa.[367]

363. "Working Group I: The Scientific Basis," Intergovernmental Panel on Climate Change, 2001, http://www.ipcc.ch/ipccreports/tar/wg1/005.htm□

364. Fred Pearce, Debate Heats Up Over IPCC Melting Glaciers Claim, *New Scientist*, January 11, 2010, http://www.newscientist.com/article/dn18363-debate-heats-up-over-ipcc-melting-glaciers-claim.html□

365. Jonathan Leake and Chris Hastings, "World Misled Over Himalayan Glacier Meltdown," *Sunday Times*, January 17, 2010, http://www.timesonline.co.uk/tol/news/environment/article6991177.ece□

366. Christopher Booker, "Amazongate: New Evidence of the IPCC's Failures," *Telegraph*, January 30, 2010, http://www.telegraph.co.uk/comment/columnists/christopherbooker/7113582/Amazongate-new-evidence-of-the-IPCCs-failures. html□

367. Lawrence Solomon, "Climategate Is One of Many Known IPCC Failings," *Financial Post*, February 26, 2010, http://network.nationalpost.com/np/blogs/fpcomment/archive/2010/02/06/392245.aspx

Perhaps the most bizarre case of logical disconnect in the climate change hysteria involves the predictions of disaster if the Himalayan glaciers continue to melt. Lester Brown, president of the Earth Policy Institute, predicts that if this happens there will be mass starvation in Asia.[368] The theory goes like this: the meltwater from the glaciers is essential for irrigation of food crops throughout much of Asia. The Ganges, Indus, Mekong, Yellow, Yangtze, and many other rivers flow from the Himalayas, providing water for over one-third of the human population. If these glaciers were to melt completely, there would be no more meltwater for irrigation, and so food production would plummet, resulting in mass starvation. This seems plausible to many people and has been repeated countless times in the media as another "catastrophic" aspect of climate change.

After hearing Lester Brown speak at length about this doomsday scenario, it dawned on me that his thesis was illogical. On the one hand he is saying the meltwater (from the melting glaciers) is essential for food production, and on the other hand he insists that we must try to stop the glaciers from melting so they will not disappear. Obviously if the glaciers stop melting, there will be no more meltwater from them. So my questions for Lester Brown, and the IPCC, are, Are you saying you want the glaciers to stop melting? Then where would the irrigation water come from? I might add, How about if the glaciers started growing again, reducing water flows even further, perhaps advancing on the towns where the food is grown?

It has since been revealed that only 3 to 4 percent of the water flowing into the Ganges River is glacial meltwater. Ninety-six percent of the river flow is from snow that fell in the previous winter and melted in the summer, and from rainfall during monsoons.[369] Therefore the people will not likely starve if the glaciers melt completely. A warmer world with higher CO_2concentrations, and likely more precipitation, will allow expansion of agricultural land and will result in faster-growing, more productive crops. Forests and crops will grow where now there is only a sheet of ice. I say let the glaciers melt.

Arctic and Antarctic Sea Ice

The Arctic and Antarctic regions are polar opposites in more ways than one. Whereas the Arctic is mainly an ocean surrounded by continents, the Antarctic is a large continent, almost centered on the South Pole, surrounded by seas. The Antarctic is colder than the Arctic largely due

368. Lester R. Brown, "Melting Mountain Glaciers Will Shrink Grain Harvests in China and India," Earth Policy Institute, March 20, 2008, http://www.earthpolicy.org/index.php?/plan_b_updates/2008/update71

369. Palava Bagla, "No Sign of Himalayan Meltdown, Indian Report Finds," *Observatory*, November 15, 2009, http://www.thegwpf.org/the-observatory/91-no-sign-of-himalayan-meltdown-indian-report-finds.html

370

to its high elevation.[370] The Antarctic ice sheet began to form 20 million years ago and has been a permanent fixture since then, advancing and retreating with the pulses of glaciation over the past 2.5 million years during the Pleistocene Ice Age. The Arctic was largely ice-free until the onset of the Pleistocene and since then has had varying degrees of ice cover as glacial periods have waxed and waned.

Much has been made recently of the fact that the extent of summer sea ice in the Arctic has shrunk substantially. In September of 2007, typically the low month after summer melting, there was about three million square kilometers of ice cover, about two million less than the average since records were first made. Many pundits immediately predicted that the Arctic would be ice-free in the summer within 20 to 30 years, and that this would be our fault entirely. The fact that the area of ice recovered by about one million square kilometers in 2008 and again in 2009 didn't dampen the shrillness of their predictions. In September of 2012 the extent if ice cover again reached a record low, but winter ice cover continued to remain relatively steady, close to the average since measurements began.

Our knowledge of the extent of sea ice in the Arctic and Antarctic began in 1979, the first year satellites were used to photograph the Polar Regions on a continual basis. Before 1979 it is not possible to reconstruct the comings and goings of sea ice, as unlike glaciers, sea ice leaves no trace when it melts. There is an implicit assumption among the true believers that the reduction in sea ice observed in 2007 and 2012 is unique in the historical record and that we are now on a one-way trip to an ice-free Arctic Sea (see Figure 7 on next page). Putting aside the fact that mariners consider an ice-free sea a good thing, it is not possible to conclude a long-term trend in the extent of Arctic sea ice from 30 years of satellite observation.

Between 1903 and 1905 the Norwegian Raold Amundsen became the first person to navigate the Northwest Passage in a 47-ton sailing ship equipped with a small gasoline motor.[371] We do not know the extent of ice over the entire Arctic at that time but the fact that a small boat could sail through the passage indicates the present era was not the only time the area of ice was reduced.

Between 1940 and 1944, years before we had any idea of the extent of sea ice during the summers and winters, a small Canadian trawler name the *St. Roch* navigated the Northwest Passage twice, from west to east and from east to west.[372][373] It was not an icebreaker and it had only a 150-horsepower diesel engine and sails. From 1910 to 1940 there was a well-documented rise in the average global temperature of nearly half

370. "Antarctic Climate," Wikipedia, http://en.wikipedia.org/wiki/Antarctica#Climate
371. "Roald Amundsen," Wikipedia, http://en.wikipedia.org/wiki/Roald_Amundsen
372. Noel Sheppard, "Reports of Record Arctic Ice Melt Disgracefully Ignore History," NewsBusters, September 9, 2007, http://newsbusters.org/blogs/noel-sheppard/2007/09/09/reports-record-arctic-ice-melt-disgracefully-ignore-history
373. "Second Through the Passage, First West to East," Athropolis, http://www.athropolis.com/arctic-facts/fact-st-roch.htm

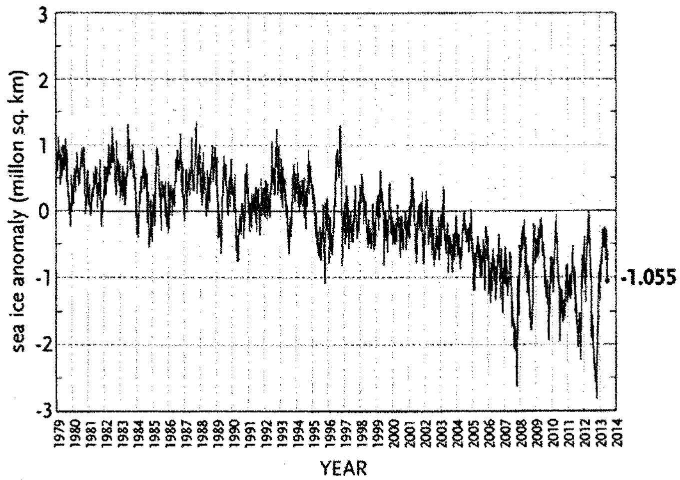
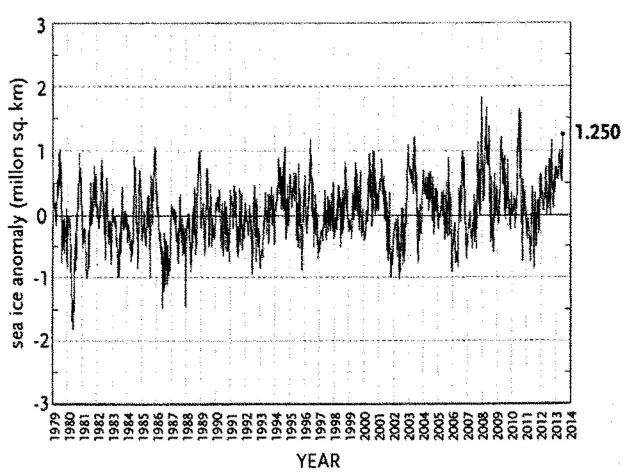


Figure 7. *Northern Hemisphere Sea Ice Anomaly (1979–2008 mean).*The extent of sea ice in the Arctic showed a clear downward trend from 1995 to 2007. Since 2007 it has recovered by about one-third over the lowest area. Only time will tell what the trend will be in the coming decades.

Figure 8. *Southern Hemisphere Sea Ice Anomaly (1979–2008 mean).* Graph showing the deviance from the 1979 to 2008 average extent of sea ice in the Antarctic. The winter of 2007 saw the greatest extent of Antarctic sea ice since measurements were first taken, coincident with the least extent in the Arctic. Whereas the extent of Arctic sea ice has shown a recent downward trend, the extent of Antarctic sea ice has shown an upward trend.



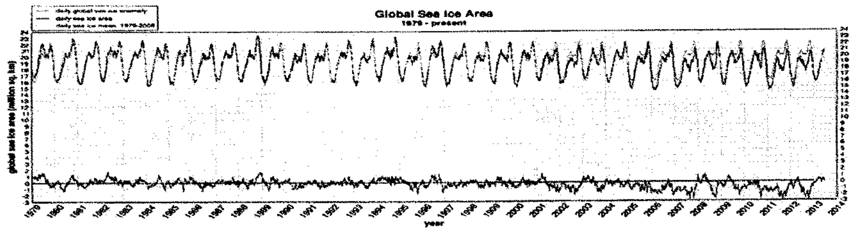


Figure 9. Global sea ice area, 1979 to present. The top line shows the total sea ice cover for the Arctic and the Antarctic. The bottom line shows the divergence from the mean of Arctic and Antarctic sea ice cover. As you can see, there is no significant trend when Arctic and Antarctic sea ice areas are added together.

a degree Celsius. There is every possibility that Arctic ice was as reduced when the *St. Roch* sailed through the passage as it has been in recent years. We will never know.

While all the media's and activist's attention has been on Arctic sea ice, the Antarctic has been playing out its own history in a very different way. The winter sea ice around Antarctica has grown above the average from 1979 to 2008 (See Figure 8). This has proven problematic for believers as it indicates Antarctica is cooling, contrary to what they have been led to believe by predictions based on computer models. In December 2008 *Nature* published an article claiming the Antarctic was warming.[374] Many climate activists, including Al Gore, seized on this article to bolster their belief in human-caused warming.[375] It turned out that the *Nature* article had been largely based on a computer model rather than real measurements of temperature. This represented another turning point in the questioning of the science used to claim humans were definitely causing the earth to warm up.[376]

In 2009 the U.S. Geological Survey (USGS) published a paper in which it reported sea ice had retreated in one part of the Antarctic Peninsula.[377] The paper made it clear that ice was growing in other parts of Antarctica and it was not clear whether the total amount of ice on and around the continent was shrinking or growing. In Greenpeace-like fashion the USGS then issued a media release claiming the sea ice was "disappearing" in Antarctica and that sea level rise was imminent.[378] News services

374. Eric J. Steig et al., "Warming of the Antarctic Ice-Sheet Surface Since the 1957 International Geophysical Year," *Nature* 457 (22 January 2009): 459–462, http://www.nature.com/nature/journal/v457/n7228/abs/nature07669.html□375. Al Gore, "The Antarctic Is Warming," February 5, 2009, http://blog.algore.com/2009/02/the_antarctic_is_warming.html 376. Christopher Booker, "Despite the Hot Air the Antarctic Is Not Warming Up," *Telegraph*, January 24, 2009, ...
... http://www.telegraph.co.uk/comment/columnists/christopherbooker/4332784/Despite-the-hot-air-the-Antarctic-is-not- warming-up.html□377. Ferrigno, J.G, Coastal-Change and Glaciological Map of the Palmer Land Area, Antarctica: 1947–2009,"□U.S. Geological Survey, 2009, http://pubs.usgs.gov/imap/i-2600-c/
378. "Ice Shelves Disappearing on Antarctic Peninsula: Glacier Retreat and Sea Level Rise Are Possible Consequences," U.S. Geological Survey Newsroom, February 22, 2010, http://www.usgs.gov/newsroom/article.asp?ID=2409&from=rss_home

picked up this story, which gave the impression Antarctica was melting away. Perhaps the USGS scientists feel the need to sensationalize their otherwise good research in order to get more funding. I don't know, but it certainly misleads the public about what is really happening down there.

The University of Illinois' website, *The Cryosphere Today*, contains the entire record of sea ice since 1979.[379] (The Cryosphere is the area of the earth covered with ice.) Figure 9 (on previous page) shows the global sea ice cover, adding together the Arctic and the Antarctic, from 1979 until the present.[380] This is our total knowledge of the history of sea ice cover on planet Earth. There is no obvious trend up or down because increased ice cover in the Antarctic offsets most of the reduced ice cover in the Arctic. So even the very short record we do have for global sea ice cover provides no evidence of rapid global warming.

Coral Reefs, Shellfish, and "Ocean Acidification"

It has been widely reported in the media, based on a few scientific papers, that the increasing levels of CO_2 in the atmosphere will result in "ocean acidification," threatening coral reefs and all marine shellfish with extinction within 20 years.[381] The story goes like this: The oceans absorb about 25 percent of the CO_2 we emit into the atmosphere each year. The higher the CO_2 content of the atmosphere, the more CO_2 will be absorbed by the oceans. When CO_2 is dissolved in water, some of it is converted into carbonic acid that has a weak acidic effect. If the sea becomes more acidic, it will dissolve the calcium carbonate that is the main constituent of coral and the shells of clams, shrimp, crabs, etc. It is one more doomsday scenario, predicting the seas will "degrade into a useless tidal desert,"[382]

In his latest book, *Eaarth: Making a Life on a Tough New Planet*, Bill McKibben claims, "Already the ocean is more acid than anytime in the last 800,000 years, and at current rates by 2050 it will be more corrosive than anytime in the past 20 million years." In typical hyperbolic fashion, McKibben, the author of the well-know essay, "The End of Nature," uses the words *acid* and *corrosive* as if the ocean will burn off your skin and flesh to the bone if you dare swim in it in 2050. This is just plain fear-mongering.

Results of research published in the journal *Science* by M.R. Palmer et al., indicate that over the past 15 million years, "All five samples record surface seawater pH values that are within the range observed in the oceans today, and they all show a decrease in the calculated pH with depth that is similar to that observed

379. "The Cryosphere Today," Polar Research Group, University of Illinois, http://arctic.atmos.uiuc.edu/cryosphere/
380. "Global Sea Ice Area: 1979 to Present," Polar Research Group, University of Illinois, http://arctic.atmos.uiuc.edu/cryosphere/IMAGES/global.daily.ice.area.withtrend.jpg□
381. Frank Pope, "Great Barrier Reef Will Be Gone in 20 Years, Says Charlie Veron," *Sunday Times*, July 7, 2009, http://www.timesonline.co.uk/tol/news/environment/article6652866.ece
382. Richard Girling, "The Toxic Sea," *Sunday Times*, March 8, 2009, http://www.timesonline.co.uk/tol/news/environment/article5853261.ece#cid=OTC-RSS&attr=3392178

in the present-day equatorial Pacific." The five samples recorded pH values for 85,000 years ago and for 2.5, 6.4, 12.1, and 15.7 million years ago.[383]

First, one should point out that the ocean is not acidic, it has a pH of 8.1, which is alkaline, the opposite of acidic. A pH of 7 is neutral, below 7 is acidic, above 7 is alkaline. Researchers have reported in scientific journals that the pH of the seas has gone down by 0.075 over the past 250 years, "Between 1751 and 1994 surface ocean pH is estimated to have decreased from approximately 8.179 to 8.104 (a change of −0.075)."[384] One has to wonder how the pH of the ocean was measured to an accuracy of three decimal places in 1751 when the concept of pH was not introduced until 1909.[385]

It turns out that just as with climate science in general, these predictions are based on computer models. But oceans are not simple systems whose components can just be plugged into a computer. First, there is the complex mix of elements and salts dissolved in the sea. Every element on Earth is present in seawater and these elements interact in complex ways. Then there is the biological factor, tens of thousands of species that are consuming and excreting every day. The salt content of seawater gives the oceans a very large buffering capacity against change in pH. Small additions of acidic and alkaline substances can easily alter the pH of freshwater, whereas seawater can neutralize large additions of acidic and alkaline substances.

One of the most important biological phenomena in the sea is the combining of calcium, carbon, and oxygen to form calcium carbonate, $CaCO_3$, the primary constituent of corals and shells, including the skeletons of microscopic plankton. The formation of calcium carbonate is called calcification. All of the vast chalk, limestone, and marble deposits in the earth's crust are composed of calcium carbonate, which was created and deposited by marine organisms over millions of years. The carbon in calcium carbonate is derived from CO_2 dissolved in seawater. One might therefore imagine that an increase in CO_2 in seawater would enhance calcification rather than destroy it. It turns out this is precisely the case.

As is the case with terrestrial plants, it has been thoroughly demonstrated that increased CO_2 concentration in the sea results in higher rates of photosynthesis and faster growth. Photosynthesis has the effect of in- creasing the pH of the water, making it more alkaline, counteracting any minor acidic effect of the CO itself.[386] The owners of saltwater aquariums

383. M. R. Palmer et al., "Reconstructing Past Ocean pH-Depth Profiles," *Science* 282, no. 5393 (November 20, 1998): 1468– 1471, http://www.scienceonline.org/cgi/content/short/282/5393/1468 (Register with *Science* to see full article free-of-charge)

384. James C. Orr et al., "Anthropogenic Ocean Acidification Over the Twenty-First Century and Its Impact on Calcifying Organisms," *Nature* 437 (September 29, 2005): 681–686, http://www.ipsl.jussieu.fr/~jomce/acidification/paper/Orr_OnlineNature04095.pdf□

385. "pH,"Wikipedia,http://en.wikipedia.org/wiki/PH□386. "Acid Test: The Global Challenge of Ocean Acidification—A New Propaganda Film by The National Resources Defense Council

often add CO_2 to the water in order to increase photosynthesis and calcification, a practice that is similar to greenhouse growers adding CO_2 to the air in their greenhouses to promote the faster growth of plants. The vast bulk of scientific literature indicates increased CO_2 in the ocean will actually result in increased growth and calcification, as opposed to the catastrophe scenario pushed by the NRDC, Greenpeace, and many other activist organizations.[387 388]

A long list of scientific publications that support the view that increased CO_2 in seawater results in increased calcification can be found on the CO_2 Science website.[389] A paper by Atkinson et al., published in the journal *Coral Reefs*, states that their finding "seems to contradict conclusions ... that high CO may inhibit calcification."[390]

"Ocean acidification" is a perfect example of a contrived catastrophe scenario. The average person does not have a grasp of the complexities of marine chemistry and biology. The activists simply coin a new, scary term like "acidification" and then effectively extort money from people who are concerned for the future. And all this emphasis on the dangers of CO_2tends to divert people from thinking about the real dangers to coral reefs like destructive fishing methods and pollution from sewage.

Our little house by the Sea of Cortez in Cabo Pulmo in southern Baja, Mexico, looks out over a National Marine Park that contains the only large coral reef on the west coast of the Americas. Pulmo Reef is a popular dive site, known for its rich abundance of reef fish, many of which school in the thousands. It was after a dive on the reef during our first visit to Cabo Pulmo in 1999 that Eileen and I decided to make a base there. Since then we have dived and snorkeled on the reef many times each year.

In September of 2002 a tropical storm brought torrential rains that dumped over 20 inches of rainfall in a 24-hour period. It must have been a once in a 100-year event as the flooding was the worst the locals could remember. A lens of freshwater about 20 feet deep spread out over the reef as a result of the runoff from the mountains. This killed all the coral, as coral cannot live in freshwater. Only the corals below the 20-foot depth of the freshwater layer survived.

Fails the Acid Test," Science & Public Policy Institute, January 5, 2010, http://scienceandpublicpolicy.org/images/stories/papers/originals/acid_test.pdf□387. "Ocean Acidification: The Other CO_2 Problem," Natural Resources Defense Council, September 17, 2009, http://www.nrdc.org/oceans/acidification/default.asp□388. "Putting a Stop to the Arctic Meltdown," Greenpeace International, January 26, 2010, http://www.greenpeace.org/international/news/hands-off-the-arctic-260110□389. "CO_2, Global Warming and *Coral Reefs*: Prospects for the Future," *CO_2 Science*, http://www.co2science.org/education/reports/corals/part2ref.php□390. Atkinson, M.J., Carlson, B.A. and Crow, G.L. 1995, "Coral Growth in High-Nutrient, Low-pH Seawater: A Case Study of Corals Cultured at the Waikiki Aquarium, Honolulu, Hawaii," *Coral Reefs* 14, no. 4, pp. 215–223, http://www.springerlink.com/content/g2554037454q13wp/

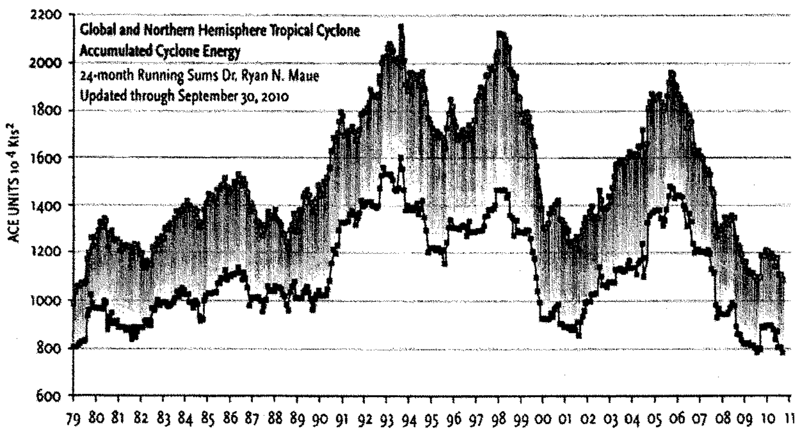


Figure 10. Global and Northern Hemisphere tropical cyclone energy 1979 to 2010. Since the peak during the 1990s, the frequency and intensity of tropical cyclones has diminished considerably.[391]

For a few years after the event virtually no living coral could be seen in the shallower waters. The reef turned white and became covered in green algae, which in turn resulted in an explosion of sea urchins where there had been very few before. By 2006 the reef began to recover noticeably with nodules of new coral becoming established. Coral polyps from the deeper regions of the reef were recolonizing the shallow waters. The sea urchins died out and fish returned in greater abundance. Today the reef is in full recovery as the coral is now growing substantially each year. It may take another 20 years or more to recover completely, and will only do so if there is not another torrential rainstorm.

I imagine some people who believe we are causing catastrophic cli- mate change would suggest we were responsible for the torrential rains that killed part of the reef. I don't believe we can be so certain, especially as such events have been occurring since long before humans began emitting billions of tons of CO_2each year. And regardless of the storm's cause, it is comforting to know that the reef can recover despite the dire predictions of the early death of coral reefs worldwide.

Storms, Hurricanes, and Severe Weather Events

Everyone likes to talk about the weather and climate activists are no exception. In the aftermath of Hurricane Katrina in 2005, which caused so much devastation to New Orleans and the surrounding regions, Al Gore gave a rousing speech

391. Ryan Maue, "Ryan N. Maue's 2010 Global Tropical Cyclone Activity Update," Florida State University, http://www.coaps.fsu.edu/~maue/tropical/

in which he predicted hurricanes would continue to become more frequent and more severe as global warming intensified.[392] Since that speech the intensity of global hurricanes has diminished by about half from the peak years of 1993 and 1998. Still, on the cover of his 2009 book, *Our Choice: A Plan to Solve the Climate Crisis*, Al Gore had four fake hurricanes airbrushed onto a photo of the earth from space.[393] [394] He continues to push the fear of hurricanes when it has become clear there is no longer any basis for such concern. In fact, scientists at the U.S. National Hurricane Center predict that global warming will result in not more but fewer hurricanes.[395] Al Gore must be aware of this.

Sea Level Rise

There is conclusive proof that increased CO_2levels will be good for plants both on the land and in the sea. If increased CO_2does make the world warmer, it will almost certainly make it wetter, which will also be good for plants and most animals, including us. Then what is so bad about global warming anyway, whether it is natural or caused by humans? The prospect that sea levels will rise in a warmer world is the main draw- back as this would threaten the infrastructure we have built in low-lying coastal areas.

The seal level has fluctuated a great deal during the Pleistocene, as ice sheets have advanced and retreated and as temperatures have risen and fallen. At the height of the last glaciation, which ended 18,000 years ago, the sea was about 120 meters (nearly 400 feet) lower than it is today (See Figure 11). There was relatively rapid glacial melting and subsequent sea level rise between 15,000 and 6000 years ago as large, lower elevation ice sheets melted and disappeared. During the past 6000 years, the rise has been slower but steady. In recent times the sea level has risen by about 20 centimeters (8 inches) per century.[396]

Clearly human activity was not responsible for the end of the last glaciation, subsequent warming, and the retreat of the world's glaciers during the past 18,000 years. To date we have no indication that the rate of sea level rise is increasing, whether by natural causes or by our impact on climate. Many predictions of future sea level rise have been based on computer models. In its 2007 report the IPCC predicted sea level would rise between 18 and 59 centimeters (7 to 23 inches) during the

392. Al Gore, "On Katrina, Global Warming," Common Dreams, December 12, 2005, http://www.commondreams.org/views05/0912-32.htm

□393. Al Gore, *Our Choice: A Plan to Solve the Climate Crisis*, (Rodale Press, November 2009). http://ourchoicethebook.com/

394. Noel Sheppard, "Al Gore Photoshops Hurricanes Into New Book's Cover," Newsbusters, November 19, 2009, http://newsbusters.org/blogs/noel-sheppard/2009/11/19/al-gore-photoshops-hurricanes-new-books-cover?page=1□

395. Jonathan Leake, "UN's Climate Link to Hurricanes in Doubt," *Sunday Times*, February 28, 2010, http://www.timesonline.co.uk/tol/news/environment/article7044158.ece□

396. "Current Sea Level Rise," Wikipedia, http://en.wikipedia.org/wiki/Current_sea_level_rise

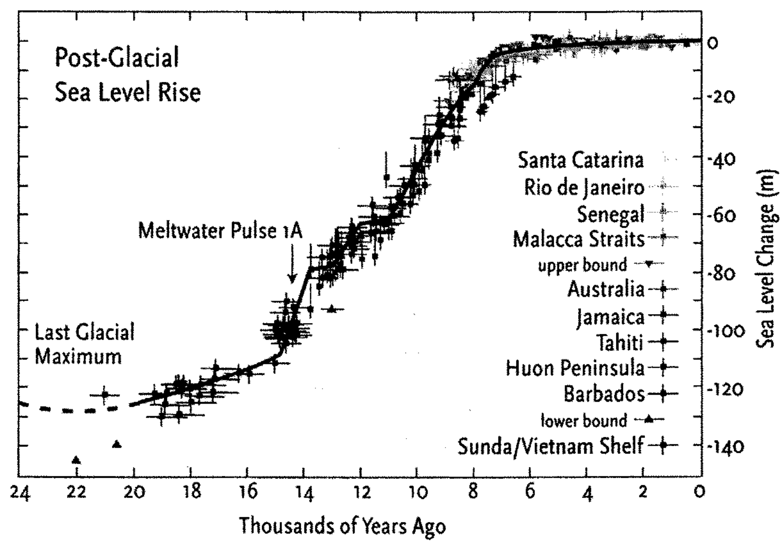


Figure 11. Graph showing that sea level was 120 meters (nearly 400 feet) lower at the height of the last glaciation.[397]

next century. The low end is entirely reasonable as this is about equal to the present rate. The high end is three times the present rate and would require a considerable amount of warming during this century. As yet there has been no warming in this century and sea level rise has not been increasing.

If the sea were to rise nearly two feet as the IPCC suggests in its extreme case, there would be disruptions to infrastructure and related activities. While natural ecosystems would adapt with little difficulty, coastal infrastructure would definitely be impacted negatively, especially our wharfs, buildings, farms, and industries. It wouldn't matter whether or not the sea level rise was due to natural or human causes.

The 120-meter (400-foot) sea level rise during the past 18,000 years did not damage the environment and was not a significant factor in human survival. We have managed to cope with the 20-centimeter (8-inch) rise over the past century. But we have built vastly more coastal infrastructure over the past century than we have in all of human history, and we will continue to do so during the next century.

What should we do about this? Is it wise to assume we are the cause of sea level rise and then to end the activities we think are responsible? Or would it make more sense

397. "Post-Glacial Sea Level," Wikipedia, http://en.wikipedia.org/wiki/File:Post-Glacial_Sea_Level.png"

to plan for a sea level rise of, say, 30 centimeters (12 inches) over the next century. If we are not the cause of sea level rise, which I believe is likely, then there is not much we can do to stop it any- way. If we plan for continued sea level rise at 50 percent above the present rate, we could avoid all or most damage by thinking ahead. We could build the dykes a little higher, not develop suburbs in areas that are susceptible to sea level rise, and generally plan our infrastructure to withstand sea level rise. How could that cause more negative impacts than an 80 percent or larger reduction in fossil fuel use worldwide in the next decade?

I repeat my assertion that we should make an effort to reduce our reliance on fossil fuels and switch to alternatives where this is technologically feasible and reasonably cost-effective. But anything approaching an 80 percent reduction in fossil fuel use over the next decade or two would do more to destroy our civilization than any plausible impact of climate change, even if we were responsible for it. Yet that is what many climate activists, including Greenpeace and Al Gore, are calling for. I believe there are more practical and logical steps that can be taken to find a balance between our environmental, social, and economic priorities. I believe it would be possible to reduce fossil fuel use by 80 percent over the next 50 to 75 years, but we must consider the economic and social cost of doing so.

Pacific Islands and Sea Level Rise

Climate change activists have made great fanfare about the possibility that many island states, such as the Marshall Islands, Kiribati, Tuvalu, and the Maldives, will be inundated and disappear due to rising sea levels caused by human-induced climate change.[398] The government of the Maldives has made the case that rich, carbon-emitting industrial nations should provide financial compensation for the loss of their countries. None of the projections of sinking island states has taken into account the fact that most of them are built on coral reefs and atolls and that coral reefs are alive. A recent survey of 27 Pacific Islands, comparing aerial photographs from up to 61 years ago with current photographs, demonstrated that 23 islands maintained the same land area or increased in size, while only four islands suffered a net loss in size. [399] [400] During this period there was a rise in sea level of 2 mm per

398. "Sea Level Rise Will Claim Island States." Seaweb, Vol. 15, no. 7 (April 6, 2010), http://www.seaweb.org/news/ou15_7.php#sealevel□

399. "Tuvalu and Many Other South Pacific Islands are Not Sinking, claims they are Due to Global Warming Driven Sea Level Rise are Opportunistic," Watts Up With That, Anthony Watts, June 2, 2010, http://wattsupwiththat.com/2010/06/02/tuvalu-and-many-other-south-pacific-islands-are-not-sinking-claims-they-are-due-to- global-warming-driven-sea-level-rise-are-opportunistic/□

400. "Pacific Islands 'Growing not Shrinking' Due to Climate Change," Paul Chapman, the *Telegraph,* June 3, 2010, http://www.telegraph.co.uk/news/worldnews/australiaandthepacific/tuvalu/7799503/Pacific-islands-growing-not-shrinking-due- to-climate-change.html

year. This indicates that the coral is able to grow as fast or faster than the rising sea, and that coral islands grow as a result of coral breaking off and forming reefs that in turn catch more coral and grow in size. Many of the coral islands in the tropics have existed for thousands of years, while during that time the sea has risen by hundreds of feet. It is therefore likely that yet another doomsday scenario regarding the impact of climate change is wildly overblown and may actually have no impact even if the sea does continue to rise.

The "Trick" to "Hide the Decline"

The most quoted email among the thousands released from the Climatic Research Unit, which led to the "Climategate" crisis, was one from the CRU's head, Phil Jones, referring to "Mike's *Nature* trick...to hide the decline."[401 402] Mike is Michael Mann, the creator of the infamous and, to many, discredited hockey stick graph. *Nature* is the science journal that shows a marked bias in support of human-caused climate change. The "trick" was to discard tree-ring data that did not fit the true believer's bias, data that showed a drop in temperature in recent decades. These climate scientists clearly colluded to hide the data that showed the decline and to substitute data that indicated unprecedented warming over the past 50 years.

In response to the "Climategate" emails the U.K. House of Commons Science and Technology Committee held hearings to determine if Phil Jones and his staff at the Climatic Research Unit had done anything un- toward. They concluded that "trick" and "hide the decline" were "colloquial terms used in private emails and the balance of evidence is that they were not part of a systematic attempt to mislead."[403 404] This is an obvious white- wash, because whether or not they are colloquial terms, "trick" means "trick" and "hide the decline" means "hide the decline." The committee did not provide an explanation of what it thought the terms meant in a "colloquial" context. It is amazing what deceptions can be perpetrated in broad daylight by people in responsible positions.

Another "independent inquiry" conducted by the University of East Anglia, where the Climatic Research Unit is housed, and supported by the Royal Society, concluded with the statement, "We saw no evidence of

401. Steve McIntyre, "IPCC and the 'Trick'," climateaudit.org, December 10, 2009, http://climateaudit.org/2009/12/10/ipcc-and-the-trick/

□402. Terry Hurlbut, "Context for 'Hide the Decline' Discovered," examiner.com, December 10, 2009, http://www.examiner.com/x-28973-Essex-County-Conservative-Examiner~y2009m12d10-Context-for-hide-the-decline-discovered

403. "The Disclosure of Climate Data From the Climatic Research Unit at the University of East Anglia," Science and Technology Committee, U.K. Government, March 31, 2010, http://www.parliament.uk/parliamentary_committees/science_technology/s_t_cru_inquiry.cfm□

404. "British Parliamentary Inquiry Clears 'Climategate' Scientists," Environmental News Service, March 31, 2010, http://www.ens-newswire.com/ens/mar2010/2010-03-31-02.html

any deliberate scientific malpractice in any of the work of the Climatic Research Unit."[405] The inquiry was headed by Lord Oxburgh, who has deep personal and financial interests in climate policy. He is the chair of a multinational wind energy company and the chair of the Carbon Capture and Storage Association.[406] Missing from the inquiry's report is the fact that the inquiry did not examine the "Climategate" emails or consider evidence from anyone other than the CRU staff. In this report the "trick" "to hide the decline" was not even mentioned; never mind the many other indications of impropriety that were contained in the emails.[407] Phil Jones himself clearly requested that his colleagues delete previous emails containing damaging information.[408]

The Enigmatic Dr. Lovelock

James Lovelock is one of the most insightful and at the same time most enigmatic of scientists. He is certainly one of the leading experts on atmospheric chemistry. Earlier passages in this book have shown Lovelock to be profoundly pessimistic about the future of civilization and the earth's environment. In an interview in 2006, he stated, "We have given Gaia a fever and soon her condition will worsen to a state like a coma...Before this century is over, billions of us will die, and the few breeding pairs of people that survive will be in the Arctic where the climate remains tolerable... a broken rabble led by brutal war lords".[409 410] Nice visuals! Cue James Cameron! I feel a Hollywood blockbuster coming on. Yet recently, in the wake of the "Climategate" scandal and the failure of the Copenhagen climate summit, Lovelock has had some change of heart.

Speaking at the London Science Museum in March 2010 Lovelock said, "It is worth thinking that what we are doing in creating all these car- bon emissions, far from being something frightful, is stopping the onset of a new ice age.... If we hadn't appeared on the earth, it would be due to go through another ice age and we can look at our part as holding that up. I hate all this business about feeling guilty about what we're doing." This sounds surprisingly like the line of thinking I challenged him with

405. "Report of the International Panel Set Up by the University of East Anglia to Examine the Research of the Climatic Research Unit," University of East Anglia, April 12, 2010, http://www.uea.ac.uk/mac/comm/media/press/CRUstatements/SAP

□406. Lawrence Solomon, "Climate-Change Partisans Find Mere Sins of Omission," *National Post*, April 16, 2010, http://network.nationalpost.com/NP/blogs/fullcomment/archive/2010/04/15/lawrence-solomon-climategate-scientists-we-re-not-guilty.aspx

407. James Delingpole, "Climategate: the Final Nail in the Coffin of 'Anthropogenic Global Warming'?" *Telegraph*, November 20, 2009, http://blogs.telegraph.co.uk/news/jamesdelingpole/100017393/climategate-the-final-nail-in-the-coffin-of-anthropogenic- global-warming/

408. Bishop Hill, "Climate Cuttings 33," November 20, 2009, http://bishophill.squarespace.com/blog/2009/11/20/climate-cuttings-33.html□

409. Michael McCarthy, "Environment in Crisis: 'We Are Past the Point of No Return'," *Independent*, January 16, 2006, http://www.independent.co.uk/environment/environment-in-crisis-we-are-past-the-point-of-no-return-523192.html□

410. James Lovelock, "The Earth Is About to Catch a Morbid Fever That May Last as Long as 100,000 Years," *Independent*, January 16, 2006, http://www.independent.co.uk/opinion/commentators/james-lovelock-the-earth-is-about-to-catch-a-morbid-fever-that- may-last-as-long-as-100000-years-523161.html

during my visit to his home in 2002. His other colleagues have undoubtedly raised similar points, that there is a possibility we are a positive force rather than an entirely negative one.

It is clear Lovelock was rattled by the revelations in the thousands of leaked emails from the Climatic Research Unit. During his first interview after the "Climategate" scandal he stated, "Fudging the data in any way whatsoever is quite literally a sin against the holy ghost of science. I'm not religious, but I put it that way because I feel so strongly. It's the one thing you do not ever do." And he was surprisingly warm toward skeptics, allowing, "What I like about skeptics is that in good science you need critics that make you think: 'Crumbs, have I made a mistake here?' If you don't have that continuously, you really are up the creek...If you make a [computer] model, after a while you get suckered into it. You begin to for- get that it's a model and think of it as the real world."[411]

Some of his recent statements are chilling. Lovelock contends that, "We need a more authoritative world...even the best democracies agree that when a major war approaches, democracy must be put on hold for the time being. I have a feeling that climate change may be an issue as severe as a war. It may be necessary to put democracy on hold for a while."[412] If we are indeed preventing a new ice age, then why is it like a war, and why must we suspend democracy? Perhaps Lovelock just can't make up his mind which it is, catastrophe or salvation. In any case he provides good reason why brilliant scientists who have been cloistered in labs and research institutes most of their lives should not be running the government.

Conclusion

Beginning in the 1980s a widespread alarmist view has developed regard- ing future climate change. The United Nations, most national academies of science, the majority of political parties, the mainstream media, many scientists, and virtually all environmental activist groups have come to believe that if human emissions of CO_2 continue at present levels the global temperature will soar, resulting in untold destruction to civilization and the environment. This has caused many countries to consider, and even to adopt, policies to reduce fossil use to levels that could cripple their economies.[413]

As of 2013 it has become clear that the global temperature stopped rising 16 years ago, after a 20-year period of increasing temperature. This is despite the fact that CO_2 emissions have continued to rise at an increasing

411. Leo Hickman, "James Lovelock: 'Fudging Data Is a Sin Against Science'," *Guardian*, March 29, 2010, http://www.guardian.co.uk/environment/2010/mar/29/james-lovelock

□412. Ibid.□413. "New Energy for America," Organizing for America, http://my.barackobama.com/page/content/newenergy_more rate. No scientist professes to know why global warming has stopped, but many continue to believe humans are driving a "climate catastrophe." Experts and opinion leaders who have publicly bought into the climate crisis hypothesis are obviously reluctant to change their views. They can't do so without losing face, having invested their reputations in such a high- profile issue. There is a sense that the true believers have become the real deniers.[414]

Considering that the increase in temperature has stopped for the time being, and noting the three issues of the "Climategate" scandal, the col- lapse of the Copenhagen conference, and the errors in the 2007 IPCC report, it seems clear that the foundation of climate change alarmism has been shaken. Many top scientists have made public statements to distance themselves from the supposed prevailing view.[415] [416] [417] One of the most influential skeptical voices is that of physicist Freeman Dyson, considered one the world's most brilliant thinkers by many of his peers.[418] A feature article that made his views on climate clear appeared in the *New York Times Magazine* in March 2009 and turned a lot of heads.[419] He said, "The cli- mate-studies people who work with models always tend to overestimate their models," and "They come to believe models are real and forget they are only models." He explained, "Most of the evolution of life occurred on a planet substantially warmer than it is now, and substantially richer in car- bon dioxide." Dyson referred to Al Gore as climate change's "chief propagandist," and as someone who preaches "lousy science, distracting public attention from more serious and more immediate dangers to the planet."

While the author of this article politely derided Dyson's point of view, there was no doubt about where one of the great thinkers of our time stands on the subject. I think one Freeman Dyson is worth 10,000 true believers who mimic one another, falsely claiming that there is an "over- whelming consensus" and extolling, "the vast body of evidence showing the world is warming because of man-made greenhouse gas emissions" without providing any details of the "vast body of evidence."

In recent months a number of mainstream media outlets, including many British and American newspapers, have abandoned their strong biases and are now publishing articles that are balanced and even skeptical of human-caused warming. The collapse of the "overwhelming

414. "In Denial: The Meltdown of the Climate Campaign," Steven F. Hayward, *The Weekly Standard*, March 15, 2010, http://www.weeklystandard.com/articles/denial

□415. "The Deniers," Wikipedia, http://en.wikipedia.org/wiki/The_Deniers:_The_world-renowned_scientists_who_stood_up_against_global_warming_hysteria,_political_persecution,_and_fraud

□416. Marc Morano, "Scientists Write Open Letter to Congress," ClimateDepot, July 1, 2009, http://climatedepot.com/a/1745/Scientists-Write-Open-Letter-to-Congress-You-Are-Being-Deceived-About-Global-Warming--Earth-has-been-cooling-for-ten-years

417. Neil Reynolds, "Please Remain Calm: The Earth Will Heal Itself," *Globe and Mail*, July 19, 2010, http://www.theglobeandmail.com/news/opinions/please-remain-calm-the-earth-will-heal-itself/article1642767/□

418. "Freeman Dyson," Wikipedia, http://en.wikipedia.org/wiki/Freeman_Dyson□419. Nicholas Dawidoff, "The Civil Heretic," *New York Times*, March 25, 2009, http://www.nytimes.com/2009/03/29/magazine/29Dyson-t.html

consensus" is good news for everyone who believes this topic should be discussed openly and objectively. There is a breath of fresh air in the climate change debate.

There is much work to do in trying to validate or reject the assertions of the major players in climate science. They include the Climatic Research Unit of the University of East Anglia, the U.S. National Oceanic and Atmospheric Administration, the Goddard Institute of Space Science of the U.S. National Aeronautics and Space Agency (NASA), and the Intergovernmental Panel on Climate Change. All these top agencies are implicated in the "Climategate" scandal and are being investigated by various authorities. The U.K. Institute of Physics' submission to the Parliamentary Committee investigating the leaked emails from the Climatic Research Unit made these observations:[420]

1. The Institute is concerned that, unless the disclosed e-mails are proved to be forgeries or adaptations, worrying implications arise for the integrity of scientific research in this field and for the credibility of the scientific method as practised in this context.

2. The CRU e-mails as published on the Internet provide prima facie [at first sight] evidence of determined and coordinated refusals to comply with honourable scientific traditions and freedom of information law. The principle that scientists should be willing to expose their ideas and results to independent testing and replication by others, which requires the open exchange of data, procedures and materials, is vital. The lack of compliance has been confirmed by the findings of the Information Commissioner. This extends well beyond the CRU itself – most of the e-mails were exchanged with researchers in a number of other international institutions who are also involved in the formulation of the IPCC's conclusions on climate change.

3. It is important to recognize that there are two completely different categories of data set that are involved in the CRU e-mail exchanges:

- those compiled from direct instrumental measurements of □land and ocean surface temperatures such as the CRU, GISS □and NOAA data sets; and
- historic temperature reconstructions from measurements of □'proxies', for example, tree-rings.

4. The second category relating to proxy reconstructions are the basis for the conclusion that 20th century warming is unprecedented.

420. Steve McIntyre, "Institute of Physics Submission," *Climate Audit*, February 26, 2010, http://climateaudit.org/2010/02/26/institute-of-physics-submission/

Published reconstructions may represent only a part of the raw data available and may be sensitive to the choices made and the statistical techniques used. Different choices, omissions or statistical processes may lead to different conclusions. This possibility was evidently the reason behind some of the [rejected] requests for further information.

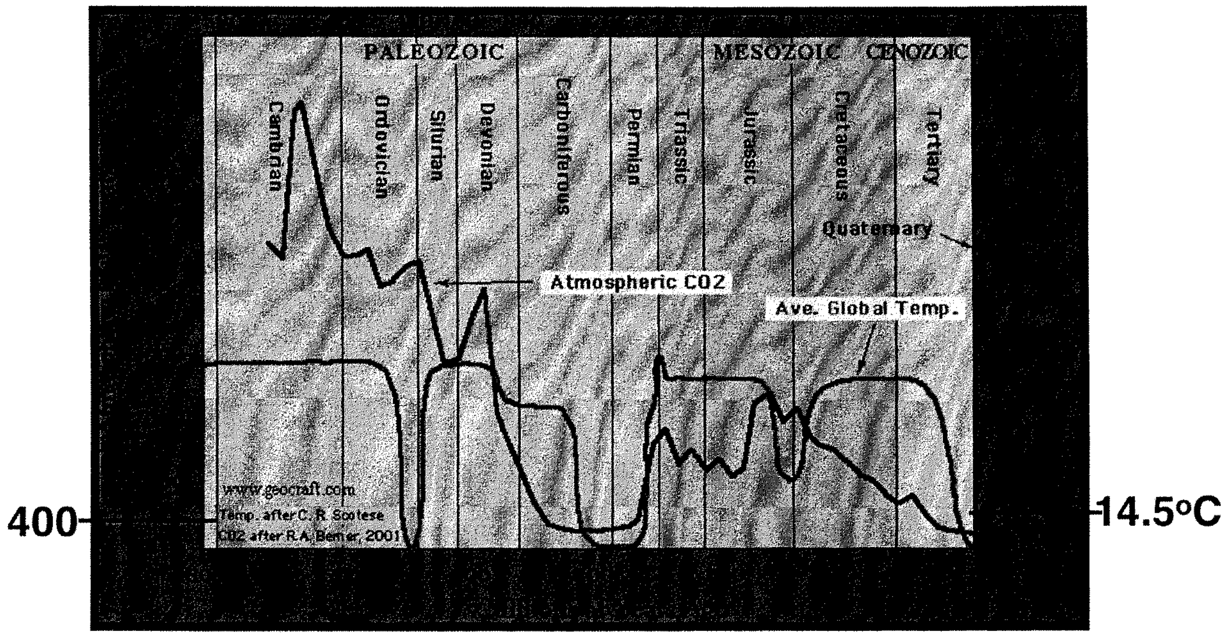
5. The e-mails reveal doubts as to the reliability of some of the re- constructions and raise questions as to the way in which they have been represented; for example, the apparent suppression, in graphics widely used by the IPCC, of proxy results for recent decades that do not agree with contemporary instrumental temperature measurements.

The Institute of Physics has no reason to exaggerate or to hold any bias. The Institute makes it clear that the information provided by the Climatic Research Unit may not be credible or trustworthy. Clearly it will be some time before the "science is settled."

On May 29, 2010, Britain's top science body, the Royal Society, an- nounced it would review its literature on climate change in order to reflect the skeptical view. The Royal Society stated, "Any public perception that science is somehow fully settled is wholly incorrect—there is always room for new observations, theories, measurements." Along with the change of tone by the London Science Museum this marks a sharp turning point, from certainty and "overwhelming consensus," to a balanced dialogue on the subject. One can only hope that other major science bodies will adopt the same policy.

At this writing the developments in the climate change debate are changing faster than the climate itself. The public is becoming more skeptical by the day, while the believers work doubly hard to shore up their position, assuring us warming will eventually return in earnest. This may be, but it is not happening now, and even If warming does recur in future, that by itself won't prove that we are the main cause. I remain open to new information and continue to follow the discussion on a daily basis.

Some readers will argue that I have only presented the skeptical side of the debate. This is only because the historical evidence, what has actually occurred, does not support the idea that we are the primary cause of global warming, never mind that its impacts will be "catastrophic." All the pre- dictions based on computer models in this world can't change history or manufacture the future. For that we must patiently wait. Meanwhile we should embark on the path toward a future that focuses on sustainable energy as outlined in Chapter 15. We could gradually reduce our over-whelming reliance on fossil fuels and replace some of them with cleaner, sustainable energy sources. This will satisfy many agendas, including the agenda of the believers in human-caused climate change.



Global CO2 and Temperature Over the Past 600 Million Years

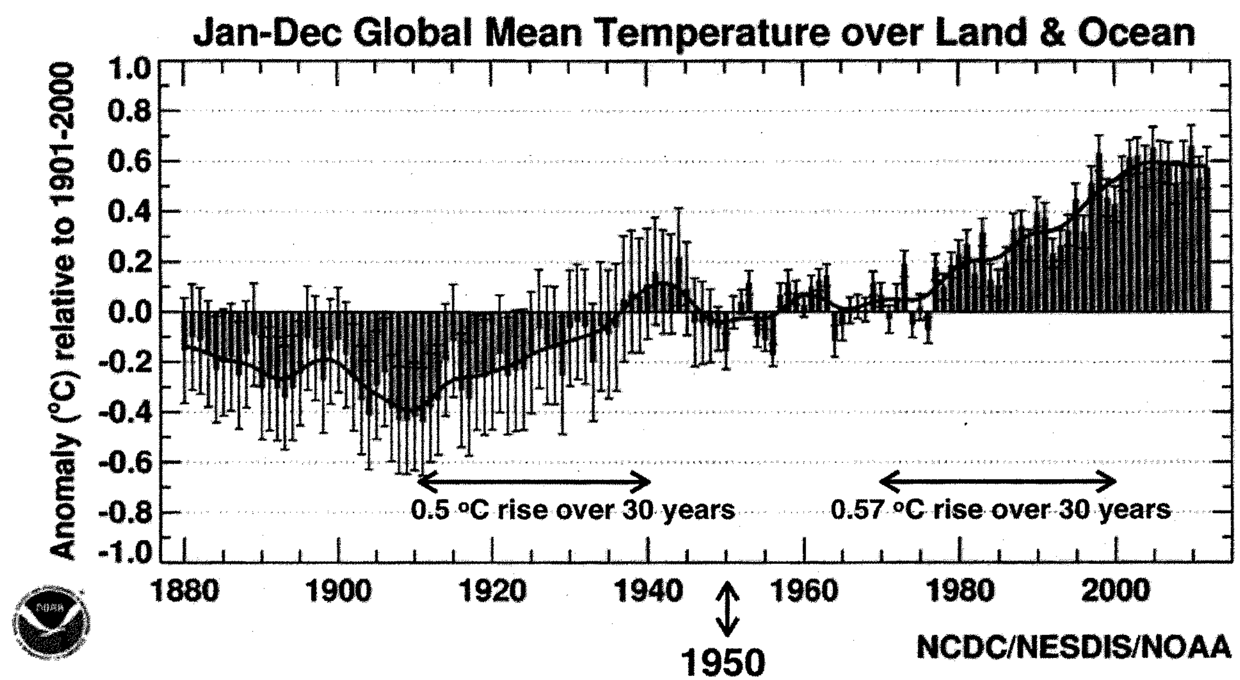
http://www.scotese.com/climate.htm
http://www.aps.org/units/fps/newsletters/200807/monckton.cfm

"Some Degree of Expert Judgement is Inevitable"

Table 1.2 | Likelihood terms associated with outcomes used in the AR5.

Term	Likelihood of the Outcome
Virtually certain	99–100% probability
Very likely	90–100% probability
Likely	66–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Exceptionally unlikely	0–1% probability

Notes:
Additional terms that were used in limited circumstances in the AR4 (*extremely likely* = 95–100% probability, *more likely than not* = >50–100% probability, and *extremely unlikely* = 0–5% probability) may also be used in the AR5 when appropriate.



"It is **extremely likely** that human influence has been the **dominant cause** of the observed warming **since the mid-20th century". IPCC 2013**

Senator WHITEHOUSE. Thank you very much, Dr. Moore. We now turn to our final witness, Mr. Robert Bryce. He has served as a senior fellow at the Center for Energy Policy and the Environment at the Manhattan Institute since April 2010. He is a journalist and author based in Austin, Texas. From 2006 to 2010 he worked as a managing editor of the online publication Energy Tribune. Mr. Bryce received his BFA from the University of Texas at Austin in 1986.

Mr. Bryce, please proceed.

STATEMENT OF ROBERT BRYCE, SENIOR FELLOW, MANHATTAN INSTITUTE FOR POLICY RESEARCH

Mr. BRYCE. Thank you, and good afternoon.

Over the past decade or so, the U.S. Government has enacted policies to encourage the use of renewable energy in general and wind energy in particular. These policies are, in theory, designed to address the issue of climate change.

But the facts show three certain things. First, the wind energy sector has been getting billions of dollars in Federal subsidies, even though it is killing significant numbers of some of America's most iconic wildlife. Second, Federal authorities have largely turned a blind eye to the wind industry's slaughter of our wildlife. And finally and most importantly, this slaughter is being done in the name of climate change, but whatever reductions in carbon dioxide emissions that may be occurring due to the deployment of wind turbines are so small as to be insignificant.

I began writing about the Migratory Bird Treaty Act and the Eagle Protection Act in the late 1980's. At that time the Fish and Wildlife Service estimated that roughly 600,000 birds per year were being killed after coming in contact with illegal oil pits in the oil fields of Texas, New Mexico and Oklahoma. In response, the Fish and Wildlife Service rightly began a multi-State, multi-jurisdictional crackdown on these illegal operations. They brought more than 200 cases against the oil and gas industry at that time for violations of the Migratory Bird Treaty Act and Eagle Protection Act.

Today, biologists are estimating that U.S. wind turbines are killing about 900,000 bats and 600,000 birds per year. The Fish and Wildlife Service's own biologists have documented dozens of cases of eagle kills by wind turbines, including at least six bald eagles. They have documented now eagle kills in 14 States. Between 2007 and 2011, they found a twelvefold increase in the annual rate of eagles being killed by wind turbines. And yet to date, the Fish and Wildlife Service and the Department of Justice have brought exactly one, I repeat, one, prosecution against the wind industry for clear and continuing violations of some of America's oldest wildlife laws.

Furthermore, and most astoundingly, the Interior Department is now considering permits that would allow the wind industry to kill eagles and other migratory birds for up to 30 years.

Now, let me discuss the more important issue here of CO_2 emissions, and let me be blunt. The birds and bats that are being killed by America's wind turbines are effectively being killed for no reason. Widespread deployment of wind turbines is not an effective climate change strategy. In fact, wind turbines are nothing more than climate change scarecrows. This is not an opinion, this is basic math.

The American Wind Energy Association estimates that in 2012, 60,000 megawatts of wind turbine capacity in the United States resulted in a reduction in CO_2 emissions of roughly 80 million tons. This amounts to two-tenths of 1 percent of global carbon dioxide emissions. Climate change activists repeatedly tell us to do the math. OK, let's do the math. Since 1982, global carbon dioxide emissions have been rising by an average of 500 million tons per year. Therefore, if we wanted to use wind energy merely to stabilize carbon dioxide emissions globally, and remember, this will not cut existing demand for coal, oil or natural gas, it would require the installation of roughly 375,000 megawatts of new wind energy capacity every year.

The power density of wind energy is 1 watt per square meter. Therefore, the math is simple. It would require, to stabilize CO_2 emissions growth, it would require covering a land area of roughly 375,000 square kilometers, an area the size of Germany, and we would have to do so every year. If we reduce that to a daily basis, ladies and gentlemen, it would require us to cover roughly 1,000 square kilometers, a land area the size of 17 Manhattan islands, with wind turbines, and we would have to do so every year. And because of the noise those wind turbines make, no people could live on that vast area of land. And further, and most obviously, the more wind turbines we erect, the more birds and bats we will kill.

About 5 years ago I testified in this same Senate office building about our energy policy here in the United States. If we are going to agree that CO_2 emissions are a problem, and we want to do something about it without destroying our economy, we must embrace the technologies that are affordable, scalable and are lower carbon than oil and coal. That means end to end, natural gas to nuclear.

Thank you.

[The prepared statement of Mr. Bryce follows:]

21 February 2014

Killing Wildlife In the Name of Climate Change

By
Robert Bryce
Senior Fellow, Manhattan Institute for Policy Research

Written Remarks for a Hearing of the Senate Committee on the Environment and Public Works, Dirksen Senate Office Building, February 25, 2014

Good afternoon.

The focus of this hearing is on the economic benefits of ecosystems and wildlife and how they "are valuable to a wide range of industries," including tourism. The purpose is also to examine "how the Administration is preparing to protect" ecosystems "in a changing climate."

The facts show that federally subsidized efforts that are being undertaken to, in theory, address climate change, are damaging America's wildlife. Furthermore, those same efforts have, for years, been allowing an entire industry to avoid federal prosecution under some of America's oldest wildlife laws.

My discussion will focus largely on the wind-energy sector, an industry that has been getting federal subsidies since 1992, and the impact that the wind-energy business is having on wildlife.[i]

There are two key questions that must be addressed:

* Are all energy providers getting equal treatment under the law when it comes to wildlife protection? The answer to that question is no.

* Is widespread deployment of wind turbines an effective climate-change strategy? The answer, again, is no.

Energy companies are not being treated equally when it comes to enforcement of federal wildlife laws.

I have been writing about the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act since the late 1980s.[ii] In the late 1980s and early 1990s, the US Fish and Wildlife Service brought hundreds of enforcement cases against the oil and gas industry in Texas, Oklahoma, and New Mexico, for violations of those laws. And rightly so.

At that time, the Fish and Wildlife Service estimated that about 600,000 birds per year were being killed after coming in contact with illegal or improperly maintained pits in the oil fields.[iii]

In 2009, I resumed writing about the enforcement of the Migratory Bird Treaty Act, (enacted in 1918)[iv] and Bald and Golden Eagle Protection Act (enacted in 1940)[v] after groups like the American Bird Conservancy began calling attention to the threat that wind turbines were posing to birds and bats.[vi]

A July 2008 study of bird kills by wind turbines at Altamont Pass, California, estimated that the massive wind farm was killing 80 golden eagles *per year*. Those birds are protected by the Bald and Golden Eagle Protection Act.[vii] In addition to the eagle kills, the study, funded by the Alameda County Community Development Agency, estimated that about 2,400 other raptors, including burrowing owls, American kestrels, and red-tailed hawks – as well as about 7,500 other birds, nearly all of which are protected under the Migratory Bird Treaty Act – were being killed every year at Altamont.[viii]

In 2009, a biologist with the Fish and Wildlife Service estimated wind turbines were killing some 440,000 birds per year.[ix]

The bird-kill studies in 2008 and 2009 underscored the pernicious double standard at work. In the late '80s, the Fish and Wildlife Service, found widespread violations of the Migratory Bird Treaty Act by the oil and gas industry. In response, it launched a multi-state, multi-jurisdictional crackdown on the oil and gas industry.

By 2009, the agency's own biologists were finding that the wind industry was causing similar levels of wildlife mortality to what had occurred two decades earlier in the oilfield, and yet there were no prosecutions. There were no multi-state law-enforcement actions. Instead, there was widespread silence on the issue and what appeared to be the Interior Department's issuance of a de facto get-out-of-jail-free-card for the wind industry because it had been deemed "green" by some advocates.

At the same time the wind industry was getting a free pass on bird kills, the Fish and Wildlife Service continued prosecuting traditional energy companies for violating the Migratory Bird Treaty Act. On July 10, 2009, Oregon-based PacifiCorp agreed to pay $1.4 million in fines and restitution for killing 232 eagles in Wyoming over a two-year period. The birds were electrocuted by the company's power lines.[x]

In 2011, the Fish and Wildlife Service filed criminal indictments against three drillers who were operating in North Dakota's Bakken field. One of those companies, Continental Resources, was indicted for killing a single bird, a Say's phoebe. Brigham Oil & Gas was charged with killing two mallards and Newfield Production was indicted for the deaths of two mallards, one northern pintail, and one red-necked duck.[xi]

In 2012, investigators found that the Pine Tree wind project in California had killed at least six golden eagles.[xii] In early 2013, Jill Birchell, a special agent in charge with the Division of Law Enforcement of the Fish and Wildlife Service, told me that a total of nine golden eagles had been killed at the Pine Tree project.[xiii] A biological assessment of the Pine Tree project estimated that the wind project was killing some 1,595 birds, or about 12 birds per megawatt of installed capacity, per year.[xiv]

Given the number of dead eagles being found at Pine Tree, and the projections of other bird mortality, the obvious question is this: Why haven't the owners of the Pine Tree project been prosecuted for violating the Migratory Bird Treaty Act and the Eagle Protection Act?

I can only speculate as to why there hasn't been a prosecution. But it's worth noting that the Pine Tree project is owned by the Los Angeles Department of Water and Power. Prosecuting such a high-profile governmental entity for repeatedly violating some of America's oldest wildlife-protection laws would be politically embarrassing. On its website, the LADWP claims that the Pine Tree facility is the "largest municipally owned wind farm in the US." The agency also says the Pine Tree project "displaces at least 200,000 tons of greenhouse gases" per year.[xv]

In March 2013, a peer-reviewed study published in the *Wildlife Society Bulletin*, estimated that in 2012 alone, US wind turbines killed 888,000 bats and 573,000 birds. Those bird kills included 83,000 raptors.[xvi] In September 2013, some of the Fish and Wildlife Service's top raptor biologists reported that the number of eagles being killed by wind turbines has increased dramatically over the last few years, going from two in 2007 to 24 in 2011. In all, the biologists found that wind turbines have killed some 85 eagles since 1997. And Joel Pagel, the lead author of the report, told me that that the eagle-kill figures they used are "an absolute minimum." Among the carcasses: six bald eagles.

Pagel's study was published just five months after the Fish and Wildlife Service issued a report which said flatly "there are no conservation measures that have been scientifically shown to reduce eagle disturbance and blade-strike mortality at wind projects."[xvii]

The Pagel study is key because it shows that as more wind projects have been built, more birds have been killed. In 2007, the US had about 17,000 megawatts of installed capacity. By 2011, that figure had nearly tripled to about 47,000 megawatts.[xviii] Over that time period, the number of documented eagle kills increased by a factor of 12.

Furthermore, when I interviewed Pagel by phone shortly after his report was published in the *Journal of Raptor Research*, he told me that since he completed his report, he and his colleagues have documented additional eagle kills by wind turbines in Idaho, Montana, Nevada, and North Dakota. Pagel refused to say how many additional eagle-kills they'd confirmed, but said, "it's quite a few." Pagel went on to say that there are now "14 states where eagles have been killed" by wind turbines. "That's a very large geographical area," he said, adding that more than half of the eagle carcasses "were found incidentally," and that there were "no systematic surveys" of the wind projects by people who had been trained to look for dead birds.[xix]

To clarify that last comment: Pagel said that most of the dead eagles that have been killed by wind turbines were found by people who were not looking for them. Therefore, the actual total of dead eagles is likely far higher than what Pagel and his colleagues are reporting. "We don't know how many eagles are being killed at wind farms," Pagel said, "but it's definitely more than what we have reported."

The September report from Pagel and his colleagues appears to have embarrassed federal law enforcement authorities into finally take action against the wind industry. On November 22, the Justice Department announced that it had reached a $1 million settlement with the owner of two Wyoming wind projects which had illegally killed golden eagles and other federally protected birds. The plea deal, with Duke Energy, marks the first time that the federal government has enforced the Migratory Bird Treaty Act against the wind industry. By bringing criminal charges against Duke – for killing 14 golden eagles and 149 other protected birds – the Justice Department ended the legal double standard on enforcement of the Act.[xx]

It's not at all clear what happens next. Although the Fish and Wildlife Service says it has several active bird-kill investigations on other wind projects, no prosecutions have been announced.

The situation got even murkier in December, when the Interior Department announced that it would consider granting some wind-energy companies permits that may allow them to kill or injure bald and golden eagles for up to 30 years without penalty. A number of environmental groups oppose the 30-year permit deal, including the American Bird Conservancy, Conservation Law Center, and the National Audubon Society.[xxi]

Immediately after the deal was announced, Audubon issued a statement with the headline "Interior Dept. Rule Greenlights Eagle Slaughter at Wind Farms." The statement calls the permit deal "a stunningly bad move." It also quotes the group's president and CEO, David Yarnold: "Instead of balancing the need for conservation and renewable energy, Interior wrote the wind industry a blank check." He went on, saying "It's outrageous that the government is sanctioning the killing of America's symbol, the Bald Eagle."[xxii]

Let me be clear: there is no such thing as a free lunch, particularly when it comes to energy production. Every form of energy comes with positives and negatives. What is problematic is the selective enforcement of our wildlife laws. If we are going to have a protected class of energy producers who are exempt from federal laws, then the Interior Department should make that policy clear. If the Justice Department and Interior Department are not going to enforce the law equally – if justice is not going to be blind – then perhaps policymakers should consider repealing our wildlife laws altogether.

Before moving on, let me briefly mention the issue of bat kills. Earlier this month, I interviewed Merlin Tuttle, one of the world's foremost experts on bats. He told me "Anyone familiar with bat population biology is deeply concerned about the impact of wind turbines on the long term viability of a number of bat species."

Tuttle, who is the founder of Bat Conservation International, as well as the Bats and Wind Energy Cooperative, said that bats have slow reproductive rates.[xxiii] And while some wind-energy companies have been conscientious in their efforts to mitigate the impact of their facilities on bats, other companies have not. The result: "We are at great risk of needlessly creating new endangered species. We risk losing the benefits of bats to natural systems and agriculture."[xxiv]

Widespread deployment of wind turbines is not an effective climate-change strategy.

In discussing energy sources, we must cast aside the social marketing of renewable energy and discard pre-conceived notions as to what qualifies as "green." Instead, we must focus on basic physics and math.

I am an ardent proponent of nuclear energy because of its negligible carbon dioxide emissions and its incredibly high power density. No other form of energy production can produce as much energy from such a small footprint as a nuclear reactor. This is due to basic physics. Allow me to explain this by using a common metric in physics: power density, which is a measure of the energy flow that can be harnessed from a given area, volume, or mass.

The concept of power density can be understood by looking at the San Onofre Nuclear Generating Station in Southern California. SONGS has a capacity of about 2,200 megawatts (2.2 billion watts.)[xxv] The plant, which is slated for closure, covers 214 acres or 866,027 square meters.[xxvi]Therefore, the nuclear plant has a power density of about 2,500 watts per square meter.[xxvii]

Now let's compare that to the power density of wind energy, which is 1 watt per square meter. And I can back up that number with a half dozen studies.[xxviii]

Therefore, to replace the San Onofre plant with wind energy would require setting aside 2.2 billion square meters of land. That's 2,200 square kilometers. Put another way, if we wanted to replace the San Onofre Generating Station solely with wind energy, California policymakers would have to set aside a land area nearly as large as Sacramento County.[xxix] And because of the low-frequency noise and infrasound that wind turbines make, no people could live on that county-sized piece of land.

It is essential to understand the concept of power density because it is directly related to the wildlife-kill issue. To produce significant quantities of energy with wind energy requires vast swaths of land to be covered with wind turbines. And the more wind turbines that are installed, the more birds and bats will be killed. That can be seen by the Pagel study mentioned above, which shows that as wind-energy installations in the US have increased, so have the verified numbers of eagle kills.

When we look at the main justification for renewable energy projects, and wind energy in particular, climate change is nearly always mentioned. For instance, the Global Wind Energy Council claims "The greatest benefit of wind power is its contribution to reduction of carbon dioxide emissions."[xxx] On its website, the American Wind Energy Association says "Mitigating climate change poses an immediate need to reduce greenhouse gas pollution. Fortunately, wind energy can play a major role in reducing CO2 emissions."[xxxi] And in a December 6, 2013 press release that focused on the bird-kill issue, the American Wind Energy Association claimed that wind energy "is one of the cheapest, fastest, most readily scalable ways available now to address climate change."[xxxii]

Those claims are among many similar ones that have been made over the past few years by renewable-energy advocates. Here's the reality: Wind turbines are nothing more than climate-change scarecrows.

The proliferation of wind turbines over the past few years has not, and will not, result in statistically significant reductions in global carbon dioxide emissions. That is not an opinion. It is simple math.

In 2012, the American Wind Energy Association claims that wind energy reduced domestic carbon dioxide emissions by 80 million tons.[xxxiii] That sounds significant. It's equal to about 1.4 percent of US carbon dioxide emissions in 2012. But the issue isn't US carbon dioxide emissions. As President Obama said in his State of the Union speech on January 28, "Over the past eight years the United States has reduced our total carbon pollution more than any other nation on Earth."[xxxiv]

The daunting challenge we face is global carbon dioxide emissions. In 2012, those emissions totaled 34.5 billion tons.[xxxv] Thus, in 2012, the 60,000 megawatts of domestic wind-generation capacity reduced global carbon dioxide emissions by about two-tenths of 1 percent.

Since 1982, global carbon dioxide emissions have been increasing by an average of about 500 million tons per year.[xxxvi] If we take the American Wind Energy Association's claim that 60,000 megawatts of wind-energy capacity can reduce carbon dioxide emissions by about 80 million tons per year, then simple math shows that if we wanted to stop the growth in global carbon dioxide emissions by using wind energy alone, we would have to install about 375,000 megawatts of new wind-energy capacity every year. If we assume each turbine has a capacity of two megawatts, that would mean installing 187,500 wind turbines every year, or nearly 500 every day.

How much land would all those wind turbines require? Again, the math is straightforward. As I noted earlier, the power density of wind energy is 1 watt per square meter.

Therefore, attempting to halt the growth in carbon dioxide emissions with wind energy alone would require covering a land area of about 375 billion square meters or 375,000 square kilometers -- an area the size of Germany -- *and we would have to do so every year.*

What would that mean on a daily basis? Using wind alone to stop the growth in carbon dioxide emissions would require us to cover about 1,000 square kilometers with wind turbines -- a land area about 17 times the size of Manhattan Island -- and *we would have to do so every day.*[xxxvii] Given the ongoing backlash against the wind industry that is already underway here in the US, as well as in Canada, Europe, and Australia, the silliness of such a proposal is obvious.

The hard but unavoidable truth about wind energy is that it not even a viable option to *stop the growth in global carbon dioxide emissions, much less make a significant dent in existing demand for carbon-based fuels.*

If we are going to agree that carbon dioxide is a problem, and that we must reduce carbon dioxide emissions in order to protect wildlife, then we must embrace the technologies that are most effective at reducing our production of that gas. And that means N2N, natural gas to nuclear.

A surge in availability of low-cost natural gas has been a key driver of the recent reductions in US carbon dioxide emissions. Furthermore, it is beyond argument that that if we are going to be serious about making further reductions in emissions, we will have to get serious about nuclear energy, not just on a national basis, but on a global basis.

That point was made in November, when some of the world's top climate scientists, including James Hansen, a former NASA scientist, Kerry Emanuel of the Massachusetts Institute of Technology, Tom Wigley of the University of Adelaide in Australia, and Ken Caldeira of the Carnegie Institution, wrote an open letter that was clearly aimed at anti-nuclear groups like the Sierra Club, Greenpeace, and the Natural Resources Defense Council. The letter says that while renewables "like wind and solar and biomass" are growing, those sources "cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires." It went on, saying that "in the real world there is no credible path to climate stabilization that does not include a substantial role for nuclear power." The four concluded their epistle by saying that if environmental activists have "real concern about risks from climate change" then they should begin "calling for the development and deployment of advanced nuclear energy."[xxxviii]

Rather than get serious about nuclear, the US and other countries have been subsidizing the paving of vast areas of the countryside with 500-foot-high bird- and bat-killing whirligigs that are nothing more than climate talismans. Wind turbines are not going to stop changes in the earth's climate. Instead, they are token gestures -- giant steel scarecrows -- that are deceiving the public into thinking that we as a society are doing something to avert the possibility of climate change.

Even though wind energy has not been, and cannot be, an effective strategy to address global climate change, the US government and state-level policymakers are continuing to pursue this failed strategy through tax breaks, mandates, and subsidies. Those policies are leading the deployment of still more bird- and bat-killing wind turbines. According to the latest projections from the Energy Information Administration, domestic wind-energy capacity is expected to increase by about 25 percent, to about 75 gigawatts, by the end of 2015.[xxxix] And most, perhaps all, of that additional 15 gigawatts of wind-energy capacity, will be getting taxpayer money in the form of the production tax credit, the 2.3 cent per kilowatt-hour subsidy that is given to the owners of qualifying wind projects.

Given the studies already done on wind energy's deleterious impact on wildlife, combined with the "energy sprawl" that will come with the industry's continuing expansion, it is virtually certain that as the wind sector adds more turbines, more federally protected wildlife – including more bald eagles, an animal that has been on the Great Seal of the United States since 1782 -- will be killed.[xl] And thanks to the production tax credit, taxpayers will be subsidizing the slaughter.

The question at hand is obvious: why are policymakers implementing an energy policy that is a known killer of wildlife in exchange for what are infinitesimally small reductions in carbon dioxide emissions?

If the federal government is going to be serious about addressing climate change and in protecting this nation's wildlife, it must focus on the energy sources that have small footprints, are able to provide large amounts of dispatchable energy at reasonable cost, and can provide significant reductions in carbon dioxide emissions when compared to the two sources that dominate our current energy mix: oil and coal.[xli]

Those energy sources are natural gas and nuclear energy.

Thank you.

END

[i] Department of Energy, "Renewable Electricity Production Tax Credit," undated, http://energy.gov/savings/renewable-electricity-production-tax-credit-ptc

[ii] See Robert Bryce, "Crackdown Due on Foul Water Holes: Birds Fall Victim to Slime in 3 States," *Tulsa Tribune*, November 17, 1989, http://www.robertbryce.com/articles/440-crackdown-due-on-foul-water-holes-birds-fall-victim-to-slime-in-3-states
See also, Robert Bryce, "Oil Waste Pits Trap Unwary Birds," *Christian Science Monitor*, March 19, 1990, http://www.csmonitor.com/1990/0319/apit.html

[iii] Robert Bryce, "Oil Waste Pits Trap Unwary Birds," *Christian Science Monitor*, March 19, 1990, http://www.csmonitor.com/1990/0319/apit.html

[iv] http://www.fws.gov/laws/lawsdigest/migtrea.html

[v] http://www.fws.gov/midwest/midwestbird/eaglepermits/bagepa.html

[vi] Robert Bryce, "Windmills Are Killing Our Birds," *Wall Street Journal*, September 7, 2009, http://online.wsj.com/news/articles/SB10001424052970203706604574376543308399048

[vii] Fish and Wildlife Service data. Available: http://www.fws.gov/midwest/Eagle/guidelines/bgepa.html

[viii] Alameda County Community Development Agency, "Altamont Pass Wind Resource Area Bird Fatality Study," July 2008, 1-3. Available: http://www.altamontsrc.org/alt_doc/m30_apwra_monitoring_report_exec_sum.pdf

[ix] Albert M. Manville II, "Towers, Turbines, Power Lines, And Buildings—Steps Being Taken By The U.S. Fish And Wildlife Service To Avoid Or Minimize Take Of Migratory Birds At These Structures," Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics 262–272, undated (2009), http://www.partnersinflight.org/pubs/mcallenproc/articles/pif09_anthropogenic%20impacts/manville_pif09.pdf, 268

[x] Fish and Wildlife Service data. Available: http://www.fws.gov/news/newsreleases/showNews.cfm?newsId=750629CF-E286-4B51-379292C1D9377C411

[xi] Christopher Helman, "Judge Throws Out Criminal Case Against Oil Companies for Killing Birds at Drilling Sites," *Forbes*, January 18, 2012, http://www.forbes.com/sites/christopherhelman/2012/01/18/judge-throws-out-criminal-case-against-oil-companies-for-killing-birds-at-drilling-sites/

[xii] Louis Sahagun, "US probes golden eagles' deaths at DWP wind farm," *Los Angeles Times*, February 16, 2012, http://articles.latimes.com/2012/feb/16/local/la-me-eagles-20120216

[xiii] Author phone interview with Birchell, March 4, 2013.

[xiv] Center for Biological Diversity press release, http://www.biologicaldiversity.org/news/press_releases/2011/wind-energy-project-10-20-2011.html

[xv] Los Angeles Department of Water and Power news release, undated, http://www.ladwpnews.com/external/content/document/1475/248767/1/Pine%20Tree%20Fact%20Sheet.final.pdf

[xvi] K. Shawn Smallwood, "Comparing bird and bat fatality-rate estimates among North American wind-energy projects," *Wildlife Society Bulletin*, March 26, 2013, http://onlinelibrary.wiley.com/doi/10.1002/wsb.260/abstract

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[xvii] http://www.fws.gov/windenergy/PDF/Eagle%20Conservation%20Plan%20Guidance-Module%201.pdf, iv.
[xviii] BP Statistical Review of World Energy 2013.
[xix] Author phone interview with Pagel, September 16, 2013.
[xx] http://www.justice.gov/opa/pr/2013/November/13-enrd-1253.html
[xxi] http://www.abcbirds.org/abcprograms/policy/collisions/pdf/Groups_opposed_30yr_eagle_take_permits.pdf
[xxii] http://www.audubon.org/newsroom/press-releases/2013/interior-dept-rule-greenlights-eagle-slaughter-wind-farms-says-audubon-
[xxiii] For more on the BWEC, see: http://www.batsandwind.org/index.php
[xxiv] Author interview with Tuttle by phone, February 17, 2014.
[xxv] http://www.songscommunity.com/docs/DecommissioningSanOnofreFactsheet.pdf
[xxvi] Tetra Tech, "California's Coastal Power Plants: Alternative Cooling System Analysis," undated, http://www.opc.ca.gov/webmaster/ftp/project_pages/OTC/engineering%20study/Chapter_7N_San_Onofre_Nuclear_Generating_Station.pdf, N-3.
[xxvii] 2.2 billion watts / 866,027 m2 = 2,558 W/ m2
[xxviii] For instance, see:

1. David J.C. MacKay, "Illuminating the Future of Energy," *New York Times,* August 28, 2009, http://www.nytimes.com/2009/08/29/business/energy-environment/29iht-sustain.html?pagewanted=all, which puts the power density of wind at 2 to 3 W/m2.
2. Jesse Ausubel, "Renewable and Nuclear Heresies," *International Journal of Nuclear Governance, Economy, and Ecology*, Vol 1., No. 3, 2007, 233, http://phe.rockefeller.edu/docs/HeresiesFinal.pdf, which puts wind's power density at 1.2 W/m2.
3. Vaclav Smil, "Power Density Primer: Understanding the Spatial Dimension of the Unfolding Transition to Renewable Electricity Generation, (Part V – Comparing the Power Densities of Electricity Generation) " Vaclavsmil.com, May 14, 2010, http://www.vaclavsmil.com/wp-content/uploads/docs/smil-article-power-density-primer.pdf, which puts wind's power density at 0.5 to 1.5 W/m2.
4. Todd A. Kiefer, "Twenty-First Century Snake Oil: Why the United States Should Reject Biofuelas as Part of a Rational National Security Energy Strategy," Waterloo Institute for Complexity and Innovation, January 2013, http://wici.ca/new/wp-content/uploads/2013/02/Kiefer-Snake-Oil2.pdf, 33, 68, note 119. Kiefer puts wind's power density at 1.13 W/m2.
5. Amanda S. Adams and David W. Keith, "Are global wind power resource estimates overstated?" *Environmental Research Letters*, February 25, 2013, http://iopscience.iop.org/1748-9326/8/1/015021/pdf/1748-9326_8_1_015021.pdf, which put wind's power density at 1 W/m2.
6. Author's own calculations, based on data on 16 different projects that ranged in size from 40 megawatts to more than 2,000 megawatts. The projects were geographically diverse – Texas, Pennsylvania, Wyoming, Kansas, Ontario, and

Australia -- and totaled more than 5,000 megawatts of capacity. Author's finding: the power density of wind energy is 0.89 watts per square meter.

In summary, the power-density calculations of wind energy are as follows:
Jesse Ausubel: 1.2
David J.C. MacKay: 2
Vaclav Smil: 1
Todd Kiefer: 1.13
Adams/Keith: 1
Robert Bryce: 0.89

Add those figures together and divide by six, and you get an average power density for wind energy of 1.2 watts per square meter -- exactly what I reported in my 2010 book, *Power Hungry: The Myths of "Green" Energy and the Real Fuels of the Future*. If we toss out the high and low estimates (MacKay's 2 watts per square meter, and my 0.89 watts per square meter) then the average power density of wind is 1.08 watts per square meter.

[xxix] Sacramento County covers 2502 square kilometers. See: http://en.wikipedia.org/wiki/List_of_counties_in_California

[xxx] Global Wind Energy Coalition, http://www.gwec.net/faq/how-much-co2-emissions-can-wind-avoid/

[xxxi] American Wind Energy Association, http://www.awea.org/Issues/Content.aspx?ItemNumber=854

[xxxii] American Wind Energy Association, http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=5910

[xxxiii] American Wind Energy Association, http://awea.rd.net/Resources/Content.aspx?ItemNumber=5097

[xxxiv] Full text available here: http://www.nytimes.com/2014/01/29/us/politics/state-of-the-union-address-text.html?_r=0

[xxxv] BP Statistical Review of World Energy 2013.

[xxxvi] BP Statistical Review of World Energy 2013.

[xxxvii] Manhattan Island covers about 59 square kilometers. See: http://en.wikipedia.org/wiki/Manhattan

[xxxviii] https://plus.google.com/104173268819779064135/posts/Vs6Csiv1xYr

[xxxix] Capacity at the end of 2012 was roughly 60 gigawatts. See: BP Statistical Review of World Energy 2013. For the latest EIA projections, see EIA, Short-Term Energy Outlook, February 11, 2014, http://www.eia.gov/forecasts/steo/report/renew_co2.cfm

[xl] http://www.greatseal.com/committees/finaldesign/

[xli] Together, oil and coal provide about 63 percent of global energy consumption. See: BP Statistical Review of World Energy 2013.

13 March 2014

Mara Stark-Alcala
Senate Committee on Environment and Public Works
410 Dirksen Senate Office Building
Washington, DC 20510

Dear Ms. Stark-Alcala,
Please see below for my responses to the questions from Senator Vitter.

1. **Your testimony focuses primarily on the challenges the wind energy industry faces with wildlife and measurable emissions reductions. I was recently made aware of a debate surrounding a solar energy facility near the California-Nevada border regarding bird kills. In your research have you found similar challenges with solar energy that you have discovered with the wind industry?**

   I'm particularly interested to know about your examinations of solar energy in the context of land use and wildlife issues.

Response: I am not aware of any mortality studies that have been done on concentrated-solar projects like the one you mention. Further, given that there are relatively few of those facilities now in existence, I would not assume that those types of studies are being done.

2. **We have been told for years that we are behind European nations in enacting policies that will have a positive impact in combatting global climate change. This includes enacting policies like a renewable energy mandate and implementing a cap-and-trade scheme.**

   I'm concerned that a number of the policies my colleagues support will increase energy prices and make it more difficult for consumers to pay their electricity bills. Do you have thoughts on using the European model of transforming our energy economy?

Response: I've attached to this email a recent study I did for the Manhattan Institute on that very topic. Given the higher costs of renewable energy, my report shows that if the US were to attempt to adopt nationwide mandates similar to the policies now being followed in the EU, household electricity costs would rise by about 29 percent. Annually, such a policy would cost the average household about $377. (See page 10 of my report.)

Furthermore, it is rather astounding to me to hear politicians and pundits advocating policies that would have the US follow the EU at the very same time that the EU-member countries are backing away from their renewable-energy programs. Germany alone has spent about $100 billion over the last decade or so on subsidies for renewable energy. And yet what is Germany doing today? It is building more coal-fired power plants.

The hard truth is that the US is leading the world in reducing its CO2 emissions and those reductions are largely the result of increased use of natural gas, a fuel the US has in abundance.

3. **Given the bird and bat kill issue, which is undeniable, is the deployment of wind turbines a viable CO2 strategy for protecting wildlife?**

Response: I don't see how any technology that kills significant numbers of some of our most iconic wildlife can be considered a viable strategy for wildlife protection.

As I stated in my written comments to the Senate EPW committee, wind energy cannot even meet incremental demand growth for electricity much less displace significant quantities of hydrocarbons. If policymakers wanted to use wind just to offset the growth in global CO2 emissions (growing at about 500 million tons per year) we would have to set aside a land area the size of Germany, and cover that entire land mass with wind turbines, and we would have to do so every year. The silliness of such a proposal is obvious.

4. **At the hearing, I asked FWS Director Ashe about the need for consultation under the Endangered Species Act related to the EPA's new source performance standards (NSPS). Consultation is required when any federal action, including a planning action, may impact an endangered or threatened species or designated critical habitat.**

   Given that the NSPS has carbon standards that will make it impossible to build a new coal fired power plant, I expect a shift in energy production to sources like wind and solar. Do you agree that there will be a shift in energy production to those sources? If that is the case, do you believe additional wind and solar energy will have impacts on endangered or threatened species and designated critical habitat?

Response: In my view, the Obama administration's war on coal is forcing the US to become too reliant on natural gas. That said, there's no question that we are seeing a major push toward the use of wind and solar energy. Much of that push is due to state-level mandates for renewable energy. As I made clear in my testimony, a major threat facing rare and endangered species (and in particular, rare and endangered bats and birds) is the proliferation of wind turbines. We are seeing more "energy sprawl" at the very time that we, if we are truly concerned about wildlife, should be seeking energy and power systems that have small footprints.

The unfortunate truth is that many of the "Big Green" environmental groups have abandoned the most concentrated forms of energy -- and nuclear power in particular -- and are embracing the most dilute forms. Instead of protecting wildlife and open spaces, they've been captured by the renewable-energy industry into advocating policies that run counter to the ideals they should be advocating.

I appreciate the opportunity to provide more information to the committee.

All the best

RB

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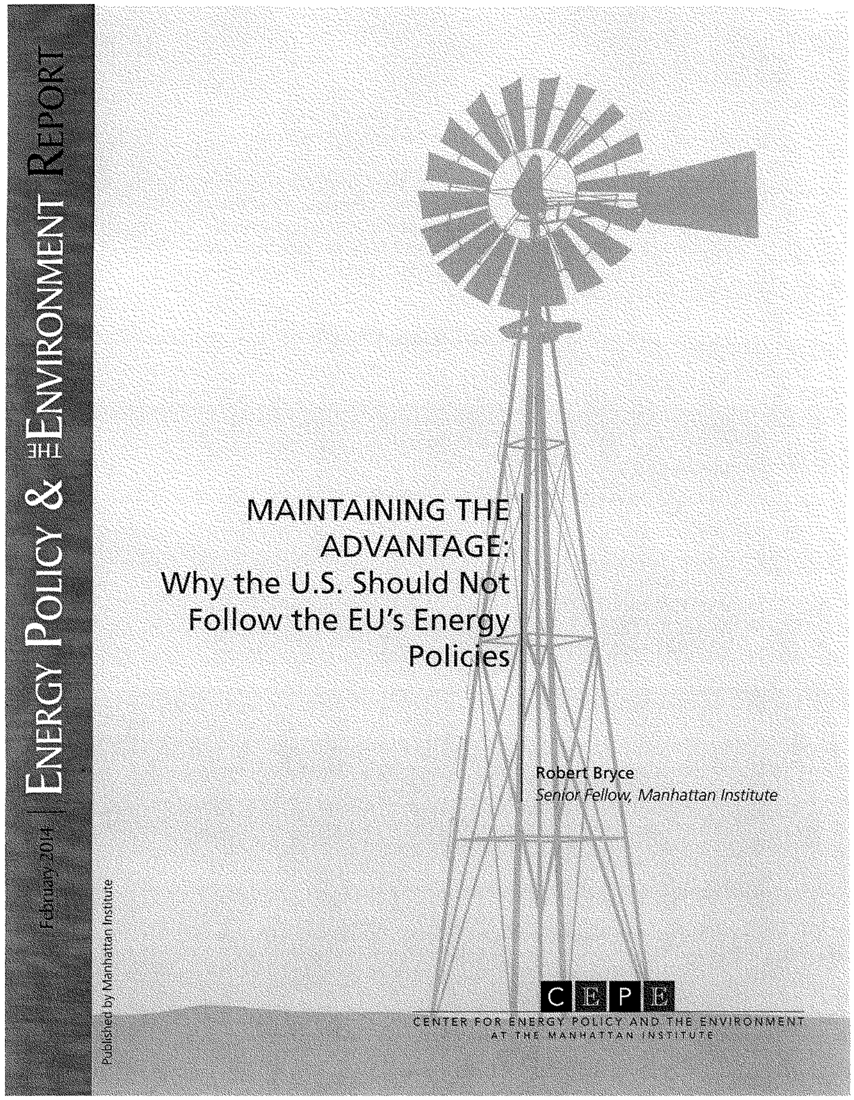

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MAINTAINING THE ADVANTAGE: Why the U.S. Should Not Follow the EU's Energy Policies

Robert Bryce
Senior Fellow, Manhattan Institute

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CENTER FOR ENERGY POLICY AND THE ENVIRONMENT AT THE MANHATTAN INSTITUTE

Over the past decade, the United States and the European Union have taken markedly different approaches to the electricity markets that power their economies. Seeking drastic reductions in carbon emissions, the EU has emphasized rigid and extensive mandates, market interventions (including a "cap and trade" regime to reduce emissions), and subsidies aimed at promoting renewable energy. The U.S. government, as well as numerous states, while also promoting renewables and seeking lower emissions, has interfered far less. U.S. electricity markets operate more freely than their European counterparts. So, too, do other U.S. energy sectors. This has contributed to the recent boom in extraction of both oil and natural gas in the U.S.

As a result of these policy differences, electricity prices in Europe now are far higher than those in the United States, for both residential and industrial consumers. Between 2005 and late 2013, the average price of residential electricity in the EU rose by 55 percent, and industrial electric rates jumped by 26 percent. The average U.S. household now pays 12 cents per kilowatt-hour—about a third of what the same amount of electricity costs in Germany. European steelmakers now pay twice as much for their electricity as do U.S. manufacturers.

EU policies have raised its electricity costs by:

- Giving large subsidies to wind- and solar-energy producers—subsidies that must be paid for by consumers.
- Mandating the use of renewable energy, which is more expensive and which requires backup power for times when the sun doesn't shine and the wind doesn't blow. Because of this need for backup power, consumers must pay for both renewables and backup gas-fired plants.
- Implementing a flawed cap-and-trade system whose market distortions have discouraged efficiency (and, ironically, increased coal use).

For its higher electricity costs, Europe has not received the benefit of higher carbon-emissions reductions: between 2005 and 2012, U.S. carbon dioxide emissions fell more than those of the EU did. Furthermore, in 2012, Germany's carbon dioxide emissions actually rose by 1.3 percent over 2011 levels, while U.S. emissions fell by 3.9 percent.

Despite this clear contrast between the two economies, some U.S. policymakers—from the president to state legislators—have called on the U.S. to implement EU-style electricity policies.

There is no doubt that such a move would raise U.S. electricity prices and erode, or even eliminate, this country's competitive edge in energy. This paper estimates that the net effect of the U.S. adopting a renewable-energy goal like the EU's would be to increase the monthly electricity bill of an average household by about 29 percent.

California—the U.S. state whose policies are most like Europe's—offers a case study in what not to do. Thanks to the state's renewables mandates, cap-and-trade system, and aggressive promotion of solar power, California consumers are paying far more than their fellow Americans for electricity.

Instead of emulating Europe's failed policies, the U.S. should:

- Eliminate its own renewable-energy subsidies.
- Remove excessive restrictions on coal-fired electricity generation plants.
- Encourage "N2N" (natural gas to nuclear) sources of electricity.
- Not impose unnecessary regulations on the process of hydraulic fracturing, which is essential to the production of natural gas from shale.
- Maintain—and improve—safety standards in all facets of energy production, including drilling, refining, transportation, and storage.

About the Author

ROBERT BRYCE is a senior fellow at the Manhattan Institute's Center for Energy Policy and the Environment. He has been writing about energy for two decades and his articles have appeared in numerous publications ranging from *The Wall Street Journal* to *The New York Times* and the *Atlantic Monthly* to the *Washington Post*. Bryce's first book, *Pipe Dreams: Greed, Ego, and the Death of Enron*, was named one of the best nonfiction books of 2002 by *Publishers Weekly*. In 2008, he published *Gusher of Lies: The Dangerous Delusions of "Energy Independence"*. A review of Gusher of Lies in *The New York Times* called Bryce "something of a visionary and perhaps even a revolutionary." His fourth book, *Power Hungry: The Myths of "Green" Energy and the Real Fuels of the Future*, was published in April 2010 by PublicAffairs. *The Wall Street Journal* called *Power Hungry* "precisely the kind of journalism we need to hold truth to power." *The Washington Times* said Bryce's "magnificently unfashionable, superlatively researched new book dares to fly in the face of all current conventional wisdom and cant." Bryce appears regularly on major media outlets including CNN, FOX News, PBS, NPR, and the BBC. He received his B.F.A. from the University of Texas at Austin in 1986.

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Maintaining the Advantage: Why the U.S. Should Not Follow the EU's Energy Policies

Robert Bryce

INTRODUCTION

The European Union and the United States both rely on abundant and reliable electricity for every sector of their economies. Over the past decade, however, the two economic powerhouses have pursued notably different approaches to their electricity markets. Nations in the EU, in a quest to reduce the carbon emissions associated with fossil fuels, have mandated a shift toward the use of solar, wind, and other renewable-energy sources. The U.S. and its state governments have taken a far less intrusive approach, while at the same time expanding the development of natural gas and other fossil fuels.

As a result of this policy difference, there is now a sharp divide between the two economies on electricity prices and emissions reductions. Prices are higher in Europe, yet emissions reductions are greater in the U.S. Between 2005 and late 2013, the average price of residential electricity in the EU rose by 55 percent, and industrial electric rates jumped by 26 percent.[1] In 2012, the average household price of electricity among the 27 members of the European Union was $0.26.[2] In Denmark—a country that many wind-energy proponents admire—a kilowatt-hour of electricity for residential customers cost $0.41. In Germany—by far, Europe's biggest economy, largest electricity consumer, and most important manufacturer—the cost was $0.35. In Spain, another country that has provided huge subsidies to the renewable-energy sector, it was $0.29.[3]

Meanwhile, in the U.S., the average residential cost of electricity in 2012 was about $0.12.[4]

Even as Americans pay less for electricity because their federal and state governments impose fewer emissions-related mandates and regulations, the U.S. has reduced its emissions more than the EU has. Between 2005 and 2012, U.S. carbon dioxide emissions fell by 10.9 percent. Over that same time frame, those emissions from the EU-27 fell by 9.9 percent. In fact, European policies have created perverse incentives whose results contradict the policy goals. In 2012, for example, Germany's carbon dioxide emissions *rose* by 1.3 percent over 2011 levels. (That same year, U.S. emissions fell by 3.9 percent.)[5]

Despite this contrast, influential voices in the U.S. federal and state governments—the president, senators and representatives, governors and state legislators—have been advocating (and sometimes implementing) emissions-related regulations that emulate Europe's. They are mistaken. Both the energy price divide and the difference in emissions reductions results are signs that Americans should not copy the EU's approach. Instead, the U.S. should adhere to the policies that have made it a world leader in energy production, electricity generation, and carbon-dioxide-emissions reductions.

I. HISTORY AND EFFECTS OF RECENT EU ENERGY POLICY MOVES

For much of the past decade, the European Union has been using government intervention in the market as a tool to reduce emissions of greenhouse gases. In 2005, the European Commission launched the world's first cap-and-trade system. Two years later, the EU agreed to enact its first "energy action plan," which resulted in the commitments known as "20/20/20": by 2020, European governments agreed that they would achieve three goals: establish legally binding agreements to cut their greenhouse gas emissions by 20 percent from 1990 levels; rely on renewables for 20 percent of their energy; and reduce their energy consumption by 20 percent from 2007 levels.[6]

The EU has indeed seen some reductions in its emissions since these policies were adopted. Between 2005 and 2012, carbon dioxide emissions in the EU-27 fell by 9.9 percent.[7] Nonetheless, it is far from certain that the bloc will meet its 20 percent reduction goal by 2020.

What is certain, though, is that these programs—along with big subsidies paid to renewable-energy providers—have resulted in dramatic increases in electricity prices. Between 2009 and 2013, the average energy bill for EU consumers increased by some 17 percent, while energy costs for industrial users jumped by 21 percent.[8]

The increased prices have not bought a well-functioning regulatory system. Instead, the EU is struggling to fix its cap-and-trade system, the Emissions Trading Scheme. The first and most extensive such system in the world, the ETS sets a cap on the total amount of greenhouse gases discharged by some 11,000 factories and other installations throughout the EU (as well as Iceland, Norway, and Lichtenstein). Each unit has permits to discharge a certain amount of greenhouse gases, and those that need to discharge more must buy capacity from those that need less. In theory, this should create incentives to reduce emissions without crippling industry. But the ETS has never worked so smoothly in practice.

In fact, the ETS has been embroiled in allegations of corruption for years. In 2009, Europol (the EU's criminal intelligence agency) discovered fraudulent activities in the system that had led to the loss of some $7 billion in tax revenue.[9] The ETS has also angered many of the biggest industrial users in Europe, some of which are taking legal action for what they say is an under-allocation of carbon allowances. The companies—which include Dow Chemical, Shell, and ExxonMobil—may seek as much as $5.5 billion in compensation.[10]

But the biggest problem for the trading scheme has been a collapse in its prices. In 2008, the spot price for one ton of carbon credit was about 25 euros.[11] By December 2013, that price had fallen to about 5 euros.[12] The price collapse was due to simple supply and demand. Too many credits were issued at the outset of the scheme. And since the program was created, demand for the credits has fallen. This price collapse has had an unforeseen result: a reduction in gas-fired electricity production. Natural gas–fired power plants emit about half as much carbon dioxide as comparable coal-fired ones.[13] But thanks to the

ETS, utilities have found it less expensive to buy carbon credits and burn coal than to pay Europe's high prices for natural gas.

In fact, coal use in Europe's biggest countries is rising. In 2012, coal use in both Spain and the U.K. jumped by 24 percent over 2011 levels. In France, coal consumption rose 20 percent; in the Netherlands, by 8 percent; and in Germany, by about 4 percent.[14] Along with the ETS, several other forces are also pushing up coal use. These include higher natural gas prices and a surge in low-cost coal imported from the U.S.[15] Another significant factor is the decline in Europe's ability to exploit its own natural gas resources.

In 2012, gas production in the U.K. fell by 14.4 percent when compared with 2011. In Germany, gas production fell by 12.5 percent; in France, by 10.2 percent; in Denmark, by 9.2 percent; and in the Netherlands, by 0.4 percent.[16] But those single-year decline numbers do not tell the full story. Since 2005, natural gas production in the U.K. has fallen by 53 percent. In Germany, production has dropped by nearly 43 percent; in Denmark, production is down by nearly 39 percent; and in Italy, it has dropped by 29 percent.[17]

Even without declines in production, Europe would face a vast gap between its natural gas usage and its production. In 2012, the 27 members of the EU produced about 6 trillion cubic feet of gas while consumption was roughly 17 trillion cubic feet.[18] And the EU will need more gas to meet its emissions-reduction targets because natural gas combustion produces only half the carbon emissions of coal. So the bloc faces a future of rising imports. For many European nations, the only realistic source will be one whose reliability seems open to question: Russia. The Russian gas giant Gazprom has twice cut off gas customers during the winter. It cut off gas supplies to Ukraine in the winter of 2005–06 and in 2008–09.[19] In 2012, Russia provided about 32 percent of the EU's natural gas imports.[20]

Germany: An Object Lesson

No other European country has been as aggressive in pursuing lower carbon emissions as Germany.

The EU's Share of Global CO_2

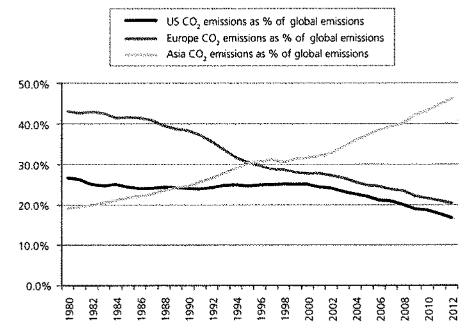
Though the EU is committed to addressing the possibility of climate change, the 27 member countries of the European Union account for only about 14 percent of global carbon dioxide emissions. (In 2011, the EU-27 emitted 4.6 billion tons of carbon dioxide.[21] That same year, global emissions of that gas totaled 33.7 billion tons.) For comparison: between 2003 and 2012, China's total carbon dioxide emissions grew by nearly 4.9 billion tons.[22] Therefore, even if the EU could somehow reduce its emissions dramatically, it's not clear that this would make a major difference in global carbon emissions, given the rapid rise of China and other Asian countries.

Consequently, Germany—even more than Europe as a whole—has experienced major increases in the cost of energy. Germany also provides a good example of how the rapid push for renewable energy has interfered with electricity markets and forced consumers to subsidize both renewable and conventional electricity generation. (This year, according to calculations done by the *Financial Times*, the cumulative cost of the subsidies given to renewable energy in Germany since 2000 will hit $149 billion.)[2]

In 2013, the surcharge that is added to German customers' electric bills to offset the cost of renewable-energy subsidies was 5.3 euro cents (7.25 U.S. cents) per kilowatt-hour.[24] This year, that surcharge was increased by nearly 19 percent, to 6.3 euro cents (8.5 U.S. cents) per kilowatt-hour. Today, then, the surcharges for renewables on German electricity amount to about 70 percent of the *full average retail price* of residential electricity in the United States.[25]

In 2013 alone, thanks to fees and surcharges for green energy, German consumers were charged some $26 billion for electricity that had a market value of just $4 billion.[26] Enormous additional costs are looming. Germany's environment minister recently estimated that over the next two and a half decades, the country may have to spend as much as $1.3 trillion as it tries

Figure 1. Regional GHG Emission Shares Since 1980



Source: BP Statistical Review of World Energy 2013

Since 1980, the share of global carbon dioxide emissions coming from the U.S. and Europe has declined dramatically. Over that same period, Asia's emissions have more than doubled their share. Therefore, any reductions in carbon dioxide emissions that are achieved by the U.S. or Europe are having a smaller effect over time.

to reach its emissions-reducing targets: producing 35 percent of its electricity from renewables by 2020 and 80 percent by 2050.[27]

In addition to the high costs, the rush to adopt more renewables has distorted the country's electricity markets so much that Germany now pays natural gas–fired generators to keep their units available when they are needed to keep the electric grid from going dark. Furthermore, rather than cut Germany's need for hydrocarbons, the *Energiewende* (or "energy revolution," as the program is called) has caused coal consumption in Germany to surge. The reason, as we have described above, is that buying emissions permits on the ETS is far less expensive than burning natural gas.

In 2012, Germany consumed about 1.6 million barrels of oil equivalent per day in the form of coal. That's the highest level since 2008.[28] In 2013, coal provided fully half of Germany's electricity, an increase of about 5 percent over 2012. Going forward, Germany's coal needs are likely to continue rising. About 7,300 megawatts of new coal plants are scheduled to come online by 2015.[29]

Nuclear energy might have provided a long-term alternative to coal. (In 2012, nuclear reactors provided about 100 terawatt-hours of electricity to Germany's electric grid, thus accounting for about 16 percent of the country's power. For comparison: in 2012, wind energy provided about 28 terawatt-hours, and solar provided about 46 terawatt-hours).[30] But in the wake of the Fukushima disaster in 2011, Germany shut down eight of its nuclear reactors.[31] And the German government has committed to retiring all its remaining nuclear reactors by 2022.[32] That move will also help drive the nation back to coal.

The combined rush to adopt renewables and quit nuclear power has had devastating effects on Germany's utility companies. Since 2008, E.On, the country's biggest utility, has seen its market capitalization fall by about two-thirds.[33] RWE, Germany's second-largest utility, has had similar stumbles, with its stock price down by more than half since 2010.[34] One RWE official recently told *The Economist* magazine that "conventional power generation, quite frankly, as a business unit, is fighting for its economic survival."[35]

Of course, Europe's ailing economy, which has reduced demand for power, has also contributed to the problems facing Germany's electricity providers. Nevertheless, the price of electricity has fallen much further than it would have in an unencumbered market. The cause is the subsidies given to solar and wind generators. Between mid-2011 and late 2013, wholesale electricity prices fell from more than 60 euros per megawatt-hour to less than 40 euros. Those price reductions have made many conventional power plants uneconomic. The result: utilities across Europe are shutting gas-fired power plants. By one estimate, some 30,000 megawatts of gas-fired generation capacity have been shuttered since 2008.[36] Yet the traditional generators are still needed for periods when the sun isn't shining and the wind isn't blowing. In fact, the more dependent a region or nation is on renewables, the more it needs a backup supply of absolutely reliable power that won't be affected by shifts in the weather. Without such backup power, a grid that depends on renewables is certain to suffer brownouts and/or blackouts.

Accordingly, Germany has been forced to pay electricity generators to keep open gas-fired power plants that were rendered unprofitable because of the subsidies being paid to the renewable-energy providers. Those subsidies led to a surge of electricity production from wind and solar that helped drive down the price of power in the wholesale market. In early 2013, for example, E.On threatened to shut down a new gas-fired power plant, the Irsching-5, in Bavaria. The plant, which had cost $500 million to build and could generate 846 megawatts at top capacity, was operating only 25 percent of the time. Under Germany's energy policies, E.On's CEO in March 2013 declared that it was "not possible to operate gas-fired power plants however clean, efficient and good for the climate and the country they may be."[37]

After weeks of negotiations, E.On announced that it had struck a deal with German regulators and a regional grid operator, in which the operator agreed to pay the company tens of millions of euros per year in "capacity payments"—or, to put it more simply, subsidies—to keep open both the Irsching-5 plant and a second facility, the Irsching-4.[38]

Consequently, Germany's electricity consumers are now paying high energy bills to subsidize *both* renewable and conventional electricity generation.

The Backlash Against Expensive Regulations

The expensive governmental interventions in the EU's energy markets have provoked a backlash from industry. In September 2013, the Federation of German Industries (BDI), an influential trade association, declared that the costs of *Energiewende* had become an enormous burden and that "the international competitiveness of German industry is in danger."[39] And the BDI's director-general, Markus Kerber, warned that companies in Germany "are already starting to lower investments" in the country.[40] At about the same time, the German Chemical Industry Association said that "spiralling energy costs will soon drive us into the wall. It has become dangerous."[41]

In late 2013,giant German industrial company BASF estimated that it could save nearly $700 million per year in energy costs if it were to relocate all its plants to the U.S. That clearly will not be happening but is indicative of the energy-cost advantage that the U.S. now enjoys. And that advantage does have practical consequences. BASF, the world's biggest chemical maker by sales, has doubled the amount of capital that it invests in the U.S. In 2010, the company was investing about $500 million per year in the U.S. By 2013, that figure had jumped to $1 billion per year, and BASF expects to continue its annual investments at that level through 2017.[42]

The soaring cost of energy is also hurting individual Germans. In September 2013, *Der Spiegel*, one of Germany's most respected publications, reported that some 300,000 German residences were having their electricity cut off because of unpaid bills. Soaring energy costs are creating a situation where increasing numbers of Germans are living in "energy poverty"—a state of deprivation due to low consumption of energy. It is striking that the term, which is usually used in discussions of poor people in developing nations, should be useful in describing Germany, one of the world's richest countries.

Countries throughout the European Union have begun scaling back their subsidies and mandates for renewable energy because of soaring costs and dubious environmental gains. The big news came on January 22, 2014, when the European Commission scrapped plans to mandate that a predetermined percentage of electricity come from renewables by 2030 in member nations. Instead, it set an EU-wide goal for renewables of "at least 27 percent." That's an increase over the 20 percent goal that EU members are supposed to achieve by 2020, but far short of what renewable-energy lobbyists wanted. One wind lobbyist called the new goal "very weak" and a "non-target."[43]

Meanwhile, throughout the European Union, countries have been slashing renewable-energy subsidies. In 2012, both France and Germany cut subsidies for solar energy.[44] And Germany has said that it will end its solar subsidies completely next year.[45] In 2013, Spain—where the government has piled up some $35 billion in debt (known as the tariff deficit) by subsidizing renewable energy—announced that it, too, was cutting payments for renewables.[46] In late 2013, the U.K. and Romania announced that they also would cut subsidies for renewables. The U.K. is reducing subsidies for onshore wind and solar.[47] Romania is cutting subsidies for wind, solar, and small hydropower projects.[48]

Price Comparison

As European consumers and industrial users struggle with mounting energy costs, matters look very different across the Atlantic. Electricity and natural gas prices in the United States are significantly lower than they are in Europe, giving the U.S. a competitive advantage. Industrial rates for electricity in the U.S. are less than half those in Germany and about 38 percent lower than industrial rates in the Netherlands. In December, the Center for European Policy Studies, a Brussels-based think tank, found that European steelmakers pay twice as much for electricity and four times as much for natural gas as steel producers operating in the U.S.[50] American consumers are also benefiting directly from the U.S. energy market by paying far less for electricity than Europeans are, as we have described above. In 2012, the average German residential electricity customer was paying nearly

Germany's Share of Global CO_2

In 2012, Germany emitted 815 million tons of carbon dioxide, or about 2.4 percent of global emissions of that gas. While it's true that Germany has had success at cutting its emissions, which fell by 7.7 percent between 2005 and 2012, it's also apparent that Germany's actions alone will not have a major effect on global emissions. Meanwhile, the U.S.—without imposing nationwide renewable mandates or cap-and-trade policies—has had better success at cutting its carbon dioxide emissions than Germany has. Between 2005 and 2012, U.S. carbon dioxide emissions fell by 708 million tons—a reduction nearly as large as the emissions of the entire German economy.[49]

Figure 2. Residential Cost of Electricity in US Versus Other Developed Countries in 2012

Country	Cost per kilowatt-hour (in US dollars)
EU	$0.26
Denmark	0.41
France	0.19
Germany	0.35
Ireland	0.26
Italy	0.28
Japan	0.26
Netherlands	0.24
Spain	0.29
Sweden	0.25
Switzerland	0.22
U.K.	0.20
U.S.	0.12

Source: Eurostat and International Energy Agency (IEA)

Figure 3. Cost of Natural Gas and Electricity for Industrial Users in European Countries and the U.S., 2012 (in U.S. Dollars)

Country	Natural Gas	Electricity
Belgium	$35.99	$126.61
Czech Republic	48.82	144.87
Denmark	N/A	104.15
Finland	45.75	103.89
France	51.14	116.33
Germany	51.04	148.71
Greece	66.76	133.74
Hungary	47.85	131.57
Ireland	45.58	155.2
Italy	N/A	291.79
Luxembourg	50.53	111.7
Netherlands	38.62	109.51
Poland	43.96	114.59
Portugal	52.70	147.3
Slovak Republic	52.53	169.74
Slovenia	64.38	117.77
Spain	43.97	N/A
Sweden	63.32	89.19
Switzerland*	71.71	130.24
Turkey*	41.15	148.22
U.K.	38.45	134.17
U.S.	12.74	66.98

Source: IEA, Key World Energy Statistics 2013, 43

*Not a member of the European Union

Note: Natural gas prices are calculated on the gross calorific value of 1 megawatt-hour of electricity generated from natural gas. Electricity prices are for 1 megawatt-hour.

N/A: Data not available from IEA

three times as much as his U.S. counterpart. The average Dane was paying about 3.4 times as much.

The price differences for electricity are paralleled by a similar gap in natural gas prices. The U.S. now has a price advantage for natural gas that is second to no other country on the planet, with the possible exception of Qatar. Since 2009, U.S. natural gas prices have averaged about $4 or less per million BTU.[51] In the EU, that same amount of gas will cost three to four times as much. In Japan, it will cost about five times as much.[52] That kind of price differential has important consequences for industry. Between 2010 and 2012, for example, the cost of gas for steel production in the EU jumped by 34 percent.[53] (Over that same time period, the spot price of natural gas in the U.S. fell by 37 percent.)

2. BEHIND THE U.S. PRICE ADVANTAGE

Like Europe, the U.S. has seen a push for the use of renewables in electricity generation. Over the past decade or so, a majority of U.S. states have implemented renewable portfolio standards or renewable-energy goals.[54] The result of those mandates, along with significant subsidies at the state and federal levels, has been rapid growth in the production of non-hydro renewable energy. Between 2005 and 2012, the production of energy from wind, biomass, and solar grew by about 72 percent. In 2012, those non-hydro renewables provided 2.3 percent of domestic energy use, or about 1 million barrels of oil equivalent per day.[55]

However, U.S. policies have been neither so extreme nor so centralized as those of Europe. Moreover, governments in the U.S. have supported—or, at least, not suppressed—a remarkable boom in the supply of natural gas, brought about by new technologies for its extraction. (A notable exception is the state of New York, which continues to have a ban on hydraulic fracturing.)

Over the past half-decade or so, domestic drillers have perfected the use of horizontal drilling and hydraulic fracturing, and in doing so have dramatically increased their ability to produce oil and natural gas from shale formations. The result has been dramatic increases in oil and natural gas production, which has lowered the price of natural gas and thus helped keep electricity prices far lower than they are in Europe.

In 2013, U.S. oil production rose by about 1 million barrels per day, the biggest year-on-year increase since record keeping began back in 1859.[56] Production gains are so dramatic that the U.S. could soon surpass both Russia and Saudi Arabia in daily production. (To put that increase in perspective, consider that in 2013, *just the increase* in U.S. oil production equaled the combined energy output of all the solar panels, wind turbines, and biomass-to-energy plants in the country.)

Meanwhile, in the realm of natural gas, the U.S. has already surpassed Russia as the world's biggest producer. In 2013, U.S. natural gas production averaged 70 billion cubic feet per day, a record high for domestic production and a 41 percent increase over 2005 levels.[57]

That surge has helped lower natural gas prices and spur dramatic increases in consumption. For instance, between 2005 and 2012, natural gas consumption jumped by 1.7 million barrels of oil equivalent per day. In contrast, over that same period, non-hydro renewable production increased by 604,000 barrels of oil equivalent. Thus, over that seven-year period, *just the increase* in natural gas consumption in the U.S. was nearly triple the increase in energy production that was seen in solar, wind, and biomass production.

Even as it has increased its oil and gas production, the U.S. also has seen a significant *decrease* in its carbon dioxide emissions. Between 2005 (when the EU implemented its Emissions Trading Scheme) and 2012, U.S. emissions of carbon dioxide fell by 10.9 percent.[58] The U.S. has not imposed national renewable-energy mandates, an emissions trading system, or a carbon tax; yet it has seen a bigger percentage decline in its carbon dioxide emissions than the EU has.

As Europe spends tens of billions of dollars on renewable-energy mandates and subsidies, the U.S. is reaping hundreds of billions of dollars worth of economic stimulus from lower-cost natural gas and oil. A September 2013 study by consulting firm IHS estimated that development of "unconventional" oil and gas (a term that applies to shale and other so-called tight geological formations) is adding nearly $300 billion, or a full 2 percent, to America's annual GDP. IHS also estimated that more than 2.1 million jobs in the U.S. are now supported by unconventional oil and gas activity. That number could rise as high as 3.9 million jobs by 2025.[59]

A few weeks after the IHS study came out, Wallace Tyner, an energy economist at Purdue University, along with two of his Purdue colleagues, estimated that the positive economic impact of the shale revolution on the U.S. economy was even higher—some $473 billion per year, or about 3 percent of GDP and that those benefits would likely continue until 2035.[60]

Those price advantages enhance other competitive advantages that the U.S. has in sectors ranging from transportation and manufacturing to industrial processing and fertilizer production. It is no surprise, then, that low-cost natural gas is attracting foreign investors that are building new industrial facilities to use the resource. Last year, for example, an Egyptian company, Orascom, began construction on a new $1.8 billion fertilizer plant in Iowa,[61] and Vallourec, a French company, opened a new $1.1 billion steel mill in the Rust Belt town of Youngstown, Ohio.[62]

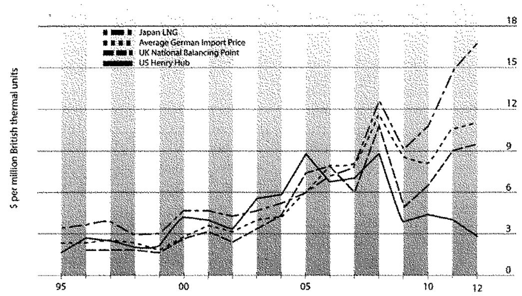
Foreign companies are also investing directly in the U.S. oil and gas sector. Between 2008 and 2012 alone, foreign companies invested more than $26 billion in the U.S. drilling sector.[63]

3. THE RISKS OF EMULATING THE EU'S ENERGY POLICIES

As we have seen, the European Union's mandates for the use of renewables have resulted in higher prices (directly paid for electricity as well as indirectly paid via subsidies extended to renewable and conventional power suppliers). And the EU's cap-and-trade regime has distorted markets, discouraging the use of both nuclear and natural gas power plants and thus helping to spur increased use of coal, which emits far more carbon dioxide for the electricity that it yields.

Despite this record, some policymakers in the U.S. are pushing for this country to adopt the policies that have failed the EU. In 2012, in his State of the Union address, President Obama called for a national clean energy standard that would mandate the use of renewable energy.[64] In December 2013, the president signed a memorandum directing all branches of the federal government to get at least 20 percent of their electricity from renewable sources by 2020. If achieved, this would more than double renewable use by the federal government. In a December 5 press release, the White House claimed that the move would "reduce pollution in our communities, promote American

Figure 4. Natural Gas Prices in the U.S., Germany, U.K., and Japan, 1990–2012 (in U.S. Dollars)



Source: BP Statistical Review of World Energy 2013

Over the past decade or so, while natural gas prices in other major developed countries have been increasing, those same prices in the U.S. have been flat or falling. That low-cost gas is attracting industry and creating jobs.

energy independence, and support homegrown energy."[65] The mandate on renewable electricity use for federal agencies is important because the federal government consumes roughly 57 terawatt-hours of electricity per year.[66] That is approximately 1.5 percent of all the electricity sold in the U.S.[67]

Meanwhile, in the U.S. Senate, Jeff Bingaman (D-NM) introduced a bill in 2012 for a national "clean energy" standard that would have mandated big increases in the use of renewable energy. His bill had eight cosponsors, one of whom was John Kerry, now the U.S. secretary of state.[68]

At the state level, some legislators have already enacted European-style programs for renewable-energy use. Indeed, as we have described in an earlier paper, an ample majority of U.S. states now have renewable-sources mandates in place.[69]

How might EU policies affect U.S. electricity prices? We can estimate that impact by comparing the amount of electricity generated by solar and wind—which provided about 3 percent of the electricity generated in the U.S. in 2012—with the higher costs that would come with ramping up the output of those sources to meet a 27 percent mandate[70] (the level specified in the European Commission's January 22, 2014, press release).

To simplify the calculations, let's assume that there will be no increase in electricity consumption in the U.S. over the coming years. Further, let's assume that half of the mandated increase in renewable electricity production will come from solar and the other half will come from wind and that the costs of those energy sources will remain flat. The 50-50 allocation for solar and wind is reasonable, given the ongoing rural and suburban backlash against large wind projects and the rapid growth in solar. (In 2012 alone, solar capacity in the U.S. grew by 84 percent.) Furthermore, Germany is now producing nearly twice as much electricity from solar as it is from wind.

Now, let's look at the difference in the cost of electricity generated from natural gas with that from wind and solar. According to the Energy Information Administration, for electricity generation plants entering service in 2018, producing a megawatt-hour of electricity from natural gas will cost $65.60. Generating that same amount of energy from onshore wind will cost $86.60. Therefore, producing a megawatt-hour of electricity from wind will cost an additional $21, or 32 percent, more than producing it from natural gas. Producing a megawatt-hour of electricity from solar photovoltaic modules will cost $144.30. That's an additional $78.70, or 120 percent, more per megawatt-hour.[71] (These calculations are purposely ignoring the even-higher-cost renewable sources of offshore wind, which is expected to cost $221.50 per megawatt-hour, and solar thermal, which is expected to cost $261.50 per megawatt-hour.)

In 2012, domestic electricity sales totaled 3,694 terawatt-hours.[72] Of that sum, we generated about 121 terawatt-hours from wind and 4 terawatt-hours from solar.[73] A 27 percent national goal would mean that 997 terawatt-hours of domestic electricity would have to be generated from wind and solar. If we subtract the existing solar and wind production (125 terawatt-hours) from the mandated sum of 997 terawatt-hours, the U.S. would need to generate an additional 872 terawatt-hours of renewable electricity. And as specified, half of that amount, or 436 terawatt-hours, would have to come from solar, and the remaining 436 terawatt-hours would have to come from wind.

By calculating the price differential between natural gas–fired electricity and those for wind and solar, it is apparent that the additional cost of meeting the 27 percent renewable-energy mandate would be roughly $43.4 billion per year.[74] While those additional electricity costs will be spread across the residential, commercial, and industrial sectors, the added cost of the renewable mandates will ultimately be borne by individual consumers and households.

There are now about 115 million households in the U.S.[75] Thus, the additional cost per household of a national 27 percent renewable-energy mandate would be about $377 per year, or $31.41 per month. In 2012, the average monthly electricity bill for residential customers in the U.S. was $107.28.[76] Therefore, the net effect of adopting a renewable-energy goal like that adopted by the EU will be increased electric costs across the entire economy that will, in effect, increase the monthly electricity bill of an average household by about 29 percent.

It is important to note, though, that we need not confine ourselves to speculation about the impact of EU policies in the United States. We have a real-world test case, whose history confirms that mandates and market interventions raise electricity costs while failing to achieve globally significant reductions in carbon emissions.

California: EU Policies in an American State

California, often considered a bellwether of national trends, has adopted a panoply of EU-model low-carbon policies: California legislators have passed mandates on everything from renewable electricity to lower-carbon motor fuel. And the state now has its own cap-and-trade system.

As a result, the Golden State has some of the most expensive electricity in the country. The cap-and-trade regime alone will cause rate increases of up to 8 percent, according to the California Public Utilities Commission.[77] The mandates and other interventions will almost certainly make the state's electricity even more expensive. In 2012, the average price of a kilowatt-hour of electricity in California was 13.53 cents.[78] The nationwide average price was 9.87 cents.[79] California also has some of the most expensive industrial and commercial rates in the continental United States. In 2012, industrial electric rates in California were 10.49 cents per kilowatt-hour. Only five other states in the continental U.S.—all of them on the East Coast—had higher industrial rates.[80]

But those figures actually understate some of the energy premiums being paid by California residents. In November 2013, according to the Bureau of Labor Statistics, residential electricity users in the region around Los Angeles were paying an average of 21.5 cents per kilowatt-hour—66 percent higher than average for U.S. residential users that month.

Southern California residents were also paying significantly more for gasoline and natural gas than consumers in other states.[81]

Furthermore, according to the latest data from the Jacksonville Electric Authority, which does quarterly surveys of residential electric rates, California now has the dubious distinction of having three of the six most expensive utilities in the United States. The October 1, 2013, data show that a residential customer who relies on Southern California Edison (which charges more than any other utility in the country) will pay $316.06 per month to consume 1,250 kilowatt-hours of electricity. By comparison, a residential customer in San Antonio, Texas, who uses that same quantity of energy will pay $120.86.[82]

A. The Renewable Mandate

By law, California's utilities are required to get one-third of their electricity from renewable sources by 2020.[84] Implementing that mandate will be costly. In 2009, the California Public Utilities Commission (CPUC) said that the 33 percent goal was "highly ambitious, given the magnitude of the infrastructure build-out required."[85] The CPUC estimated the cost of that infrastructure "at approximately $115 billion between now and 2020."[86] That $115 billion amounts to some $3,100 for every Californian.[87]

Infrastructure needs are part of the reason a 2013 study by Navigant Consulting found that the renewable-energy mandates "will likely lead to increased prices and rates as utilities attempt to incrementally phase renewable energy into their portfolios."[88] The study, which was done for a coalition of business groups called Californians for Affordable and Reliable Electricity, pointed out that renewable-energy resources typically cost more (on a per-unit-of-energy basis) than conventional, fossil-based resources and generally require new transmission capacity.[89] Those facts, combined with the fact that California's biggest utilities will have to add large volumes of new renewable resources by 2020, mean that, according to Navigant, many costs associated with the renewable mandates "have not yet begun to be reflected in rates. Higher cost resources going forward are ... being added to their portfolios at a higher rate than before."

More evidence of renewable-energy policies' surging costs can be seen in documents filed by one of the state's biggest utilities, Pacific Gas & Electric, in 2013. The utility said that the cost impact of its renewable-energy contracts have "not yet been captured on customer bills. PG&E forecasts that its energy procurement costs will increase in 2014. The cost of generation from renewable sources is a contributing factor to PG&E's procurement cost increase, which is expected to increase the system average bundled rate by 7.9 percent in 2014."[90]

In exchange for these extra present-day and future costs, California policy counts on lower carbon emissions. But on this point, too, the Golden State's experience is like the EU's: in 2012, the state's carbon dioxide emissions *rose* by nearly 11 percent over 2011

Figure 5. Residential Electric Rate Comparison: Three of the Six U.S. Utilities with the Most Expensive Electricity Are in California

Location	Entity	Total cost of 1,250 kilowatt-hours
Southern California	Southern California Edison	$316.06
Fairbanks, AK	Golden Valley Electric Association	271.25
Newark, NJ	Public Service Electric & Gas Co.	206.05
Los Angeles, CA	Department of Water & Power	199.73
Milwaukee, WI	We-Energies	184.85
Sacramento, CA	Sacramento Municipal Utility District	180.66

Source: Jacksonville Electric Authority, "Quarterly Electric Rate Comparison"; data current as of October 1, 2013[83]
Note: Costs shown include base rates, fuel adjustment charges, and applicable franchise fees.

levels. The rise was largely attributed to the shutdown of the San Onofre nuclear plant and the subsequent need to burn more natural gas to replace electricity that had come from the reactor.[91]

B. The Storage Mandate

In addition to the cost of renewables and cap-and-trade, the state must also cope with another set of costs imposed by its commitment to renewables. As we have mentioned, gas-fired plants have been required to back up renewables during times when the sun doesn't shine and the wind doesn't blow, so using renewables has been associated with higher carbon emissions. In an attempt to address this problem, the CPUC is requiring the state's large utilities to invest in technologies for storing electricity. Unfortunately, aside from a small handful of pumped-hydro systems, there are no proven large-scale electricity storage technologies currently available. (And pumped-hydro systems are expensive and require the right geography and abundant water resources). Nonetheless, the commission's mandate requires companies to install enough storage by 2024 to power about 1 million homes. In response to the commission's proposal, Southern California Edison has said that the move "could cost up to $3 billion with uncertain net benefits for customers."[92]

C. The Solar Subsidy

California is rapidly adding rooftop-solar installations. Those systems will also add costs. In August, the CPUC released a report on a policy known as "net metering," which allows homeowners, school districts, and businesses to offset the cost of their electricity consumption with the power that they produce from their rooftop solar installations. By 2020, according to the report, the net-metering policy will cost California's *non*-solar customers about $1.1 billion per year.[93]

In short, California, like the EU, has adopted policies that are drastically increasing the cost of energy in the name of climate change. But those policies will, even in the best-case scenario, have only an infinitesimal effect on carbon dioxide emissions and therefore, on global climate.

4. MAINTAINING THE U.S. AADANTAGE

For decades, the U.S. economy has prospered thanks to cheap, abundant, reliable supplies of energy. Domestic policymakers should focus on ensuring that this remains the case. Therefore, they should not follow the EU's lead.

Instead, they should eliminate renewable-energy subsidies and remove excessive restrictions on coal-fired electricity generation plants. If policymakers want to continue reducing carbon dioxide emissions, they should encourage "N2N" (natural gas to nuclear) policies and not impose unnecessary regulations on the process of hydraulic fracturing, which is essential to the production of natural gas from shale. Finally, to ensure the continued growth of the U.S. energy sector, the industry and the government must maintain and even improve its high safety standards.

Eliminate Renewable-Energy Subsidies

For years, the production tax credit, the primary subsidy for wind-energy projects, has paid wind-energy generators for each kilowatt-hour of electricity they produce. That subsidy has been the primary

California's Share of Global CO_2

In 2010, California's carbon dioxide emissions totaled 370 million tons.[94] At that level, the Golden State produces about 1 percent of global carbon dioxide emissions.[95] To put those figures into perspective, consider that since 1982, global carbon dioxide emissions have been increasing by an average of about 500 million tons per year.[96] The vast majority of those emissions increases are coming from Asia, which has been increasing its emissions by an average of about 390 million tons per year since 1982. Therefore, even if California could somehow reduce its carbon emissions to zero, that reduction would not even cover one year of the annual increases in carbon dioxide emissions that are now occurring in Asia.

driver of the expansion of wind energy in the United States. It has also been the culprit in the distortion of U.S. electricity markets, as it has led to a situation known as "negative pricing."

In some markets, in order to collect the subsidy, wind generators have actually been paying grid operators to take the electricity they are generating so that they can collect the tax credit, which, in 2013, was 2.3 cents per kilowatt-hour. In some cases, the owners of wind-energy projects *have been able to pay grid operators as much as $34 per megawatt-hour to take their electricity*—and still make money.[97] When grid operators receive these payments, wholesale electricity prices in some markets have dropped dramatically. As has happened in Europe, those price reductions have been particularly problematic for the companies that own nuclear reactors, which have relatively high fixed costs.

In a 2012 study of the production tax credit, David Dismukes, associate director of the Center for Energy Studies at Louisiana State University, summarized the problem with the subsidy: it facilitates "market distortions in wholesale electricity markets, harming reliability by causing essential conventional generation, such as natural gas, to operate at times at a loss, or simply not operate at all."[98] In addition, the study—which Dismukes wrote for the American Energy Alliance, a conservative advocacy group—concluded that wind generation "has already led to billions in hidden costs for electricity consumers to cover the costs of interconnecting these intermittent, remotely-located resources, and providing backup generation when federally-subsidized wind resources fail to perform."[99]

On December 31, 2013, the production tax credit expired. But that doesn't mean that the subsidies have stopped. Existing wind projects that began generating electricity while the subsidy was in effect will continue collecting the lucrative tax credit. (The subsidy usually lasts for the first ten years of a given project's operation.)[100] And as those subsidies continue to be doled out, the wind industry's preferred status will continue distorting the wholesale power market.

Lobby groups like the American Wind Energy Association have been trying to get the tax credit extended.[101] In 2012, after a lengthy battle, the wind-energy subsidy was extended for one year, at a cost to taxpayers of $12 billion.[102] In late 2013, the congressional Joint Tax Committee estimated that another one-year extension would cost taxpayers an additional $6.1 billion.[103] Policymakers should not renew the production tax credit. Wind energy is now a mature industry that doesn't need more taxpayer handouts.

Remove Excessive Restrictions on Coal-Fired Generators

Although natural gas clearly has a number of advantages over coal, natural gas prices have historically been volatile. Therefore, there is a risk to the nation in relying too much on natural gas. Moreover, coal is the largest source of electricity for about half of all the states in the U.S.[104] In 2013, coal provided more electricity than any other source, with about 39 percent of the domestic market.[105] So the U.S. cannot and should not quit using coal to generate electricity.

The U.S. has about 237 billion tons of coal reserves—about 28 percent of the world's known deposits. That is more than 250 years of supply at current rates of production.[106] To say that the U.S. is the Saudi Arabia of coal is a serious understatement; the U.S. is the OPEC of coal. America's coal resources contain 900 billion barrels of oil equivalent.[107] This is nearly as much as the 1.2 trillion barrels of proven oil reserves held by OPEC.[108]

Despite America's abundance of coal, the U.S. Environmental Protection Agency (EPA) in 2013 declared that it would prohibit the construction of new coal-fired power plants unless they could reduce their carbon dioxide emissions through the use of carbon capture and sequestration, a technology that has never been proved at commercial scale. Furthermore, the Obama administration is moving forward with new regulations including the Mercury and Air Toxics Standards rule and the Cross-State Air Pollution Rule, which could force about 8 percent of all existing coal-fired power plants to close.[109]

Effectively outlawing the use of coal for power generation in the U.S. would be a serious mistake, particularly given that countries in Asia and Europe continue to build new coal-fired power plants. In fact, global coal demand is growing faster than that for any other fuel. Between 2002 and 2012—a period during which U.S. coal consumption fell by about 21 percent—global coal consumption soared, growing by 26.5 million barrels of oil equivalent per day. The growth in coal demand nearly matches the global growth in consumption of oil, natural gas, nuclear, and wind energy *combined* over that time period.[110] And the International Energy Agency expects coal demand to continue rising. In December 2013, the agency issued a report concluding that "coal demand knows only one direction: up." By 2018, the agency projects that global demand will increase to some 92 million barrels of oil equivalent per day.[111] If that occurs, global coal use could exceed global oil demand.

There is no need to eliminate coal to achieve lower carbon emissions and reduced pollution. The newest coal-fired power plants being built in the U.S. are far cleaner and more efficient than their older counterparts. Consider, for example, the 1,600-megawatt Prairie State Energy Campus, located in southern Illinois, which began operating in 2012. The plant, which cost about $5 billion, uses supercritical combustion technology to wring more electricity from the coal, and it produces about 0.182 pounds of sulfur dioxide and 0.07 pounds of nitrogen oxide per megawatt-hour.[112] At that level, the facility will easily comply with the EPA's Cross-State Air Pollution Rule, which limits power-plant emissions to 0.30 pounds of sulfur dioxide and 0.17 pounds of nitrogen oxide per megawatt-hour.[113]

Four decades ago, Congress made a serious mistake when it passed the Power Plant and Industrial Fuel Use Act, which effectively prohibited the building of new natural gas-fired power plants.[114] Government should not repeat this error by banning any energy source—especially not a source that the U.S. has in superabundance, on which it has relied for more than a century. The U.S. needs coal-fired generation to maintain a diverse energy portfolio. To forgo the use of coal when global consumption of that fuel is growing so quickly would forgo a valuable resource at home while failing to have a significant impact on global carbon emissions (primarily because of rising coal use in Asia, Europe, and elsewhere).

N2N

Natural gas and nuclear energy have been key contributors to the growth of the U.S. economy. They have also been essential elements in the reduction of America's carbon dioxide emissions. In September 2013, Max Luke, a policy analyst at the Breakthrough Institute, estimated that the combination of natural gas and nuclear energy has reduced America's carbon dioxide emissions by about 54 billion tons over the last six decades. For comparison, Luke found that the wind, solar, and geothermal reduced emissions by just 1.5 billion tons over that same period.[115]

N2N—natural gas to nuclear—provides the best "no regrets" energy policy because natural gas and nuclear provide significant environmental benefits with relatively low economic costs. Natural gas and nuclear are lower-carbon than oil or coal. They emit almost zero air pollution. Better yet, both sources have high power densities, meaning that they generate large amounts of energy from relatively small footprints. And they can be scaled up to meet future demand.

While natural gas consumption in the U.S. is rising rapidly (up by nearly 16 percent between 2005 and 2012), the U.S. nuclear sector is struggling. Several factors, including the age of the reactor fleet, are contributing to the nuclear sector's difficulties. But as we have described, one of the biggest problems for the owners of domestic nuclear reactors is excessive subsidies provided to wind-energy generators. Those subsidies, by driving down the cost of wholesale electricity, severely cut revenue for the owners of reactors.

Since 2005, nuclear production in the U.S. has declined slightly. That decline is likely to continue over the next few years, as a number of reactors have recently been permanently shut down, including ones at San Onofre in California, Kewaunee in Wisconsin, and Crystal River 3 in Florida. At the end of this year, another reactor, Vermont Yankee, will also be retired. Five new reactors are now under construction (in Georgia, South Carolina, and Tennessee), but four are unlikely to come online before 2018. And given ongoing reactor retirements, the new capacity coming online will likely serve only to keep U.S. nuclear energy production at, or near, current levels.

To maintain a diverse energy portfolio, the U.S. should not abandon nuclear technology, where it has long been a leader. (In fact, the U.S. has long been the world's biggest producer of electricity from nuclear. In 2012, the U.S. produced about 810 terawatt-hours of electricity from nuclear, nearly twice the amount produced by France.)[116] Policymakers should support ongoing research and development of small modular reactors as well as new, passively safe reactor designs. Furthermore, if the U.S. is going to adopt policies aimed at reducing carbon dioxide emissions, it must encourage the deployment of nuclear energy, which is the only zero-carbon source of reliable, 24/7 electricity.

Keep Primary Regulatory Oversight of Drilling and Hydraulic Fracturing at the State Level

Although the environmental and economic benefits of increased natural gas production and consumption are obvious, some "green" groups want to remove regulatory oversight of the drilling sector from the states and hand it to the EPA.[118] This would be a mistake. For decades, the states have done a good job of regulating the drilling sector. Moving that to the federal government could slow the growth of one of America's most important sectors.

Some groups are pushing an even more radical agenda: they want to ban hydraulic fracturing, the technology that drives much of the natural gas boom. Over the last few decades, hydraulic fracturing—a process that uses high-pressure pumps to inject water, sand, and small quantities of chemicals into oil-and-gas-rich rock in order to liberate those hydrocarbons and bring them to the surface—has been used safely on more than 1 million wells in the U.S.[119]

The U.S. Carbon Dioxide Advantage

In May 2012, the International Energy Agency reported that U.S. carbon dioxide emissions had fallen by 92 million tons, or 1.7 percent, since 2011, "primarily due to ongoing switching from coal to natural gas in power generation." The Paris-based agency continued: "U.S. emissions have now fallen by 430 million tons (7.7 percent) since 2006, the largest reduction of all countries or regions." The IEA credited the reduction to "a substantial shift from coal to gas in the power sector."117 In other words, market forces in the U.S. (the flood of natural gas into the marketplace that was made possible by innovation in the oil and gas sector) have done more to cut carbon dioxide emissions in America than all the government-mandated programs in Europe.

Despite that long safety record, activists in New York have persuaded that state's regulators to impose a moratorium on hydraulic fracturing. France, too, has banned hydraulic fracturing.[120] Greenpeace has launched an effort to ban the process in Britain.[121] An American environmental group, Food & Water Watch, says that it wants to implement a ban on the process in the U.S.[122] Furthermore, MoveOn.org, a liberal activist group, has launched petition efforts to ban hydraulic fracturing on all public lands. By late January, that petition had about 61,000 signatures.[123] MoveOn.org has also launched efforts to ban the process in California, Massachusetts, Florida, Illinois, Ohio, Colorado, and elsewhere.[124]

The hard reality is that the U.S. must continue drilling for oil and gas—and it must continue using hydraulic fracturing—if it wants to keep energy cheap, abundant, and reliable. Any attempt to remove regulatory oversight from the states and give it to federal agencies would impose unnecessary costs. Policymakers should resist such proposals, and they should turn away efforts to ban hydraulic fracturing. The shale revolution was made possible by hydraulic fracturing. If it is banned, the U.S. could soon see natural gas prices that are as high, or higher, than what is now seen in Europe.

Remain Vigilant on Safety

If the U.S. is to maintain its energy advantage over the rest of the world, American citizens must be assured that the energy sector is operating safely. Unfortunately, over the past year or so, a number of high-profile accidents involving pipelines and trains have occurred. In March 2013, a pipeline carrying heavy crude burst, spilling about 5,000 barrels of oil near the town of Mayflower, Arkansas. In July, a train carrying crude oil from North Dakota derailed in Lac-Mégantic, Quebec; the ensuing fire destroyed much of the town and killed more than 40 people. In December, another accident and fire involved a train carrying crude oil;[125]¢The accident, which occurred near Casselton, North Dakota, did not result in any deaths but required the temporary evacuation of some 2,000 local residents.[126] Major accidents in the oil and gas sector are rare. But like accidents in the airline industry—which are also very rare—they receive tremendous amounts of media attention.

One way to reduce high-profile accidents on rail lines, of course, is to speed the permitting process for new pipelines, which are a far safer method of transportation. And while the spotlight is now clearly on the transportation of energy, the industry also needs to be vigilant about safety—and continue to improve its safety protocols—in all its operations, from managing refineries and drilling rigs to proper training of its truck drivers.

CONCLUSION

To address the issues of carbon dioxide and climate change, the European Union in general and Germany in particular have rushed to impose mandates and subsidies for renewable energy upon the market. Those policies have resulted in dramatically higher energy costs. Meanwhile, thanks to ongoing innovation in the U.S. oil and gas sector and the profusion of natural gas that resulted from that innovation, the U.S. has reduced its carbon dioxide emissions more rapidly than the EU has, and it has done so at much lower cost. The lesson is clear: markets work, and they work best when governmental interventions are not excessive. U.S. policymakers must take a hard look at the experience of the EU and seek to avoid those same mistakes.

Endnotes

1 Pricing data from Europe's Energy Portal, a private provider of energy-price data. EU calculations based on prices January 2005–October 2013; prices not adjusted for inflation.

2 Eurostat press release, May 27, 2013, http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-27052013-AP/EN/8-27052013-AP-EN.PDF.

3 IEA data, Key World Energy Statistics 2012, http://www.iea.org/publications/freepublications/publication/kwes.pdf, 42-3.

4 Ibid. For more recent data, see EIA data, http://www.eia.gov/electricity/monthly/update/end_use.cfm. In March 2013, the average price of electricity was 9.7 cents, with residential electricity costing 11.6 cents, commercial costing 10 cents, and industrial costing 6.7 cents.

5 *BP Statistical Review of World Energy 2013*.

6 "EU Must Improve Its Aim on Energy," editorial, *Financial Times*, December 1, 2013, http://www.ft.com/intl/cms/s/0/f954b812-5903-11e3-a7cb-00144feabdc0.html?ftcamp=published_links/rss/home_us/feed//product&siteedition=uk#axzz2mKOxLHMY.

7 Netherlands Environmental Assessment Agency, "Trends in Global CO2 Emissions Report," 2013, http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2013-trends-in-global-co2-emissions-2013-report-1148.pdf, 16-17.

8 EurActiv, "Energy CEOs Call for End to Renewable Subsidies," October 11, 2013, http://www.euractiv.com/energy/energy-ceos-call-renewable-subsi-news-531024.

9 Reuters, "Timeline: Scandals in the E.U. Carbon Market," January 20, 2011, http://www.reuters.com/article/2011/01/20/us-carbon-scandals-idUSTRE70J4M120110120.

[10] Michael Szabo, "Heavy Industry to Challenge EU CO2 Permit Quotas," Reuters, December 11, 2013, http://in.reuters.com/article/2013/12/11/carbon-complaint-idINL6N0JQ2UU20131211.

[11] Brad Plumer, "Europe's Cap-and-Trade Program Is in Trouble: Can It Be Fixed?," *Washington Post*, April 20, 2013, http://www.washingtonpost.com/blogs/wonkblog/wp/2013/04/20/europes-cap-and-trade-program-is-in-trouble-can-it-be-fixed.

[12] Alessandro Vitelli and Mathew Carr, "EU Emission Slump Tests Brokers: Carbon & Climate," Bloomberg, December 19, 2013, http://www.bloomberg.com/news/2013-12-19/eu-emission-slump-tests-broker-survival-skills-carbon-climate.html.

[13] See http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html.

[14] *BP Statistical Review of World Energy 2013*.

[15] See http://www.eia.gov/todayinenergy/detail.cfm?id=13151.

[16] Eurostat data, http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Natural_gas_consumption_statistics.

[17] *BP Statistical Review of World Energy 2013*.

[18] Eurostat, op. cit. Note that these data are in million terajoules. I have converted the data to exajoules and assumed that 1 exajoule is roughly equal to 1 trillion cubic feet of natural gas.

[19] Vladimir Soldatkin, Olesya Astakhova, and Denis Pinchuk, "Russia's Gazprom May Gain Despite Cheaper Gas to Ukraine," Reuters, December 18, 2013, http://www.reuters.com/article/2013/12/18/russia-ukraine-gazprom-idUSL6N0JX1R720131218.

[20] Eurostat, op. cit.

[21] European Environmental Agency data, http://www.eea.europa.eu/publications/ghg-trends-and-projections-2012.

[22] *BP Statistical Review of World Energy 2013*.

[23] Chris Bryant, "Soaring Renewable Energy Costs Set to Stoke German Energy Debate," *Financial Times*, October 15, 2013.

[24] See http://energytransition.de/2012/09/timeline-energiewende.

[25] For price increase, see Harald Heubaum, "Can Sigmar Gabriel Reboot Germany's Low-Carbon Agenda?," RTCC.org, December 17, 2013, http://www.rtcc.org/2013/12/17/sigmar-gabriel-the-man-to-reboot-germanys-low-carbon-agenda. In October 2013, the average residential price of electricity in the U.S. was 12.3 cents. See http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

[26] *Der Spiegel*, "Germany's Energy Poverty: How Electricity Became a Luxury Good," September 4, 2013, http://www.spiegel.de/international/germany/high-costs-and-errors-of-german-transition-to-renewable-energy-a-920288.html.

[27] Reuters, "German 'Green Revolution' May Cost 1 Trillion Euros—Minister," February 20, 2013, http://www.reuters.com/article/2013/02/20/us-germany-energy-idUSBRE91J0AV20130220.

[28] EIA data, http://www.eia.gov/countries/country-data.cfm?fips=GM#coal.

[29] Platts, "German Coal Extends Dominance in Power Mix as Gas Wanes," October 9, 2013, http://www.platts.com/latest-news/coal/london/analysis-german-coal-extends-dominance-in-power-26352497.

[30] *BP Statistical Review of World Energy 2013*.

[31] See http://www.eia.gov/todayinenergy/detail.cfm?id=13151.

[32] See http://www.bbc.co.uk/news/world-europe-13592208.

[33] Reuters data, http://uk.reuters.com/business/quotes/chart?symbol=EONGn.DE.

[34] Bloomberg data, http://www.bloomberg.com/quote/RWE:GR/chart.

[35] *The Economist*, "How to Lose Half a Trillion Euros," October 16, 2013, http://www.economist.com/news/briefing/21587782-europes-electricity-providers-face-existential-threat-how-lose-half-trillion-euros.

[36] Ibid.

[37] Tino Andresen and Tara Patel, "Europe Gas Carnage Shown by EON Closing 3-Year-Old Plant," Bloomberg, March 12, 2013, http://www.bloomberg.com/news/2013-03-12/europe-gas-carnage-shown-by-eon-closing-3-year-old-plant-energy.html.

[38] Reuters, "E.ON Says Reaches Deal to Keep Irsching Plant Open," http://www.reuters.com/article/2013/04/26/eon-irsching-idUSL6N0DD1MB20130426.

[39] Ambrose Evans-Pritchard, "Germany Industry in Revolt as Green Dream Causes Cost Spiral," *The Telegraph*, September 19, 2013, http://www.telegraph.co.uk/finance/newsbysector/energy/10321173/Germany-industry-in-revolt-as-green-dream-causes-cost-spiral.html.
[40] Bryant, "Soaring Renewable Energy Costs Set to Stoke German Energy Debate."
[41] Evans-Pritchard, "Germany Industry in Revolt."
[42] William Boston, "BASF Seizes on U.S. Gas Boom," *Wall Street Journal*, December 18, 2013, http://online.wsj.com/news/articles/SB40001424052702303949504579263903951305372?cb=logged0.5145747985225171.
[43] See http://www.renewableenergyworld.com/rea/news/article/2014/01/renewable-energy-loses-out-in-europes-lame-duck-climate-plan?cmpid=WNL-Friday-January24-2014.
[44] For France, see http://www.pv-tech.org/news/france_retroactively_cuts_fit_by_20; for Germany, see http://www.businessweek.com/news/2012-03-29/germany-cuts-solar-aid-to-curb-prices-panel-installations.
[45] Sonia van Gilder Cooke, "Will Austerity Derail Europe's Clean-Energy Movement?," *Time*, February 10, 2012, http://content.time.com/time/world/article/0,8599,2106390,00.html.
[46] Andres Cala, "Renewable Energy in Spain Is Taking a Beating," *New York Times*, October 8, 2013, http://www.nytimes.com/2013/10/09/business/energy-environment/renewable-energy-in-spain-is-taking-a-beating.html?_r=0.
[47] See http://www.bbc.co.uk/news/uk-politics-25210963.
[48] See http://www.euractiv.com/energy/romania-slashes-renewable-energy-news-532416.
[49] *BP Statistical Review of World Energy 2013*.
[50] See http://www.energypost.eu/climate-policy-bumps-competitiveness-europe.
[51] EIA data, http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm. For current prices, see http://www.bloomberg.com/energy.
[52] See, e.g., *BP Statistical Review of World Energy*, June 2013, slide pack, http://www.bp.com/content/dam/bp/ppt/Statistical-Review-2013/statistical_review_of_world_energy_2013.pptx, 19.
[53] See http://www.ceps.eu/book/steel-industry-european-union-composition-and-drivers-energy-prices-and-costs, steel report, 40.
[54] EIA data, http://www.eia.gov/todayinenergy/detail.cfm?id=4850.
[55] *BP Statistical Review of World Energy 2013*.
[56] See http://fuelfix.com/blog/2013/12/26/2013-oil-boom-is-biggest-ever-data-shows.
[57] See http://online.wsj.com/article/DN-CO-20131113-010207.html; see also EIA data, http://www.eia.gov/forecasts/steo/report/natgas.cfm.
[58] *BP Statistical Review of World Energy 2013*.
[59] See http://www.naturalgasintel.com/articles/43296.
[60] See http://dialogue.usaee.org/index.php/assessment-of-the-economic-impacts-of-the-shale-oil-and-gas-boom. This estimate is based on U.S. GDP of $16 trillion.
[61] Debi Durham, "Iowa Defends Orascom Fertilizer Plant Incentives," *Quad City Times*, February 28, 2013, http://qctimes.com/news/opinion/editorial/columnists/iowa-defends-orascom-fertilizer-plant-incentives/article_f5ac78ba-815b-11e2-a9f1-001a4bcf887a.html. For the project's total value, see Ventures Africa, August 29, 2013, http://www.ventures-africa.com/2013/08/work-orascoms-iowa-fertiliser-plant-schedule.
[62] *The Business Journal*, "Vallourec Execs Hail 'Great Day' for Youngstown Mill," June 12, 2013, http://businessjournaldaily.com/company-news/vallourec-execs-hail-great-day-youngstown-mill-2013-6-12.
[63] EIA data, http://www.eia.gov/todayinenergy/detail.cfm?id=10711&src=email.
[64] See http://www.washingtonpost.com/blogs/wonkblog/post/obama-wants-a-clean-energy-standard-what-does-that-mean/2012/01/25/gIQAlUyFQQ_blog.html.
[65] See http://www.whitehouse.gov/the-press-office/2013/12/05/fact-sheet-presidential-memorandum-federal-leadership-energy-management; and http://www.whitehouse.gov/the-press-office/2013/12/05/presidential-memorandum-federal-leadership-energy-management.
[66] According to the EIA, in 2011, the U.S. government consumed 196 trillion Btu worth of electricity. At 3,412 Btu per kilowatt-hour, that works out to about 57 terawatt-hours. For the consumption data, see http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0112.

[67] In 2012, U.S. electricity sales totaled 3,694 TWh.

[68] See http://www.energy.senate.gov/public/index.cfm/democratic-news?ID=67e21415-e501-42c3-a1fb-c0768242a2aa; and http://www.eia.gov/analysis/requests/bces12.

[69] Robert Bryce, "The High Cost of Renewable-Electricity Mandates," Manhattan Institute, February 2012, http://www.manhattan-institute.org/html/eper_10.htm.

[70] In 2012, total U.S. electricity generation was 4,256 terawatt-hours. Wind energy generated 121.4 TWh and solar 4.4 TWh. See *BP Statistical Review of World Energy* 2013.

[71] EIA data, http://www.eia.gov/forecasts/aeo/electricity_generation.cfm.

[72] *BP Statistical Review of World Energy 2013*.

[73] Ibid.

[74] Here's the math: 436 terawatt-hours is 436 million megawatt-hours. Thus, for solar, 436 million megawatt-hours times the cost differential over natural gas ($78.70) = $34.3 billion. For wind, which costs $21 more per megawatt-hour than natural gas: $21 MWh x 436 million MWh = $9.1 billion. The sum of those two figures is $43.4 billion.

[75] See http://quickfacts.census.gov/qfd/states/00000.html.

[76] EIA data, http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf.

[77] Ibid., 32.

[78] EIA data, http://www.eia.gov/electricity/sales_revenue_price/pdf/table4.pdf.

[79] EIA data, http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_03.

[80] EIA data, http://www.eia.gov/electricity/sales_revenue_price/pdf/table4.pdf.

[81] BLS data, "Average Energy Prices, Los Angeles-Riverside-Orange County, November 2013," http://www.bls.gov/ro9/cpilosa_energy.htm.

[82] Jacksonville Electric Authority, "Quarterly Electric Rate Comparison, October 1, 2013, https://www.jea.com/Manage_My_Account/Get_Help/Understand_My_Bill/JEA_Rates/Electric_Rate_Comparison.aspx.

[83] Ibid.

[84] See http://articles.latimes.com/2013/sep/09/business/la-fi-electric-rates-bill-20130910.

[85] California Public Utilities Commission, "33% Renewables Portfolio Standards: Implementation Analysis Preliminary Results," executive summary, June 2009, http://www.cpuc.ca.gov/NR/rdonlyres/B123F7A9-17BD-461E-AC34-973B906CAE8E/0/ExecutiveSummary33percentRPSImplementationAnalysis.pdf, 1.

[86] Ibid., 4.

[87] California's population is approximately 36.9 million.

[88] Navigant Consulting, http://careaboutenergy.org/wp-content/uploads/Preliminary-Assessment-of-Regulatory-Cost-Drivers-in-Californias-Energy-Market_16Aug2013.pdf, 3.

[89] Ibid., 12.

[90] Ibid., 23.

[91] See http://rhg.com/notes/state-by-state-contributions-to-recent-us-emissions-trends.

[92] Evan Halper, "Power Struggle: Green Energy Versus a Grid That's Not Ready," *Los Angeles Times*, December 2, 2013, http://www.latimes.com/nation/la-na-grid-renewables-20131203,0,1019786.story#ixzz2mW7vUvq6.

[93] Dana Hull, "Report Says Popular Solar 'Net Metering' Policy Will Cost California's Non-Solar Customers $1.1 Billion a Year by 2020," *San Jose Mercury News*, September 26, 2013, http://www.mercurynews.com/business/ci_24182761/popular-solar-net-metering-policy-will-cost-california.

[94] EIA data, http://www.eia.gov/state/rankings/?sid=U.S.#/series/226.

[95] In 2010, global CO2 emissions totaled 32.8 billion tons.

[96] *BP Statistical Review of World Energy 2013*.

[97] David Dismukes, "Removing Big Wind's Training Wheels: The Case for Ending the Production Tax Credit," American Energy Alliance, November 1, 2012, http://www.americanenergyalliance.org/wp-content/uploads/2012/10/Dismukes-Removing-Big-Winds-Training-Wheels.pdf, 16. See also Kennedy Maize, "How the Wind Production Tax Credit Is Anti-Nuclear," Power, July 7, 2013, http://www.powermag.com/how-the-wind-production-tax-credit-is-anti-nuclear.

[98] Dismukes, "Removing Big Wind's Training Wheels," 5.

[99] Ibid, 2.
[100] See http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F.
[101] See http://www.powermag.com/wind-production-tax-credit-expires-with-uncertain-impact.
[102] See http://dailycaller.com/2013/01/01/fiscal-cliff-deal-includes-one-year-extension-for-wind-tax-credits; see also http://www.reuters.com/article/2012/08/14/us-usa-obama-energy-idUSBRE87D0BI20120814.
[103] See http://thehill.com/blogs/regwatch/energyenvironment/326117-wind-tax-credit-comes-under-fire-
[104] See http://www.heritage.org/research/reports/2013/12/epa-power-plant-regulations-a-backdoor-energy-tax.
[105] See http://oilprice.com/Energy/Coal/Coals-Makes-a-2014-Comeback.html.
[106] *BP Statistical Review of World Energy 2013.*
[107] Congressional Research Service, "U.S. Fossil Fuel Resources: Terminology, Reporting, and Summary," March 25, 2011, http://assets.opencrs.com/rpts/R40872_20110325.pdf.
[108] OPEC data, http://www.opec.org/opec_web/en/data_graphs/330.htm,14.
[109] See http://oilprice.com/Energy/Coal/Coals-Makes-a-2014-Comeback.html.
[110] *BP Statistical Review of World Energy 2013.* Between 2002 and 2012, global coal used jumped by 26.5 million barrels of oil equivalent per day. Over that same time frame, oil consumption grew by 11.3 million barrels of oil equivalent per day, natural gas increased by 14.3 million barrels of oil equivalent per day, and nuclear fell by 1 million barrels of oil equivalent per day, largely because of Japan's shutdown of its nuclear facilities after the Fukushima disaster. (Hydropower increased by 4.7 million barrels of oil equivalent per day. Wind increased by 2.1 million barrels of oil equivalent per day.)
[111] IEA, "Medium-Term Coal Market Report 2013," December 16, 2013, http://www.iea.org/newsroomandevents/speeches/131216_MCMR13_launch_presentation_Sadamori.pdf, 6. The graphic shows that demand should reach about 4.6 billion tons of oil equivalent by 2018. At 7.33 barrels per ton of oil equivalent, that works out to 92.4 million barrels of oil equivalent per day.
[112] For cost data, see http://www.powermag.com/prairie-state-energy-campus-washington-county-illinois. For emissions, see http://www.energy-pc.com/PrairieStatesEnergyCampus.htm.
[113] For more information, see http://www.epa.gov/airtransport/CSAPR/basic.html.
[114] For more on this, see Robert Bryce, "Is There Still a Case for Coal?," Manhattan Institute, May 2012, http://www.manhattan-institute.org/html/ir_13.htm.
[115] Max Luke, "Nuclear and Gas Account for Most Carbon Displacement Since 1950," Breakthrough Institute, September 3, 2013, http://thebreakthrough.org/index.php/programs/energy-and-climate//nuclear-and-gas-account-for-most-carbon-displacement-since-1950.
[116] *BP Statistical Review of World Energy 2013.*
[117] IEA press release, May 24, 2012, http://www.iea.org/newsroomandevents/news/2012/may/name,27216,en.html.
[118] See http://newyork2.sierraclub.org/sites/newyork.sierraclub.org/files/documents/2013/02/FracAct_Facts_3_11.pdf.
[119] See http://ohiodnr.com/Portals/11/pdf/fracking-fact-sheet.pdf.
[120] David Jolly, "France Upholds Ban on Hydraulic Fracturing," *New York Times*, October 11, 2013, http://www.nytimes.com/2013/10/12/business/international/france-upholds-fracking-ban.html.
[121] Greenpeace data, http://www.greenpeace.org.uk/media/press-releases/greenpeace-launches-nationwide-legal-block-fracking-20131010.
[122] Food & Water Watch, http://www.foodandwaterwatch.org/water/fracking.
[123] See http://petitions.moveon.org/sign/president-obama-ban-fracking.
[124] See http://pac.petitions.moveon.org/sign/ban-fracking-in-califoria?source=none&fb_test=0; http://petitions.moveon.org/sign/ban-fracking-in-ma; http://petitions.moveon.org/sign/commissioners-ban-fracking; http://petitions.moveon.org/sign/ban-fracking-in-illinois-1; http://petitions.moveon.org/sign/we-the-people-of-ohio; and http://petitions.moveon.org/sign/ban-hydaulic-fracturing.
[125] See http://www.latimes.com/nation/nationnow/la-na-nn-north-dakota-train-20131230,0,6177728.story#axzz2p4XfN7Ux.
[126] See http://www.foxnews.com/us/2013/12/31/no-injuries-reported-in-fiery-north-dakota-train-derailment.

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Senator WHITEHOUSE. Thank you very much, Mr. Bryce.

We have a few minutes, so I will try to be very brief. Let me first thank Christopher Brown for being here. Mr. Brown, you said in your testimony that there was room for improvement in the relationship between your fishing community and the scientific community and improved data collection. Could you just briefly elaborate on that?

Mr. BROWN. Yes. The Magnusson Act has almost a reckless pursuit of its desires. What we are attempting to achieve with it is just not possible. Dr. Sulowsky, as I stated, has done extensive stable isotope analyses and determined that it will be impossible to recover a number of stocks without first removing the ones that compete with them.

The Magnusson Act is a wonderful document, but it is in need of supplement. It is in need of consideration of things that were beyond its possibility to understand and define when it was established.

Senator WHITEHOUSE. And do you approve of initiatives like Captain Rule's effort with the Virginia Institute of Marine Science scientists to bring fishermen and scientists together in data collection and the experiment, I guess you would call it, the initiative that is underway with Dr. Parker in the University of Rhode Island joining with the Rhode Island Lobstermen's Association?

Mr. BROWN. Yes, I approve of those actions wholeheartedly. Magnusson calls for a co-managed fishery. Co-management finds its roots in the co-authoring of science. Until we are co-authors of science, this industry is co-manager of nothing.

Senator WHITEHOUSE. Thank you very much. We very often talk about the Department of Fish and Wildlife, Division of Fish and Wildlife, but we end up usually talking more about the wildlife than the fish. So I am delighted that you are here.

David, can you say a brief word about the public-private nature of the partnerships that the National Wildlife Refuge Association supports?

Mr. HOUGHTON. Yes, absolutely. A great example would be Everglades National Wildlife Refuge and Conservation Area. This was established last year and it is a partnership with ranchers. In fact, there are about a million acres of ranchers who would like to participate in the National Wildlife Refuge.

So an area that is large and connected will allow endangered species like Florida black bear or Florida panther to move throughout the landscape as that landscape changes with changing climate. But those are not the only critters that benefit. Ranchers that have been there for 500 years will have an upside. There is a military base in the middle of this. So our men and women of the military will be able to train as they see in combat, which has a big benefit to them.

Last, the Everglades supplies the water supply for 6.5 million people. So we can bring climate change adaptation, and we can also help a 500 year old tradition of ranching, the military and water for 6.5 million people, all with conservation action of the Everglades headwaters.

Senator WHITEHOUSE. Thank you very much.

Before I turn to our ranking member to close out the hearing, I would like to submit for the record reports from the U.S. Global Climate Change Research Program, the National Climate Assessment, the National Academies and the Intergovernmental Panel on Climate Change, which all agree that human activities have altered the world's climate. There is in fact clear scientific consensus among the scientific community that human-induced climate change is a reality.

I would also like to submit a 2010 report entitled A Human Health Perspective on Climate Change for the record. These same reports note the negative effects of climate change on human health and the economy through rising sea levels, coastal flooding, increased frequency of drought and negative health effects.

I would also like to submit for the record a National Wildlife Federation study that details the detrimental effects of carbon pollution on our wildlife, like mercury emissions from electric power plants, which affect wildlife and fish. I would also like to submit a Fish and Wildlife Service fact sheet on migratory bird mortality and a Sibley Guides article which states that as many as 976 million bird deaths a year are attributable to collisions with windows, 72 million bird deaths are estimated as a result from pesticides, and at least 39 million bird deaths are from domestic feral cats, 15 million birds a year are killed in North American in the carefully managed annual waterfowl hunt, and the greatest threat to all birds continues to be loss or degradation of habitat due to human development and disturbance.

[The referenced information follows:]

NATIONAL WILDLIFE FEDERATION

INSPIRING AMERICANS TO PROTECT WILDLIFE FOR OUR CHILDREN'S FUTURE.

Fact Sheet

GLOBAL WARMING

Mercury Pollution from Coal-fired Power Plants

A Dangerous Threat to People and Wildlife

Mercury pollution is a serious problem across the nation. Every state in America has issued health advisories warning people to limit or avoid eating certain species of fish due to toxic mercury contamination, many of which cover every waterbody in the state. Coal-fired power plants are by far the largest source of mercury pollution in America, placing our public health and wildlife at grave risk. The Environmental Protection Agency (EPA) is poised to take action to reduce this dangerous threat to current and future generations of people and wildlife. Recent attempts by Congress to prevent EPA from doing its job are misguided and prevent the use of modern technologies readily available to reduce mercury pollution from power plants and other sources.

Why is Mercury a Problem?

Mercury is a highly potent neurotoxin that adversely affects the function and development of the central nervous system in both people and wildlife. Exposure to mercury is particularly dangerous for pregnant and breastfeeding women, as well as children, since mercury is most harmful in the early stages of development.

In the U.S., 1 in 6 women of childbearing age (15-44) has blood mercury levels that exceed those considered safe by the EPA for a developing baby. This amounts to approximately 630,000 babies born every year at risk of developmental problems because of prenatal mercury exposure.[1] According to the Center for Disease Control, health effects linked to prenatal and childhood methylmercury exposure include problems with language, memory, attention, visual skills, and lower IQs.[2]

As a result of these risks, the Food and Drug Administration (FDA) advises small children and women who are pregnant not to eat shark, swordfish, king mackerel, or tilefish because these fish are highly contaminated with mercury, and to eat at most two meals a week of popular seafood containing lower levels of mercury such as shrimp, canned light tuna, salmon, pollock, and catfish.[3] Additionally, state health departments issue separate warnings for recreationally caught fish (see Table 2). Since 2006, the number of fish consumption advisories resulting from mercury contamination has increased from 3,080 to 3,361 in 2008.[4]

Mercury exposure is not only a risk for people; it is a significant threat to our wildlife as well. While humans can control their mercury intake, wildlife cannot choose to specifically avoid eating mercury contaminated prey. It is not only fish-eating wildlife that are at risk - high levels of mercury have been found in far more species, and in far more habitats, than previously thought.

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Risks of Mercury Pollution, cont'd.

Scientists have found alarming levels of mercury accumulation in a wide range of wildlife species, including birds, mammals, reptiles, and amphibians in both fresh and saltwater ecosystems.[5]

There are multiple and varied health impacts associated with high mercury levels in different wildlife species, but the primary consequence is increased vulnerability due to reproductive and neurological problems (which can lead to behavioral abnormalities). For example, fish have difficulty schooling and decreased spawning success; birds lay fewer eggs and have trouble caring for their chicks; and mammals have impaired motor skills that affect their ability to hunt and find food.[6] In addition, some evidence indicates that elevated mercury levels can adversely affect species' immune systems. All these effects combine to create a severe threat to wildlife survival.

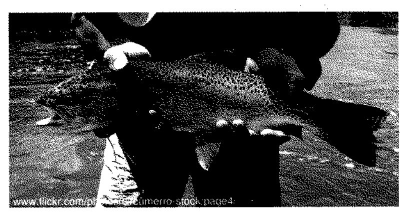
Where Does Mercury Come From?

Mercury is a naturally occurring, toxic heavy metal. However, human activity has significantly increased mercury levels in the environment over the past several centuries. Once emitted to the air, mercury falls to the earth and builds up in our waters and soils where it is transformed into methylmercury - a highly toxic form that accumulates in the tissues of wildlife and people. Mercury increases in concentration with each step up the food chain. As a result, large predator fish such as walleye and trout can have mercury levels over one million times that of the surrounding water. In turn, people and wildlife who consume fish or other species with high mercury levels are at risk of serious health problems.

Coal-fired power plants are the single largest source of mercury contamination in the U.S., responsible for approximately 50% of human-caused mercury emissions.[7] Other sources include waste incinerators that burn mercury-containing products and chlorine manufacturers. However, unlike these sources, power plants are not currently required to limit their mercury pollution. As a result, significant amounts of mercury pollution are released into the air every year from America's approximately 600 coal-fired plants.[8] Mercury emissions primarily fall locally, so these plants are major contributors to local contamination problems and "hotspots".[9] Additionally, some mercury emissions also stay in the atmosphere and travel longer distances, resulting in mercury contamination hundreds or even thousands of miles away.[10]

Mercury Impacts on Fish

Mercury pollution not only threatens our public health and wildlife, it also adversely impacts one of our most treasured pastimes – recreational fishing. In most states in America, it is no longer safe to take our families fishing and cook up the catch of the day.



Sport fishing is not just a recreational pastime, it is also a major contributor to our local and national economy. In fact, as Table 1 indicates, in 2006, the over 38 million people who fished in the U.S. generated nearly $40 billion in revenue.

CONFRONTING GLOBAL WARMING Fact Sheet

NATIONAL WILDLIFE FEDERATION

What Can Be Done?

Given the severe threats to public health and wildlife from mercury exposure, emissions from coal-fired power plants should not remain uncontrolled when mercury pollution control technology is readily available. Fortunately, EPA is finally in the process of developing standards under the Clean Air Act to limit emissions of toxic mercury from power plants. It is crucial that the EPA enforce the law and fulfill its obligation to protect public health from this dangerous pollutant.

EPA needs to hear from you! Contact NWF for more information about how you can help ensure that EPA moves forward and sets stringent standards to protect public health and wildlife from preventable mercury pollution.

Contact your Federal Legislators! EPA's long overdue efforts to reduce mercury emissions from coal plants must go forward. However, big polluters and their Washington lobbyists are putting the pressure on Congress to prevent EPA from reducing toxic mercury pollution. Congress must not block these critical public health and wildlife safeguards, so please let your Senators and Representatives know that you support EPA's efforts to cut mercury pollution.

For more information and what you can do to get involved, visit www.nwf.org/cleanairact

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[1] Kathryn Mahaffey, Robert P. Cliffner, and Catherine Bodurow, "Blood Organic Mercury and Dietary Mercury Intake: National Health and Nutrition Examination Survey, 1999 and 2000," Environmental Health Perspectives, 112(5): 562-570, April 2004; Kathryn R. Mahaffey, U.S. EPA, "Methylmercury Epidemiology Update," Slide #9 of presentation given at the National Forum on Contaminants in Fish, San Diego, January 2004.

[2] Agency for Toxic Substances and Disease Registry, 2011. http://www.atsdr.cdc.gov/alerts/970626.html

[3] *What You Need to Know About Mercury in Fish and Shellfish, 2004.* U.S. Food and Drug Administration. http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm115662.htm

[4] *National Listing of Fish Advisories,2008.* U.S. Environmental Protection Agency. http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/fs2008.cfm

[5] *Mercury Connections, 2005.* BioDiversity Research Institute. *http://www.briloon.org/mercury/mercon_ex_sum.htm; Poisoning Wildlife, 2006.* National Wildlife Federation. http://www.nwf.org/nwfwebadmin/binaryVault/PoisoningWildlifeMercuryPollution1.pdf

[6] Ibid.

[7] U.S. Environmental Protection Agency, *2005 National Emissions Inventory,* http://www.epa.gov/hg/about.htm

[8] U.S. Energy Information Administration, *Count of Electric Power Industry Power Plants, by Sector, by Predominant Energy Sources within Plant 2001-2009,* http://www.eia.doe.gov/cneaf/electricity/epa/epat5p1.html

[9] *Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States, 2007.* Hubbard Brook Research Foundation. http://www.hubbardbrookfoundation.org/mediainfo/

[10] Kuiken, T. and F. Stadler. 2003. Cycle of Harm: Mercury's Pathway from Rain to Fish in the Environment. National Wildlife Federation. http://openlibrary.org/books/OL3319165M/Cycle_of_harm

Table 1: Number of Anglers and Total Expenditures for Fishing by State (2006)

State	Total Anglers	Resident	Nonresident	Total Expenditures
Alabama	866,000	656,000	210,000	$699,532,000
Alaska	371,000	175,000	196,000	$516,749,000
Arizona	422,000	330,000	92,000	$802,405,000
Arkansas	655,000	430,000	225,000	$420,571,000
California	1,985,000	1,816,000	169,000	$2,420,503,000
Colorado	661,000	490,000	171,000	$542,937,000
Connecticut	361,000	299,000	62,000	$243,552,000
Delaware	151,000	79,000	72,000	$96,775,000
Florida	3,419,000	2,441,000	978,000	$4,308,583,000
Georgia	1,151,000	1,033,000	118,000	$1,020,411,000
Hawaii	169,000	104,000	65,000	$110,516,000
Idaho	350,000	206,000	144,000	$282,972,000
Illinois	824,000	757,000	67,000	$774,319,000
Indiana	720,000	624,000	96,000	$627,167,000
Iowa	437,000	397,000	40,000	$322,648,000
Kansas	404,000	319,000	85,000	$242,444,000
Kentucky	721,000	580,000	141,000	$855,417,000
Louisiana	839,000	720,000	119,000	$1,006,136,000
Maine	403,000	261,000	142,000	$257,124,000
Maryland	735,000	471,000	264,000	$568,211,000
Massachusetts	590,000	486,000	104,000	$769,631,000
Michigan	1,652,000	1,308,000	344,000	$1,671,114,000
Minnesota	1,380,000	1,091,000	289,000	$2,725,366,000
Mississippi	565,000	496,000	69,000	$240,332,000
Missouri	1,077,000	871,000	206,000	$1,093,206,000
Montana	291,000	172,000	119,000	$226,349,000
Nebraska	198,000	169,000	29,000	$181,280,000
Nevada	141,000	114,000	27,000	$144,634,000
New Hampshire	245,000	121,000	124,000	$172,413,000
New Jersey	738,000	550,000	188,000	$752,273,000
New Mexico	248,000	164,000	84,000	$301,101,000
New York	1,278,000	1,049,000	229,000	$925,701,000
North Carolina	1,403,000	993,000	410,000	$1,124,274,000
North Dakota	88,000	88,000		$93,729,000
Ohio	1,310,000	1,204,000	106,000	$1,062,036,000
Oklahoma	611,000	525,000	86,000	$501,786,000
Oregon	642,000	529,000	113,000	$496,941,000
Pennsylvania	988,000	845,000	143,000	$1,291,211,000
Rhode Island	160,000	93,000	67,000	$153,694,000
South Carolina	938,000	625,000	313,000	$1,404,133,000
South Dakota	134,000	89,000	45,000	$131,089,000
Tennessee	872,000	658,000	214,000	$599,683,000
Texas	3,008,000	2,781,000	227,000	$3,237,212,000
Utah	375,000	288,000	87,000	$371,087,000
Vermont	114,000	64,000	50,000	$63,749,000
Virginia	974,000	743,000	231,000	$733,777,000
Washington	823,000	725,000	98,000	$904,796,000
West Virginia	377,000	291,000	86,000	$333,454,000
Wisconsin	1,490,000	1,094,000	396,000	$1,647,035,000
Wyoming	203,000	96,000	107,000	$521,479,000
U.S. Total	38,557,000	30,510,000	8,047,000	$39,993,537,000

Source: *2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.* U.S. Fish and Wildlife Service. http://www.census.gov/prod/2008pubs/fhw06-nat.pdf

Table 2: Mercury Fish Consumption Advisories by State (2011)

State	Number of Advisories	Statewide advisory information
Alabama	60	statewide coastal advisory
Alaska	9	statewide coastal advisory
Arizona	12	
Arkansas	19	
California	56	
Colorado	21	
Connecticut	11	statewide freshwater advisory
Delaware	7	statewide coastal advisory
D.C.	0	
Florida	328	statewide freshwater advisory
Georgia	129	
Hawaii	1	statewide coastal advisory
Idaho	21	statewide freshwater advisory
Illinois	26	statewide freshwater advisory
Indiana	64	statewide freshwater advisory
Iowa	9	
Kansas	2	
Kentucky	11	statewide freshwater advisory
Louisiana	48	
Maine	1	statewide freshwater advisory
Maryland	52	statewide freshwater advisory
Massachusetts	125	statewide freshwater advisory
Michigan	120	statewide freshwater advisory
Minnesota	1,039	statewide freshwater advisory
Mississippi	10	statewide coastal advisory
Missouri	3	statewide freshwater advisory
Montana	48	statewide freshwater advisory
Nebraska	57	
Nevada	7	
New Hampshire	8	statewide freshwater advisory
New Jersey	96	statewide freshwater advisory
New Mexico	25	
New York	92	
North Carolina	3	statewide freshwater & coastal advisories
North Dakota	4	statewide freshwater advisory
Ohio	113	statewide freshwater advisory
Oklahoma	16	statewide freshwater advisory
Oregon	13	statewide freshwater advisory
Pennsylvania	75	statewide freshwater advisory
Rhode Island	21	statewide freshwater advisory
South Carolina	71	
South Dakota	10	
Tennessee	19	
Texas	18	statewide coastal advisory
Utah	14	
Vermont	9	statewide freshwater advisory
Virginia	27	
Washington	11	statewide freshwater advisory
West Virginia	13	statewide freshwater advisory
Wisconsin	89	statewide freshwater advisory
Wyoming	4	statewide freshwater advisory

Source: US EPA , Fish Advisories
http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/advisories_index.cfm

For information specific to your area check your state agency's listing of fish advisories.

SPM

Summary for Policymakers

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A. Introduction

The Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) considers new evidence of climate change based on many independent scientific analyses from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models. It builds upon the Working Group I contribution to the IPCC's Fourth Assessment Report (AR4), and incorporates subsequent new findings of research. As a component of the fifth assessment cycle, the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) is an important basis for information on changing weather and climate extremes.

This Summary for Policymakers (SPM) follows the structure of the Working Group I report. The narrative is supported by a series of overarching highlighted conclusions which, taken together, provide a concise summary. Main sections are introduced with a brief paragraph in italics which outlines the methodological basis of the assessment.

The degree of certainty in key findings in this assessment is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*). Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement[1]. Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment[2]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. (See Chapter 1 and Box TS.1 for more details about the specific language the IPCC uses to communicate uncertainty).

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections of the underlying report and in the Technical Summary. These references are given in curly brackets.

B. Observed Changes in the Climate System

Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Global-scale observations from the instrumental era began in the mid-19th century for temperature and other variables, with more comprehensive and diverse sets of observations available for the period 1950 onwards. Paleoclimate reconstructions extend some records back hundreds to millions of years. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean, the cryosphere, and the land surface.

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (see Figures SPM.1, SPM.2, SPM.3 and SPM.4). {2.2, 2.4, 3.2, 3.7, 4.2–4.7, 5.2, 5.3, 5.5–5.6, 6.2, 13.2}

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1 In this Summary for Policymakers, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence (see Chapter 1 and Box TS.1 for more details).

2 In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely: 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely* (see Chapter 1 and Box TS.1 for more details).

SPM

B.1 Atmosphere

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (see Figure SPM.1). In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). {2.4, 5.3}

- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C[3], over the period 1880 to 2012, when multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest dataset available[4] (see Figure SPM.1). {2.4}

- For the longest period when calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming (see Figure SPM.1). {2.4}

- In addition to robust multi-decadal warming, global mean surface temperature exhibits substantial decadal and interannual variability (see Figure SPM.1). Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade)[5]. {2.4}

- Continental-scale surface temperature reconstructions show, with *high confidence*, multi-decadal periods during the Medieval Climate Anomaly (year 950 to 1250) that were in some regions as warm as in the late 20th century. These regional warm periods did not occur as coherently across regions as the warming in the late 20th century (*high confidence*). {5.5}

- It is *virtually certain* that globally the troposphere has warmed since the mid-20th century. More complete observations allow greater confidence in estimates of tropospheric temperature changes in the extratropical Northern Hemisphere than elsewhere. There is *medium confidence* in the rate of warming and its vertical structure in the Northern Hemisphere extra-tropical troposphere and *low confidence* elsewhere. {2.4}

- *Confidence* in precipitation change averaged over global land areas since 1901 is *low* prior to 1951 and *medium* afterwards. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes area-averaged long-term positive or negative trends have *low confidence* (see Figure SPM.2). {TS TFE.1, Figure 2; 2.5}

- Changes in many extreme weather and climate events have been observed since about 1950 (see Table SPM.1 for details). It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale[6]. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, *confidence* in changes in heavy precipitation events is at most *medium*. {2.6}

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3 In the WGI contribution to the AR5, uncertainty is quantified using 90% uncertainty intervals unless otherwise stated. The 90% uncertainty interval, reported in square brackets, is expected to have a 90% likelihood of covering the value that is being estimated. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate. A best estimate of that value is also given where available.

4 Both methods presented in this bullet were also used in AR4. The first calculates the difference using a best fit linear trend of all points between 1880 and 2012. The second calculates the difference between averages for the two periods 1850–1900 and 2003–2012. Therefore, the resulting values and their 90% uncertainty intervals are not directly comparable. {2.4}

5 Trends for 15-year periods starting in 1995, 1996, and 1997 are 0.13 [0.02 to 0.24] °C per decade, 0.14 [0.03 to 0.24] °C per decade, and, 0.07 [–0.02 to 0.18] °C per decade, respectively.

6 See the Glossary for the definition of these terms: cold days/cold nights, warm days/warm nights, heat waves.

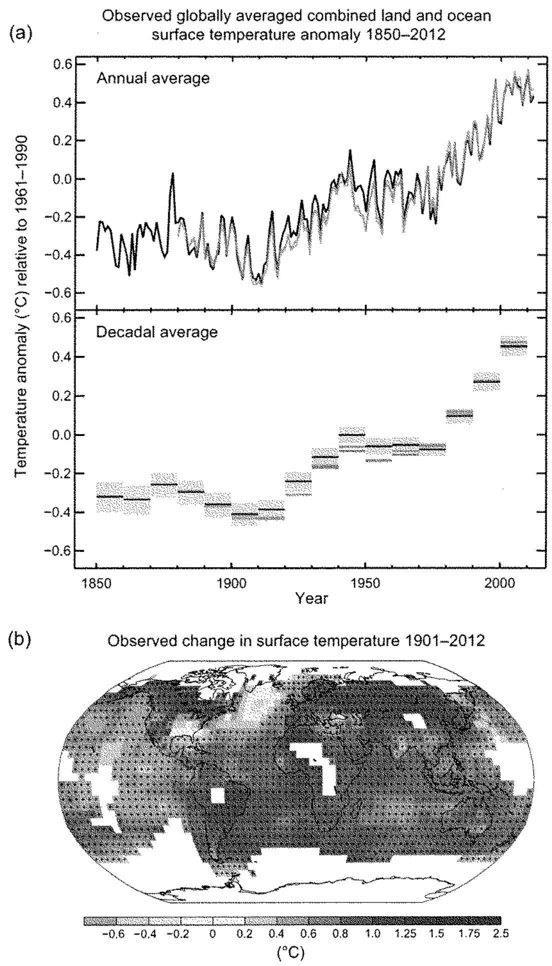

Figure SPM.1 | (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961–1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. For a listing of the datasets and further technical details see the Technical Summary Supplementary Material. {Figures 2.19–2.21; Figure TS.2}

Table SPM.1 | Extreme weather and climate events: Global-scale assessment of recent observed changes, human contribution to the changes, and projected further changes for the early (2016–2035) and late (2081–2100) 21st century. Bold indicates where the AR5 (black) provides a revised* global-scale assessment from the SREX (blue) or AR4 (red). Projections for early 21st century were not provided in previous assessment reports. Projections in the AR5 are relative to the reference period of 1986–2005, and use the new Representative Concentration Pathway (RCP) scenarios (see Box SPM.1) unless otherwise specified. See the Glossary for definitions of extreme weather and climate events.

Phenomenon and direction of trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of a human contribution to observed changes	Likelihood of further changes: Early 21st century	Likelihood of further changes: Late 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely* {2.6} *Very likely* *Very likely*	**_Very likely_** {10.6} *Likely* *Likely*	*Likely* {11.3}	*Virtually certain* {12.4} *Virtually certain* *Virtually certain*
Warmer and/or more frequent hot days and nights over most land areas	*Very likely* {2.6} *Very likely* *Very likely*	**_Very likely_** {10.6} *Likely* *Likely* (nights only)	*Likely* {11.3}	*Virtually certain* {12.4} *Virtually certain* *Virtually certain*
Warm spells/heat waves. Frequency and/or duration increases over most land areas	**_Medium confidence_ on a global scale** *Likely* in large parts of Europe, Asia and Australia {2.6} *Medium confidence* in many (but not all) regions *Likely*	**_Likely_**[a] {10.6} Not formally assessed *More likely than not*	Not formally assessed[b] {11.3}	*Very likely* {12.4} *Very likely* *Very likely*
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely* more land areas with increases than decreases[c] {2.6} *Likely* more land areas with increases than decreases *Likely* over most land areas	**_Medium confidence_** {7.6, 10.6} *Medium confidence* *More likely than not*	*Likely* over many land areas {11.3}	**_Very likely_ over most of the mid-latitude land masses and over wet tropical regions** {12.4} *Likely* over many areas *Very likely* over most land areas
Increases in intensity and/or duration of drought	**_Low confidence_ on a global scale** *Likely* changes in some regions[d] {2.6} *Medium confidence* in some regions *Likely* in many regions, since 1970[e]	**_Low confidence_** {10.6} *Medium confidence*[f] *More likely than not*	*Low confidence*[g] {11.3}	**_Likely (medium confidence)_ on a regional to global scale**[h] {12.4} *Medium confidence* in some regions *Likely*[e]
Increases in intense tropical cyclone activity	**_Low confidence_ in long term (centennial) changes** *Virtually certain* in North Atlantic since 1970 {2.6} *Low confidence* *Likely* in some regions, since 1970	**_Low confidence_**[i] {10.6} *Low confidence* *More likely than not*	*Low confidence* {11.3}	**_More likely than not_ in the Western North Pacific and North Atlantic**[j] {14.6} *More likely than not* in some basins *Likely*
Increased incidence and/or magnitude of extreme high sea level	*Likely* (since 1970) {3.7} *Likely* (late 20th century) *Likely*	**_Likely_**[k] {3.7} *Likely*[k] *More likely than not*[k]	*Likely*[l] {13.7}	**_Very likely_**[l] {13.7} *Very likely*[m] *Likely*

* The direct comparison of assessment findings between reports is difficult. For some climate variables, different aspects have been assessed, and the revised guidance note on uncertainties has been used for the SREX and AR5. The availability of new information, improved scientific understanding, continued analyses of data and models, and specific differences in methodologies applied in the assessed studies, all contribute to revised assessment findings.

Notes:

[a] Attribution is based on available case studies. It is *likely* that human influence has more than doubled the probability of occurrence of some observed heat waves in some locations.

[b] Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells.

[c] In most continents, *confidence* in trends is not higher than *medium* except in North America and Europe where there have been *likely* increases in either the frequency or intensity of heavy precipitation with some seasonal and/or regional variation. It is *very likely* that there have been increases in central North America.

[d] The frequency and intensity of drought has *likely* increased in the Mediterranean and West Africa, and *likely* decreased in central North America and north-west Australia.

[e] AR4 assessed the area affected by drought.

[f] SREX assessed *medium confidence* that anthropogenic influence had contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes. SREX assessed *low confidence* in the attribution of changes in droughts at the level of single regions.

[g] There is *low confidence* in projected changes in soil moisture.

[h] Regional to global-scale projected decreases in soil moisture and increased agricultural drought are *likely (medium confidence)* in presently dry regions by the end of this century under the RCP8.5 scenario. Soil moisture drying in the Mediterranean, Southwest US and southern African regions is consistent with projected changes in Hadley circulation and increased surface temperatures, so there is *high confidence* in *likely* surface drying in these regions by the end of this century under the RCP8.5 scenario.

[i] There is *medium confidence* that a reduction in aerosol forcing over the North Atlantic has contributed at least in part to the observed increase in tropical cyclone activity since the 1970s in this region.

[j] Based on expert judgment and assessment of projections which use an SRES A1B (or similar) scenario.

[k] Attribution is based on the close relationship between observed changes in extreme and mean sea level.

[l] There is *high confidence* that this increase in extreme high sea level will primarily be the result of an increase in mean sea level. There is *low confidence* in region-specific projections of storminess and associated storm surges.

[m] SREX assessed it to be *very likely* that mean sea level rise will contribute to future upward trends in extreme coastal high water levels.

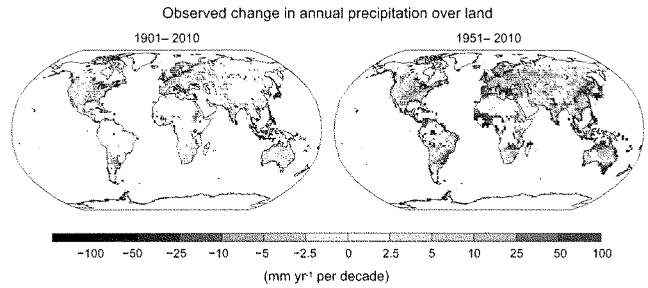

Figure SPM.2 | Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 (trends in annual accumulation calculated using the same criteria as in Figure SPM.1) from one data set. For further technical details see the Technical Summary Supplementary Material. {TS TFE.1, Figure 2; Figure 2.29}

B.2 Ocean

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*). It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010 (see Figure SPM.3), and it *likely* warmed between the 1870s and 1971. {3.2, Box 3.1}

- On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. Since AR4, instrumental biases in upper-ocean temperature records have been identified and reduced, enhancing confidence in the assessment of change. {3.2}

- It is *likely* that the ocean warmed between 700 and 2000 m from 1957 to 2009. Sufficient observations are available for the period 1992 to 2005 for a global assessment of temperature change below 2000 m. There were *likely* no significant observed temperature trends between 2000 and 3000 m for this period. It is *likely* that the ocean warmed from 3000 m to the bottom for this period, with the largest warming observed in the Southern Ocean. {3.2}

- More than 60% of the net energy increase in the climate system is stored in the upper ocean (0–700 m) during the relatively well-sampled 40-year period from 1971 to 2010, and about 30% is stored in the ocean below 700 m. The increase in upper ocean heat content during this time period estimated from a linear trend is *likely* 17 [15 to 19] × 10^{22} J [7] (see Figure SPM.3). {3.2, Box 3.1}

- It is *about as likely as not* that ocean heat content from 0–700 m increased more slowly during 2003 to 2010 than during 1993 to 2002 (see Figure SPM.3). Ocean heat uptake from 700–2000 m, where interannual variability is smaller, *likely* continued unabated from 1993 to 2009. {3.2, Box 9.2}

- It is *very likely* that regions of high salinity where evaporation dominates have become more saline, while regions of low salinity where precipitation dominates have become fresher since the 1950s. These regional trends in ocean salinity provide indirect evidence that evaporation and precipitation over the oceans have changed (*medium confidence*). {2.5, 3.3, 3.5}

- There is no observational evidence of a trend in the Atlantic Meridional Overturning Circulation (AMOC), based on the decade-long record of the complete AMOC and longer records of individual AMOC components. {3.6}

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[7] A constant supply of heat through the ocean surface at the rate of 1 W m^{-2} for 1 year would increase the ocean heat content by 1.1 × 10^{22} J.

B.3 Cryosphere

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*) (see Figure SPM.3). {4.2–4.7}

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- The average rate of ice loss[8] from glaciers around the world, excluding glaciers on the periphery of the ice sheets[9], was *very likely* 226 [91 to 361] Gt yr^{-1} over the period 1971 to 2009, and *very likely* 275 [140 to 410] Gt yr^{-1} over the period 1993 to 2009[10]. {4.3}

- The average rate of ice loss from the Greenland ice sheet has *very likely* substantially increased from 34 [–6 to 74] Gt yr^{-1} over the period 1992 to 2001 to 215 [157 to 274] Gt yr^{-1} over the period 2002 to 2011. {4.4}

- The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 [–37 to 97] Gt yr^{-1} over the period 1992–2001 to 147 [72 to 221] Gt yr^{-1} over the period 2002 to 2011. There is *very high confidence* that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica. {4.4}

- The annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate that was *very likely* in the range 3.5 to 4.1% per decade (range of 0.45 to 0.51 million km^2 per decade), and *very likely* in the range 9.4 to 13.6% per decade (range of 0.73 to 1.07 million km^2 per decade) for the summer sea ice minimum (perennial sea ice). The average decrease in decadal mean extent of Arctic sea ice has been most rapid in summer (*high confidence*); the spatial extent has decreased in every season, and in every successive decade since 1979 (*high confidence*) (see Figure SPM.3). There is *medium confidence* from reconstructions that over the past three decades, Arctic summer sea ice retreat was unprecedented and sea surface temperatures were anomalously high in at least the last 1,450 years. {4.2, 5.5}

- It is *very likely* that the annual mean Antarctic sea ice extent increased at a rate in the range of 1.2 to 1.8% per decade (range of 0.13 to 0.20 million km^2 per decade) between 1979 and 2012. There is *high confidence* that there are strong regional differences in this annual rate, with extent increasing in some regions and decreasing in others. {4.2}

- There is *very high confidence* that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century (see Figure SPM.3). Northern Hemisphere snow cover extent decreased 1.6 [0.8 to 2.4] % per decade for March and April, and 11.7 [8.8 to 14.6] % per decade for June, over the 1967 to 2012 period. During this period, snow cover extent in the Northern Hemisphere did not show a statistically significant increase in any month. {4.5}

- There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s. Observed warming was up to 3°C in parts of Northern Alaska (early 1980s to mid-2000s) and up to 2°C in parts of the Russian European North (1971 to 2010). In the latter region, a considerable reduction in permafrost thickness and areal extent has been observed over the period 1975 to 2005 (*medium confidence*). {4.7}

- Multiple lines of evidence support very substantial Arctic warming since the mid-20th century. {Box 5.1, 10.3}

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[8] All references to 'ice loss' or 'mass loss' refer to net ice loss, i.e., accumulation minus melt and iceberg calving.

[9] For methodological reasons, this assessment of ice loss from the Antarctic and Greenland ice sheets includes change in the glaciers on the periphery. These peripheral glaciers are thus excluded from the values given for glaciers.

[10] 100 Gt yr^{-1} of ice loss is equivalent to about 0.28 mm yr^{-1} of global mean sea level rise.

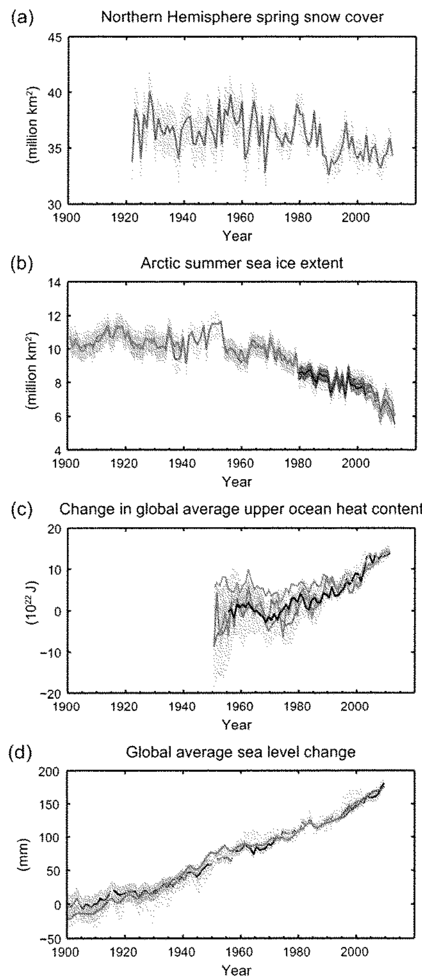

Figure SPM.3 | Multiple observed indicators of a changing global climate: (a) Extent of Northern Hemisphere March-April (spring) average snow cover; (b) extent of Arctic July-August-September (summer) average sea ice; (c) change in global mean upper ocean (0–700 m) heat content aligned to 2006–2010, and relative to the mean of all datasets for 1970; (d) global mean sea level relative to the 1900–1905 mean of the longest running dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. All time-series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. See Technical Summary Supplementary Material for a listing of the datasets. {Figures 3.2, 3.13, 4.19, and 4.3; FAQ 2.1, Figure 2; Figure TS.1}

B.4 Sea Level

The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (see Figure SPM.3). {3.7, 5.6, 13.2}

- Proxy and instrumental sea level data indicate a transition in the late 19th to the early 20th century from relatively low mean rates of rise over the previous two millennia to higher rates of rise (*high confidence*). It is *likely* that the rate of global mean sea level rise has continued to increase since the early 20th century. {3.7, 5.6, 13.2}

- It is *very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 and 2010, and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010. Tide-gauge and satellite altimeter data are consistent regarding the higher rate of the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. {3.7}

- Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise (*high confidence*). Over the period 1993 to 2010, global mean sea level rise is, with *high confidence*, consistent with the sum of the observed contributions from ocean thermal expansion due to warming (1.1 [0.8 to 1.4] mm yr^{-1}), from changes in glaciers (0.76 [0.39 to 1.13] mm yr^{-1}), Greenland ice sheet (0.33 [0.25 to 0.41] mm yr^{-1}), Antarctic ice sheet (0.27 [0.16 to 0.38] mm yr^{-1}), and land water storage (0.38 [0.26 to 0.49] mm yr^{-1}). The sum of these contributions is 2.8 [2.3 to 3.4] mm yr^{-1}. {13.3}

- There is *very high confidence* that maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 5 m higher than present, and *high confidence* that it did not exceed 10 m above present. During the last interglacial period, the Greenland ice sheet *very likely* contributed between 1.4 and 4.3 m to the higher global mean sea level, implying with *medium confidence* an additional contribution from the Antarctic ice sheet. This change in sea level occurred in the context of different orbital forcing and with high-latitude surface temperature, averaged over several thousand years, at least 2°C warmer than present (*high confidence*). {5.3, 5.6}

B.5 Carbon and Other Biogeochemical Cycles

The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (see Figure SPM.4). {2.2, 3.8, 5.2, 6.2, 6.3}

- The atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased since 1750 due to human activity. In 2011 the concentrations of these greenhouse gases were 391 ppm[11], 1803 ppb, and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively. {2.2, 5.2, 6.1, 6.2}

- Concentrations of CO_2, CH_4, and N_2O now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. The mean rates of increase in atmospheric concentrations over the past century are, with *very high confidence*, unprecedented in the last 22,000 years. {5.2, 6.1, 6.2}

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[11] ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of gas molecules to the total number of molecules of dry air. For example, 300 ppm means 300 molecules of a gas per million molecules of dry air.

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- Annual CO_2 emissions from fossil fuel combustion and cement production were 8.3 [7.6 to 9.0] GtC[12] yr^{-1} averaged over 2002–2011 (*high confidence*) and were 9.5 [8.7 to 10.3] GtC yr^{-1} in 2011, 54% above the 1990 level. Annual net CO_2 emissions from anthropogenic land use change were 0.9 [0.1 to 1.7] GtC yr^{-1} on average during 2002 to 2011 (*medium confidence*). {6.3}

- From 1750 to 2011, CO_2 emissions from fossil fuel combustion and cement production have released 375 [345 to 405] GtC to the atmosphere, while deforestation and other land use change are estimated to have released 180 [100 to 260] GtC. This results in cumulative anthropogenic emissions of 555 [470 to 640] GtC. {6.3}

- Of these cumulative anthropogenic CO_2 emissions, 240 [230 to 250] GtC have accumulated in the atmosphere, 155 [125 to 185] GtC have been taken up by the ocean and 160 [70 to 250] GtC have accumulated in natural terrestrial ecosystems (i.e., the cumulative residual land sink). {Figure TS.4, 3.8, 6.3}

- Ocean acidification is quantified by decreases in pH[13]. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*), corresponding to a 26% increase in hydrogen ion concentration (see Figure SPM.4). {3.8, Box 3.2}

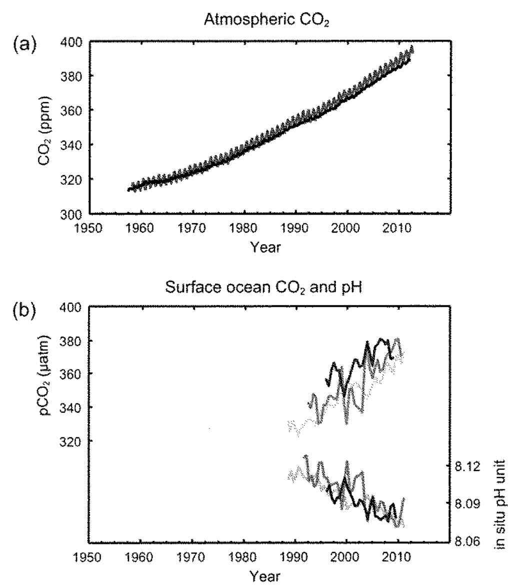

Figure SPM.4 | Multiple observed indicators of a changing global carbon cycle: (a) atmospheric concentrations of carbon dioxide (CO_2) from Mauna Loa (19°32'N, 155°34'W – red) and South Pole (89°59'S, 24°48'W – black) since 1958; (b) partial pressure of dissolved CO_2 at the ocean surface (blue curves) and in situ pH (green curves), a measure of the acidity of ocean water. Measurements are from three stations from the Atlantic (29°10'N, 15°30'W – dark blue/dark green; 31°40'N, 64°10'W – blue/green) and the Pacific Oceans (22°45'N, 158°00'W – light blue/light green). Full details of the datasets shown here are provided in the underlying report and the Technical Summary Supplementary Material. {Figures 2.1 and 3.18; Figure TS.5}

[12] 1 Gigatonne of carbon = 1 GtC = 10^{15} grams of carbon. This corresponds to 3.667 $GtCO_2$.

[13] pH is a measure of acidity using a logarithmic scale: a pH decrease of 1 unit corresponds to a 10-fold increase in hydrogen ion concentration, or acidity.

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C. Drivers of Climate Change

Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing[14] (RF) quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated. Positive RF leads to surface warming, negative RF leads to surface cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes. Some emitted compounds affect the atmospheric concentration of other substances. The RF can be reported based on the concentration changes of each substance[15]. Alternatively, the emission-based RF of a compound can be reported, which provides a more direct link to human activities. It includes contributions from all substances affected by that emission. The total anthropogenic RF of the two approaches are identical when considering all drivers. Though both approaches are used in this Summary for Policymakers, emission-based RFs are emphasized.

Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750 (see Figure SPM.5). {3.2, Box 3.1, 8.3, 8.5}

- The total anthropogenic RF for 2011 relative to 1750 is 2.29 [1.13 to 3.33] W m^{-2} (see Figure SPM.5), and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43% higher than that reported in AR4 for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect (negative RF). {8.5}

- The RF from emissions of well-mixed greenhouse gases (CO_2, CH_4, N_2O, and Halocarbons) for 2011 relative to 1750 is 3.00 [2.22 to 3.78] W m^{-2} (see Figure SPM.5). The RF from changes in concentrations in these gases is 2.83 [2.26 to 3.40] W m^{-2}. {8.5}

- Emissions of CO_2 alone have caused an RF of 1.68 [1.33 to 2.03] W m^{-2} (see Figure SPM.5). Including emissions of other carbon-containing gases, which also contributed to the increase in CO_2 concentrations, the RF of CO_2 is 1.82 [1.46 to 2.18] W m^{-2}. {8.3, 8.5}

- Emissions of CH_4 alone have caused an RF of 0.97 [0.74 to 1.20] W m^{-2} (see Figure SPM.5). This is much larger than the concentration-based estimate of 0.48 [0.38 to 0.58] W m^{-2} (unchanged from AR4). This difference in estimates is caused by concentration changes in ozone and stratospheric water vapour due to CH_4 emissions and other emissions indirectly affecting CH_4. {8.3, 8.5}

- Emissions of stratospheric ozone-depleting halocarbons have caused a net positive RF of 0.18 [0.01 to 0.35] W m^{-2} (see Figure SPM.5). Their own positive RF has outweighed the negative RF from the ozone depletion that they have induced. The positive RF from all halocarbons is similar to the value in AR4, with a reduced RF from CFCs but increases from many of their substitutes. {8.3, 8.5}

- Emissions of short-lived gases contribute to the total anthropogenic RF. Emissions of carbon monoxide (CO) are *virtually certain* to have induced a positive RF, while emissions of nitrogen oxides (NO_x) are *likely* to have induced a net negative RF (see Figure SPM.5). {8.3, 8.5}

- The RF of the total aerosol effect in the atmosphere, which includes cloud adjustments due to aerosols, is −0.9 [−1.9 to −0.1] W m^{-2} (*medium confidence*), and results from a negative forcing from most aerosols and a positive contribution

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[14] The strength of drivers is quantified as Radiative Forcing (RF) in units watts per square metre (W m^{-2}) as in previous IPCC assessments. RF is the change in energy flux caused by a driver, and is calculated at the tropopause or at the top of the atmosphere. In the traditional RF concept employed in previous IPCC reports all surface and tropospheric conditions are kept fixed. In calculations of RF for well-mixed greenhouse gases and aerosols in this report, physical variables, except for the ocean and sea ice, are allowed to respond to perturbations with rapid adjustments. The resulting forcing is called Effective Radiative Forcing (ERF) in the underlying report. This change reflects the scientific progress from previous assessments and results in a better indication of the eventual temperature response for these drivers. For all drivers other than well-mixed greenhouse gases and aerosols, rapid adjustments are less well characterized and assumed to be small, and thus the traditional RF is used. {8.1}

[15] This approach was used to report RF in the AR4 Summary for Policymakers.

from black carbon absorption of solar radiation. There is *high confidence* that aerosols and their interactions with clouds have offset a substantial portion of global mean forcing from well-mixed greenhouse gases. They continue to contribute the largest uncertainty to the total RF estimate. {7.5, 8.3, 8.5}

- The forcing from stratospheric volcanic aerosols can have a large impact on the climate for some years after volcanic eruptions. Several small eruptions have caused an RF of –0.11 [–0.15 to –0.08] W m^{-2} for the years 2008 to 2011, which is approximately twice as strong as during the years 1999 to 2002. {8.4}

- The RF due to changes in solar irradiance is estimated as 0.05 [0.00 to 0.10] W m^{-2} (see Figure SPM.5). Satellite observations of total solar irradiance changes from 1978 to 2011 indicate that the last solar minimum was lower than the previous two. This results in an RF of –0.04 [–0.08 to 0.00] W m^{-2} between the most recent minimum in 2008 and the 1986 minimum. {8.4}

- The total natural RF from solar irradiance changes and stratospheric volcanic aerosols made only a small contribution to the net radiative forcing throughout the last century, except for brief periods after large volcanic eruptions. {8.5}

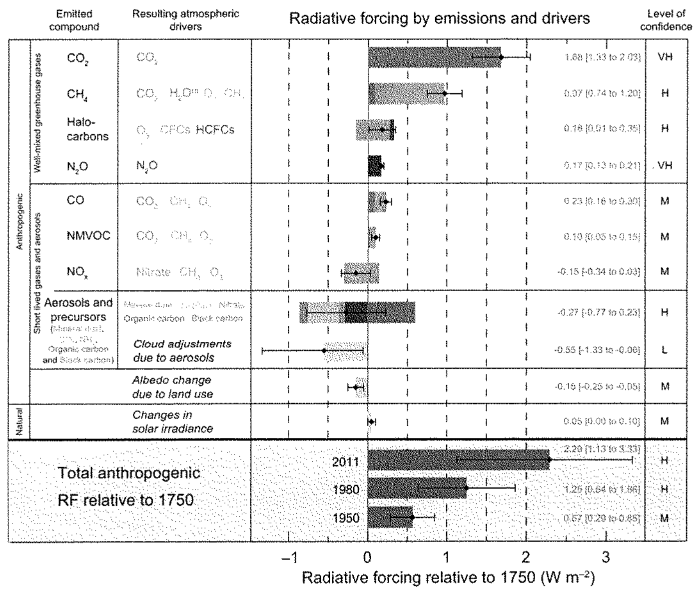

Figure SPM.5 | Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF[14]), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH – *very high*, H – *high*, M – *medium*, L – *low*, VL – *very low*). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail induced cirrus), and HFCs, PFCs and SF_6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes is difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750. For further technical details, including uncertainty ranges associated with individual components and processes, see the Technical Summary Supplementary Material. {8.5; Figures 8.14–8.18; Figures TS.6 and TS.7}

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D. Understanding the Climate System and its Recent Changes

Understanding recent changes in the climate system results from combining observations, studies of feedback processes, and model simulations. Evaluation of the ability of climate models to simulate recent changes requires consideration of the state of all modelled climate system components at the start of the simulation and the natural and anthropogenic forcing used to drive the models. Compared to AR4, more detailed and longer observations and improved climate models now enable the attribution of a human contribution to detected changes in more climate system components.

Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. {2–14}

D.1 Evaluation of Climate Models

Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*). {9.4, 9.6, 9.8}

- The long-term climate model simulations show a trend in global-mean surface temperature from 1951 to 2012 that agrees with the observed trend (*very high confidence*). There are, however, differences between simulated and observed trends over periods as short as 10 to 15 years (e.g., 1998 to 2012). {9.4, Box 9.2}

- The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean (*medium confidence*). The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle. However, there is *low confidence* in quantifying the role of changes in radiative forcing in causing the reduced warming trend. There is *medium confidence* that natural internal decadal variability causes to a substantial degree the difference between observations and the simulations; the latter are not expected to reproduce the timing of natural internal variability. There may also be a contribution from forcing inadequacies and, in some models, an overestimate of the response to increasing greenhouse gas and other anthropogenic forcing (dominated by the effects of aerosols). {9.4, Box 9.2, 10.3, Box 10.2, 11.3}

- On regional scales, the confidence in model capability to simulate surface temperature is less than for the larger scales. However, there is *high confidence* that regional-scale surface temperature is better simulated than at the time of the AR4. {9.4, 9.6}

- There has been substantial progress in the assessment of extreme weather and climate events since AR4. Simulated global-mean trends in the frequency of extreme warm and cold days and nights over the second half of the 20th century are generally consistent with observations. {9.5}

- There has been some improvement in the simulation of continental-scale patterns of precipitation since the AR4. At regional scales, precipitation is not simulated as well, and the assessment is hampered by observational uncertainties. {9.4, 9.6}

- Some important climate phenomena are now better reproduced by models. There is *high confidence* that the statistics of monsoon and El Niño-Southern Oscillation (ENSO) based on multi-model simulations have improved since AR4. {9.5}

- Climate models now include more cloud and aerosol processes, and their interactions, than at the time of the AR4, but there remains *low confidence* in the representation and quantification of these processes in models. {7.3, 7.6, 9.4, 9.7}

- There is robust evidence that the downward trend in Arctic summer sea ice extent since 1979 is now reproduced by more models than at the time of the AR4, with about one-quarter of the models showing a trend as large as, or larger than, the trend in the observations. Most models simulate a small downward trend in Antarctic sea ice extent, albeit with large inter-model spread, in contrast to the small upward trend in observations. {9.4}

- Many models reproduce the observed changes in upper-ocean heat content (0–700 m) from 1961 to 2005 (*high confidence*), with the multi-model mean time series falling within the range of the available observational estimates for most of the period. {9.4}

- Climate models that include the carbon cycle (Earth System Models) simulate the global pattern of ocean-atmosphere CO_2 fluxes, with outgassing in the tropics and uptake in the mid and high latitudes. In the majority of these models the sizes of the simulated global land and ocean carbon sinks over the latter part of the 20th century are within the range of observational estimates. {9.4}

D.2 Quantification of Climate System Responses

Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing. {Box 12.2, Box 13.1}

- The net feedback from the combined effect of changes in water vapour, and differences between atmospheric and surface warming is *extremely likely* positive and therefore amplifies changes in climate. The net radiative feedback due to all cloud types combined is *likely* positive. Uncertainty in the sign and magnitude of the cloud feedback is due primarily to continuing uncertainty in the impact of warming on low clouds. {7.2}

- The equilibrium climate sensitivity quantifies the response of the climate system to constant radiative forcing on multi-century time scales. It is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration. Equilibrium climate sensitivity is *likely* in the range 1.5°C to 4.5°C (*high confidence*), *extremely unlikely* less than 1°C (*high confidence*), and *very unlikely* greater than 6°C (*medium confidence*)[16]. The lower temperature limit of the assessed *likely* range is thus less than the 2°C in the AR4, but the upper limit is the same. This assessment reflects improved understanding, the extended temperature record in the atmosphere and ocean, and new estimates of radiative forcing. {TS TFE.6, Figure 1; Box 12.2}

- The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. Estimates of these quantities for recent decades are consistent with the assessed *likely* range of the equilibrium climate sensitivity to within assessed uncertainties, providing strong evidence for our understanding of anthropogenic climate change. {Box 12.2, Box 13.1}

- The transient climate response quantifies the response of the climate system to an increasing radiative forcing on a decadal to century timescale. It is defined as the change in global mean surface temperature at the time when the atmospheric CO_2 concentration has doubled in a scenario of concentration increasing at 1% per year. The transient climate response is *likely* in the range of 1.0°C to 2.5°C (*high confidence*) and *extremely unlikely* greater than 3°C. {Box 12.2}

- A related quantity is the transient climate response to cumulative carbon emissions (TCRE). It quantifies the transient response of the climate system to cumulative carbon emissions (see Section E.8). TCRE is defined as the global mean

[16] No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies.

surface temperature change per 1000 GtC emitted to the atmosphere. TCRE is *likely* in the range of 0.8°C to 2.5°C per 1000 GtC and applies for cumulative emissions up to about 2000 GtC until the time temperatures peak (see Figure SPM.10). {12.5, Box 12.2}

- Various metrics can be used to compare the contributions to climate change of emissions of different substances. The most appropriate metric and time horizon will depend on which aspects of climate change are considered most important to a particular application. No single metric can accurately compare all consequences of different emissions, and all have limitations and uncertainties. The Global Warming Potential is based on the cumulative radiative forcing over a particular time horizon, and the Global Temperature Change Potential is based on the change in global mean surface temperature at a chosen point in time. Updated values are provided in the underlying Report. {8.7}

D.3 Detection and Attribution of Climate Change

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. {10.3–10.6, 10.9}

- It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period. {10.3}

- Greenhouse gases contributed a global mean surface warming *likely* to be in the range of 0.5°C to 1.3°C over the period 1951 to 2010, with the contributions from other anthropogenic forcings, including the cooling effect of aerosols, *likely* to be in the range of –0.6°C to 0.1°C. The contribution from natural forcings is *likely* to be in the range of –0.1°C to 0.1°C, and from natural internal variability is *likely* to be in the range of –0.1°C to 0.1°C. Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period. {10.3}

- Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (see Figure SPM.6). For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. It is *likely* that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. {2.4, 10.3}

- It is *very likely* that anthropogenic influence, particularly greenhouse gases and stratospheric ozone depletion, has led to a detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere since 1961. {2.4, 9.4, 10.3}

- It is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s (see Figure SPM.6). There is evidence for human influence in some individual ocean basins. {3.2, 10.4}

- It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content in the atmosphere (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence*), to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*), and to changes in surface and sub-surface ocean salinity (*very likely*). {2.5, 2.6, 3.3, 7.6, 10.3, 10.4}

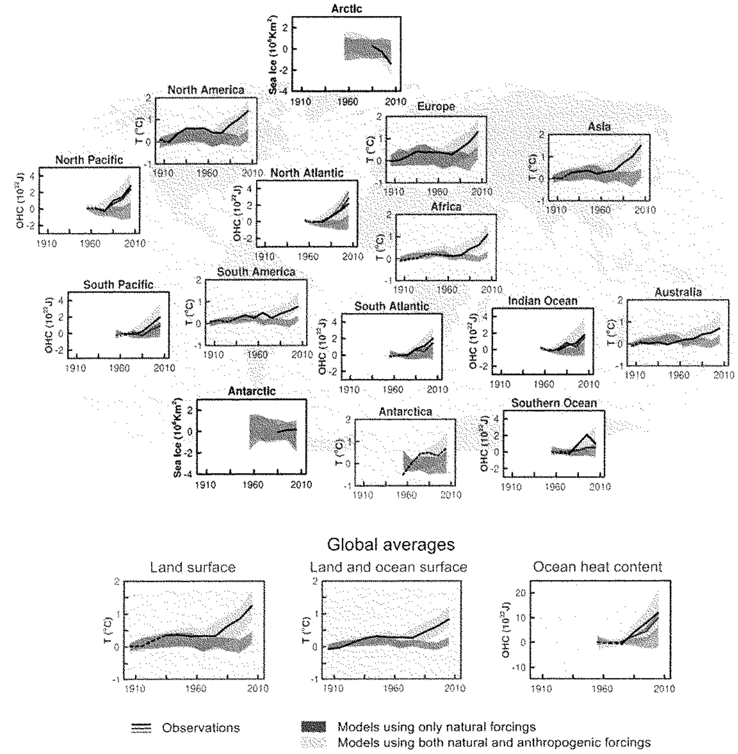

Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions see the Technical Summary Supplementary Material. {Figure 10.21; Figure TS.12}

- There has been further strengthening of the evidence for human influence on temperature extremes since the SREX. It is now *very likely* that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations (see Table SPM.1). {10.6}

- Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979. There is *low confidence* in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and *low confidence* in estimates of natural internal variability in that region (see Figure SPM.6). {10.5}

- Anthropogenic influences *likely* contributed to the retreat of glaciers since the 1960s and to the increased surface mass loss of the Greenland ice sheet since 1993. Due to a low level of scientific understanding there is *low confidence* in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. {4.3, 10.5}

- It is *likely* that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. {10.5}

- It is *very likely* that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s. This is based on the *high confidence* in an anthropogenic influence on the two largest contributions to sea level rise, that is thermal expansion and glacier mass loss. {10.4, 10.5, 13.3}

- There is *high confidence* that changes in total solar irradiance have not contributed to the increase in global mean surface temperature over the period 1986 to 2008, based on direct satellite measurements of total solar irradiance. There is *medium confidence* that the 11-year cycle of solar variability influences decadal climate fluctuations in some regions. No robust association between changes in cosmic rays and cloudiness has been identified. {7.4, 10.3, Box 10.2}

E. Future Global and Regional Climate Change

Projections of changes in the climate system are made using a hierarchy of climate models ranging from simple climate models, to models of intermediate complexity, to comprehensive climate models, and Earth System Models. These models simulate changes based on a set of scenarios of anthropogenic forcings. A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. In all RCPs, atmospheric CO_2 concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of CO_2 to the atmosphere during the 21st century (see Box SPM.1). Projections in this Summary for Policymakers are for the end of the 21st century (2081–2100) given relative to 1986–2005, unless otherwise stated. To place such projections in historical context, it is necessary to consider observed changes between different periods. Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period is 0.61 [0.55 to 0.67] °C. However, warming has occurred beyond the average of the AR5 reference period. Hence this is not an estimate of historical warming to present (see Chapter 2).

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. {6, 11–14}

- Projections for the next few decades show spatial patterns of climate change similar to those projected for the later 21st century but with smaller magnitude. Natural internal variability will continue to be a major influence on climate, particularly in the near-term and at the regional scale. By the mid-21st century the magnitudes of the projected changes are substantially affected by the choice of emissions scenario (Box SPM.1). {11.3, Box 11.1, Annex I}

- Projected climate change based on RCPs is similar to AR4 in both patterns and magnitude, after accounting for scenario differences. The overall spread of projections for the high RCPs is narrower than for comparable scenarios used in AR4 because in contrast to the SRES emission scenarios used in AR4, the RCPs used in AR5 are defined as concentration pathways and thus carbon cycle uncertainties affecting atmospheric CO_2 concentrations are not considered in the concentration-driven CMIP5 simulations. Projections of sea level rise are larger than in the AR4, primarily because of improved modelling of land-ice contributions.{11.3, 12.3, 12.4, 13.4, 13.5}

E.1 Atmosphere: Temperature

Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform (see Figures SPM.7 and SPM.8). {11.3, 12.3, 12.4, 14.8}

- The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 will *likely* be in the range of 0.3°C to 0.7°C (*medium confidence*). This assessment is based on multiple lines of evidence and assumes there will be no major volcanic eruptions or secular changes in total solar irradiance. Relative to natural internal variability, near-term increases in seasonal mean and annual mean temperatures are expected to be larger in the tropics and subtropics than in mid-latitudes (*high confidence*). {11.3}

- Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to *likely* be in the ranges derived from the concentration-driven CMIP5 model simulations, that is, 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5). The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean (*very high confidence*) (see Figures SPM.7 and SPM.8, and Table SPM.2). {12.4, 14.8}

- Relative to the average from year 1850 to 1900, global surface temperature change by the end of the 21st century is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*high confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). Warming is *unlikely* to exceed 4°C for RCP2.6, RCP4.5 and RCP6.0 (*high confidence*) and is *about as likely as not* to exceed 4°C for RCP8.5 (*medium confidence*). {12.4}

- It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is *very likely* that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur (see Table SPM.1). {12.4}

E.2 Atmosphere: Water Cycle

Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions (see Figure SPM.8). {12.4, 14.3}

- Projected changes in the water cycle over the next few decades show similar large-scale patterns to those towards the end of the century, but with smaller magnitude. Changes in the near-term, and at the regional scale will be strongly influenced by natural internal variability and may be affected by anthropogenic aerosol emissions. {11.3}

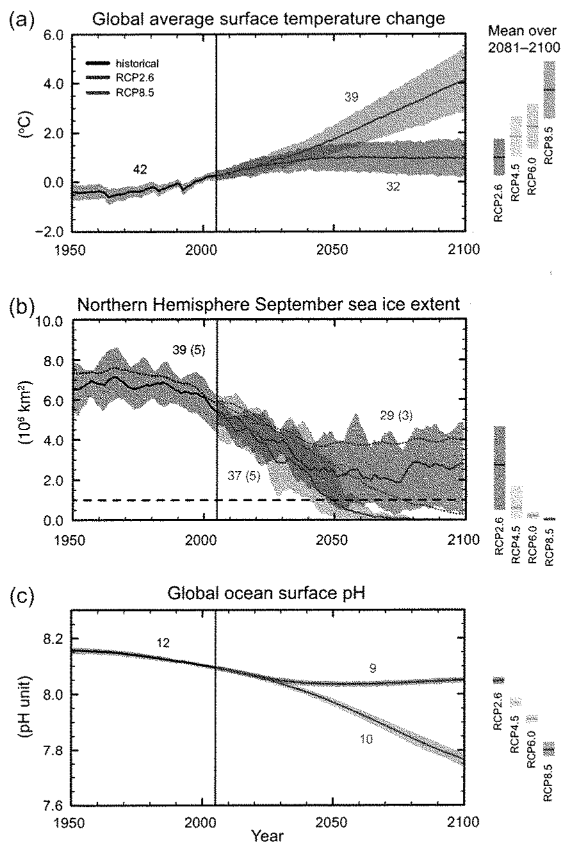

Figure SPM.7 | CMIP5 multi-model simulated time series from 1950 to 2100 for (a) change in global annual mean surface temperature relative to 1986–2005, (b) Northern Hemisphere September sea ice extent (5-year running mean), and (c) global mean ocean surface pH. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as colored vertical bars. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. For sea ice extent (b), the projected mean and uncertainty (minimum-maximum range) of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice is given (number of models given in brackets). For completeness, the CMIP5 multi-model mean is also indicated with dotted lines. The dashed line represents nearly ice-free conditions (i.e., when sea ice extent is less than 10^6 km² for at least five consecutive years). For further technical details see the Technical Summary Supplementary Material {Figures 6.28, 12.5, and 12.28–12.31; Figures TS.15, TS.17, and TS.20}

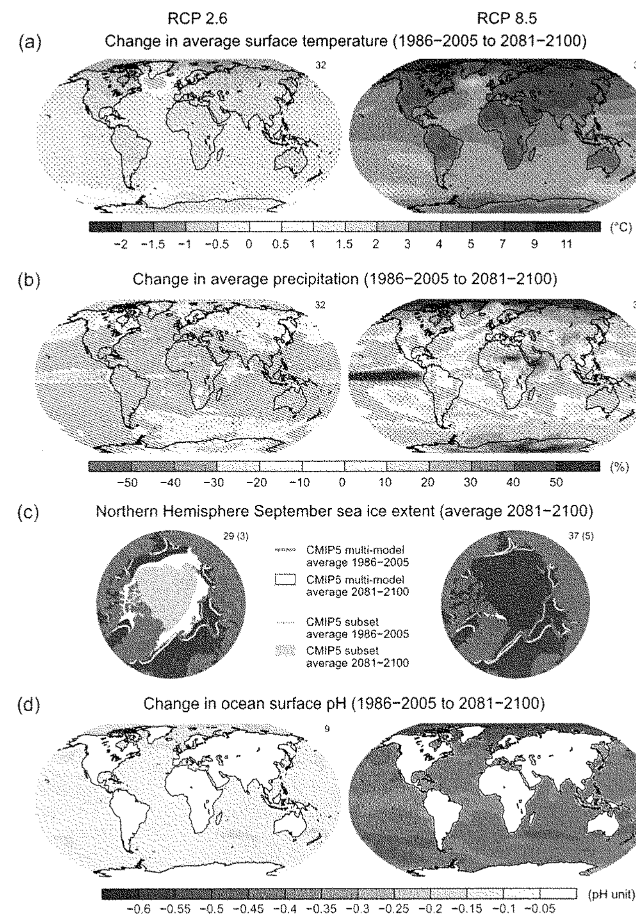

Figure SPM.8 | Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation, (c) Northern Hemisphere September sea ice extent, and (d) change in ocean surface pH. Changes in panels (a), (b) and (d) are shown relative to 1986–2005. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. For panels (a) and (b), hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change (see Box 12.1). In panel (c), the lines are the modelled means for 1986–2005; the filled areas are for the end of the century. The CMIP5 multi-model mean is given in white colour, the projected mean sea ice extent of a subset of models (number of models given in brackets) that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent is given in light blue colour. For further technical details see the Technical Summary Supplementary Material. {Figures 6.28, 12.11, 12.22, and 12.29; Figures TS.15, TS.16, TS.17, and TS.20}

- The high latitudes and the equatorial Pacific Ocean are *likely* to experience an increase in annual mean precipitation by the end of this century under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase by the end of this century under the RCP8.5 scenario (see Figure SPM.8). {7.6, 12.4, 14.3}

- Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent by the end of this century, as global mean surface temperature increases (see Table SPM.1). {7.6, 12.4}

- Globally, it is *likely* that the area encompassed by monsoon systems will increase over the 21st century. While monsoon winds are *likely* to weaken, monsoon precipitation is *likely* to intensify due to the increase in atmospheric moisture. Monsoon onset dates are *likely* to become earlier or not to change much. Monsoon retreat dates will *likely* be delayed, resulting in lengthening of the monsoon season in many regions. {14.2}

- There is *high confidence* that the El Niño-Southern Oscillation (ENSO) will remain the dominant mode of interannual variability in the tropical Pacific, with global effects in the 21st century. Due to the increase in moisture availability, ENSO-related precipitation variability on regional scales will *likely* intensify. Natural variations of the amplitude and spatial pattern of ENSO are large and thus *confidence* in any specific projected change in ENSO and related regional phenomena for the 21st century remains *low*. {5.4, 14.4}

Table SPM.2 | Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005. {12.4; Table 12.2, Table 13.5}

		2046–2065		2081–2100	
	Scenario	**Mean**	***Likely* range[c]**	**Mean**	***Likely* range[c]**
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range[d]**	**Mean**	***Likely* range[d]**
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes:

[a] Based on the CMIP5 ensemble; anomalies calculated with respect to 1986–2005. Using HadCRUT4 and its uncertainty estimate (5–95% confidence interval), the observed warming to the reference period 1986–2005 is 0.61 [0.55 to 0.67] °C from 1850–1900, and 0.11 [0.09 to 0.13] °C from 1980–1999, the reference period for projections used in AR4. *Likely* ranges have not been assessed here with respect to earlier reference periods because methods are not generally available in the literature for combining the uncertainties in models and observations. Adding projected and observed changes does not account for potential effects of model biases compared to observations, and for natural internal variability during the observational reference period {2.4; 11.2; Tables 12.2 and 12.3}

[b] Based on 21 CMIP5 models; anomalies calculated with respect to 1986–2005. Where CMIP5 results were not available for a particular AOGCM and scenario, they were estimated as explained in Chapter 13, Table 13.5. The contributions from ice sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as largely independent of scenario. This treatment does not imply that the contributions concerned will not depend on the scenario followed, only that the current state of knowledge does not permit a quantitative assessment of the dependence. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

[c] Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean surface temperature change in 2046–2065 *confidence* is *medium*, because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for 2081–2100. The *likely* ranges for 2046–2065 do not take into account the possible influence of factors that lead to the assessed range for near-term (2016–2035) global mean surface temperature change that is lower than the 5–95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding. {11.3}

[d] Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean sea level rise *confidence* is *medium* for both time horizons.

SPM

E.3 Atmosphere: Air Quality

- The range in projections of air quality (ozone and PM2.5[17] in near-surface air) is driven primarily by emissions (including CH_4), rather than by physical climate change (*medium confidence*). There is *high confidence* that globally, warming decreases background surface ozone. High CH_4 levels (as in RCP8.5) can offset this decrease, raising background surface ozone by year 2100 on average by about 8 ppb (25% of current levels) relative to scenarios with small CH_4 changes (as in RCP4.5 and RCP6.0) (*high confidence*). {11.3}

- Observational and modelling evidence indicates that, all else being equal, locally higher surface temperatures in polluted regions will trigger regional feedbacks in chemistry and local emissions that will increase peak levels of ozone and PM2.5 (*medium confidence*). For PM2.5, climate change may alter natural aerosol sources as well as removal by precipitation, but no confidence level is attached to the overall impact of climate change on PM2.5 distributions. {11.3}

E.4 Ocean

The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation. {11.3, 12.4}

- The strongest ocean warming is projected for the surface in tropical and Northern Hemisphere subtropical regions. At greater depth the warming will be most pronounced in the Southern Ocean (*high confidence*). Best estimates of ocean warming in the top one hundred meters are about 0.6°C (RCP2.6) to 2.0°C (RCP8.5), and about 0.3°C (RCP2.6) to 0.6°C (RCP8.5) at a depth of about 1000 m by the end of the 21st century. {12.4, 14.3}

- It is *very likely* that the Atlantic Meridional Overturning Circulation (AMOC) will weaken over the 21st century. Best estimates and ranges[18] for the reduction are 11% (1 to 24%) in RCP2.6 and 34% (12 to 54%) in RCP8.5. It is *likely* that there will be some decline in the AMOC by about 2050, but there may be some decades when the AMOC increases due to large natural internal variability. {11.3, 12.4}

- It is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century for the scenarios considered. There is *low confidence* in assessing the evolution of the AMOC beyond the 21st century because of the limited number of analyses and equivocal results. However, a collapse beyond the 21st century for large sustained warming cannot be excluded. {12.5}

E.5 Cryosphere

It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease. {12.4, 13.4}

- Year-round reductions in Arctic sea ice extent are projected by the end of the 21st century from multi-model averages. These reductions range from 43% for RCP2.6 to 94% for RCP8.5 in September and from 8% for RCP2.6 to 34% for RCP8.5 in February (*medium confidence*) (see Figures SPM.7 and SPM.8). {12.4}

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[17] PM2.5 refers to particulate matter with a diameter of less than 2.5 micrometres, a measure of atmospheric aerosol concentration.

[18] The ranges in this paragraph indicate a CMIP5 model spread.

SPM

- Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent, a nearly ice-free Arctic Ocean[19] in September before mid-century is *likely* for RCP8.5 (*medium confidence*) (see Figures SPM.7 and SPM.8). A projection of when the Arctic might become nearly ice-free in September in the 21st century cannot be made with confidence for the other scenarios. {11.3, 12.4, 12.5}

- In the Antarctic, a decrease in sea ice extent and volume is projected with *low confidence* for the end of the 21st century as global mean surface temperature rises. {12.4}

- By the end of the 21st century, the global glacier volume, excluding glaciers on the periphery of Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (*medium confidence*). {13.4, 13.5}

- The area of Northern Hemisphere spring snow cover is projected to decrease by 7% for RCP2.6 and by 25% in RCP8.5 by the end of the 21st century for the model average (*medium confidence*). {12.4}

- It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases. By the end of the 21st century, the area of permafrost near the surface (upper 3.5 m) is projected to decrease by between 37% (RCP2.6) to 81% (RCP8.5) for the model average (*medium confidence*). {12.4}

E.6 Sea Level

Global mean sea level will continue to rise during the 21st century (see Figure SPM.9). Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets. {13.3–13.5}

- Confidence in projections of global mean sea level rise has increased since the AR4 because of the improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes. {13.3–13.5}

- Global mean sea level rise for 2081–2100 relative to 1986–2005 will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5 (*medium confidence*). For RCP8.5, the rise by the year 2100 is 0.52 to 0.98 m, with a rate during 2081 to 2100 of 8 to 16 mm yr^{-1} (*medium confidence*). These ranges are derived from CMIP5 climate projections in combination with process-based models and literature assessment of glacier and ice sheet contributions (see Figure SPM.9, Table SPM.2). {13.5}

- In the RCP projections, thermal expansion accounts for 30 to 55% of 21st century global mean sea level rise, and glaciers for 15 to 35%. The increase in surface melting of the Greenland ice sheet will exceed the increase in snowfall, leading to a positive contribution from changes in surface mass balance to future sea level (*high confidence*). While surface melting will remain small, an increase in snowfall on the Antarctic ice sheet is expected (*medium confidence*), resulting in a negative contribution to future sea level from changes in surface mass balance. Changes in outflow from both ice sheets combined will *likely* make a contribution in the range of 0.03 to 0.20 m by 2081–2100 (*medium confidence*). {13.3–13.5}

- Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. However, there is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century. {13.4, 13.5}

[19] Conditions in the Arctic Ocean are referred to as nearly ice-free when the sea ice extent is less than 10^6 km^2 for at least five consecutive years.

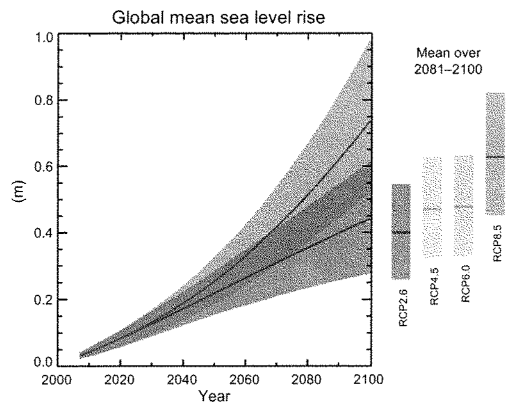

Figure SPM.9 | Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed *likely* range is shown as a shaded band. The assessed *likely* ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. For further technical details see the Technical Summary Supplementary Material {Table 13.5, Figures 13.10 and 13.11; Figures TS.21 and TS.22}

- The basis for higher projections of global mean sea level rise in the 21st century has been considered and it has been concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed *likely* range. Many semi-empirical model projections of global mean sea level rise are higher than process-based model projections (up to about twice as large), but there is no consensus in the scientific community about their reliability and there is thus *low confidence* in their projections. {13.5}

- Sea level rise will not be uniform. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change. {13.1, 13.6}

E.7 Carbon and Other Biogeochemical Cycles

Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere (*high confidence*). Further uptake of carbon by the ocean will increase ocean acidification. {6.4}

- Ocean uptake of anthropogenic CO_2 will continue under all four RCPs through to 2100, with higher uptake for higher concentration pathways (*very high confidence*). The future evolution of the land carbon uptake is less certain. A majority of models projects a continued land carbon uptake under all RCPs, but some models simulate a land carbon loss due to the combined effect of climate change and land use change. {6.4}

- Based on Earth System Models, there is *high confidence* that the feedback between climate and the carbon cycle is positive in the 21st century; that is, climate change will partially offset increases in land and ocean carbon sinks caused by rising atmospheric CO_2. As a result more of the emitted anthropogenic CO_2 will remain in the atmosphere. A positive feedback between climate and the carbon cycle on century to millennial time scales is supported by paleoclimate observations and modelling. {6.2, 6.4}

Table SPM.3 | Cumulative CO_2 emissions for the 2012 to 2100 period compatible with the RCP atmospheric concentrations simulated by the CMIP5 Earth System Models. {6.4, Table 6.12, Figure TS.19}

Scenario	Cumulative CO_2 Emissions 2012 to 2100[a]			
	GtC		$GtCO_2$	
	Mean	Range	Mean	Range
RCP2.6	270	140 to 410	990	510 to 1505
RCP4.5	780	595 to 1005	2860	2180 to 3690
RCP6.0	1060	840 to 1250	3885	3080 to 4585
RCP8.5	1685	1415 to 1910	6180	5185 to 7005

Notes:
[a] 1 Gigatonne of carbon = 1 GtC = 10^{15} grams of carbon. This corresponds to 3.667 $GtCO_2$.

- Earth System Models project a global increase in ocean acidification for all RCP scenarios. The corresponding decrease in surface ocean pH by the end of 21st century is in the range[18] of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0, and 0.30 to 0.32 for RCP8.5 (see Figures SPM.7 and SPM.8). {6.4}

- Cumulative CO_2 emissions[20] for the 2012 to 2100 period compatible with the RCP atmospheric CO_2 concentrations, as derived from 15 Earth System Models, range[18] from 140 to 410 GtC for RCP2.6, 595 to 1005 GtC for RCP4.5, 840 to 1250 GtC for RCP6.0, and 1415 to 1910 GtC for RCP8.5 (see Table SPM.3). {6.4}

- By 2050, annual CO_2 emissions derived from Earth System Models following RCP2.6 are smaller than 1990 emissions (by 14 to 96%). By the end of the 21st century, about half of the models infer emissions slightly above zero, while the other half infer a net removal of CO_2 from the atmosphere. {6.4, Figure TS.19}

- The release of CO_2 or CH_4 to the atmosphere from thawing permafrost carbon stocks over the 21st century is assessed to be in the range of 50 to 250 GtC for RCP8.5 (*low confidence*). {6.4}

E.8 Climate Stabilization, Climate Change Commitment and Irreversibility

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond (see Figure SPM.10). Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2. {12.5}

- Cumulative total emissions of CO_2 and global mean surface temperature response are approximately linearly related (see Figure SPM.10). Any given level of warming is associated with a range of cumulative CO_2 emissions[21], and therefore, e.g., higher emissions in earlier decades imply lower emissions later. {12.5}

- Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of >33%, >50%, and >66% to less than 2°C since the period 1861–1880[22], will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1570 GtC (5760 $GtCO_2$), 0 and about 1210 GtC (4440 $GtCO_2$), and 0 and about 1000 GtC (3670 $GtCO_2$) since that period, respectively[23]. These upper amounts are reduced to about 900 GtC (3300 $GtCO_2$), 820 GtC (3010 $GtCO_2$), and 790 GtC (2900 $GtCO_2$), respectively, when accounting for non-CO_2 forcings as in RCP2.6. An amount of 515 [445 to 585] GtC (1890 [1630 to 2150] $GtCO_2$), was already emitted by 2011. {12.5}

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[20] From fossil fuel, cement, industry, and waste sectors.

[21] Quantification of this range of CO_2 emissions requires taking into account non-CO_2 drivers.

[22] The first 20-year period available from the models.

[23] This is based on the assessment of the transient climate response to cumulative carbon emissions (TCRE, see Section D.2).

SPM

- A lower warming target, or a higher likelihood of remaining below a specific warming target, will require lower cumulative CO_2 emissions. Accounting for warming effects of increases in non-CO_2 greenhouse gases, reductions in aerosols, or the release of greenhouse gases from permafrost will also lower the cumulative CO_2 emissions for a specific warming target (see Figure SPM.10). {12.5}

- A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Due to the long time scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years. {Box 6.1, 12.4, 12.5}

- It is *virtually certain* that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries. The few available model results that go beyond 2100 indicate global mean sea level rise above the pre-industrial level by 2300 to be less than 1 m for a radiative forcing that corresponds to CO_2 concentrations that peak and decline and remain below 500 ppm, as in the scenario RCP2.6. For a radiative forcing that corresponds to a CO_2 concentration that is above 700 ppm but below 1500 ppm, as in the scenario RCP8.5, the projected rise is 1 m to more than 3 m (*medium confidence*). {13.5}

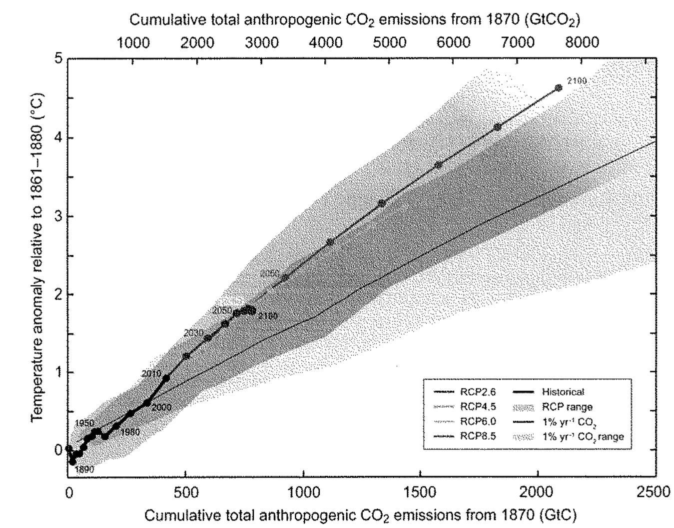


Figure SPM.10 | Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labeled for clarity (e.g., 2050 indicating the decade 2040–2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO_2 increase of 1% per year (1% yr^{-1} CO_2 simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO_2 emissions, the 1% per year CO_2 simulations exhibit lower warming than those driven by RCPs, which include additional non-CO_2 forcings. Temperature values are given relative to the 1861–1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines. For further technical details see the Technical Summary Supplementary Material. {Figure 12.45; TS TFE.8, Figure 1}

- Sustained mass loss by ice sheets would cause larger sea level rise, and some part of the mass loss might be irreversible. There is *high confidence* that sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming with respect to pre-industrial. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment. {5.8, 13.4, 13.5}

- Methods that aim to deliberately alter the climate system to counter climate change, termed geoengineering, have been proposed. Limited evidence precludes a comprehensive quantitative assessment of both Solar Radiation Management (SRM) and Carbon D ioxide Removal (CDR) and their impact on the climate system. CDR methods have biogeochemical and technological limitations to their potential on a global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce ocean acidification. If SRM were terminated for any reason, there is *high confidence* that global surface temperatures would rise very rapidly to values consistent with the greenhouse gas forcing. CDR and SRM methods carry side effects and long-term consequences on a global scale. {6.5, 7.7}

SPM

Box SPM.1: Representative Concentration Pathways (RCPs)

Climate change projections in IPCC Working Group I require information about future emissions or concentrations of greenhouse gases, aerosols and other climate drivers. This information is often expressed as a scenario of human activities, which are not assessed in this report. Scenarios used in Working Group I have focused on anthropogenic emissions and do not include changes in natural drivers such as solar or volcanic forcing or natural emissions, for example, of CH_4 and N_2O.

For the Fifth Assessment Report of IPCC, the scientific community has defined a set of four new scenarios, denoted Representative Concentration Pathways (RCPs, see Glossary). They are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W m^{-2} for RCP2.6, 4.5 W m^{-2} for RCP4.5, 6.0 W m^{-2} for RCP6.0, and 8.5 W m^{-2} for RCP8.5. For the Coupled Model Intercomparison Project Phase 5 (CMIP5) results, these values should be understood as indicative only, as the climate forcing resulting from all drivers varies between models due to specific model characteristics and treatment of short-lived climate forcers. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5). The RCPs can thus represent a range of 21st century climate policies, as compared with the no-climate policy of the Special Report on Emissions Scenarios (SRES) used in the Third Assessment Report and the Fourth Assessment Report. For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100. Each RCP provides spatially resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models. While the RCPs span a wide range of total forcing values, they do not cover the full range of emissions in the literature, particularly for aerosols.

Most of the CMIP5 and Earth System Model simulations were performed with prescribed CO_2 concentrations reaching 421 ppm (RCP2.6), 538 ppm (RCP4.5), 670 ppm (RCP6.0), and 936 ppm (RCP 8.5) by the year 2100. Including also the prescribed concentrations of CH_4 and N_2O, the combined CO_2-equivalent concentrations are 475 ppm (RCP2.6), 630 ppm (RCP4.5), 800 ppm (RCP6.0), and 1313 ppm (RCP8.5). For RCP8.5, additional CMIP5 Earth System Model simulations are performed with prescribed CO_2 emissions as provided by the integrated assessment models. For all RCPs, additional calculations were made with updated atmospheric chemistry data and models (including the Atmospheric Chemistry and Climate component of CMIP5) using the RCP prescribed emissions of the chemically reactive gases (CH_4, N_2O, HFCs, NO_x, CO, NMVOC). These simulations enable investigation of uncertainties related to carbon cycle feedbacks and atmospheric chemistry.

U.S. Fish & Wildlife Service

Migratory Bird Mortality

Many Human-Caused Threats Afflict our Bird Populations

Migratory Bird Management

Mission

To conserve migratory bird populations and their habitats for future generations, through careful monitoring and effective management.

Are Birds in Danger?
Of the 836 species of birds protected under the Migratory Bird Treaty Act, about a quarter are known to be in trouble. There are 78 bird species listed as Endangered and 14 species listed as Threatened in the U.S. An additional 144 species are on the National list of Birds of Conservation Concern 2001 (some whose populations are declining precipitously). It cannot be assumed that the remainder of U.S. birds are safe, as population data on essentially a third of these species are lacking, making status determination very difficult if not impossible. The problems that birds face in the U.S. are symptomatic of the problems they face globally.

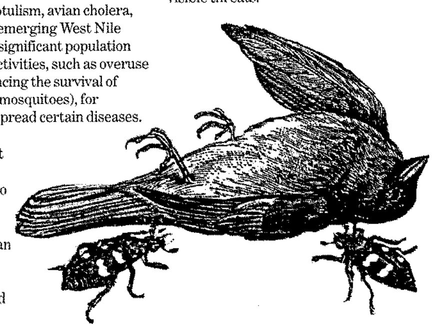
What Are the Human-Caused Threats to Birds?
Birds face tremendous challenges to their survival every day. The majority of these challenges are related to human activities. Vast numbers of birds are killed due to collisions with human structures and equipment, poisoning by pesticides and contaminants, and attacks by cats and other introduced predators.

Diseases such as botulism, avian cholera, salmonellosis, and emerging West Nile virus can also have significant population impacts. Human activities, such as overuse of pesticides (enhancing the survival of pesticide-resistant mosquitoes), for example, can help spread certain diseases.

The greatest threat to birds, and all wildlife, continues to be loss and/or degradation of habitat due to human development and disturbance. For migratory birds and other species that require multiple areas for wintering, breeding, and stopover points, the effects of habitat loss can be complex and far-reaching.

Added to deaths from natural causes, such as adverse weather, predation, or starvation, human-related bird deaths may result in greater mortality than a population can withstand. In other words, it is the cumulative or combined impact of all mortality factors that concerns scientists most. Thus, anything done to reverse human-related bird deaths – and thus potential impacts to bird populations – are of considerable interest to the Service.

How Many Birds are Killed?
The U.S. Fish and Wildlife Service estimates that a minimum of 10 billion birds breed in North America. Fall populations may be on the order of 20 billion. These figures represent only educated guesses. Mortality figures are also difficult to determine. Based on modeling and other approaches, estimates have been made for some of the most visible threats.



Collisions. Building window strikes may account for 97 to 976 million bird deaths each year. Communication towers conservatively kill 4 to 5 million birds annually (possibly closer to 40 to 50 million; a nationwide cumulative impacts study should help resolve this question). Strikes at high tension transmission and distribution power lines very conservatively kill tens of thousands of birds annually. Taking into account the millions of miles of bulk transmission and distribution lines in the U.S., and extrapolating from European studies, actual mortality could be as high as 174 million deaths annually. Electrocutions probably kill tens of thousands of birds but the problem is barely monitored. Cars may kill 60 million birds or more each year, private and commercial aircraft far fewer, while wind turbine rotors kill an estimated 33,000 birds annually.

Poisoning. In one recent study, pesticides were estimated to result in the direct deaths of at least 72 million birds annually. This is an underestimate of the total deaths, given that delayed deaths from poisoned prey, orphaned chicks, and neurological problems were not included and the study site was limited. Oil spills may kill hundreds of thousands or more, depending on the severity and timing of the spill. Up to two million birds are killed annually in oil and wastewater pits, mainly in the western states.

Cats. Many citizens would be surprised to learn that domestic and feral cats may kill hundreds of millions of songbirds and other avian species each year. A recent study in Wisconsin estimated that in that state alone, domestic rural cats kill roughly 39 million birds annually. Add the deaths caused by feral cats, or domestic cats in urban and suburban areas, and this mortality figure would be much higher.

Cats cause tremendous bird mortality.

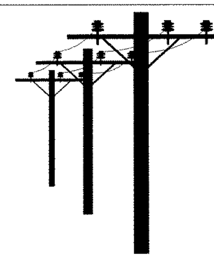
By-Catch. Tens to hundreds of thousands of seabirds are estimated to die in U.S. fisheries each year. Monitoring for this, however, is again very limited.

What Are We Doing to Reduce Mortality?
While the "incidental, accidental or unintentional take" of migratory birds is not permitted by the Service and is a criminal violation of the Migratory Bird Treaty Act, the Service attempts to work with those industries and individuals whose actions result in bird deaths, rather than pursuing criminal prosecution first.

For over 25 years, the Service has been a *co-founding partner of the Avian Power Line Interaction Committee* helping develop two voluntary guidance documents to reduce bird strikes and electrocutions. More recently, the Service *co-founded the Avian Subcommittee of the National Wind Coordinating Committee*, working to reduce bird strikes at wind turbines, and we *founded and chair the Communication Tower Working Group*, working to reduce bird strikes at communication towers. We also *co-chair the Interagency Seabird Working Group*, implementing a national plan of action to reduce seabird bycatch in longline fishing gear.

Because of jurisdictional and ownership issues, working to reduce cat-caused mortality, building window strikes, and oil spills is a more complex undertaking. Here, we *support initiatives such as the Cats Indoors Program and the Fatal Light Awareness Program*, which encourages building owners to turn off skyscraper lights during spring and fall night-time songbird migrations. For threats that can be addressed by individual citizen action, we design public education materials with related messages such as encouraging homeowners to reduce home pesticide use and consumers to select environmentally-friendly products, such as shade-grown coffee.

Declining bird populations are probably most often the result of combined or cumulative impacts of all mortality, thus addressing each of the contributing factors is a priority.



Close-phased wires are a potential electrocution hazard.

What Else Is Needed to Reduce Mortality?
Research is critical. In the case of collisions, for example, we don't understand specifically how light attracts birds to communication towers, tall buildings, wind turbines, transmission towers, or other lit structures. We need to learn if deterrents such as low-frequency sound, colored markers, or structural modifications reduce avian collisions. We also lack an understanding of how birds select stopover areas during spring and fall migrations. Without it, we cannot effectively manage habitats and recommend against building new structures in critical bird-use areas. Above all, the cumulative impacts of collisions on bird populations must be assessed– they are currently unknown. With the exponential increase in new structures, avian monitoring must be a priority. All of this information should be transmitted to land managers, industry representatives, and affected agencies.

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Migratory birds are some of nature's most magnificent resources. Their conservation is a critical and challenging endeavor for the Migratory Bird Management Program and all who value nature.

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Division of Migratory Bird Management
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January 2002

Senator WHITEHOUSE. So with that, I turn to my distinguished ranking member.

Senator INHOFE. I would like to ask the question, then, how many of those birds you referred to are bald eagles.

Mr. Bryce, I really enjoyed your testimony. In my opening statement I said some of the things that you had repeated, or I think we got that from you, concerning the extensive land that is used by renewable fuels as opposed to the traditional fuels. Is there anything you would like to say, how can we justify all the land that is used for renewables as opposed to traditional forms? And I refer to oil and gas.

Mr. BRYCE. Thank you, Senator.

My short response, sir, is density is green. Regardless of your stance on environmental issues, left, right, center, we can all agree that small footprints are ideal. And that is where I part with the traditional left and the green left when it comes to the issue of energy production. I have a new book coming out in May in which I break this down. The power density of energy is 1 watt per square meter. To replace coal-fired power plants in the United States, then, if we wanted to replace them all with wind energy, it would require setting aside a land area the size of Italy.

With regard to renewable fuels and biofuels, I have been a longtime of the corn ethanol scam. Why? Because the power density is simply too low. Further, from a moral standpoint, I reject the idea of burning food to make fuel.

But the problem, sir, is fundamentally, again, basic physics and basic math. We don't have enough land, because the power density is so low, to make significant quantities of energy based on renewable energy in general, but particularly wind energy and biofuels.

Senator INHOFE. And I appreciate that very much. I would like to, let me just go ahead and, Dr. Moore, when you talked about the various ages that we went through, I often use the one very close to what you said, I would say in 1895, we went into a period of time that was a cold period, and from about 1918 to 1945 a warmer period, from 1945 to in the 1970's, a cooler period. The interesting thing about that is, the greatest surge in emissions of CO_2 happened right at the end of, during and at the end of World War II, which precipitated, not a warm period but a cooler period, is that correct?

Dr. MOORE. There certainly was a pause at that time. It went up and down. But CO_2 emissions have continuously increased since they began in earnest after the Second World War. I think the pause that is occurring now is actually more fundamental in terms of, why isn't the temperature continuing to increase like it did between 1970 and 2000? It has basically just leveled off flat, even though CO_2 emissions continue to increase, not just continue to accumulate, but continue to increase.

Senator INHOFE. The same thing that has been going on since the turn of the century, 2000, for the last 10, 12 years.

Mr. MOORE. Correct. Actually, if you look at the last 17 years, from 1996, it is flat. So this is the thing that everybody is struggling to explain, and people who still firmly believe that humans are the main cause are coming up with, there are 14 explanations now that have been put forward, some of which actually contradict each other.

So it is a bit of an act of desperation, because one of the real problems was when the IPCC was first set up, it only included the World Meteorological Organization, which is meteorologists who are always concerned with very short time spans of what is going to happen in the next 5 days, and the United Nations Environment Program, which is environmentalists. So weathermen and environmentalists got control of the whole climate change agenda.

At the same time, their mandate was only to look at human effects on climate change, rather than the vast number of natural effects that have been affecting climate change since the beginning of the earth.

Senator INHOFE. And reference has been made to IPCC several times during the course of this hearing. I suggest to you, and I would ask you if you agree, when you talk about IPCC, you are talking about United Nations, that is where this thing started. And I would suggest to my chairman, as long as we are putting things into the record, unless there is some reason that it can't be done, I would like to have the last chapter of my book called The Greatest Hoax, it is on the history of the IPCC and the United Nations entered into the record also.

Senator WHITEHOUSE. I can't see any reason why it shouldn't be, and assuming there is none, it will be, without objection.

Senator INHOFE. Very good.

[The referenced information was not recieved at time of print.]

Senator INHOFE. I think it is really important to look at this and realize, the IPCC, whatever happened to Climate Gate? The media just drops this thing, and yet that was totally discredited during that period of time. We had a witness here that had a background with MIT. One of the lead scientists with MIT is one that totally contradicted, Richard Lindsay, that is right.

So anyway, I just hope that we can look at this realistically, and when you stop and realize no one is taking an issue with this, that since we started talking about the legislation that would do what the President is trying to do right now through regulation, since he couldn't get it through, one of the reasons was that the science is not settled. And the second reason is that people agree, they understand that the cost of this, if they would implement the cap and trade as proposed in legislation, the cost would be somewhere between $300 billion and $400 billion a year. And as our own administrator of the EPA said, the first one appointed by President Obama, it really wouldn't make any difference what we do here in the United States, because this isn't where the problem is. That isn't a question, other than think about it.

Thank you, Mr. Chairman.

Senator WHITEHOUSE. Thank you very much. Thank you very much, Ranking Member Inhofe. As any witness in this proceeding and frankly, any previous witness of prior proceedings in this committee will know, there are widely divergent views of the world reflected here. You see it in its full flourish today as well.

So I will bring this hearing to conclusion. The record will remain open for an additional 2 weeks. I will also add a statement for the record of the U.S. Geological Survey, Department of the Interior, and there is also a collection of data regarding the funding sources of the Manhattan Institute for Policy Research.

[The referenced information follows:]

STATEMENT FOR THE RECORD
U.S. GEOLOGICAL SURVEY
DEPARTMENT OF THE INTERIOR
BEFORE THE
SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
SUBCOMMITTEE ON OVERSIGHT
REGARDING
NATURAL RESOURCE ADAPTATION: PROTECTING ECOSYSTEMS AND ECONOMIES

February 25, 2014

The USGS has played a key role in advancing climate change science since long before there was such a discipline. The USGS works closely with partners from all levels of Government, the private and non-profit sectors, and even individual citizens to ensure that our research informs decisions for mitigating and adapting to climate change. Some of our work, such as our base maps of landscapes and watersheds, go back to our founding 130 years ago. A number of our streamgages have been measuring streamflow for over 100 years. The archive of Landsat mid-resolution land imagery goes back over 40 years and is the longest such continuous record. Hundreds of partners rely on our expertise in collecting and interpreting exceptional data sets about the Earth and its processes. It is our perspective that such data should be the starting point of any discussion of global climate change.

Through ongoing collection of data, we are developing a better understanding of the patterns of that change and its impacts on critical natural resources. ("Global change" is sometimes used more generally to describe change in climate, land use and land cover, ecosystems, and human society. For our purposes today, "climate change" and "global change" are the same.) "Stressors," "drivers," and "inputs" are the factors affecting an Earth system. Changes in one system have impacts that in turn alter other systems; current research is investigating the nature of these feedbacks.

Climate Change Impacts

Global climate change is affecting weather, plants and animals, ecosystems and agriculture, and infrastructure. The most recent decade was the warmest on record for the United States, and the number of annual frost-free days has been increasing since the 1980s. Overall precipitation has increased for the country, and the timing and intensity of precipitation events have also changed, resulting in increased seasonal flooding and drought for several U.S. regions.

Climate change affects at what elevation pine trees grow, how far north reptiles can survive, when flowers bloom, when snow stops and rain begins, how long bears hibernate, and how quickly a virus can spread. Such climate-influenced changes in ecosystems have both direct and indirect effects on human health and livelihoods, including impacts to food production from fisheries, pollination, storm surge protection provided by coastal habitats, clean water, and recreational and tourism opportunities.

A specific example is the change in the fire regime of the western United States. Warmer temperatures, reduced snowpack, and earlier onset of springtime are leading to increased wildfire activity in a region that has already experienced extended drought over the past decades. Warmer winter conditions allow naturally occurring bark beetles to breed more frequently and successfully, and the dead trees left behind by these beetles make extensive crown fires more likely. In 2011, the Las Conchas wildfire in New Mexico resulted in the loss of vegetation that would otherwise decrease erosion from hillsides. Sediment and ash eroded by post-fire floods were washed downstream into the Rio Grande, which supplies 50% of the drinking water for Albuquerque. Water withdrawals by the city from the Rio Grande were stopped entirely for a week and were reduced for several months, due to the increased cost of treating water with high sediment content.

As this example illustrates, climate change impacts can create complex chains of events and often cross jurisdictional boundaries, so coordination of science and planning activities is essential to ensure that conservation and management goals are met. Such coordination is an important part of the USGS mission, and we have undertaken several efforts to implement it.

Coordinated Activities

In 2009 the Secretary of the Interior issued Secretarial Order 3289 to better coordinate climate activities across the bureaus within Interior. The order identified Climate Science Centers (CSCs) as Department entities, with the intent of providing support for a full range of DOI resources. It also identified the Landscape Conservation Cooperatives (LCCs) as similarly Department-wide assets. Funding for the CSCs is focused on fish, wildlife and their habitats. The CSCs are consortia of universities partnered with the USGS. They are overseen by the National Climate Change and Wildlife Science Center (NCCWSC), which was established as part of the development of climate change adaptation strategies over the last decade. The CSCs and the NCCWSC are supported by Congressional appropriations but do not have permanent statutory authority. As outlined in the President's FY2014 budget request, the USGS works with the DOI CSCs to develop actionable science and enhance the coordination of regional climate science with decision makers, develop vulnerability assessments as a key component of adaptation planning, and build closer ties with tribal science needs.

One important activity of the recently created DOI CSCs is to provide regional coordination of climate adaptation science. At all levels of government, and especially within natural resource and environmental management agencies, both management attention and scientific resources are being directed to understanding and planning for climate change. Regional coordination of these climate activities is important to ensure that all agencies make effective use of limited resources and to eliminate redundancy in climate research.

The National Research Council in 2009 recommended strengthening links between the science community and decision makers, and focusing more on users' needs. These recommendations are important parts of conducting actionable science. The CSCs work closely with our partners, including the LCCs and the NOAA Regional Integrated Science and Assessments program, to identify on-the-ground needs for climate science for adaptation. We will continue building such relationships with other climate change activities across the Government.

In 2013, the President's Climate Action Plan highlighted the importance of providing actionable science, and also of identifying vulnerable people, places, and resources, and being climate-smart about the response to disasters like Superstorm Sandy. The USGS incorporates these goals into many science areas. For example, we are developing basic information about carbon storage in ecosystems and geologic basins and are building a visualization tool to assist managers in understanding how their decisions will affect carbon storage, helping to advance the President's goal of increasing the storage of carbon on public lands. We also play a role in the President's climate data initiative through long-term Earth observing systems such as the streamgage network and the Landsat satellites. The streamgage network has about 8,000 stations and many have been operating for up to 80 years, with some of the oldest records going back over a century. Landsat represents a major data collection supporting the climate data initiative and will be used to identify land uses and regions in the Nation that are most vulnerable to or resilient in the face of climate change. Landsat provides land use and climate change information needed to optimize the production of renewable fuels, respond to changing patterns of wildfire occurrence and water availability, reduce carbon pollution, sustain natural resources, and develop climate adaptation plans.

Below are specific examples of potential climate change impacts on the Nation's natural resources and of tools the USGS is developing to enable decision makers to mitigate and adapt to these impacts. This is certainly not an exhaustive list.

Western Trout Fisheries

The USGS, working closely with the U.S. Forest Service, Trout Unlimited, and academic partners, has been studying the potential influences of climate change on western trout populations. Trout fishing just in Idaho and New Mexico generates nearly $900 million annually. Trout depend on an ample supply of clean, cold water for survival. Many of the trout species in the West such as cutthroat trout, bull trout, Gila trout, and Apache trout, have already been affected by land-use change, introduction of non-native species, water withdrawal and other factors, leading to the protection of some species or subspecies under the U.S. Endangered Species Act.

However, resource managers need answers to specific questions. What are the potential impacts of climate change to trout and can we identify the potential geographic locations where trout populations could be most impacted? Recent results from our collaborative research on western trout species and subspecies suggest that all species examined have a high risk of potential impact from either climate change—such as drought, wildfire, summer temperatures or winter floods—throughout some portion of their range. The challenge that lies ahead is how these results can be integrated into development of effective adaptation plans. As outlined previously, the implementation of an actionable science approach will help the Nation achieve effective adaptation planning for western trout species.

Vulnerability Assessments

Effective climate adaptation strategies and management responses require a good understanding of how ecosystems are likely to respond to climate change. Climate change vulnerability assessment tools are being used to identify species and habitats at greatest risk from climate change, to help us understand why they are vulnerable, and to inform conservation strategies designed to reduce those vulnerabilities. These strategies may range from maintaining the most vulnerable species and ecosystems, to investing in those most resilient to changes and likely to persist.

The USGS, in concert with partner agencies across government, has planned a searchable, public registry on climate change vulnerability assessments. The goal is to make information about ongoing and completed assessments more readily available, so that resources devoted to such assessments can be most efficiently used. Currently, the plan is to bring in vulnerability assessments from beyond the Federal government. Paperwork is proceeding through the Federal Register process to open the registry to all sources of vulnerability assessments.

While our understanding of climate impacts in a changing world has advanced significantly, important challenges remain for future response planning, including maintaining long-term monitoring networks with limited resources; refining models that couple climate and natural resource management to improve science available for decisions; and closing gaps in the global carbon budget to improve forecasts of climate change. We look forward to further discussions with the committee on this matter.

For more information

Burrows MT, Schoeman DS, Buckley LB, et al. 2011. The pace of shifting climate in marine and terrestrial ecosystems. Science 334: 652-655.

Chen IC, Hill JK, Ohlemuller R, et al. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024-1026.

Cheung WWL, Lam VWY, Sarmiento JL, et al. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries 10: 235-251.

Crimmins TM, Crimmins MA, and Bertelsen CD. 2010. Complex responses to climate drivers in onset of spring flowering across a semi-arid elevation gradient. Journal of Ecology 98: 1042-1051.

Dawson TP, Jackson ST, House JI, et al. 2011. Beyond predictions: Biodiversity conservation in a changing climate. Science 332: 53-58.

Glick P, Stein BA, and Edelson N. 2011a. Scanning the conservation horizon: a guide to climate change vulnerability assessment. Washington, DC: National Wildlife Federation. www.nwf.org/vulnerabilityguide Viewed 27 September 2012

Glick P, Chmura H, and Stein BA. 2011b. Moving the conservation goalposts: a review of climate change adaptation literature. Washington, DC: National Wildlife Federation.

Grimm NB, Chapin III FS, Bierwagen B, Gonzalez P, Groffman PM, Luo Y, Melton F, Nadelhoffer K, Pairis A, Raymond PA, Schimel J, and Williamson CE. 2013. The impacts of climate change on ecosystem structure and function. Frontiers in Ecology and the Environment 11: xxx-yyy.

Haak, A.L., Williams, J.E., Isaak, D., Todd, A., Muhlfeld, C., Kershner, J.L., Gresswell, R., Hostetler, S., and Neville, H.M., 2010, The potential influence of changing climate on the persistence of salmonids of the inland west: U.S. Geological Survey Open-File Report 2010–1236, 74 p.

Isaak, D., C. Muhlfeld, A. Todd, R. Al-Chakhady, J. Roberts, J. Kershner, K. Fausch, S. Hostetler. 2012. The Past as a Prelude to the Future for Understanding 21st Century Climate Effects on Rocky Mountain Trout. Fisheries. Vol 37, N12, Dec, 542-556.

Jönsson AM, Appelberg G, Harding S, and Bärring L. 2009. Spatio-temporal impact of climate change on the activity and voltinism of the spruce bark beetle, Ips typographus. Global Change Biology 15: 486–499.

Littell, J. S., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western U. S. ecoprovinces, 1916-2003. Ecological Applications 19:1003-1021.

National Research Council. 2009. Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

National Fish, Wildlife and Plants Climate Adaptation Partnership. 2012. National Fish, Wildlife and Plants Climate adaptation Strategy. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service. Washington, DC.

Reed TE, Schindler DE, and Waples RS. 2011. Interacting effects of phenotypic plasticity and evolution on population persistence in a changing climate. Conservation Biology 25: 56–63.

Rowland EL, Davison JE, and Graumlich LJ. 2011. Approaches to evaluating climate change impacts on species: A guide to initiating the adaptation planning process. Environmental Management 47: 322-337.

Schoennagel T, Veblen TT, Negron JF, and Smith JM. 2012. Effects of mountain pine beetle on fuels and expected fire behavior in lodgepole pine forests, Colorado, USA. PLoS ONE 7(1): e30002.

Smith CR, Grange LJ, Honig DL et al. 2012. A large population of king crabs in Palmer Deep on the west Antarctic Peninsula shelf and potential invasive impacts. Proceedings of the Royal Society B 279:1017–1026.

Staudinger MD, Grimm NB, Staudt A, Carter SF, Chapin III FS, Kareiva P, Ruckelshaus M, and Stein BA. 2012. Impacts of climate change on biodiversity, ecosystems, and ecosystem services: technical input to the 2013 National Climate Assessment. 296 pp. Cooperative Report to the 2013 National Climate Assessment, Available at: http://assessment.globalchange.gov.

Urban MC, Tewksbury JJ, and Sheldon KS. 2012. On a collision course: competition and dispersal differences create no-analogue communities and cause extinctions during climate change. Proceedings of the Royal Society B-Biological Sciences: 1471-2954.

USGCRP (US Global Change Research Program). 2009. Global Climate Change Impacts in the United States. Cambridge University Press, Cambridge, UK.

U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Available at http://www.census.gov/prod/2012pubs/fhw11-nat.pdf

Senator INHOFE. I would like to add, I would like to sit around and visit and thank all the witnesses for coming, but we are 8 minutes into a vote right now.

Senator WHITEHOUSE. And we are going to make a quick escape.

I thank very much the witnesses for appearing. We appreciate your time this afternoon.

[Whereupon, at 3:41 p.m., the committee was adjourned.]

[Additional material submitted for the record follows.]

STATEMENT TO THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
OF THE UNITED STATES SENATE

Hearing on
"Review of the President's Climate Action Plan"

16 January 2014

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I am Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. I have devoted 30 years to conducting research on topics including climate of the Arctic, the role of clouds and aerosols in the climate system, and the climate dynamics of extreme weather events. As President of Climate Forecast Applications Network (CFAN) LLC, I have worked with decision makers on climate impact assessments, assessing and developing meteorological hazard and climate adaptation strategies, and developing subseasonal climate forecasting strategies to support adaptive management.

I am increasingly concerned that both the climate change problem and its solution have been vastly oversimplified.[1] My research on understanding the dynamics of uncertainty at the climate science-policy interface has led me to question whether these dynamics are operating in a manner that is healthy for either the science or the policy process.[2] I see a growing gap between what science is currently providing in terms of information about climate variability and change, and the information needed to understand and manage associated risks.

My testimony focuses on the following issues of central relevance to the President's Climate Change Program:

- Evidence reported by the IPCC AR5 weakens the case for human factors dominating climate change in the 20th and early 21st centuries.
- Climate change in the U.S. and the importance of natural variability on understanding the causes of extreme events
- Sound science to manage climate impacts requires improved understanding of natural climate variability and its impact on extreme weather events

The IPCC AR5 WGI Report – a weaker case for anthropogenic global warming

Last September, the Intergovernmental Panel on Climate Change (IPCC) released the 5th Assessment Report (AR5) from Working Group I (WGI) – The Physical Science Basis. Over the past two decades, the IPCC's reports have expressed increasingly confident consensus views of the importance of anthropogenic influence on the global climate, as reflected by these statements from the Summary for Policy Makers (SPM):

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[1] Curry, JA and Webster PJ 2011: Climate science and the uncertainty monster. *Bull Amer Meteorol. Soc.*, 92, 1667-1682. http://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS3139.1

[2] Judith Curry, Statement to the Subcommittee on Environment of the U.S. House of Representatives Hearing on Policy Relevant Climate Science in Context, 25 April 2013.

- AR4 (2007): "*Most of the observed increase in global average temperatures since the mid-20th century is **very likely** (>90% confidence) due to the observed increase in anthropogenic greenhouse gases.*" (SPM AR4)

- AR5 (2013): "*It **is extremely likely** (>95% confidence) that human influence has been the dominant cause of the observed warming since the mid-20th century.*" (SPM AR5)

The AR5 statement of 'extremely likely' implies that the overall arguments have strengthened. However, several key elements of the AR5 WGI report point to a weakening of the case for attributing most of the warming to human influences, relative to the previous assessment AR4 (2007):

- Lack of warming since 1998 and the growing discrepancies between observations and climate model projections
- Evidence of decreased climate sensitivity to increases in atmospheric CO_2 concentrations
- Evidence that sea level rise during 1920-1950 is of the same magnitude as in 1993-2012
- Increasing Antarctic sea ice extent

The following summarizes the key points, using the figures and text from the IPCC AR5 WG1 Report and comparing them with the AR4.

Recent hiatus in surface warming and discrepancies with climate models

The IPCC AR5 notes the lack of surface warming since 1998:

> "*[T]he rate of warming over the past 15 years (1998–2012) [is] 0.05 [–0.05 to +0.15] °C per decade which is smaller than the rate calculated since 1951 (1951–2012) [of] 0.12 [0.08 to 0.14] °C per decade.*" (AR5 SPM)

The significance of this hiatus in warming since 1998 arises from comparison with climate model projections. The IPCC AR4 stated:

> "*For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios.*" (AR4 SPM)

The fifth phase of the Coupled Model Intercomparison Project (CMIP5)[3] has produced a multi-model dataset that includes long-term simulations of twentieth-century climate and projections for the twenty-first century and beyond. CMIP5 provides the climate model simulations used in the AR5. Figure 1 summarizes the near-term projections from CMIP5 of global mean surface temperature anomalies. The observed global temperature record, particularly since 2005, are on the low end of the model envelope that contains 90% of the climate model simulations, and observations in 2011-2012 are below the 5-95% envelope of the CMIP5 simulations. Overall, the trend in the model simulations is substantially larger than the observed trend over the past 15 years.[4]

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[3] Taylor, Karl E., Ronald J. Stouffer, Gerald A. Meehl, 2012: An Overview of CMIP5 and the Experiment Design. *Bull. Amer. Meteor. Soc.*, **93**, 485–498. http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-11-00094.1

[4] A revised version of Figure 11.25 from the AR5 WG1 Report is given by Ed Hawkins http://www.climate-lab-book.ac.uk/2013/updates-to-comparison-of-cmip5-models-observations/, which also includes the new surface temperature climatology by Cowtan and Way (2013) *Roy. Meteorol. Soc.* http://onlinelibrary.wiley.com/doi/10.1002/qj.2297/abstract. It is seen that this new climatology is slightly warmer, but does not significantly change the climate model discrepancies with observations

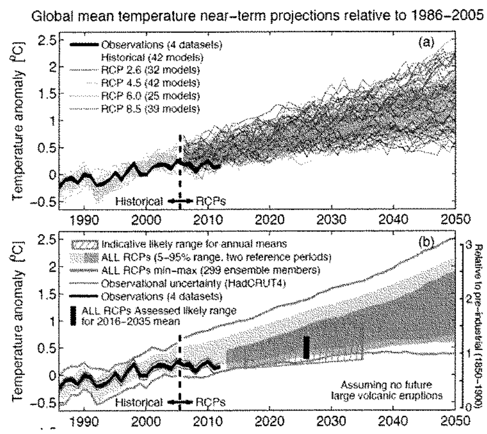

Figure 1. Comparison the global average surface temperatures from the surface temperature data sets with the CMIP5 simulations. The red-hatched region shows the likely range for annual mean global surface teperature during the period 2016–2035 based on expert judgment. From Figure 11.25 (IPCC AR5 WG1).

Regarding projections for the period 2012-2035, the CMIP5 5-95% trend range is 0.11°C–0.41°C per decade. The IPCC then cites 'expert judgment' as the rationale for lowering the projections (indicated by the red hatching):

> *"However, the implied rates of warming over the period from 1986–2005 to 2016–2035 are lower as a result of the hiatus: 0.10°C–0.23°C per decade, suggesting the AR4 assessment was near the upper end of current expectations for this specific time interval."* (AR5 Chapter 11)

This lowering of the projections (and decreasing the trend) relative to the results from the raw CMIP5 model simulations was done based on expert judgment that some models are too sensitive to anthropogenic forcing.

While the near term projections were lowered relative to the CMIP5 simulations, the AR5 states with regards to extended-range warming:

> *"Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges derived from the concentration driven CMIP5 model simulations."* (AR5 Chapter 12)

In Table SPM.2, which provides a summary of the CMIP5 simulations for the different emission scenarios for the periods 2046-2065 and 2081-2100, a note in the caption states:

> *"The likely ranges for 2046−2065 do not take into account the possible influence of factors that lead to the assessed range for near-term (2016−2035) global mean surface temperature change that is lower than the 5−95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding."* (AR5 SPM)

This statement acknowledges that there is an uncertainty and possible bias leading to high values that has not been taken into account due to lack of understanding. Although this statement is made explicitly only for the period 2046-2065, the issue is also not accounted for in the later period. This kind of *insufficient scientific understanding* is not a good basis for high confidence in the climate model simulations and projections.

Regarding the current hiatus, the IPCC concludes that:

> "*. . . the hiatus is attributable, in roughly equal measure, to a decline in the rate of increase in effective radiative forcing (ERF) and a cooling contribution from internal variability (expert judgment, medium confidence). The decline in the rate of increase in ERF is primarily attributed to natural (solar and volcanic) forcing but there is low confidence in quantifying the role of forcing trend in causing the hiatus, because of uncertainty in the magnitude of the volcanic forcing trend and low confidence in the aerosol forcing trend.*" (AR5 Chapter 11)

In summary:

- After expecting a global mean surface temperature increase of 0.2°C per decade in the early decades of the 21st century based on climate model simulations and statements in the AR4, the warming over the past 15 years is only ~0.05°C.
- The IPCC AR5 bases its surface temperature projection of 0.10 to 0.23°C per decade for the period 2016-2036 on expert judgment, which is lowered relative to the climate model results that predict substantially greater warming
- The IPCC does not have a convincing or confident explanation for the current hiatus in warming.

Sensitivity of climate to doubled CO2 concentrations

The equilibrium climate sensitivity (ECS) is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration. The IPCC AR4 conclusion on climate sensitivity is stated as:

> "*The equilibrium climate sensitivity. . . is likely to be in the range 2°C to 4.5°C with a best estimate of about 3°C and is very unlikely to be less than 1.5°C. Values higher than 4.5°C cannot be excluded.*" (AR4 SPM)

The IPCC AR5 conclusion on climate sensitivity is stated as:

> *Equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C (high confidence), extremely unlikely less than 1°C (high confidence), and very unlikely greater than 6°C (medium confidence)* (AR5 SPM)

The bottom of the 'likely' range has been lowered from 2 to 1.5°C in the AR5, whereas the AR4 stated that ECS is very unlikely to be less than 1.5°C. It is also significant that the AR5 does not cite a best estimate, whereas the AR4 cites a best estimate of 3°C. Further the AR5 finds values of ECS exceeding 6°C to be very unlikely, whereas the AR4 did not have sufficient confidence to identify an upper bound at this confidence level. The stated reason for not citing a best estimate in the AR5 is the substantial discrepancy between observation-based estimates of ECS (lower), versus estimates from climate models (higher). Figure 1 of Box 12.2 in the AR5 WG1 report shows that 11 out of 19 observational-based studies of ECS have values below 1.5°C in the range of their ECS probability distribution.

Hence the AR5 reflects greater uncertainty and a tendency towards lower values of the ECS than the AR4. The discrepancy between observational and climate model-based estimates of climate sensitivity is substantial and of significant importance to policymakers -- sensitivity, and the level of uncertainty in its value, is a key input into the economic models that drive cost-benefit analyses and estimates of the social cost of carbon.

Sea level rise

In the AR5 SPM, the following statements are made regarding sea level rise:

> *"It is very likely that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm* yr^{-1} *between 1901 and 2010, 2.0 [1.7 to 2.3] mm* yr^{-1} *between 1971 and 2010 and 3.2 [2.8 to 3.6] mm* yr^{-1} *between 1993 and 2010.* ***It is likely that similarly high rates occurred between 1920 and 1950."*** (AR5 SPM)

> *"It is* ***very likely*** *that there is a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s."* (AR5 SPM)

The rate of global mean sea level as portrayed in AR5 is shown in Figure 2 below.

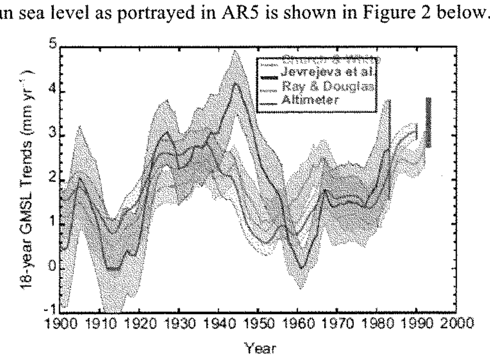

Figure 2. 18-year trends of global mean sea level rise estimated at 1-year intervals. The time is the start date of the 18-year period, and the shading represents the 90% confidence. The estimate from satellite altimetry is also given, with the 90% confidence given as an error bar. [AR5 WGI Figure 3.14]

In AR5 SPM there are significant changes relative to the AR4 WG1 SPM concerning the estimated contributions to sea level rise from different sources:

Table 1: Contributions to sea level rise from different sources (mm per year)

	AR4 (1993-2003)	AR5 (1993-2010)
Thermal expansion	1.6	1.1
Glaciers and ice caps	0.77	0.76
Greenland ice sheet	0.21	0.33
Antarctic ice sheet	0.21	0.27
Land water storage	---	0.38
Sum	0.28	0.28
Observed sea level rise	3.1	3.2

Thermal expansion is one third smaller in AR5 and land water storage with a substantial amount is completely new in AR5, while the sum of these sources remained constant. With regards to land water storage, a recent paper[5] estimated that the human impacts, particularly unsustainable ground water use, have contributed a sea-level rise of about 0.77 mm yr^{-1} between 1961 and 2003, which is twice as large as the estimate used in the AR5.

Global sea level has been rising for the past several thousand years. The key issue is whether the rate of sea level rise is accelerating owing to anthropogenic global warming. It is seen that the rate of rise during 1930-1950 was comparable to, if not larger than, the value in recent years. Hence the data does not seem to support the IPCC's conclusion of a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s. Further, the growing realization of the importance of land water storage to sea level rise is diminishing the percentage of sea level rise that is associated with warming. Better understanding of natural versus anthropogenic components of sea level rise and the impacts of land use (especially groundwater depletion) on sea level rise is needed to effectively evaluate policy responses to sea level rise.

Sea ice

The IPCC AR5 reports the following trends in sea ice:

> *"Continuing the trends reported in AR4, the annual Arctic sea ice extent* ***decreased*** *over the period 1979–2012: the rate of this decrease was very likely between 3.5 and 4.1% per decade* (AR5 SPM)
>
> *"It is very likely that the annual Antarctic sea ice extent* ***increased*** *at a rate of between 1.2 and 1.8% per decade between 1979 and 2012.* (AR5 SPM)

AR5 Chapter 10 states:

> *"Anthropogenic forcings are very likely to have contributed to Arctic sea ice loss since 1979. There is low confidence in the scientific understanding of the observed increase in Antarctic sea ice extent since 1979, due to the incomplete and competing scientific explanations for the causes of change and low confidence in estimates of internal variability."* (AR5 Chapter 10)
>
> *"Arctic temperature anomalies in the 1930s were apparently as large as those in the 1990s and 2000s. There is still considerable discussion of the ultimate causes of the warm temperature anomalies that occurred in the Arctic in the 1920s and 1930s."* (AR5 Chapter 10)

The increase in Antarctic sea ice is not understood and is not simulated correctly by climate models. Further, Arctic surface temperature anomalies in the 1930's were as large as the recent temperature anomalies. Notwithstanding the simulations by climate models that reproduce the decline in Arctic sea ice, more convincing arguments regarding causes of sea ice variations requires understanding and ability to simulate sea ice variations in *both* hemispheres.

A key issue in understanding the recent decline in Arctic sea ice extent is to understand to what extent the decline is caused by anthropogenic warming versus natural climate variability.

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[5] Pokhrel et al. 2013: Model estimates of sea-level change due to anthropogenic impacts on terrestrial water storage. *Nature Geoscience.* http://www.nature.com/ngeo/journal/v5/n6/full/ngeo1476.html

Analysis[6] of the CMIP3 and CMIP5 simulations found that about 41% of the recent sea ice decline could be attributed to anthropogenic warming from the CMIP3 models, and about 60% from the CMIP5 models. A recent paper seeks to interpret the multi-decadal natural variability component of the Arctic sea ice in context of a 'stadium wave'.[7] This paper suggests that a transition to recovery of the natural variability component of the sea ice extent has begun in the Eurasian Arctic sector, and that the recovery will reach its maximum extent circa 2040.

Summary

Multiple lines of evidence presented in the IPCC AR5 WG1 report suggest that the case for anthropogenic warming is weaker than the previous assessment AR4 in 2007. Anthropogenic global warming is a proposed theory whose basic mechanism is well understood, but whose magnitude is highly uncertain. The growing evidence that climate models are too sensitive to CO_2 has implications for the attribution of late 20th century warming and projections of 21st century climate.

If the recent warming hiatus is caused by natural variability, then this raises the question as to what extent the warming between 1975 and 2000 can also be explained by natural climate variability.

The stadium wave hypothesis[8] predicts that the warming hiatus could extend to the 2030's. Based upon climate model projections, the probability of the hiatus extending beyond 20 years is vanishing small. If the hiatus does extend beyond 20 years, then a very substantial reconsideration will be needed of the 20th century attribution and the 21st century projections of climate change.

Climate change in the U.S.

The prospect of increased frequency and severity of extreme weather in a warmer climate is proposed as potentially the most serious near term impact of climate change. Metaphors such as climate change 'loading the dice' for severe weather or causing 'weather on steroids' are frequently used to communicate an elevated probability of extreme weather events as a result of human-caused climate change. Because of their large socioeconomic impacts, weather catastrophes act as focusing events for the public in the politics surrounding the climate change debate. The perception that humans are causing an increase in extreme weather events is a primary motivation for the President's Climate Change Plan:

> *". . . climate change is no longer a distant threat – we are already feeling its impacts across the country and the world. Last year was the warmest year ever in the contiguous United States and about one-third of all Americans experienced 10 days or more of 100-degree heat. The 12 hottest years on record have all come in the last 15 years. . . And increasing floods, heat waves, and droughts have put farmers out of business, which is already raising food prices dramatically."*

In 2012, the IPCC published a *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX)[8]. The following draws from the SREX, the IPCC AR5 WG1 report, and climatic data for the U.S. provided by NOAA and the Berkeley Earth Surface Temperature project.

[6] Stroeve, J. et al. 2012: Trends in Arctic sea ice extent from CMIP3, CMIP5 and observations. Geophys. Res. Lett., 39, L16502

[7] Wyatt, MG and JA Curry, 2013: Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century. Climate Dynamics, http://curryja.files.wordpress.com/2013/10/stadium-wave1.pdf

[8] https://ipcc-wg2.gov/SREX/

U.S. surface temperatures

Figure 3 shows the latest analysis of annual surface temperature anomalies for the continental U.S. since 1850, from Berkeley Earth Surface Temperature Project. The year 2012 was the warmest year on record for the U.S., followed by 2006, 1998, and 1934. Globally, 2012 ranked as the 8th or 9th warmest year, with Argentina also recording its warmest year. It is seen that the annual average temperature for 2013 was relatively cool, and ranked only as the 42nd warmest year for the continental U.S.

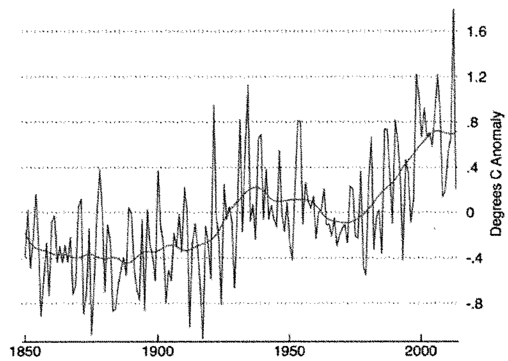

Figure 3. Annual average surface temperature anomalies for the continental U.S. since 1850. Data and plot from the Berkeley Earth Surface Temperature Project.

Summer heat extremes

Figure 4 shows the number of daily record high summertime daily maximum temperatures (T_{max}) and minimum temperatures (T_{min}) for the continental U.S. since 1895. The number of daily record T_{max} shows no trend, with a strong maximum during the 1930's. The number of daily record T_{min} also shows a maximum in the 1930's, but also shows an overall increasing trend since the 1970's.

The EPA also cites evidence that summertime heat waves were frequent and widespread in the 1930s, and these remain the most severe heat waves in the U.S. historical record.[9] Overall, any evidence of an anthropogenic effect (greenhouse gases, aerosols, land use) on summertime record high temperatures is more likely to be seen in T_{min} than in T_{max}.

[9] http://www.epa.gov/climatechange/images/indicator_figures/high-low-temp-figure1-2013.gif

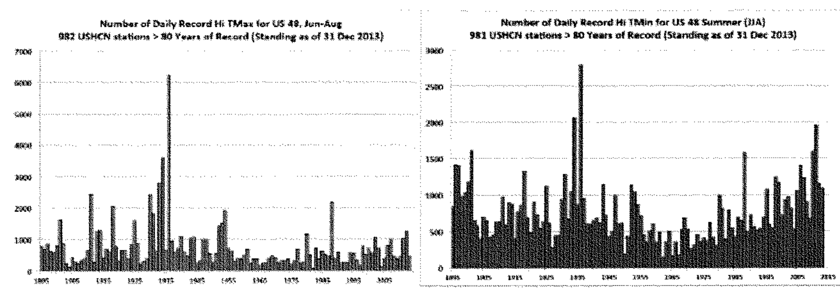

Figure 4. Number of daily record high T_{max} (red; left) and T_{min} (blue; right) for the summer season (Jun-Aug) for the continental U.S. Data obtained from 981 USHCN stations with surface temperature records exceeding 80 years and standing as of 12/31/13. Figure courtesy of John Christy, University of Alabama Huntsville.

Winter cold extremes

Figure 5 shows the number of daily record wintertime maximum (T_{max}) and minimum (T_{min}) temperatures for the continental U.S. since 1895. A declining trend in wintertime T_{min} records is seen, with very few records for the period 1997-2013. The wintertime T_{max} records do not show any particular trend, with a cluster of records during the 1930's and the 1980's standing out years with the largest number of wintertime T_{max} records.

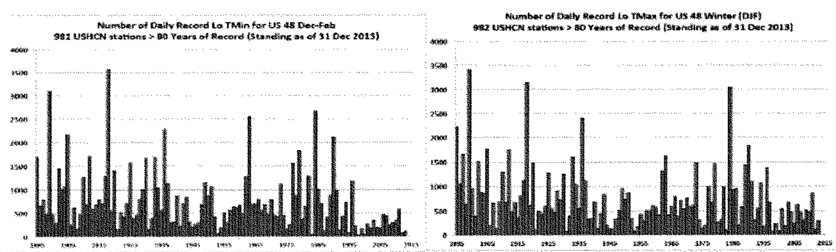

Figure 5. Number of daily record low T_{min} (top) and T_{max} (bottom) for the winter season (Dec-Feb) for the continental U.S. Data obtained from 981 USHCN stations with surface temperature records exceeding 80 years, and standing as of 12/31/13. Figure courtesy of John Christy, University of Alabama Huntsville.

Last week, the central and eastern U.S. was in the midst of a major cold wave, with large regions dropping below 0°F and wind chills reaching below -30°F. On one hand, some have stated that such cold is clear evidence that global warming is nonsense. On the other, some have argued that the cold wave is another example of extreme weather forced by increased greenhouse gases. Neither statement is supported by the evidence. There is nothing in Figure 5 to suggest that extreme cold air outbreaks (as reflected in record temperatures) are becoming more frequent in the U.S. With regards to the polar vortex, such circulation patterns are not uncommon. Analogues for a similar pattern and associated major wintertime cold air outbreak occurred in 1977, 1978, 1985, 1993 and 1994.[10]

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[10] personal communication, Joe Bastardi of WeatherBell

Precipitation

Extremes in precipitation (drought and heavy rainfall events) are shown in Figure 6. These data reflect NOAA's Climate Extreme Index, which is calculated as the percentage of the U.S. being falling in the upper or lower tenth percentile of the local period of record. Drought is represented by the Palmer Drought Severity Index (PDSI) and heavy rainfall events are characterized from extremes in 1-day precipitation.

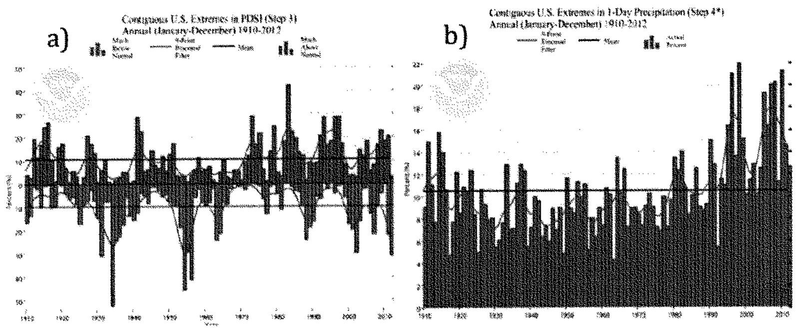

Figure 6. Annual frequency (%) of extremes in a) the Palmer Drought Severity Index; and b) extremes in 1-day precipitation. Figures obtained from the NOAA NCDC Climate Extremes Index
a) http://www.ncdc.noaa.gov/extremes/cei/graph/3/01-12 b) http://www.ncdc.noaa.gov/extremes/cei/graph/4/01-12

Figure 6a shows that the most extreme droughts were observed in the 1930's and 1950's. The largest positive extremes (wet) are seen since the 1980's. Figure 6b shows the historical distribution of extremes in 1-day rainfall rates. The highest values are clustered in the period since the 1990. It is unclear whether an increase in flooding can be attributed to the increase in extreme rainfall rates owing to the confounding factors of land use change and urbanization. Combined, Figures 6a and 6b present a picture of increasing precipitation and decreasing frequency of extreme drought.

Sea level rise

As cited above, the IPCC AR5 finds a mean global sea level rise of 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010, and states that there is very likely a substantial contribution from anthropogenic forcings since the 1970s. In many locations, local factors dominate the sea level variations: rising or subsidence from geologic processes, coastal engineering projects, and human impacts on terrestrial water storage including reservoir operation, ground water use and irrigation.

Figure 7 shows local trends in sea level for the U.S. coast. The predominant arrow color is green (0-3 mm/yr), which is nominally below mean global sea level rise. In Florida, sea level is rising at a rate of only 0.75 to 2.4 mm/yr. By contrast, Louisiana sea level rise exceeds 9 mm/yr. The Mid Atlantic coast has sea level rises ranging from 2.5 to 6 mm/yr. Along the coast of the Gulf of Alaska, sea level is *decreasing* at rates exceeding -10 mm/yr.

Many locations have a rate of sea level rise that differs significantly from the global average value. This occurs owing to the dominance of local factors (geologic and/or land use) on sea level rise. Projected rates of sea level rise for the period 2081-2100 depend on emission scenarios, and range from 3 to 15 mm/yr, with most scenarios projecting a substantial acceleration over the current rate. Sea level rise projections using climate models may be too high owing to biases in sensitivity to greenhouse gases, and projections based on semi-empirical models may be too high owing to insufficient consideration given to land water storage. Assessing vulnerability of individual locations to anthropogenically-induced sea level rise also needs to account for local factors (e.g. geologic and land use) driving sea level rise as well as natural variability in sea level rise.

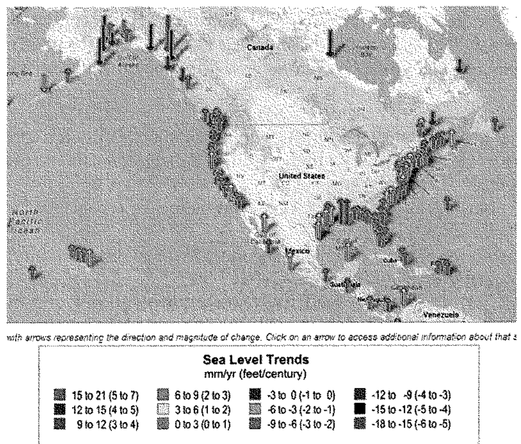

Figure 7. Local trends in sea level determined from tide stations, with arrows representing the direction and magnitude of the change. http://tidesandcurrents.noaa.gov/sltrends/

Summary

With regards to the impacts of climate change on the continental U.S., the following trends are seen over the past century are seen:

- declining frequency of wintertime cold extremes
- declining frequency of drought
- increasing frequency of heavy rain events
- increasing sea level rise that is dominated by local factors in many locations

There is a large component of natural variability seen in the 100+ year data record particularly for drought and heat waves, each of which had maximum extremes during the 1930's. Sea level rise also shows a maxima during the 1930's to 1940's.

There is a widespread perception that extreme weather events are worsening, as reflected by this statement from President Obama's State of the Union address:

> *"Heat waves, droughts, wildfires, and floods – all are now more frequent and intense. We can choose to believe that Superstorm Sandy, and the most severe drought in decades, and the worst wildfires some states have ever seen were all just a freak coincidence. Or we can choose to believe in the overwhelming judgment of science – and act before it's too late."*[11]

In the U.S., most types of weather extremes were worse in the 1930's and even in the 1950's than in the current climate, while the weather was overall more benign in the 1970's. This sense that extreme weather events are now more frequent and intense is symptomatic of 'weather amnesia' prior to 1970. The extremes of the 1930's and 1950's are not attributable to greenhouse warming and are associated with natural climate variability (and in the case of the dustbowl drought and heat waves, also to land use practices).

There is no *a priori* scientific reason to prefer the climate of the 1930's, the 1970's, the current climate, or a climate that is 1-2°C warmer than present. Which climate is preferable from a socioeconomic perspective:

- the current warmer climate with fewer extreme cold air outbreaks versus the climate of the 1970's with fewer heat waves?
- the current climate with fewer severe droughts and more frequent heavier rainfall, versus prior periods with overall less rainfall?
- the present climate, or a future climate that is 1-2°C warmer with overall more rainfall and less frequent drought, fewer extreme cold events but more frequent heat waves?

The preference undoubtedly varies regionally. The key issues are the adaptive capacity of societies, and the unresolved moral dilemma of how to balance obligations towards future generations against obligations to the current generation, which underlies economic debates around the discount rate.

Sound science in support of good judgment

The premise of President Obama's Climate Action Plan is that there is an overwhelming judgment of science that anthropogenic global warming is already producing devastating impacts, which is summarized by this statement from the President's Second Inaugural Address:

> *Some may still deny the overwhelming judgment of science, but none can avoid the devastating impact of raging fires and crippling drought and more powerful storms.*

This premise is not strongly supported by the scientific evidence:

- the science of climate change is not settled, and evidence reported by the IPCC AR5 weakens the case for human factors dominating climate change in the 20th and early 21st centuries
- with the 15+ year hiatus in global warming, there is growing appreciation for the importance of natural climate variability
- the IPCC AR5 and SREX find little evidence that supports an increase in most extreme weather events that can be attributed to humans, and weather extremes in the U.S. were generally worse in the 1930's and 1950's than in recent decades.

Not only is more research needed to clarify the sensitivity of climate to carbon dioxide and understand the limitations of climate models, but more research is needed on solar variability, sun-climate connections, natural internal climate variability and the climate dynamics of extreme weather events. Improved understanding of these aspects of climate variability and change is needed to help

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[11] http://www.whitehouse.gov/state-of-the-union-2013

government officials, communities, and businesses better understand and manage the risks associated with climate change.

Nevertheless, the premise of dangerous anthropogenic climate change is the foundation for a far-reaching plan to reduce greenhouse gas emissions and reduce vulnerability to extreme weather events. Elements of this Plan may be argued as important for associated energy policy reasons, economics, and/or public health and safety. However, claiming an overwhelming scientific justification for the Plan based upon anthropogenic global warming does a disservice both to climate science and to the policy process.

Motivated by the precautionary principle to avoid dangerous anthropogenic climate change, attempts to modify the climate through reducing CO_2 emissions may turn out to be futile. The stagnation in greenhouse warming observed over the past 15+ years demonstrates that CO_2 is not a control knob on climate variability on decadal time scales. Even if CO_2 mitigation strategies are successful and climate model projections are correct, an impact on the climate would not be expected for a number of decades owing to the long lifetime of CO_2 in the atmosphere and thermal inertia driven by the ocean (AR5 WG1 FAQ 12.3); solar variability, volcanic eruptions and natural internal climate variability will continue to be sources of unpredictable climate surprises.

Specifically with regards to most extreme weather events, their frequency and intensity is heavily influenced by natural internal variability. Whether or not anthropogenic climate change is exacerbating extreme weather events, vulnerability to extreme weather events will continue owing to increasing population and wealth in vulnerable regions. Climate change (regardless of whether the primary cause is natural or anthropogenic) may be less important in driving vulnerability in most regions than increasing population, land use practices, and ecosystem degradation. Regions that find solutions to current problems of climate variability and extreme weather events and address challenges associated with an increasing population are likely to be well prepared to cope with any additional stresses from climate change.

Short Biography

Judith Curry
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Dr. Judith Curry is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology and President of Climate Forecast Applications Network (CFAN). Dr. Curry received a Ph.D. in atmospheric science from the University of Chicago in 1982. Prior to joining the faculty at Georgia Tech, she held faculty positions at the University of Colorado, Penn State University and Purdue University. Dr. Curry's research interests span a variety of topics in climate; current interests include air/sea interactions, climate feedback processes associated with clouds and sea ice, and the climate dynamics of hurricanes. She has published over 190 journal articles and is author of the books *Thermodynamics of Atmospheres and Oceans* and *Thermodynamics, Kinetics and Microphysics of Clouds.* She is also Editor of the *Encyclopedia of Atmospheric Sciences*. She is a prominent public spokesperson on issues associated with the integrity of climate research, and is proprietor of the weblog Climate Etc. judithcurry.com. Dr. Curry currently serves on the DOE Biological and Environmental Research Advisory Committee, and has recently served on the NASA Advisory Council Earth Science Subcommittee, National Academies Climate Research Committee and the Space Studies Board and the NOAA Climate Working Group. Dr. Curry is a Fellow of the American Meteorological Society, the American Association for the Advancement of Science, and the American Geophysical Union.

Financial declaration

Funding sources for Curry's research have included NSF, NASA, NOAA, DOD and DOE. Recent contracts for CFAN include a DOE contract to develop extended range regional wind power forecasts and a DOD contract to predict extreme events associated with climate variability/change having implications for regional stability. CFAN contracts with private sector and other non-governmental organizations include energy and power companies, reinsurance companies, other weather service providers, NGOs and development banks. Specifically with regards to the energy and power companies, these contracts are for medium-range (days to weeks) forecasts of hurricane activity and landfall impacts. CFAN has one contract with an energy company that also includes medium-range forecasts of energy demand (temperature), hydropower generation, and wind power generation. CFAN has not received any funds from energy companies related to climate change or any topic related to this testimony.

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For more information:

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STATEMENT OF DR. ROGER PIELKE, JR.
to the COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
of the UNITED STATES SENATE

HEARING on CLIMATE CHANGE: IT'S HAPPENING NOW
18 July 2013

Short Biographical Note

My academic degrees are in mathematics, public policy and political science. I began studying extreme weather and climate in 1993 at the National Center for Atmospheric Research in Boulder, CO. Over the past 20 years I have collaborated with researchers around the world to publish dozens of peer-reviewed papers on hurricanes, floods, tornadoes, Australian bushfires, earthquakes and other subjects related to extreme events. Since 2001, I have been a professor of environmental studies at the University of Colorado. A longer bio can be found as an appendix to this testimony. My views on climate policy and politics, not discussed in this testimony, can be found in my recent book, *The Climate Fix* (Basic Books, 2011).

Take-Home Points

- It is misleading, and just plain incorrect, to claim that disasters associated with hurricanes, tornadoes, floods or droughts have increased on climate timescales either in the United States or globally.[1] It is further incorrect to associate the increasing costs of disasters with the emission of greenhouse gases.
- Globally, weather-related losses ($) have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%) and insured catastrophe losses have not increased as a proportion of GDP since 1960.
- Hurricanes have not increased in the US in frequency, intensity or normalized damage since at least 1900. The same holds for tropical cyclones globally since at least 1970 (when data allows for a global perspective).
- Floods have not increased in the US in frequency or intensity since at least 1950. Flood losses as a percentage of US GDP have dropped by about 75% since 1940.
- Tornadoes have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.
- Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[2] Globally, "there has been little change in drought over the past 60 years."[3]
- The absolute costs of disasters will increase significantly in coming years due to greater wealth and populations in locations exposed to extremes. Consequent, disasters will continue to be an important focus of policy, irrespective of the exact future course of climate change.

To avoid any confusion

Because the climate issue is so deeply politicized, it is necessary to include several statements beyond those reported above.

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[1] The IPCC defines climate timescales to be 30-50 years and longer.
[2] This quote comes from the US Climate Change Science Program's 2008 report on extremes in North America.
[3] Sheffield et al. in Nature, http://www.nature.com/nature/journal/v491/n7424/full/nature11575.html

- Humans influence the climate system in profound ways, including through the emission of carbon dioxide via the combustion of fossil fuels.[4]
- Researchers have detected and (in some cases) attributed a human influence in other measures of climate extremes beyond those discussed in this testimony, including surface temperatures and precipitation.
- The inability to detect and attribute changes in hurricanes, floods, tornadoes and drought does not mean that human-caused climate change is not real or of concern.
- It does mean however that some activists, politicians, journalists, corporate and government agency representatives and even scientists who should know better have made claims that are unsupportable based on evidence and research.
- Such false claims could undermine the credibility of arguments for action on climate change, and to the extent that such false claims confuse those who make decisions related to extreme events, they could lead to poor decision making.
- A considerable body of research projects that various extremes may become more frequent and/or intense in the future as a direct consequence of the human emission of carbon dioxide.[5]
- Our research, and that of others, suggests that assuming that these projections are accurate, it will be many decades, perhaps longer, before the signal of human-caused climate change can be detected in the statistics of hurricanes (and to the extent that statistical properties are similar, in floods, tornadoes, drought).[6]

The remainder of this written testimony provides data and references to support the claims made in the "take-home points" above. The "take-home points" are broadly supported by peer-reviewed research, US governmental assessments of climate science and the recent report of the Intergovernmental Panel on Climate Change in its Special Report on Extreme Events (IPCC SREX 2012).[7]

<u>Global Weather-Related Disaster Loss ($) Trends</u>

What the IPCC SREX (2012) says:

- "There is high confidence, based on high agreement and medium evidence, that economic losses from weather- and climate-related disasters have increased"
- "There is medium evidence and high agreement that long-term trends in normalized losses have not been attributed to natural or anthropogenic climate change"

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[4] See, e.g., Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[5] There are exceptions, for instance, the IPCC SREX (2012) concludes of winter storms, "There is medium confidence that there will be a reduction in the number of extratropical cyclones averaged over each hemisphere."

[6] Crompton, RP, RA Pielke and KJ McAneney (2011), Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data. *Environ. Res. Lett.* **6** (1) doi: 10.1088/1748-9326/6/1/014003

[7] IPCC SREX (2012) refers to IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.) Cambridge University Press.

- "The statement about the absence of trends in impacts attributable to natural or anthropogenic climate change holds for tropical and extratropical [winter] storms and tornadoes"
- "The absence of an attributable climate change signal in losses also holds for flood losses."

What the data says:

1. **Globally, weather-related losses have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%).**

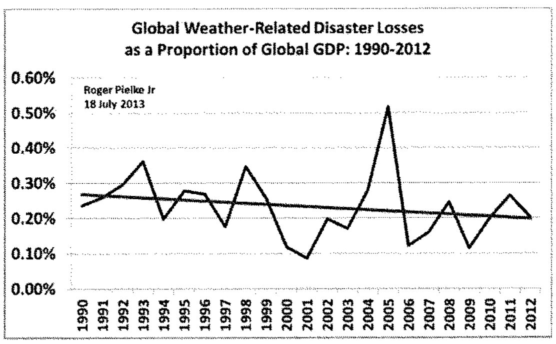

Figure 1. Global weather-related disasters as a proportion of global GDP, 1990-2012. Source of loss data: Munich Re.[8] Source of GDP data: United Nations.[9]

2. **Insured catastrophe losses have not increased as a proportion of GDP since 1960.**

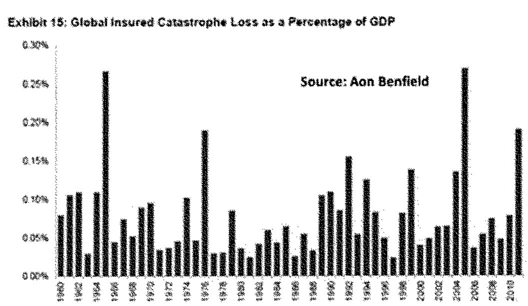

Figure 2. Global insured catastrophe loss as a percentage of global GDP. Source: Aon Benfield.[10]

[8] http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/great_natural_catastrophes.aspx
[9] http://unstats.un.org/unsd/snaama/dnllist.asp
[10] http://thoughtleadership.aonbenfield.com/Documents/20130103_reinsurance_market_outlook_external.pdf

Note: The peer-reviewed literature on this subject is extensive and robust. Neumayer and Barthel (2011), in a study conducted at the London School of Economics and supported financially by Munich Reinsurance conclude:

> "[B]ased on historical data, there is no evidence so far that climate change has increased the normalized economic loss from natural disasters."[11]

Hurricanes

What the IPCC SREX (2102) says:

- "Low confidence in attribution of any detectable changes in tropical cyclone activity to anthropogenic influences."

What the data says:

3. **Hurricanes have not increased in the US in frequency, intensity or normalized damage since at least 1900.**

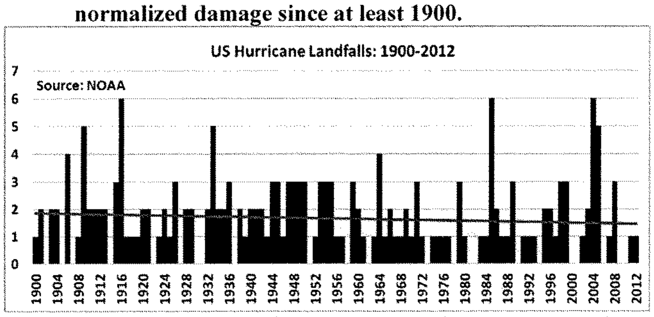

Figure 3a. Number of landfalling US hurricanes from 1900-2012. The red line shows the linear trend, exhibiting a decrease from about 2 to 1.5 landfalls per year since 1900. Source: NOAA.[12]

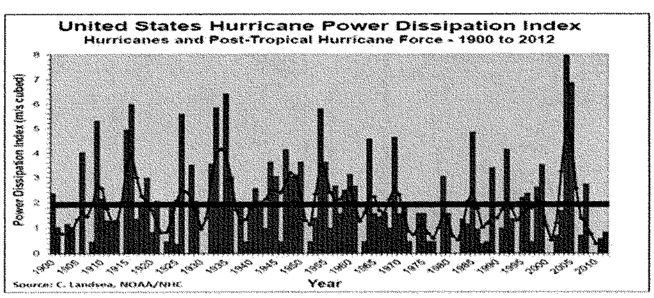

Figure 3b. Intensity of US hurricanes at landfall, 1900-2012 (measured as the summed power dissipation for each year). The heavy black line shows the linear trend. Source NOAA, figure courtesy Chris Landsea, NOAA/NHC.

[11] Neumayer, E. and F. Barthel. 2011. Normalizing Economic Loss from Natural Disasters: A Global Analysis, *Global Environmental Change*, **21**:13-24

[12] http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

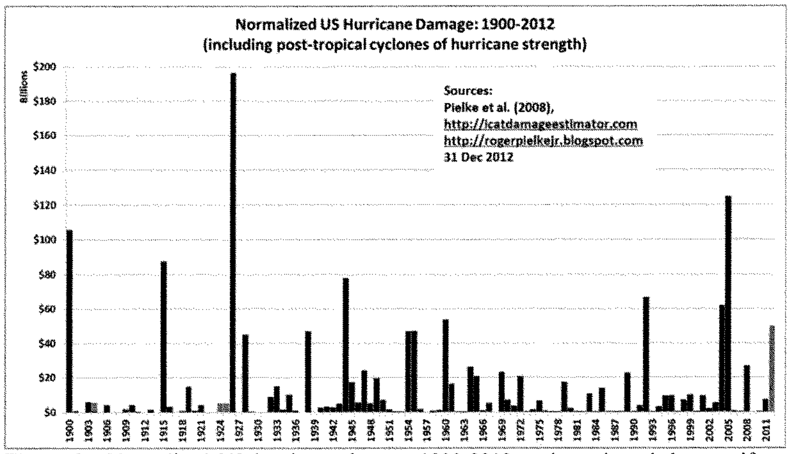

Figure 3c. Normalized US hurricane damage 1900-2012, estimated total damage if each past hurricane season occurred with 2012 levels of development. After Pielke et al. 2008.[13] Note that the figure includes Superstorm Sandy (2012) in gray and placeholders for the three other post-tropical cyclones of hurricanes which made landfall in 1904, 1924 and 1925.

4. **There are no significant trends (up or down) in global tropical cyclone landfalls since 1970 (when data allows for a comprehensive perspective), or in the overall number of tropical cyclones.**

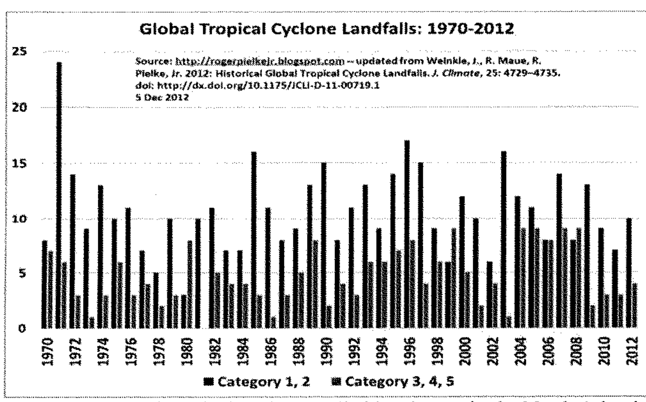

Figure 4a. Global tropical cyclone (called hurricanes in the North Atlantic) landfalls, 1970-2012, after Weinkle et al. 2012.[14]

[13] Pielke, Jr., R.A., J. Gratz, C.W. Landsea, D. Collins, M. Saunders, and R. Musulin (2008), Normalized Hurricane Damages in the United States: 1900-2005. *Natural Hazards Review* 9:29-42. Data updated to 2012 values using the ICAT Damage Estimator: http://www.icatdamageestimator.com

[14] Weinkle, J, R Maue and R Pielke (2012), Historical Global Tropical Cyclone Landfalls. Journal of Climate, **25**:4729-4735

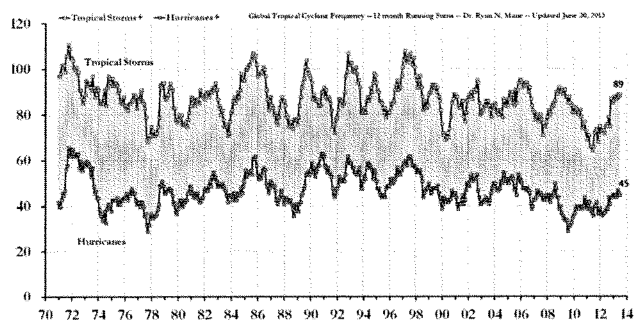

Figure 4b. Total count of tropical cyclones of tropical storm (top curve) and hurricane strength, 12-month running sums 1970 through June 30, 2013. Figure courtesy Ryan Maue.[15]

Floods

What the IPCC SREX (2012) says:

- "There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales"
- "there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes.."

What the data says:

5. **Floods have not increased in the US in frequency or intensity since at least 1950.**

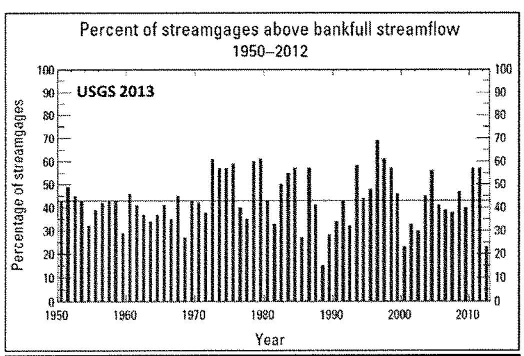

Figure 5. One measure of flood frequency from the USGS, percent of US streamguages above "bankfull streamflow." The USGS explains: "The bankfull streamflow is defined as the highest daily mean streamflow value expected to occur, on average, once in every 2.3 years."[16]

[15] After Maue, R. N. (2011), Recent historically low global tropical cyclone activity. , *Geophys. Res. Letts.* **38**:L14803, doi:10.1029/2011GL047711.

6. **Flood losses as a percentage of US GDP have dropped by about 75% since 1940.**

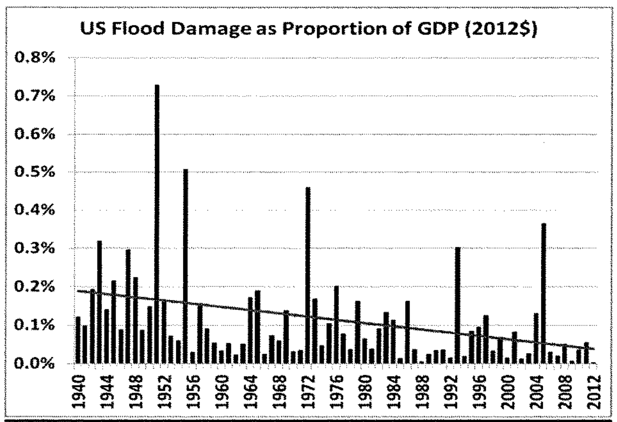

Figure 6. US flood losses as a percentage of US GDP. Annual flood losses have decreased from about 0.2% of US GDP to <0.05% since 1940. Flood loss data from NOAA HIC: http://www.nws.noaa.gov/hic/ GDP data from OMB: http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist10z1.xls[17]

Note: A 2005 peer-reviewed paper examined flood trends around the world and concluded: "observations to date provide no conclusive and general proof as to how climate change affects flood behaviour."[18]

Tornadoes

What the IPCC SREX (2012) says:

- "There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail"

What the data says:

7. **Tornadoes have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.**

[16] Xiaodong Jian, David M. Wolock, Harry F. Lins, and Steve Brady, Streamflow of 2012—Water Year Summary, U.S. Geological Survey, Reston, Virginia, May 2013.

[17] After Downton, M., J.Z.B. Miller, and R. A. Pielke, Jr. (2005), Reanalysis of the U.S. National Flood Loss Database. *Natural Hazards Review* **6**:13-22

[18] Kundzewicz, Z.W., D. Graczyk, T. Maurer, I. Przymusińska, M. Radziejewski, C. Svensson and M. Szwed, 2005(a):Trend detection in river flow time-series: 1. annual maximum flow. *Hydrol. Sci. J.*, **50**:797-810.

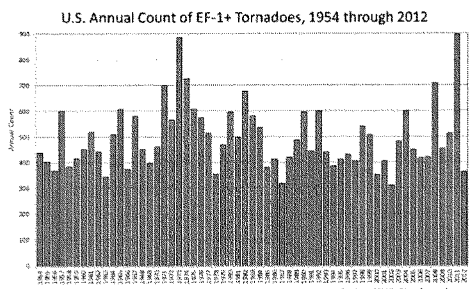

Figure 7a. Count of US tornadoes of at least EF1 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

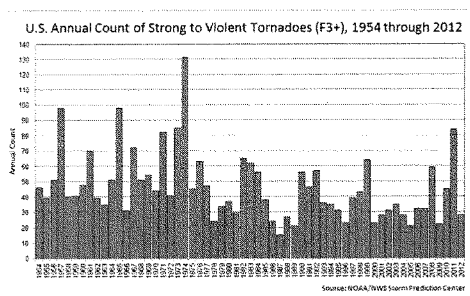

Figure 7b. Count of US tornadoes of at least EF3 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

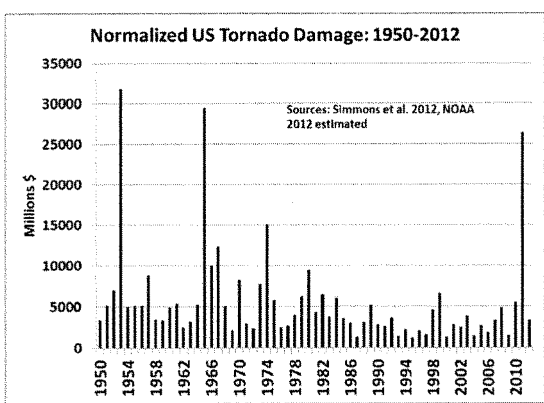

Figure 7c. Normalized US tornado damage, estimated total damage if tornadoes of past years occurred with 2012 levels of development. After Simmons et al. 2012. Note 2012 estimated.[19]

[19] Simmons, KM, D Sutter and R Pielke (2013), Normalized tornado damage in the United States: 1950-2011. *Environ. Hazards* **12**:132-14

Drought

What the IPCC SREX (2012) says:

- "There is medium confidence that since the 1950s some regions of the world have experienced a trend to more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia."
- For the US the CCSP (2008)[20] says: "droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[21]

What the data says:

8. **Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[22]**

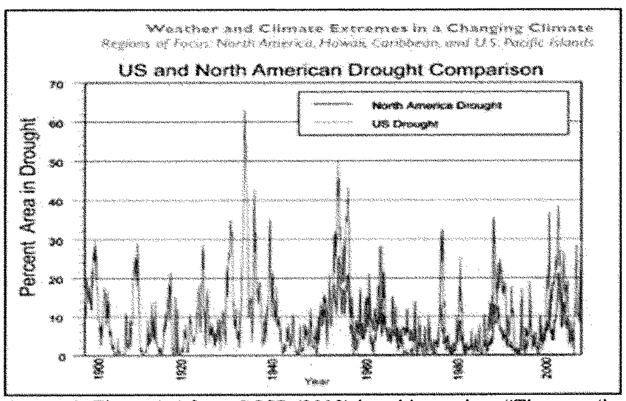

Figure 8. Figure 2.6 from CCSP (2008) has this caption: "The area (in percent) of area in severe to extreme drought as measured by the Palmer Drought Severity Index for the United States (red) from 1900 to present and for North America (blue) from 1950 to present."

Note: Writing in *Nature* Senevirnate (2012) argues with respect to global trends that, "there is no necessary correlation between temperature changes and long-term drought variations, which should warn us against using any simplifications regarding their relationship."[23]

[20] CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

[21] CCSP (2008) notes that "the main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends."

[22] This quote comes from the US Climate Change Science Program's 2008 report on extremes in North America.

[23] http://www.nature.com/nature/journal/v491/n7424/full/491338a.html

Biography of Roger Pielke Jr.

Roger Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in Environmental Sciences (CIRES). Roger's research focuses on science, innovation and politics and in 2011 began to write and research on the governance of sports organizations, including FIFA and the NCAA. Roger holds degrees in mathematics, public policy and political science, all from the University of Colorado. In 2012 Roger was awarded an honorary doctorate from Linköping University in Sweden and was also awarded the Public Service Award of the Geological Society of America. Roger also received the Eduard Brückner Prize in Munich, Germany in 2006 for outstanding achievement in interdisciplinary climate research. At CIRES, Roger served as the Director of the Center for Science and Technology Policy Research from 2001-2007. Before joining the faculty of the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger is a Senior Fellow of the Breakthrough Institute, and holds academic appointments at Macquarie University in Sydney, Australia and the London School of Economics. He is also author, co-author or co-editor of seven books, including **The Honest Broker: Making Sense of Science in Policy and Politics** published by Cambridge University Press (2007). His most recent book is **The Climate Fix: What Scientists and Politicians Won't Tell you About Global Warming** (2011, Basic Books). He is currently working on a book on technology, innovation and economic growth.

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Meteorologists' views about global warming:

A survey of American Meteorological Society professional members

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Abstract

Meteorologists and other atmospheric science experts are playing important roles in helping society respond to climate change. However, members of this professional community are not unanimous in their views of climate change, and there has been tension among members of the American Meteorological Society (AMS) who hold different views on the topic. In response, AMS created the Committee to Improve Climate Change Communication to explore and, to the extent possible, resolve these tensions. To support this committee, in January 2012 we surveyed all AMS members with known email addresses, achieving a 26.3% response rate (n=1,854). In this paper we tested four hypotheses: (1) perceived conflict about global warming will be negatively associated -- and (2) climate expertise, (3) liberal political ideology, and (4) perceived scientific consensus will be positively associated -- with (a) higher personal certainty that global warming is happening, (b) viewing the global warming observed over the past 150 years as mostly human-caused, and (c) perception of global warming as harmful. All four hypotheses were confirmed. Expertise, ideology, perceived consensus and perceived conflict were all independently related to respondents' views on climate, with perceived consensus and political ideology being most strongly related. We suggest that AMS should: attempt to convey the widespread scientific agreement about climate change; acknowledge and explore the uncomfortable fact that political ideology influences the climate change views of meteorology professionals; refute the idea that those who do hold non-majority views just need to be "educated" about climate change; continue to deal with the conflict among members of the meteorology community.

Capsule

In a survey of American Meteorological Society members, perceived scientific consensus was the strongest predictor of global warming views, followed by political ideology, climate science expertise and perceived organizational conflict.

Introduction

Mounting an effective societal response to climate change will require the involvement of the government, business, and non-governmental organization sectors, as well as myriad professional groups and members of the public at large. Meteorologists and other experts in atmospheric and related sciences are one group of professionals whose involvement is particularly important. As experts on weather and weather prediction, they will play a variety of important roles in helping other stakeholder groups make informed decisions based on changing expectations about climate and weather. Their technical expertise is complemented by the fact that members of the public see climate scientists and broadcast meteorologists as trustworthy sources of information on climate change (Leiserowitz et al., 2012).

Research conducted to date with meteorologists and other atmospheric scientists has shown that they are not unanimous in their views of climate change. In a survey of earth scientists, Doran and Zimmerman (2009) found that while a majority of meteorologists surveyed are convinced humans have contributed to global warming (64%), this was a substantially smaller majority than that found among all earth scientists (82%). Another survey, by Farnsworth and Lichter (2009), found that 83% of meteorologists surveyed were convinced human-induced climate change is occurring, again a smaller majority than among experts in related areas such as ocean sciences (91%) and geophysics (88%).

There has been tension in recent years among AMS members who hold different views on climate change (Schweizer et al., 2011). Some members have expressed that their views – which question the view that human-caused global warming was occurring – are treated with hostility within the AMS (Schweizer et al., 2011). In response to this conflict, the AMS created the Committee to Improve Climate Change Communication (CICCC) (AMS Committee to Improve Climate Change Communication, 2011). The CICCC's mission is to bring all constituencies of opinion to the discussion table, and to provide venues and modes of interaction that help facilitate respectful and constructive dialogue on climate change. The CICCC's mission explicitly does not include addressing specific areas of climate science or trying to influence the outcomes of discussions.

To better understand members' views about climate change, and their perception of any remaining conflicts about climate change within AMS membership, the CICCC commissioned George Mason University researchers to survey AMS members; the top-line findings of that survey have been reported elsewhere (Maibach and Coauthors, 2012). In this paper, we report the results of two additional sets of analysis. First, to update previous research on the extent to which meteorologists are convinced of human-caused global warming, we conducted a modified replication of Doran and Zimmerman's (2009) study. Next, we tested four specific hypotheses about factors believed to influence meteorologists' views about climate change, specifically their level of certainty that climate change is occurring, their views on whether or not it is mostly human-caused, and how harmful or beneficial its results might be. The four hypothesized influencing factors are climate science expertise, political orientation, perceived scientific consensus, and perceived conflict about climate change within AMS; the specific hypotheses are presented and justified in detail below. Lastly, we analyzed open-ended responses from survey participants about the nature of the conflict about climate change within AMS; these findings will be reported in a subsequent paper.

Literature Review and Hypotheses

Climate Science Expertise. Previous research using survey data (Doran & Zimmerman, 2009) and citation analysis (Anderegg et al., 2010) has suggested that greater expertise in climate science, measured in terms of academic background and publishing record, is associated with higher conviction that human-caused global warming is occurring. For example, in Doran &

Zimmerman's survey study, while only 82% of the total sample indicated they are convinced that humans have contributed to global warming, 89% of active publishers in the peer-reviewed scientific literature and 97% of climate experts who publish primarily on climate change in the peer-reviewed scientific literature indicated they were convinced (Doran & Zimmerman, 2009; Kendall Zimmerman, 2008). As a result, our first hypothesis is:

> H1: *As compared with professionals with less expertise in climate change, professionals with more expertise will have higher levels of personal certainty that global warming is happening, will be more likely to view it is as mostly human-caused, and will be more likely to view it as harmful rather than beneficial.*

Political Ideology. Decision-making about how to mount an effective societal response to climate change in the United States has been complicated by increasing polarization over the issue, which has occurred largely along political lines. In the late 1990s, similar proportions of liberals and conservatives saw global warming as real; by 2008 (Dunlap & McCright, 2008) -- and continuing to the present (Leiserowitz et al., 2012) -- large differences had emerged such that liberals were more likely to see it as real, and conservatives had become increasingly skeptical. This growing polarization appears not to be caused by differences in scientific understanding – indeed, most Americans know very little about the science of global warming (Leiserowitz et al., 2010) – but rather by differences in political ideology and deeper underlying values (Kahan et al., 2011). Many conservatives see the solutions proposed to mitigate global warming as being more harmful than global warming itself due to their effect on the economy (McCright & Dunlap, 2011). Liberals, on the other hand, are more likely to accept the dominant scientific view, as they see the proposed responses to global warming as strengthening activities they value – namely, protection of the environment and regulation of industrial harm.

One might expect scientists' norms of objectivity to prevent their political ideology from influencing their evaluation of scientific findings. Indeed, in one study scientists' opinions on global warming policy responses varied by political ideology, but their views on the basic science did not (Rosenberg et al., 2009). However, other studies suggest scientists' views on science can be influenced by ideology. A survey of members of the American Association for the Advancement of Science showed that conservatives differed dramatically from liberals with regard to their views about the science of global warming (Nisbet, 2011): 44% of conservatives saw global warming as mostly due to human activities, compared to about 94% of liberals. We therefore hypothesized:

H2: As compared with professionals with a more conservative political orientation, professionals with a more liberal political orientation will have higher levels of personal certainty that global warming is happening, will be more likely to be view it is as mostly human-caused, and will be more likely to view it as harmful rather than beneficial.

Perceived Scientific Consensus. Public opinion research has shown that only a minority of the public (35%) agree that "most scientists think global warming is happening." (Leiserowitz et al., 2012). Also, preliminary analyses of the data from the present survey found that only 59% of AMS members agree that 81 to 100% of climate scientists think that global warming is happening (Maibach and Coauthors, 2012). Members of the public who perceive agreement about global warming among scientific experts are more likely to view global warming as real, human-caused and harmful than people who do not perceive agreement in the scientific community (Ding et al., 2011; Dunlap & McCright, 2008; Krosnick et al., 2006). We therefore hypothesized:

H3: As compared with professionals who perceive less scientific consensus about global warming, professionals who perceive more scientific consensus will have higher levels of *personal certainty that global warming is happening, will be more likely to be view it as mostly human-caused, and will be more likely to view it as harmful rather than beneficial.*

Perceived Conflict. Schweizer and colleagues (2011) found that broadcast meteorologists who perceived conflict about global warming among their peers had disengaged from the issue, and reported having done so due to the pressure they felt from committed partisans in the conflict to "choose sides". This finding parallels an argument that has been advanced in the political science literature that increasing levels of polarization in American politics has caused the moderate majority to disengage from political participation (Fiorina & Abrams, 2008). One proposed reason for this political disengagement is that moderate voters feel no incentive to participate when they see the debate as primarily being driven by ideological positioning rather than a wish for problem-solving (Fiorina & Abrams, 2008). Schweizer et al. (2011) found similar sentiments expressed by broadcast meteorologists in relation to conflict about climate change within AMS. We believe that when members of a professional group (including but not limited to meteorologists) perceive conflict within their peer group, they will tend to withdraw from the conflict by moderating their views on the issue that is causing the conflict.

This moderation of views would entail AMS members on both ends of the spectrum of views shifting closer toward the center. However, because we expected a larger number of members to have begun with views favoring human-caused global warming (prior to perceiving conflict at the AMS), we also expected any moderating influence to result in members revising their views of global warming downward more often than upward. For this reason, when averaged across the whole population of members, we would expect greater perception of conflict to be associated with a reduced level of conviction that human-caused global warming was occurring. We therefore hypothesized:

H4: As compared with professionals who perceive less conflict about global warming within the membership base of their professional society, professionals who perceive more conflict will report lower levels of personal certainty that global warming is happening, will be less likely to be view it is as mostly human-caused, and less likely to view it as harmful rather than beneficial.

Method

On 29 December 2011, we emailed all 7,197 AMS members for whom AMS had an e-mail address, excluding associate members and student members. The e-mail -- signed by the CICCC chairs -- requested participation in our survey and provided a link to the Web-based survey form (including the consent form). On 6 January 2012, and again on 11 January 2012, participants who had not yet responded received reminders by e-mail. On 27 March 2012, 375 participants who had given one specific answer (to a question on global warming causation) were emailed a request to answer one additional question (designed to clarify their view on causation). This question is described further below.

Of the 7,197 people invited to participate, 135 people were ineligible due to invalid addresses. Therefore, the valid denominator of our sample was 7,062. Of these, 1,854 people completed at least some portion of the survey beyond the consent form, yielding a minimum response rate of 26.3% (which assumes that all non-respondents were eligible to participate); this is slightly lower than the average rate for Web surveys (Shih & Fan, 2008). Of the 375 people who were sent the follow-up question, 271 responded. One of these respondents refused to answer the question, for a response rate to the follow-up question of 270 out of 375, or 72%.

Independent variables

Expertise. To assess climate science expertise, we examined three measures: whether or not respondents indicated climate science as their area of expertise, their highest degree obtained, and their peer-reviewed publishing record on climate change over the last five years. Using principal axis factor analysis, we found these measures formed a single factor; loadings for all variables were within the acceptable range (Gorsuch, 1983). We therefore decided to sum all three variables into an index of climate science expertise. For area of expertise, participants who indicated climate science as their area of expertise were scored 1; all others were scored 0. For highest degree, participants who answered "PhD (or other doctoral degree)" and "MS or MA" were scored 2 and 1, respectively; all others were scored 0. For publishing record, respondents who said they published more than 50% of their peer-reviewed papers in the last 5 years on climate change were scored 2. We asked whether they had published more or less than 50% of their papers in climate change to achieve comparability with the results of Doran & Zimmerman (2009), who also used this as one of their measures of expertise. Those who said they published fewer than 50% of their papers on climate change, or who answered "N/A" to the question on their proportion of climate change papers, were scored 1. Those who had not published in the last five years were scored 0. The scores on all three variables were summed, resulting in a composite variable with possible scores ranging from 0 to 5.

Political ideology. This measure was based on responses to the question item: "In general, do you think of yourself as:" to which participants could respond "Very conservative," "Somewhat conservative," "Moderate," "Somewhat liberal," or "Very liberal." The responses were coded 0 to 4, respectively.

Perceived consensus. Respondents were asked: "To the best of your knowledge, what proportion of climate scientists think that human-caused global warming is happening?"

Response categories were: 0 to 20%, 21 to 40%, 41 to 60%, 61 to 80%, 81 to 100%, (coded 1 to 5, respectively) and "I don't know enough to say." Respondents who indicated "I don't know" (n=156) were excluded from the analyses so that perceived consensus could be analyzed as a single continuous variable. To assess if the exclusion of "Don't know" respondents influenced our findings, we conducted additional analyses with all respondents using dummy coding, a statistical technique that allows non-continuous variables to be entered into linear regressions. This produced no significant change to the results.

Perceived conflict. Respondents were asked if they agreed or disagreed with the statement: "There is conflict among AMS members on the issue of global warming." Response options were "Strongly disagree," "Somewhat disagree," "Neither agree nor disagree," "Somewhat agree," and "Strongly agree." The responses were coded 0 to 4, respectively.

Dependent Variables

Certainty. To establish the certainty of respondents' views on global warming, we asked two questions. The first asked whether global warming is happening, and the second assessed their level of certainty that it is happening. The first question was worded: "In this survey, the term "global warming" refers to the premise that the world's average temperature has been increasing over the past 150 years, may be increasing more in the future, and that the world's climate may change as a result. Regardless of the cause, do you think that global warming is happening?" Respondents who answered either "Yes" or "No" were presented with a certainty assessment item: "How sure are you that global warming [is/is not] happening?" We then calculated a composite measure to capture the responses to the two questions in a single variable. This resulted in a 9-point certainty measure ranging from -4 (Global warming not happening – extremely sure) to +4 (Global warming happening – extremely sure), with zero (Don't know if global warming is happening) as the neutral midpoint.

Cause. If respondents indicated they agreed global warming was occurring, we subsequently asked them "Do you think that the global warming that has occurred over the past 150 years has been caused..." to which they could answer "Mostly by human activity", "Mostly by natural events", "More-or-less equally by human activity and natural events", "I do not believe we (scientists) know enough yet to determine the degree of human or natural causation, even in the general terms stated in the categories above," and "I don't know".

In order to make a more precise comparison of our results to those of Doran and Zimmerman (2009), a follow-up question was posed via email (approximately 10 weeks later) to those who answered: "I do not believe we know enough to determine the degree of human causation." Specifically, we sought to determine if these participants were convinced that human activity has contributed to global warming. Thus we asked: "Do you think human activity has contributed to the global warming that has occurred over the past 150 years?" The answer options were Yes, No, Don't know. (The full text of the follow-up email is available in the Appendix of this article.) Percentages of respondents who gave each possible response to the causation question are displayed below in Table 1. Due to the categorical nature of these responses, they could not be used as a dependent variable for linear regression analysis. Therefore, they were transformed into a dichotomous variable for use in binary logistic regression. This variable was coded 1 for all respondents who agreed global warming is caused "mostly by human activity", and 0 for respondents who made any other response.

Level of Harm/Benefit. Respondents who agreed global warming was occurring were asked the following question: "Over the next 100 years, how harmful or beneficial do you think global warming will be to people and society, if nothing is done to address it?" Response options were: very harmful, somewhat harmful, the harms and benefits will be more or less equal, somewhat beneficial, very beneficial, and don't know. Only about 10% of respondents answered "don't know." We omitted these participants so that linear regression could be used on a continuous dependent variable ranging from very beneficial (coded 0) to very harmful (coded 4), with a midpoint of "the harms and benefits will be more or less equal" (coded 2).

Analysis

Using SPSS Versions 17.0 and 19.0, we examined the distributions of all variables. To compare our results to those of Doran and Zimmerman (2009) we cross-tabulated the results for the initial and follow-up questions on global warming causation by area of expertise, publishing record in the last five years, and proportion of papers in the last five years that were on global warming.

To test our hypotheses, we conducted linear and logistic regressions. Global warming certainty and harm/benefit served as dependent variables in the linear regressions, and the view that global warming is/is not mostly human-caused (coded 1 for all respondents who agreed global warming is mostly human caused, and 0 for respondents who made any other response) served as the dependent variable in the logistic regression. In all of these analyses demographic variables, expertise, political ideology, perceived scientific consensus on global warming, and perceived conflict served as the independent variables.

It should be noted that the analyses for causation and harm/benefit only include data from the 89% of the sample who said that global warming is happening (rather than "not happening" or "don't know"). Since the other 11% did not answer the questions on global warming causation and harm/benefit, they could not be included in analyses of answers to these questions.

Results

Replication of Doran & Zimmerman (2009)

Table 1 shows the proportion of survey respondents – divided by their area of expertise (climate change vs. meteorology and atmospheric science) and their publishing record (publishing mostly on climate change vs. publishing mostly on other topics vs. non-publishing) – who report each of several different views on whether global warming is happening and what is causing it. The proportion of each group that is convinced that humans have contributed to global warming is determined by adding the proportions presented in the table's first row (respondents who indicated global warming is happening and it is mostly human-caused), second row (respondents who indicated global warming is happening and it is equally human-caused and natural) and the first row of the Insufficient Evidence subsection at the bottom of the table (respondents who indicated global warming is happening and although there is insufficient evidence to attribute cause with precision, human activity is implicated to some degree).

Climate science experts who publish mostly on climate change, and climate scientists who publish mostly on other topics, were the two groups most likely to be convinced that humans have contributed to global warming, with 93% of each group indicating their concurrence. The two groups least likely to be convinced of this were the non-publishing climate scientists and non-publishing meteorologists/atmospheric scientists, at 65% and 59%, respectively. In the middle were the two groups of publishing meteorologists/atmospheric scientists at 79% and 78%, respectively.

[Table 1 about here]

Hypothesis Tests

Confirming all four hypotheses, the regression analyses showed that greater expertise, more liberal ideology, greater perceived consensus, and lower perceived conflict each predicted higher levels of certainty global warming was occurring, higher likelihood of viewing it as mostly human caused, and greater ratings of future harm. Together, the independent variables explained 37% of the variation in certainty that global warming is occurring, and 29% of the variation in views on global warming harm, which is considered a moderate amount of explained variance in social science research (Cohen, 1992). Due to the nature of logistic regression, an equivalent statistic is unavailable for the proportion of explained variation in views on global warming causation.

In terms of strength of the relationship between the independent and dependent variables, perceived consensus was the strongest predictor of all three types of global warming views – certainty, causation, and harm/benefit. Political ideology was the second strongest predictor of view certainty and causation, and was equivalent to perceived consensus as predictor of harm/benefit. Expertise and perceived conflict were both less strong predictors of global warming views. Expertise was the second weakest predictor of global warming certainty, and the weakest predictor of causation and harm/benefit.Perceived conflict was the weakest predictor of global warming view certainty, and the second weakest predictor of causation and harm/benefit. For details of the regression analyses, see the online supplementary material.

Discussion

Our findings regarding the degree of consensus about human-caused climate change among the most expert meteorologists are similar to those of Doran and Zimmerman (2009): 93% of actively publishing climate scientists indicated they are convinced that humans have contributed to global warming. Our findings also revealed that majorities of experts view human activity as the *primary* cause of recent climate change: 78% of climate experts actively publishing on climate change, 73% of all people actively publishing on climate change, and 62% of active publishers who mostly do not publish on climate change. These results, together with those of other similar studies, suggest high levels of expert consensus about human-caused climate change (Farnsworth & Lichter 2012, Bray 2010).

Furthermore, our study was the first study of scientific professionals we know of to include expertise, political ideology and perceived scientific consensus in a regression analysis and thus compare the potential unique effects of each in shaping global warming views. We found that perceived scientific consensus, political ideology, expertise and perceived conflict are each, to greater or lesser degrees, associated with AMS members' views of global warming. Before considering implications of those findings, however, readers should consider two methodological issues that could have affected the accuracy of our results.

First, even though the response rate to our survey was well within the normative range, nearly three quarters of the AMS members invited to participate did not do so. This raises the possibility that our respondents may not accurately represent the views of the broader AMS membership. It is plausible, for example, that AMS members skeptical of global warming may have been *less* likely than the average member to respond, potentially by virtue of feeling marginalized within their professional society as a result of the views on the issue. Conversely, it is also plausible that skeptical members may have been *more* likely than the average member to respond, due to a desire to use the opportunity to have their views recognized by AMS leadership and other members. We have no way of directly assessing the comparability of our sample to the broader AMS population in terms of global warming views. We have, however, compared the demographics of our respondents to the demographics from an AMS membership survey conducted in 2005 (Murillo et al., 2008; n=5,394; survey completion rate = 48%). Our sample had fewer students (1% vs. 17% in 2005, although we intentionally did not include student members in our sample), more retired members (11% vs. 4% in 2005), more older members (59% were 50 or over, vs. 33% over 50 in 2005), more members with PhDs (52% vs. 38%), more members employed in research (41% vs. 31%), and fewer female members (15% vs. 20%). It is thus reasonable to suggest the present sample is quite similar to the overall membership of the AMS, at least demographically.

Second, our estimates of the proportion of AMS members who are convinced that global warming is occurring should be interpreted in light of an issue that arose regarding the time frame of global warming that we asked about. We asked respondents specifically about global warming that occurred over the last 150 years. However, the findings of the 2007 IPCC Report state that human activity has been the dominant cause of warming since the mid-20th century (Core Writing Team et al., 2007, p39). Six respondents sent emails to notify us that their answers would have been different if we had asked about the most recent 50-year time frame rather than the 150-year time frame; the time frame used in the question may have also influenced other respondents. Our results therefore may represent a more conservative estimate of the consensus on global warming than would have been obtained had we asked about a 50-year time frame. The relationships of the independent variables and global warming views may also have been affected by the time frame described, as we discuss further below.

Confirmation of our four hypotheses shows that meteorologists' views about global warming observed in the last 150 years are associated with, and may be causally influenced by, a range of personal and social factors. In other words, the notion that expertise is the single dominant factor shaping meteorologists' views of global warming appears to be simplistic to the point of being incorrect.

We found that perceived scientific consensus was the factor most strongly associated with AMS members' views about global warming. This suggests that scientists' thinking on scientific topics may be subject to the same kinds of social normative influences that affect the general public. Rather than rationally weighing the evidence and deciding for themselves, as would be expected under more traditional ideas of scientific judgment, scientists may also use the views of a relevant peer group as a social cue for forming their own views. Our results are consistent with those of Lewandowsky et al. (2013), who found that providing information on the scientific consensus increased the likelihood of members of the public agreeing that global warming was occurring. Our data are cross-sectional, rather than experimental as in Lewandowsky et al. (2013), so we cannot be certain of the direction of the causal relationship between perceived consensus and views on global warming for AMS members. Nevertheless, the findings of Lewandowsky et al. (2013) combined with our results suggest that perceived scientific consensus may have a substantial influence on AMS members' global warming views.

Political ideology was the factor next most strongly associated with meteorologists' views about global warming. This also goes against the idea of scientists' opinions being entirely based on objective analysis of the evidence, and concurs with previous studies that have shown scientists' opinions on topics to vary along with their political orientation (Nisbet, 2011; Rosenberg et al., 2009). The result suggests that members of professional scientific organizations have not been immune to influence by the political polarization on climate change that has affected politicians and the general public.

We found expertise to be positively associated with meteorologists' views about global warming, concurring with previous studies on the relationship between climate science expertise and global warming views (Doran & Zimmerman, 2009; Anderegg et al., 2010). This result is contrary to that found by Kahan et al. (2012b) in which members of the public with greater scientific literacy viewed climate change as a slightly *less* serious risk. The difference between the two studies is likely explained by the different measures of expertise. As opposed to comprehension of rudimentary scientific facts, knowledge acquired via graduate-level training and publishing in climate science *does* appear to increase the likelihood of viewing global warming as real, human-caused and harmful, if other factors are held constant.

While we found that higher expertise was associated with a greater likelihood of viewing global warming as real and harmful, this relationship was less strong than for political ideology and perceived consensus. At least for the measure of expertise that we used, climate science expertise may be a less important influence on global warming views than political ideology or social consensus norms. More than any other result of the study, this would be strong evidence against the idea that expert scientists' views on politically controversial topics can be completely objective.

Finally, we found that perceiving conflict at AMS was associated with lower certainty of global warming views, lower likelihood of viewing global warming as human caused, and lower ratings of predicted harm caused by global warming. This suggests that perceiving conflict within the context of their professional society may have caused AMS members to withdraw from the issue of global warming by moderating their beliefs. In addition to individual-level factors such as expertise and ideology affecting views on global warming, the polarized discursive environment in which discussion of the issue takes place may be reducing the chances of widespread engagement with it (Schweizer et al., 2011).

As our data are cross-sectional, we cannot rule out an alternative possibility for the causal direction of this relationship. Rather than perceived conflict influencing views of global warming, people with skeptical views on global warming might become relatively more likely to perceive conflict at the AMS. Nevertheless, the significant relationships obtained in this study are enough to warrant further investigation of the possibility of increasing engagement through resolving conflicts at AMS.

As we mentioned above, asking about a 150-year time frame rather than a 50-year time frame may also have changed the strength of the relationships between global warming views and other variables. For example, expertise may have been a stronger predictor of views on human causation if we had asked about a shorter timeframe. Because the evidence for human causation is much stronger for the last 50 years (Core writing team et al., 2007), we would expect experts, who are presumably familiar with this evidence, to be substantially more likely to view global warming in *this* period as human-caused than non-experts who were not familiar with the evidence. Conversely, the evidence is weaker for human causation over the past 150 years, and experts' familiarity with this weak evidence would be less likely to lead to viewing climate change as human-caused. The importance of the other independent variables – perceived consensus, political ideology, and perceived conflict – we would predict to remain largely unchanged. Because these variables are not postulated to affect global warming views through direct knowledge of scientific evidence, changing a scientific detail (the 150-year timeframe) should not affect the influence these variables have on global warming views.

Although we believe our research raises more important questions than it answers, we do see some important practical implications of our findings. First, the strong relationship between perceived scientific consensus and other views on climate change suggests that communication centered on the high level of scientific consensus may be effective in encouraging engagement by scientific professionals. This exploration of views of the consensus could be accomplished via town hall style events at professional society meetings, where participants' responses to exploratory questions are aggregated and presented back to the group for reflection, discussion and dialogue. It could also be accomplished via "world café"-style discussion events (Brown & Isaacs, 2005), such as that conducted recently by the Washington DC chapter of the AMS.

Second, the relationship between political ideology and global warming views suggests that those wishing to encourage engagement should find a way to address the political differences that are likely to exist between those with different views on climate change. One way to do this could be to recognize and affirm the value of all members' political views prior to discussions of climate science. Discourse that affirms the value of diverse worldviews has shown potential to promote less polarized discussion of scientific issues where ideology has influenced differences of opinion, such as climate change (Kahan et al., 2012a).

Third, engagement efforts should include refutation of the idea that members who do not share the consensus view in climate science are lacking in expertise. A substantial number of expert AMS members – 22% of the most expert group in our sample – do not subscribe to the position that global warming is mostly human-caused. Climate experts are not completely homogenous in their views on global warming, just as climate skeptics have been shown to have a variety of nuanced opinions (Hobson & Niemeyer, 2013). Any suggestion that all those with non-majority views simply need to be "educated" is inaccurate and likely to be insulting to a substantial number of AMS members. Discussion based on an understanding that views are more nuanced would be more productive.

Fourth, efforts to increase engagement with climate change will have minimal effects if they focus on increasing climate science knowledge alone. Although higher expertise is associated with increased tendency to view climate change as real and harmful, the increase resulting even from major gains in expertise – such as that associated with obtaining a PhD – seems to be quite modest. Increases in knowledge obtained through short-term campaigns are likely to be even smaller. For this reason, engagement campaigns should attempt to deal with other important factors such as consensus and political ideology as well as purely scientific information.

Finally, AMS and other organizations seeking to enhance the climate change readiness of the meteorology community should find ways to acknowledge and deal with the conflict. This may improve relations between members – a worthy goal in itself – and higher levels of willingness to engage with climate change may also result. Recently, the AMS CICCC and other of this article's authors have been involved in exploratory conflict analysis and mediation workshops with AMS members and other groups of meteorologists; the results to date of those efforts have been promising (Schweizer et al., 2011; Schweizer et al., in press). Given the importance of the issue, continuing these efforts and/or exploring alternative conflict analysis resolution methods would appear to be a worthy priority.

In conclusion, given the potential for human society and the earth's eco-systems to be harmed by climate change, it is imperative that members of the scientific community – and the professional societies that represent them – take all reasonable measures to ensure that what is known about the risks, and about options for managing those risks, are shared with decision makers who should be considering that information. While the difficulties of doing this are widely acknowledged (Pidgeon & Fischhoff, 2011), the problem is often attributed to the difficult dynamics associated with external communication, i.e., sharing complex scientific information with the broader community. Our research suggests that there are also important dynamics associated with internal communication, i.e., sharing information and coming to consensus within the scientific community.

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Appendix

Text of Follow-up Email

Dear fellow AMS member,

You graciously participated in a survey that I sent you in late December, 2011 on behalf of the AMS Committee to Improve Climate Change Communication. Thank you.

It has become clear that one question on the survey included an answer option that is difficult to interpret without additional information.

That question - and its answer options - was:

Do you think that the global warming that has occurred over the past 150 years has been caused...

a) Mostly by human activity

b) More-or-less equally by human activity and natural events

c) Mostly by natural events

d) I do not believe we (scientists) know enough yet to determine the degree of human or natural causation, even in the general terms stated in the categories above

e) I don't know

You answered (d), the response option that we don't know how to interpret. We are hoping to clarify what you meant by asking you one additional question.

Do you think human activity has contributed to the global warming that has occurred over the past 150 years?

Yes
No
Don't Know

Please reply to this email by typing one of the following: Yes, No, or Don't Know.

If you wish to add an explanation of your answer feel free to do so, but please begin your reply with only "Yes," "No," or "Don't Know."

Thank you very much for taking the time to do this.

Best Regards,

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References

AMS Committee to Improve Climate Change Communication, 2011: AMS CICCC charter and terms of reference. American Meteorological Society, 4 pp. [Available online at http://www.ametsoc.org/boardpges/cwce/docs/BEC/CICCC/2011-02-Charter-TOR-Members.pdf]

American Meteorological Society Council, 2012: An information statement of the American Meteorological Society: Climate change. American Meteorological Society, 7pp. [Available online at http://www.ametsoc.org/policy/2012climatechange.pdf]

Anderegg, W. R. L., J.W. Prall, J. Harold, and S.H. Schneider, 2010: Expert credibility in climate change. *Proc. Natl. Acad. Sci. USA*, **107**, 12107–12109. doi:10.1073/pnas.1003187107

Bray, D., 2010: The scientific consensus of climate change revisited. *Environ. Sci. Policy*, **13**, 340–350. doi:10.1016/j.envsci.2010.04.001

Brown, J., and D. Isaacs, 2005: *The world cafe: Shaping our futures through conversations that matter*. Berrett-Koehler Publishers, 300 pp.

Cohen, J., 1992: A power primer. *Psychol. Bull.*, **112**, 155–159. doi:10.1037/0033-2909.112.1.155

Core Writing Team, R.K. Pachauri, and A. Reisinger, Eds., 2007: *Climate change 2007: Synthesis report.* Intergovernmental Panel on Climate Change, 52 pp. [Available online at http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf]

Ding, D., E.W. Maibach, X. Zhao, C. Roser-Renouf, and A. Leiserowitz, 2011: Support for climate policy and societal action are linked to perceptions about scientific agreement. *Nat. Climate Change*, **1**, 462–466. doi:10.1038/nclimate1295

Doran, P. T., and M.K. Zimmerman, 2009: Examining the scientific consensus on climate change. *Trans., Amer. Geophys. Union*, **90**, 22-23. doi:10.1029/2009EO030002

Dunlap, R. E., and A.M. McCright, 2008: A widening gap: Republican and Democratic views on climate change. *Environment,* **50**, 26–35.

Farnsworth, S. J. and S.R. Lichter, 2009: The structure of evolving US scientific opinion on climate change and its potential consequences. *Social Science Research Network*, 26 pp. [Available online at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1450804]

Farnsworth, S. J. and S.R. Lichter, 2012: The structure of scientific opinion on climate change. *Int. J. Public Opin. R.*, **24**, 93–103. doi:10.1093/ijpor/edr033

Fiorina, M. P., and S.J. Abrams, 2008: Political polarization in the American public. *Annu. Rev. Polit. Sci.*, **11**, 563–588. doi:10.1146/annurev.polisci.11.053106.153836

Gorsuch, R. L., 1983: *Factor analysis*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hobson, K., and S. Niemeyer, 2013: "What sceptics believe": The effects of information and deliberation on climate change scepticism. *Public Understanding Sci.,* 22, 396-412. doi:10.1177/0963662511430459

Kahan, D. M, H. Jenkins-Smith, and D. Braman, 2011: Cultural cognition of scientific consensus. *J. Risk Res.*, **14**, 147–174.

Kahan, D.M., H.C. Jenkins-Smith, T. Tarantola, C.L. Silva, and D. Braman, 2012a: Geoengineering and the science communication environment: A cross-cultural experiment. *Social Science Research Network,* 41 pp. [Available online at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1981907]

Kahan, Dan M., E. Peters, M. Wittlin, P. Slovic, L.L. Ouellette, D. Braman, and G. Mandel, 2012b: The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nat. Climate Change,* **2,** 732-735. doi:10.1038/nclimate1547

Kendall Zimmerman, M., 2008: The consensus on the consensus: An opinion survey of Earth scientists on global climate change. PhD dissertation, University of Illinois at Chicago, 250 pp.

Krosnick, J. A., A.L. Holbrook, L. Lowe, & P.S. Visser, 2006: The origins and consequences of democratic citizens' policy agendas: A study of popular concern about global warming. *Clim. Change*, **77**, 7–43. doi:10.1007/s10584-006-9068-8

Leiserowitz, A., E. Maibach, C. Roser-Renouf, G. Feinberg, and P. Howe, 2012: Climate change in the American mind: Americans' global warming beliefs and attitudes in September, 2012. Yale University and George Mason University, 31 pp. [Available online at http://environment.yale.edu/climate/files/Climate-Beliefs-September-2012.pdf]

Leiserowitz, A., N. Smith, and J.R. Marlon, 2010: Americans' knowledge of climate change. Yale University, 60 pp. [Available online at http://environment.yale.edu/climate/files/ClimateChangeKnowledge2010.pdf]

Lewandowsky, S., G.E. Gignac, and S. Vaughan, 2013: The pivotal role of perceived scientic consensus in acceptance of science. *Nat. Climate Change,* **3,** 399–404.

Maibach, E., and Coauthors, 2012: American Meteorological Society member survey on global warming: preliminary findings. George Mason University Center for Climate Change Communication, 19 pp. [Available online at http://www.climatechangecommunication.org/images/files/AMS_CICCC_Survey_Preliminary_Findings-Final.pdf]

McCright, A. M., and R.E. Dunlap, 2011: The politicization of climate change and polarization in the American public's views of global warming, 2001–2010. *Sociol. Quart.*, **52**, 155-194.

Murillo, S.T., R.E. Pandya, R.Y. Chu, R. Czujko, J.A. Winkler, and E.M.C. Cutrim, 2008: AMS membership survey results: An overview and longitudinal analysis of the demographics of the AMS. *Bull. Amer. Meteor. Soc.,* **89**, 727–733. doi:10.1175/BAMS-89-5-727.

Nisbet, M.C., 2011: Climate shift: Clear vision for the next decade of public debate. American University School of Communication, 99 pp. [Available online at http://climateshiftproject.org/wp-content/uploads/2011/08/ClimateShift_report_June2011.pdf]

Pidgeon, N., and B. Fischhoff, 2011: The role of social and decision sciences in communicating uncertain climate risks. *Nat. Climate Change*, **1**, 35-41.

Rosenberg, S., A. Vedlitz, D.F. Cowman, and S. Zahran, 2009: Climate change: A profile of US climate scientists' perspectives. *Climate Change*, **101**, 311–329. doi:10.1007/s10584-009-9709-9

Schweizer, V., S. Cobb, W. Schroeder, G. Chau, E. Maibach, R. Henson, C. Mandryk, and J. Witte, 2011: Reframing the (discursive) environment in the climate change conflict for American weathercasters. Manuscript presented at the workshop *Mediation in Environmental Conflicts Management: New Frontiers*, Milan, Italy, Politecnico di Milano.

Schweizer, V., S. Cobb, W. Schroeder, G. Chau, and E. Maibach, in press: TV weathercasters and climate education in the shadow of climate change conflict. *Culture, politics and climate change: How information shapes our common future*, D. Crow and M. Boykoff, Eds., Routledge, 208 pp.

Shih, T. H., and X. Fan, 2008: Comparing response rates from web and mail surveys: A meta-analysis. *Field method.*, **20**, 249-271.

***Table 1.* Meteorologists' assessment of human-caused global warming by area and level of expertise**. Figures are percentages rounded to the nearest whole number. Numbers in the bottom four rows represent percentage of respondents giving each possible response to the follow-up email question, including non-response to the email (labeled "insufficient evidence – unknown"). These responses together add to the same number as displayed in the insufficient evidence (total) row; some differences occur due to rounding. Similarly, columns total to 100% if all numbers except those in the bottom four rows are added, and differences from 100 are due to rounding. Although 1854 people completed some portion of the survey, this table only displays the results for 1821 respondents, since 33 (less than 2% of the sample) did not answer one or more of the questions on expertise and global warming causation.

	Area of expertise:									
	Climate Science (n=232)			Meteorology & Atmospheric Science (n=1203)			Sample Total (n = 1821)			All Respondents (n=1821)
	Publication focus:			Publication focus:			Publication focus:			
Is global warming (GW) happening? If so, what is its cause?	Mostly Climate (n=124)	Mostly Other (n=82)	Non-Publishers (n=26)	Mostly Climate (n=61)	Mostly Other (n=501)	Non-Publishers (n=641)	Mostly Climate (n=231)	Mostly Other (n=790)	Non-Publishers (n=800)	
Yes; Mostly human	78	71	38	61	57	35	73	62	37	52
Yes; Equally human and natural	10	10	8	10	10	11	10	9	11	10
Yes; Mostly natural	2	1	15	5	3	9	3	3	9	5
Yes; Insufficient evidence (total)	6	16	23	11	21	27	9	18	26	20
Yes; Don't know cause	2	1	0	0	1	1	1	1	1	1
Don't know if GW is happening	1	1	8	11	6	10	3	5	11	7
GW is not happening	1	0	8	2	2	7	1	2	7	4
	Further subdivision of "Insufficient Evidence" responses									
Yes; Insufficient evidence - some human	5	12	19	8	11	14	6	11	14	11
Yes; Insufficient evidence - not sure whether any human	1	2	0	0	3	4	0	3	4	3
Yes; Insufficient evidence - unknown	1	1	4	3	7	8	2	5	7	6
Yes; Insufficient evidence - no human	0	0	0	0	0	1	0	0	1	0

A Summary and Comparison of Bird Mortality from Anthropogenic Causes with an Emphasis on Collisions[1]

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Abstract

We estimate that from 500 million to possibly over 1 billion birds are killed annually in the United States due to anthropogenic sources including collisions with human-made structures such as vehicles, buildings and windows, power lines, communication towers, and wind turbines; electrocutions; oil spills and other contaminants; pesticides; cat predation; and commercial fishing by-catch. Many of the deaths from these sources would be considered unlawful take under federal laws such as the Endangered Species Act, Migratory Bird Treaty Act, and the Bald and Golden Eagle Protection Act. In this paper, we summarize this literature and provide the basis for the mortality projections for many of the apparent significant sources. Most of the mortality projections are based on small sample sizes, and on studies typically lacking adjustments for scavenging and searcher efficiency biases. Although the estimates for each source often range by an order of magnitude, the cumulative mortality from all these sources continues to be a concern.

Key Words: avian mortality, avian fatalities, collisions, communication towers, contaminants, electrocutions, fishing by-catch, power lines, vehicles, wind turbines.

Introduction

All taxonomic groups of birds are subjected to significant human-caused mortality. Most of the anthropogenic-caused bird mortality would be considered unlawful take under the Migratory Bird Treaty Act, Endangered Species Act, and Bald and Golden Eagle Protection Act. The recently well-publicized prosecution of a utility for Golden Eagle (*Aquila chrysaetos*) electrocutions in Colorado by the United States Fish and Wildlife Service has increased the awareness of these issues (Manville this volume a). Collisions with artificial structures are a significant and well-documented source of bird mortality. Bird collisions with artificial structures and associated fatalities have been documented in the United States (US) since the late 1880s (Crawford and Engstrom 2000). A large amount of published and unpublished literature exists on avian collisions with artificial structures and vehicles. Bird mortality associated with pesticides, oil spills, oil pools, and other contaminant sources have also received significant attention. Domestic and feral cats have also been considered a major source of anthropogenic-caused mortality with estimates near 100 million annual bird deaths. However, calculating accurate numbers of bird fatalities associated with any of these sources is difficult due to limitations in the scope of most mortality studies, as compared to the extensive distribution and extent of these sources. Some individual studies have been well designed to obtain accurate fatality estimates for the particular structure(s) investigated (e.g., Kemper 1996, Johnson et al. 2002); however, most studies that are available for making these estimates lack standardized methods for searching, and often do not consider sources of bias, such as scavenging and searcher efficiency.

Many of the studies are limited to documenting avian collisions at a particular season or location. For example, many of the studies are limited to fall migration periods. Furthermore, many of the studies were conducted in response to suspected or actual large mortality events, and focus on areas where the number of fatalities may be unusually high. For example, many power line studies involved monitoring fatalities associated with lines near wetlands with high waterfowl use. In many cases, fatality estimates derived from data reported in the available literature would most likely be an over-estimate of the true mortality. Estimating the annual fatality rate for any of these sources requires a random or at least representative sample of experimental units (e.g., buildings, communication towers, miles of road, number of agricultural fields) with information replicated across time, but due to obvious logistical and financial constraints, a large representative sample of experimental units for each source has not been studied.

We did not attempt to develop our own estimates of avian mortality from sources other than wind turbines

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due to the lack of standardized information. We feel that the available data cannot be used to make projections based on averages of individual estimates. Instead, we have updated previous estimates provided in the literature based on increases in the number (e.g., buildings) or extent of collision sources. Although the many difficulties in making fatality projections is widely recognized, the shear magnitude of these projections should continue to bring an awareness and concern to anthropogenic-caused bird mortality.

Sources of Biases in Estimating Fatality Rates

Determining the extent of wildlife mortality due to environmental perturbations such as oil spills or due to collisions with structures such as power lines, buildings, communication towers, or wind plants is a difficult sampling and estimation problem (Erickson et al. 2000a, 2001). Biases associated with observer detection and scavenging rates can lead to biased mortality estimates (Morrison 2002). Observers conducting searches for carcasses often may not detect some of the carcasses for various reasons including dense vegetative cover, size of carcass and cryptic coloration of the carcasses. During fatality studies at the Buffalo Ridge wind plant in southwest Minnesota, the proportion of carcasses detected by observers, (i.e., searcher efficiency rates) for small birds (e.g., most passerines) was estimated at 30 percent when averaged across several habitat types (e.g., plowed field, corn, wetland, CRP/grassland) and across spring, summer and fall seasons (Johnson et al. 2002). In contrast, searcher efficiency rates for small birds at the Foote Creek Rim wind plant, Wyoming in short grass prairie habitat was 57 percent (Young et al. 2003). Searcher efficiency rates for large birds (e.g., waterfowl and raptors) were 49 percent on average at Buffalo Ridge, but over 90 percent at Foote Creek Rim. Similar protocols for searching (transect widths, etc.) were used at both sites. Comparisons of fatality rates at Foote Creek Rim and Buffalo Ridge that unadjusted for searcher efficiency would be very misleading.

Estimated disappearance or scavenger removal rates vary significantly in the literature. Nearly 80 percent (79.2) of the chicks placed in a mixed grazed pasture were removed within 24 hr of being placed (Wobeser and Wobeser 1992). In Maryland, approximately 75 percent of 78 trial carcasses placed in agricultural fields were removed in the first 24 hr (Balcomb 1986). During a study at a TV tower in Florida, 93 percent of 157 birds purposely placed underneath the tower at dusk to monitor predation were partially or completely removed by the next morning (Crawford 1971). In France, Pain (1991) estimated duck carcasses lasted an average of 1.5 d in open habitats, whereas those concealed by vegetation or those in water lasted between 3.3 and 7.6 d. In one orchard during this study, scavengers removed all 25 of the placed carcasses within 24 hr, with lower rates in the other orchards studied. At the Vansycle wind plant in Oregon, small carcasses or evidence of the carcass (e.g., feather spot) lasted an average of 15.0 d, and large carcasses lasted on average longer than 28 d (Erickson et al. 2000b). At the Buffalo Ridge wind plant, small carcasses persisted an average of 4.7 d, whereas small birds at Foote Creek Rim persisted 12.2 d. Disappearance rates also likely vary by species or avian group. For example, it is speculated that raptor carcasses last longer than other large bird carcasses such as game birds and waterfowl, although limited empirical data exist to test this hypothesis.

Carcass detection rates and scavenging rates do vary among sites, habitats, seasons and sizes of birds. Comparison of fatality rates that are not adjusted for these two primary sources of bias can be very misleading. Differences in observed fatality rates may only reflect true differences in scavenger densities or carcass detection rates. Many, if not most of the studies of bird mortality we present below, do not account for the biases described above. The following sections provide a review of studies of mortality for collision sources such as power lines, buildings and windows, communication towers and wind turbines.

Collision Mortality

Avian Mortality Due to Collisions with Automobiles, Trains, and Airplanes

Study examples

Although several studies have been conducted in Europe (e.g., Finnis 1960, Hodson 1962, Dunthorn and Errington 1964, Hodson and Snow 1965, Hugues 1996), we found relatively few documents that reported vehicle-related avian mortality in the United States. In Illinois, Decker (1987) traversed a 4.4-mile (7 km) stretch of road daily and estimated mortality at 33 birds per mile per year (21 birds/km/year). The most common fatalities were passerines or other small birds, including Yellow-billed Cuckoo (*Coccyzus americanus*), Blue Jay (*Cyanocitta cristata*), Red-winged Blackbird (*Agelaius phoeniceus*), and Indigo Bunting (*Passerina cyanea*). In Ontario, Canada, Ashley and Robinson (1996) searched a 2.2 mile (3.6 km) stretch of road located near wetlands three days a week and calculated that 223 birds were killed per mile per year (139 birds/km/year), most of which were passerines. No adjustments were made for searcher efficiency or scavenger removal in either of these studies.

From 1969 to 1975, Case (1978) searched the entire length of Interstate 80 in Nebraska (458 miles, 732 km) and documented a total of 7,195 Ring-necked Pheasant (*Phasianus colchicus*) vehicle collision fatalities. Based on finding 562 dead ducks over a 10-year period, Sargeant (1981) estimated that vehicles killed an average of 13,500 ducks each year in the prairie pothole regions of North and South Dakota. Mean annual mortality of ducks was estimated to be 0.250 ducks per mile (0.156 ducks/km) of interstate, 0.008 ducks per mile (0.005 ducks/km) of unsurfaced roads, and 0.042 ducks per mile (0.026 ducks/km) for all road types combined. Although the number of fatalities appears high, it was estimated to represent less than 0.2 percent of the breeding population in the study area. Much lower mortality was documented during other studies. McClure (1951) documented only four road-killed ducks while driving 76,250 miles (122,000 km) of road in Nebraska. In Minnesota, Sargeant and Forbes (1973) found only three road-killed ducks along 17 miles (27 km) of roads driven almost daily for an 18-month period. Raptors also appear susceptible to vehicle collisions in some areas. Based on driving surveys over a 10-year period in New Jersey, Loos and Kerlinger (1993) estimated that 25 raptors were killed per year within a 90-mile (145 km) survey route. Most of the fatalities were owls; however, six species of hawks were also found among road fatalities.

Annual mortality predictions

Banks (1979) summarized several studies and reported estimates of avian fatality rates ranging from 2.7 to 6.1 deaths per mile of road per year to 60 to 144 bird fatalities per mile per year. From U.S. studies reported in Banks (1979), use of the minimum (2.7) and maximum (96.25) reported values for bird deaths per mile yields estimates of 10.7 million to 380 million annual bird deaths on U.S. roads. Banks (1979) estimated total annual avian road mortality to be 57.2 million. This figure was derived from the estimate of 15.1 bird fatalities per mile reported by Hodson and Snow (1965), who conducted a fairly extensive study in England, although no scavenging or searcher efficiency bias was considered which would result in an underestimate of true fatality rates. The U.S. Census Bureau (Statistical Abstract of the United States 1999) estimated 3,944,597 miles of road in the US in 1997. Using this number to update Banks' estimate yields a 1997 estimate of approximately 60 million avian fatalities on U.S. roadways annually. The number of registered vehicles has increased 35 percent from 1980 to 1998 alone, so an alternative estimate would be 1.35 times 60 million, or approximately 80 million avian fatalities. It is believed that some of the mortality observed along roads is actually caused by collisions with adjacent power and telephone lines (C.J. Ralph, pers. comm.).

Although most avian fatalities caused by vehicles occur on roadways, avian collisions also occur with trains (Spencer 1965) and airplanes. Avian collisions with airplanes present a significant hazard to both military and commercial aircraft. The Federal Aviation Administration (FAA) keeps records of avian collision strikes involving aircraft in the US. In 1998, the U.S. Air Force reported over 3,500 bird strikes by planes, and it is estimated that civil aircraft strike over 25,000 birds per year. Data collected from 1990 to 1999 indicate that gulls (31 percent), waterfowl (31 percent) and raptors (15 percent) comprised 77 percent of the reported bird strikes causing damage (Bird Strike Committee USA 2000). No estimates for train-caused avian mortality were found in the literature. It is likely that train collisions also result in several thousand bird deaths annually in the United States.

Avian Mortality Due to Collisions with Buildings and Windows

Study examples

Numerous studies have documented extensive avian collision mortality associated with buildings and similar structures such as smokestacks or monuments. Fatalities associated with buildings are usually the result of collisions with tall buildings and collisions with windows at residential houses. Studies may be divided into two categories, studies of short-term or episodic mortality events, and longer-term studies. Some mortality events at tall buildings have involved extensive numbers of birds. At one oil flare stack in Alberta, 1,393 dead birds comprised of 24 species of passerines were found over a 2-day period in May 1980 (Bjorge 1987). Over a 3-day period in October 1964, Case et al. (1965) searched several buildings in Florida and recovered 4,707 dead birds, most of which were passerines. Also in Florida, Maehr et al. (1983) searched the base of four smokestacks over a 2-day period in September and recovered 1,265 dead passerines. The authors estimated that 5,000 birds might have collided with the structures during this period. In the fall of 1970, 707 dead birds were documented below the Empire State Building in New York (Bagg 1971). Extensive numbers of nocturnal migrant fatalities have also been documented at the Washington Monument in Washington, D.C. (Overing 1936). From October 5-8, 1954, 9,495 dead birds (mostly passerines) were found at 25 tall buildings in the eastern and southern US following a cold front during fall migration, and it was estimated that 106,804 birds were actually killed (Johnston and Haines 1957).

Several long-term studies have documented the chronic nature of collision mortality associated with some buildings (Erickson et al. 2001). Over a 3-year period in Toronto, Ontario, Ogden (1996) counted 5,454 dead birds at 54 tall glass buildings and estimated that 733 birds (mostly passerines) were killed per building per year. Following nights with inclement weather conditions, Taylor and Kershner (1986) searched one building in Florida from 1970 to 1981 and documented 5,046 avian fatalities comprised of 62 species, the majority of which were passerines. Two smokestacks in Citrus County, Florida were searched five times per week from 1982 to 1986, and 2,301 dead birds were found (Maehr and Smith 1988). From this, the authors estimated that 541.4 birds were killed per year. Fatalities included 50 species, most of which were neotropical migrant passerines. Daily searches of two smokestacks in Ontario, Canada over a 4-year period yielded 8,531 dead birds. Again, most of these were passerines (Weir 1976).

Klem (1990) searched two houses in Illinois and New York daily from 1974 to 1986. A total of 100 dead birds were found at the houses, and the author estimated that 55 percent of window collisions result in death. Over the 1989-1990 winter, 5,500 residential houses in the U.S. were searched for dead birds using a standardized procedure, and a total of 995 dead birds were found (Dunn 1993). The author estimated that an average of 0.85 birds are killed per house each winter based on actual mortality ranging from 0.65 to 7.7 birds per house per year. The fatalities were comprised of 66 species, most of which were passerines commonly found at feeders during the winter.

Annual mortality predictions

In 1995 there were an estimated 4,579,000 commercial buildings (warehouse, religious/worship, public assembly, offices, mercantile/services, lodging, health care, food sales, education) in the United States (Statistical Abstract of the United States 1999). Klem (1990) reported there were 93.5 million residential houses in 1986. Due to the large number of structures in this class, and only a few good studies, it is difficult to obtain very accurate fatality estimates for the US. Most of the building and window collision data come from studies of known or suspected problem structures. Accurately predicting the number of building-related avian fatalities would require random selection of numerous buildings of all types and sizes, followed by long-term standardized and systematic searches for dead birds.

Banks (1979) acknowledged a lack of information on building and window collision mortality, and estimated 3.5 million avian fatalities per year based on an arbitrary estimate of 1 bird fatality per square mile in the US. An estimate of 97.6 to 976 million bird deaths per year in the U.S. due to collisions with windows was based on an estimated 1 to 10 bird deaths per structure per year from a fatality study in New York (Klem 1990).

Avian Mortality Due to Collisions with High Tension Lines

Study examples

Concern over avian collisions with high-tension lines has existed at least since 1876, when Coues (1876) counted approximately 100 avian carcasses (primarily Horned Larks (*Eremophila alpestris*) beneath a 3-mile long (4.8 km) section of telegraph wire between Denver, Colorado, and Cheyenne, Wyoming. Since then, there have been numerous studies of power line collisions involving birds. Faanes (1987) searched 6 miles (9.6 km) of power lines in North Dakota in the spring and fall of 1977 and 1978. Based on a total of 633 dead birds found, he estimated that 200 avian fatalities per mile per year (125 birds/km/yr) were occurring at those sites. The power lines included in the study were located near wetlands or lakes and most of the fatalities consisted of waterbirds (46 percent) and waterfowl (26 percent), followed by shorebirds (8 percent), and passerines (5 percent).

For some types of birds, power line collisions appear to be a significant source of mortality. Waterfowl band recovery data collected prior to 1967 indicated that powerline strikes were responsible for 65 percent of the collision fatalities involving 3,015 banded birds (Stout 1967). Of 75 Trumpeter Swan (*Cygnus buccinator*) deaths recorded from 1958 to 1973, 19 percent of the fatalities were due to powerline collisions (Weaver and St. Ores 1974). During a 2-year study of Mute Swans (*C. olor*) in Rhode Island, Willey (1968) found that 26.7 percent of adult fatalities were due to collisions, mostly with powerlines.

Annual mortality predictions

The U.S. electrical energy system includes more than 500,000 miles (800,000 km) of bulk transmission lines (Edison Electric Institute 2000). Estimates for the total length of distribution lines (power lines to residences and businesses) in the US could not be found in the literature, but are far greater than for bulk transmission lines. Estimates of avian fatalities due to collisions with high-tension lines are lacking due to minimal monitoring efforts on a large-scale basis. As with most other sources of collision mortality, most monitoring and/or studies are conducted in response to a known or perceived problem, and few data have been collected at randomly-chosen sites. Based on the limited studies, waterfowl including ducks, geese, swans, cranes, and shorebirds appear to be most susceptible to collisions when powerlines are located near wetlands. In upland habitats away from wetlands, raptors and passerines appear most susceptible to collision.

In the Netherlands, where approximately 2,875 miles (4,600 km) of high-tension lines are present, Koops (1987) estimated that approximately 750,000 to 1 million birds are killed annually by collisions based on variation in extrapolation made in three other Netherlands studies. Estimates in all three studies were in the same order of magnitude. The latter study estimated (unadjusted for scavenging and searcher efficiency) 113 fatalities per km of high tension line in grasslands, 58 fatalities per km of high tension line in agricultural lands, and 489 fatalities per km of high tension line near river crossings. We use the mean estimate (adjusted for scavenging and searcher efficiency bias) of 750,000/2,875 = 261/mile of high tension line. Extrapolating the mid-range of this estimate to the 500,000 miles (800,000 km) of bulk transmission lines in the United States would lead to a fatality estimate of approximately 130 million birds per year. Given the large, but unknown number of miles of power and other high tension lines in the U.S., and the lack of standardized data in the U.S., this estimate may be off by an order of magnitude or more.

Avian Mortality Due to Collisions with Communication Towers

Study examples

Substantial concern over the recent proliferation of communication towers in the U.S. has arisen in response to large fatality events, such as an estimated kill of 5,000 to 10,000 birds, mostly Lapland Longspurs (*Calcarius lapponicus*), at 3 associated communication towers and a natural gas pumping facility in western Kansas on the night of January 22, 1998 (Evans 1998). Large, single-night fatality events are not new. Kemper (1996) counted and identified species for over 12,000 birds killed one night in 1963 at a television tower in Wisconsin. As a result of this concern, avian collision mortality associated with communication towers has received more study and review than other sources of collision mortality, with the possible exception of wind turbines. During our review we located numerous studies covering avian collision mortality with communication towers in 25 states. The vast majority of the studies were one-day searches at single towers following nights of substantial avian mortality. Most avian fatalities at communication towers involve nocturnal migrant passerines, especially warblers, vireos, and thrushes.

Erickson et al. (2001) reported on 17 studies where collision mortality was measured for periods of time ranging from one to 38 years. For studies conducted over a period of at least two years, with searches conducted on a daily or almost daily basis, the estimated mean number of annual collisions per tower ranged from approximately 82 birds per year at an 825-ft (250-m) tall television tower in Alabama (Bierly 1968, 1969, 1972; Remy 1974, 1975; Cooley 1977) to 3,199 birds per year at a 1,000-ft (305-m) tower in Eau Claire, Wisconsin (Kemper 1996). Very few of these studies measured scavenger removal and searcher efficiency. The research at Eau Claire, Wisconsin, was the longest study conducted at any one tower and covered the period from 1957 to 1994 (38 years). Two other continuous studies at individual communication towers include a study from 1960 to 1997 (37 years) at a 1,368-ft (417-m) tower in Nashville, Tennessee (Nehring 2000), and another study that took place at a 1,010-ft (308-m) tower from October 1955 to December 1983 (28 years) at Tall Timbers Research Station in Tallahassee, Florida (Crawford and Engstrom 2000). At the Tennessee tower, 19,880 fatalities were recovered over the 37-year period. At the Florida tower, 1,517 birds on average were killed per year.

Annual mortality predictions

Based on the July 2002 statistics from the Federal Communication Commission's (FCC) Antenna Structure Registry Database (FCC 2002), more than 138,000 towers were listed with the Commission, of which some 106,000 were lighted. Since an undetermined number of towers are not registered with the FCC, and the number of new towers are increasing at a high rate (Manville this volume a), the total number of communication towers may be as high or higher than 200,000. Numerous types of towers are being built, including radio, television, cellular, microwave, paging, messaging, open video, public safety, wireless data, government dispatch, and emergency broadcast towers (Manville this volume a). Due to the recent proliferation of cellular phones and the advent of digital television, approximately 5,000 to 10,000 new towers are being added each year (6-8 percent increase annually). Some have estimated there will be a total of 600,000 towers in the United States within the next 10 years, creating a potentially catastrophic impact on avian migrants (M. Manville, pers. comm.). Avian mortality appears to increase with tower height. Taller towers also tend to have more guy wires and more lights, often more solid or pulsating red lights, which may increase the potential for collision mortality.

Most lighted towers are lit due to FAA pilot warning regulations. On foggy or low cloud-ceiling nights, these lighted towers appear to attract neotropical nocturnal migrants (Manville 2000, Kerlinger 2000), increasing the risk of collision. Lighting appears to be the single most critical attractant, and preliminary research indicates that solid and pulsating red lights seem to be more attractive to birds at night during inclement weather conditions than are white strobe lights. It is speculated that the birds are attracted to the lighted towers, become disoriented and fly around them in a spiral, colliding with the tower, the guy wires, other birds, or falling to the ground in exhaustion (Larkin and Frase 1988, M. Manville, pers. comm.).

There are very few long-term studies of avian mortality at communication towers, although there are concerted efforts by both the industry and other interested parties to begin collecting standardized data and using standardized metrics following the methods and metrics recommended and used at many wind power plants (Anderson et al. 1999). Currently, much of the published and unpublished information regarding avian fatalities at communication towers is based on single observations of carcasses found at the base of the towers (Erickson et al. 2001). Based on estimates of Banks (1979) and models developed by Tall Timber Research and Bill Evans (M. Manville, pers. comm.), conservative estimates range from 4 million to 5 million avian fatalities per year (Manville this volume a). These estimates could be off by an order of magnitude, especially as the number of towers increases at a high rate each year (Manville this volume a). Further studies are obviously needed to ascertain the true impact.

Avian Mortality Due to Collisions with Wind Turbines

Study examples

Many of the early studies of bird mortality at wind plants involved examining impacts associated with single, large experimental turbines. The first study took place in Sandusky, Ohio, where a single large turbine was monitored for avian mortality during four migratory seasons. Two dead birds were found during this period (Gauthreaux 1994). Two large experimental turbines and a meteorological tower in Wyoming were monitored for avian mortality in the early 1980s. Twenty-five fatalities were found over a one-year period, most of them involving passerines that had collided with guy wires on the meteorological tower (U.S. Bureau of Reclamation 1984). At a single, 60-m tower wind turbine in Solano County, California, seven fatalities were documented from September 1982 to January 1983, and the total fatality estimate with adjustments for scavenger removal and searcher efficiency was estimated at 54 birds (Byrne 1983, 1985).

Most of the concern over bird mortality from wind turbines began at one of the first large-scale wind energy developments in the US In response to several reported incidents of avian collisions, the California Energy Commission (CEC) obtained data on bird strikes at the Altamont and Tehachapi wind plants in California through interviews and review of unpublished data collected over a 4-year period from 1984 to 1988 (CEC 1989). This study documented 108 raptor fatalities of seven species. Collisions with wind plant structures accounted for most of the avian fatalities (67 percent), including 26 Golden Eagles and 20 Red-tailed Hawks (*Buteo jamaicensis*), while collision and electrocutions associated with power lines comprised the majority of the other fatalities. Several subsequent studies were initiated to further examine fatalities at California wind plants. Many of these studies have been conducted at Altamont Pass, where more than 5,000 turbines exist within the WRA. In general, these studies focused on obtaining raptor fatality estimates with other bird fatalities recorded coincidentally. An early 2-year study documented 182 bird deaths on study plots, 68 percent of which were raptors and 26 percent of which were passerines. The most common raptor fatalities were Red-tailed Hawk (36 percent), American Kestrel (*Falco sparvarius*) (13 percent), and Golden Eagle (11 percent). Causes of raptor mortality included collisions with turbines (55 percent), electrocutions (8 percent), and wire collisions (11 percent) (Orloff and Flannery 1992). Based on the number of dead birds found, the authors estimated that as many as 567 raptors may have died over the 2-year period due to collision with wind turbines. Further investigations at Altamont continued to document levels of raptor mortality sufficient to cause concern among wildlife agencies and others (Orloff and Flannery 1992, 1996; Howell 1997).

Raptor mortality at other older wind plants in California is apparently less that what has been observed at Altamont. Researchers estimated 6,800 birds were killed annually at the San Gorgonio wind facility (more than 3000 turbines) based on 38 dead birds found while monitoring nocturnal migrants at a small sample of turbines. McCrary et al. (1983, 1984) estimated that 69 million birds pass through the Coachella Valley annually during migration; 32 million in the spring and 37 million in the fall. The 38 avian fatalities were comprised of 25 species, including 15 passerines, seven waterfowl, two shorebirds, and one raptor. Considering the high number of passerines migrating through the area relative to the number of passerine fatalities, the authors concluded that this level of mortality was biologically insignificant (McCrary et al. 1986), although the mortality estimates were based on a small sample size. During a more recent study at San Gorgonio, (Anderson, pers. comm.) documented 58 fatalities near wind turbines, including fifteen doves (mostly *Columba livia*), five waterfowl, seven rails (mostly American Coot [*Fulica americana*]), seven passerines, four gulls, three owls, two ravens, one diurnal raptor, one egret, and eleven unidentified birds. The waterfowl, rail and shorebird mortality generally occurred when water was present in the vicinity of the wind resource area, attracting large numbers of waterfowl and shorebirds.

The high levels of raptor mortality associated with the Altamont wind plant has not been documented at newer wind plants constructed in other states (*table 1*). We discuss three wind resource areas that have been monitored for mortality and have included adjustments for scavenging and searcher efficiency bias (Osborn et al. 2000, Johnson et al. 2002, Young et al. 2003, Erickson et al. 2000b), although other studies listed in *table 1* include Erickson et al. 2003a and 2003b, Howe et al. 2002, Nicholson 2003 and Johnson et al. 2002.

Several studies have been conducted at the Buffalo Ridge wind resource area, which is located an agricultural landscape in southwestern Minnesota. At the 73-turbine Phase I wind plant, eight collision fatalities were documented during the initial two-year period of operation (Osborn et al. 2000). The fatalities consisted of one Ruddy Duck (*Oxyura jamaicensis*), one Franklin's Gull (*Larus pipixcan*), one Yellow-bellied Sapsucker (*Sphyrapicus varius*), and four passerines. The estimated total number of annual fatalities for the entire wind plant was 36, equivalent to an annual mean of 0.49 collisions per turbine per year. A more extensive study of this wind plant plus two additional wind plants on Buffalo Ridge totaling over 350 turbines was conducted from 1996 through 1999. Total annual mortality was estimated to average 2.8 birds per turbine based on the 55 fatalities found during the study. Only one raptor, a red-tailed hawk, was found during the 4-year monitoring period. Most of the fatalities were passerines (76.4 percent), followed by waterfowl (9.1 percent), waterbirds and upland gamebirds (5.5 percent each). Many of the fatalities documented were nocturnal migrants (Johnson et al. 2002). Radar studies at Buffalo Ridge (Hawrot and Hanowski 1997) indicate that as many as 3.5 million birds per year may migrate over the wind development area (Johnson et al. 2002). The two largest single mortality events reported at a

Table 1–*Estimates of avian collision mortality by wind projects.*

Location of study[1]	No. turbines	No. MW	No. birds/ turbine/year	No. birds/ MW/year	No. raptors /turbine/year	No. raptors /MW/year
West (excluding California)						
Stateline, Oregon/Washington	454	300	1.69	2.56	0.053	0.080
Vansycle, Oregon	38	25	0.63	0.96	0.000	0.000
Klondike, Oregon	16	24	1.42	0.95	0.000	0.000
Nine Canyon, Washington	37	48	3.59	2.76	0.065	0.050
Foote Creek Rim, Wyoming	105	68	1.50	2.34	0.035	0.053
Subtotal	650	465	1.71	2.40	0.044	0.068
Upper Midwest						
Wisconsin (MG&E and PSC)	31	20	1.30	1.97	0.000	0.000
Buffalo Ridge, Minnesota	354	233	2.86	4.21	0.002	0.008
Subtotal	386	254	2.73	4.03	0.002	0.008
East						
Buffalo Mountain, Tennessee	3	2	7.70	11.67	0.000	0.000
Grand Total	1039	721	2.11	3.04	0.029	0.045
California (older projects)						
Altamont, California	~5400	548	na[2]	na	0.100	na
Montezuma Hills, California	600	60	na	na	0.048	na
San Gorgonio, California	~2900	300	2.31	na	0.010	na
Subtotal	~8900	878	na	na	0.067	na

Total fatality projections	Overall	Outside California
Projected annual bird fatalities[3]	20,000-37,000	9200
Raptors[4]	933	195

[1]We excluded studies of 4 small project sites in Vermont, Pennsylvania, Colorado, and Iowa that were conducted short-term and/or did not include adjustments for scavenging and searcher efficiency bias.
[2]Not available; data on scavenging or searcher efficiency or average MW of study turbines not available
[3]The per turbine/year and per MW/year estimates applied to the number of MW in U.S. at the end of 2003
[4]Based on the per turbine estimate in California (11,500 turbines) and the per MW basis outside California

U.S. wind plant were fourteen spring migrant passerines at two turbines at the Buffalo Ridge, Minnesota wind plant on one night and approximately 30 spring migrant passerines at a floodlit substation and nearby turbines in West Virginia on one night.

At the Foote Creek Rim wind plant located in Carbon County, Wyoming within native grassland-steppe and shrub-steppe habitats, total mortality associated with the 69 turbines and 5 meteorological towers was estimated to be approximately 143 birds per year, based on the 122 collision fatalities actually found during the first three years of operation (Young et al. 2003). Mean annual mortality was estimated to be 1.5 birds per turbine and 0.03 raptors per turbine per year. Of the 122 fatalities found during the study, raptors comprised only 4.0 percent, whereas passerines comprised 90.2 percent. Furthermore, while many of the fatalities at this location were nocturnal migrant passerines, the largest number of carcasses detected at a turbine during one search was two, suggesting no large mortality events of nocturnal migrants have occurred at this site.

At a 38-turbine wind plant completed on Vansycle Ridge, Oregon, which is located in an agricultural landscape, 12 avian fatalities were located during the first year of operation (Erickson et al. 2000b). The casualties were comprised of at least six species, and most of the fatalities (58 percent) were passerines. Total estimated mortality adjusted for scavenging and observer detection rate estimates, was 24 birds per year, or 0.63 birds per turbine per year. No raptors were among the fatalities (Erickson et al. 2000b).

We are unaware of any studies that directly compare communication tower mortality to wind turbine mortality; although, we do have limited information on guyed meteorological tower mortality compared with wind turbine mortality at the Foote Creek Rim, Wyoming wind plant. At this site searches of both wind turbines (600-kW, approximately 200-ft (60-m) towers) were conducted and guyed met towers (200 ft (60 m) in height) once every 28-d during the study. During this period of study, the met towers had estimates of 8.1 bird fatalities per tower per year, whereas the turbines had estimates of 1.5 bird fatalities per turbine per year (Young et al. 2003).

Annual mortality predictions

The average number of avian collision fatalities per turbine and per MW (Megawatt) are 2.11 and 3.04 per year, respectively. There were approximately 17,500 turbines and 6,374 MW of installed wind generation capacity at the end of 2003 in the United States, with approximately 6,000 turbines and 4,331 MW outside California. Therefore, on average, we calculate approximately 20,000 (3.04 times 6374 MW) to 37,000 (2.11 times 17,500 turbines) die annually from collisions with wind turbines in the United States. We estimate approximately 9,200 birds will die annually outside California from the 4331 MW of installed wind generation capacity (2003). This extrapolation assumes fatality rates observed at wind projects that have been studied are representative of rates at wind projects not studied. Fatality estimates for all birds are generally not available at most old projects in California, and for all birds and raptors from Texas and Iowa, two states with significant wind development.

Because much attention has been given to the issue of raptor/wind power interaction, we also developed separate fatality estimates for raptors. Estimates of raptor fatalities per turbine per year from individual studies through 2001 (Erickson et al. 2001) ranged from 0 at the Vansycle, Oregon; Searsburg, Vermont; Ponnequin, Colorado; Somerset County, Pennsylvania; and Buffalo Ridge, Minnesota, Phase II and Phase III sites, to 0.10 per turbine per year at the Altamont, California site (C. Thelander, pers. comm.). Based on these statistics, we estimate 933 raptors are killed annually (2003) by turbines in the United States, with approximately 80 percent of the raptor mortality occurring at the older projects in California. We project raptor mortality at wind plants outside California to be 195 per year (2003) based on relatively small number of raptors found at Buffalo Ridge Minnesota (Johnson et al. 2002), Foote Creek Rim Wyoming (Young et al. 2003), Stateline Oregon and Washington (Erickson et al. 2003a), and Nine Canyon Washington (Erickson et al. 2003b).

Other Non-collision Related Sources of Bird Mortality

The previous sections have focused on collision-related sources of bird mortality. We will now discuss in much less detail other significant sources of bird mortality which include oil spills, oil pools, cat predation, pesticides and other contaminants, electrocutions and fishing by-catch. The latter two sources are covered in more detail in Manville (this volume a, this volume b). Hunting is another obvious source of bird mortality, but since it is a permitted source, we do not discuss it.

Pesticides

Pesticides are a significant source of bird mortality in the US as well as other countries (Pimentel et al. 1991; Mineau, this volume). Large die-offs of Swainson's Hawks (*Buteo swainsoni*) were observed in Argentina due to exposure to the pesticide monocrotophos in 1996 (Di Silvestro 1996). Approximately 160 million acres of cropland are treated with pesticides each year in the US (Pimentel et al. 1991) using data collected in the 1980s and 1990s. It has been estimated that approximately 67 million birds die annually in the US due to pesticides (Pimental et al. 1991). This estimate is based on the assumption that 10 percent of the estimated 672 million birds exposed to pesticides die each year. This estimate may be conservative, since the empirical data on bird mortality at crop fields is reported as 0.1 to 3.6 per acre (Mineau 1988). Lawn, turf, golf course and other pesticide uses were not included in this estimate.

Oil Spills

Oil spills can be a significant source of bird mortality, but the occurrence of spills and the effect and are obviously difficult to predict. Over 30,000 bird carcasses were recovered, including 250 Bald Eagles (*Haliaeetus leucocephalus*) following the 1989 Exxon Valdez oil spill in Prince William Sound Alaska, but between 100,000 and 300,000 birds of all species were estimated to have died (Piatt et al. 1990). Flint et al. (1999) conservatively estimated over 1750 birds died as the result of the M/V Citrus spill near St. Paul Island, Alaska. Small spills or chronic oiling is much less publicized, yet possibly a significant source of seabird mortality (Burger 1993). Estimates of annual mortality based on counting oiled corpses on beaches from small or chronic oiling have ranged from less than 0.01 per km of shoreline to 3.68 per km. Many oiled birds which die at sea are never found on beaches. Considering the US, including the island territories, has approximately 90,000 miles of marine tidal shoreline, annual bird mortality from chronic oiling may easily be in the 10,000 to 100,000 range.

Oil Pits

Man-made pits associated with oil and gas development are another well-documented source of bird mortality. Esmoil (1995) found 282 dead birds during weekly sampling of 35 oil pits in 1989, and 334 dead birds during weekly sampling of 53 pits in 1990. The largest affected taxonomic group was passerines (41 percent). Banks (1979), based on estimates made for the San Joaquin Valley in the early 1970s, conservatively estimated 1.5 million birds die annually due to these pits.

Cat Predation

Domestic and feral cats might also be considered an anthropogenic source of bird mortality. 1990 U.S. census data report 60 million cats claimed as pets by owners, and an unknown number of unclaimed feral cats. Coleman and Temple (1996) estimated that between 8-219 million birds are killed by free-ranging cats in Wisconsin alone. These figures are derived from estimates that there are 1.4 - 2 million free-ranging cats in rural Wisconsin, that each cat on average kills between 28 and 365 animals per year, and that on average 20 to 30 percent of the animals killed by cats are birds (5 -100 birds/cat/year). We use the estimate of 100 million birds killed by cats on an annual basis, but this estimate is likely conservative. If the Wisconsin estimates are representative of the averages nationwide, this estimate is highly conservative given that there are 50 states and because it only accounts for cats claimed as pets by owners.

Electrocutions

Recent prosecution of the Moon Lake Utility for violations of the Bald and Golden Eagle Act and the Migratory Bird Treaty Act (Manville this volume a) has brought more attention to the continued problem of electrocutions of raptors from powerlines. It appears that nation wide mortality estimates from electrocutions are not available. Most data available were not collected in a systematic fashion, and do not attempt to adjust for scavenging and searcher efficiency biases.

In a review of mortality reports from utilities, wildlife rehabilitators and falconers between 1986 and 1996, 1450 raptor electrocutions representing 16 species were confirmed, with Golden Eagles accounting for the largest percentage of fatalities (Harness and Wilson 2001).

Fishing By-catch

Many groups of seabirds have been reported drowned by fishing nets and gear (Atkins and Heneman 1987) and yearly mortality may reach hundreds of thousands (Manville this volume b). Quality studies on the impacts from commercial fishing are absent except for a few studies (e.g., Brothers 1991), and most mortality reports are largely anecdotal.

Cumulative Mortality

Based on the estimates derived or reviewed in this paper, annual bird mortality from anthropogenic sources may easily approach 1 billion birds a year in the US alone (*table 2*). Buildings, power lines and cats are estimated to comprise approximately 82 percent of the mortality, vehicles 8 percent, pesticides 7 percent, communication towers 0.5 percent, and wind turbines 0.003 percent. Other sources such as mortality from electrocution, oil spills and fishing by-catch are also contributors but estimates were not made and we have not even considered the impacts from loss of habitat which could also be considered anthropogenic.

Discussion

Based on existing projections and projections made in this paper, annual avian mortality from anthropogenic causes may be near 1 billion. Given the uncertainty in the estimates, the true avian mortality, especially for communication towers, buildings and windows, vehicles, powerlines, pesticides, oil spills, fishing by-catch, cats, and vehicles could easily be different by an order of magnitude. In general, these sources of mortality continue to grow as our population grows (e.g., buildings and houses), and demand for efficient communications (e.g., cellular telephones), electricity (e.g., wind turbines and powerlines), fuel and other comforts of life grow as well. Although there is high variability in the estimated magnitude of total bird mortality for the different sources, there is also high variability in the types of birds (nocturnal migrants versus residents) and species that individual sources impact. Therefore, the significance on any one source or a particular location of a unit (e.g., a communication tower) may vary greatly depending on the species or groups of birds that may be impacted.

Many of the collision mortality studies have been conducted in response to a known or perceived risk, and therefore are probably not appropriate for extrapolation in the same manner we extrapolated for wind turbines. However, it has been argued by several researchers making mortality projections that their estimates are probably conservative (underestimates), given that scavenging and searcher efficiency biases have generally not been incorporated into the estimates. For example, Banks' (1979) estimate of vehicle mortality was based on the Hodson and Snow (1965) estimate of 15.1 birds per mile (9.4 bird/km), which was based on weekly surveys that did not adjust for scavenging and searcher efficiency.

The large uncertainties associated with estimates of mortality from one or multiple sources, along with the even larger uncertainties in bird populations (e.g., size, reproduction), makes it extremely difficult to understand the biological significance of human-caused mortality on birds at a population, regional, or even local level (Manville this volume a). Aldrich et al. (1975) estimated there are approximately 10 billion breeding landbirds in the US (excluding Alaska and Hawaii) in the spring, and approximately 20 billion breeding landbirds in the autumn, based on 1973 Breeding Bird Survey data. Based on these estimates and our mortality estimates, approximately 5-10 percent of the populations of breeding landbirds are killed each year from human caused factors. Impacts on individual species may be higher or lower depending on their population levels. The recently published Birds of Conservation Concern (BCC) by the USFWS lists 131 species that may currently have declining population numbers from numerous factors including loss of habitat and human-caused mortality. These are in addition to the 92 species currently listed as Federally threatened or endangered. Very few studies have attempted to determine the significance of human-caused mortality at a population level of an individual species. Based on an intensive radio-telemetry study of a population of Golden Eagles at the Altamont Pass wind plant, it was determined the wind plant was currently not causing a population level decline, but the long-term impact was unknown (Hunt 2002). This study of a relatively small and definable population of eagles was expensive, relatively short-term, and not conclusive.

Rosenberg and Blancher (this volume) discuss a method using Breeding Bird Survey data for better understanding the population status and the impact of human-caused mortality of individual breeding birds. Their approach uses breeding bird survey data, but given the limited and highly variable data on population sizes, survival and reproduction, there are likely huge uncertainties. Until we start to better understand mortality rates and parameters of bird populations, we will not truly understand the biological significance of the mortality. Research and monitoring efforts need to continue and expand so that we can better understand the levels and significance of these mortality sources and we can find better and more effective means for reduction and mitigation of human-caused bird mortality.

There does appear to be a greater awareness of the level of human-caused bird mortality, and there are measures being undertaken to reduce mortality from most, if not all these sources. Programs to reduce night lighting at tall buildings and encourage use of tinted windows appear to be an effective measure to reduce mortality. Marking powerlines with bird flight diverters appears to be an effective and relatively inexpensive way of reducing collision mortality along power lines (Morkill and Anderson 1991, Brown and Drewien 1995). Effective wind project siting, use of underground power lines, unguyed meteorological towers, and reduced lighting within wind projects appears to be an effective way of reducing the collision potential at wind projects (Johnson et al. in press). Programs like Audubon's "Keep Cats Indoors" likely reduce bird mortality from free-ranging cats. The U.S. ban on some granular pesticides know to be highly toxic to birds has presumably reduced cumulative mortality from pesticides. Use of unguyed cell towers and better lighting on communication towers may also be contributing to reduced avian mortality. Guidelines for pole configurations to reduce electrocution mortality (APLIC 1996) have undoubtedly help reduce the electrocution risk from power lines. The use of these measures needs to be expanded and other more effective measures need to

Table 2—*Summary of predicted annual avian mortality.*

Mortality source	Annual mortality estimate	Percent composition
Buildings[1]	550 million	58.2 percent
Power lines[2]	130 million	13.7 percent
Cats[3]	100 million	10.6 percent
Automobiles[4]	80 million	8.5 percent
Pesticides[5]	67 million	7.1 percent
Communications towers[6]	4.5 million	0.5 percent
Wind turbines[7]	28.5 thousand	<0.01 percent
Airplanes	25 thousand	<0.01 percent
Other sources (oil spills, oil seeps, fishing by-catch, etc.)	not calculated	not calculated

[1] Mid-range of fatality estimates reported from Klem (1990), 1 – 10 bird fatalities per house, extrapolated to 100 million residences
[2] Based primarily on a study in the Netherlands (Koops 1987), extrapolated to 500,000 miles of bulk transmission line in U.S.
[3] One study in Wisconsin estimated 40 million (Coleman and Temple 1996), there are 60 million cats claimed as pets in the U.S.
[4] Based primarily on one study in England (Hudson 1965, Banks 1979) that estimated 15.1 fatalities/mile of road each year, no searcher efficiency or bias adjustments in that study, updated based on increase in vehicle registrations
[5] Conservative estimate using low range of empirical fatality rate (0.1 to 3.6 birds/acre), studies typically adjusted from searcher efficiency and scavenging
[6] Estimates from models derived by Manville and Evans (M. Manville, pers. comm.).
[7] Mid-range of per turbine and per MW estimates derived from empirical data collected at several wind projects (*table 1*).

be developed to help compensate for the continued growth of human development on the landscape resulting in loss of bird habitat.

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Literature Cited

Aldrich, J. W., R. C. Banks, T. J. Cade, W. A. Calder, F. G. Cooch, S. T. Emlen, G. A. Greenwell, T. R. Howell, J. P. Hubbard, D. W. Johnston, R. F. Johnston, and L. R. Mewaldt. 1975. **Report of the American Ornithologist; Union and ad hoc Committee on Scientific and Educational Use of Birds.** Auk 92 (3, Supple.): 1A-27A.

Anderson, R. L., M. Morrison, K. Sinclair and D. Strickland. 1999. **Studying wind energy/bird interactions: A guidance document**. National Wind Coordinating Committee /RESOLVE, Washington, D.C.; 87p.

Ashley, E. P. and J. T. Robinson. 1996. **Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario**. Canadian Field-Naturalist 110: 403-412.

Atkins, N. and B. Heneman. 1987. **The dangers of gill netting to seabirds**. American Birds 41(5): 1395-1403.

Avian Power Line Interaction Committee (APLIC). 1996. **Suggested practices for raptor protection on power lines: the state of the art in 1996.**

Bagg, A. M. 1971. **The Changing Seasons**. American Birds 25(1): 16-23.

Balcomb, R. 1986. **Songbird carcasses disappear rapidly from agricultural fields**. Auk 103: 817-820.

Banks, R. C. 1979. **Human related mortality of birds in the United States**. Special Scientific Report, Wildlife No. 215. Washington, DC: Fish and Wildlife Service, U. S. Department of the Interior.; 16p.

Bierly, M. L. 1968. **Television tower casualties at Birmingham [Alabama] in 1967**. Alabama Birdlife 16: 34-35.

Bierly, M. L. 1969. **1968 Birmingham [Alabama] tower casualties**. Alabama Birdlife 17: 46-49.

Bierly, M. L. 1972. **Spring 1969 tower casualties in Birmingham**. Alabama Birdlife 20(1-2): 3.

Bird Strike Committee USA. 2000. **Understanding and reducing bird hazards to aircraft.** BSC-USA, 6100 Columbus Avenue. Sandusky, OH 44870.

Bjorge, R. R. 1987. **Birds kill at an oil industry flare stack in northwest Alberta**. The Canadian Field-Naturalist 101: 346-350.

Brothers, N. 1991. **Albatross mortality and associated bait loss in the Japanese longline fishery in the Southern Ocean.** Biological Conservation 55: 255-268.

Brown, W. M. and R. C. Drewien. 1995. **Evaluation of two power line markers to reduce crane and waterfowl collision mortality.** Wildlife Society Bulletin 23(2): 217-227.

Burger, A. E. 1993. **Mortality of seabirds assessed from beach-bird surveys in southern British Columbia.** Canadian Field-Naturalist 107(2): 164-176.

Byrne, S. 1983. **Bird movements and collision mortality at a large horizontal axis wind turbine.** Cal-Neva Wildlife Transactions 1983: 76-83.

Byrne, S. 1985. **Ecological monitoring.** In: MOD-2 wind turbine field experience in Solano County, California. Research Project 1996-3. Pacific Gas & Electric Co., San Ramon, CA; 7-1 to 7-6 and F-1 to F-35.

California Energy Commission (CEC). 1989. **Avian mortality at large wind energy facilities in California: identification of a problem.** California Energy Commission staff report P700-89-001.

Case, L. D., H. Cruickshank, A. E. Ellis, and W. F. White. 1965. **Weather causes heavy bird mortality.** Florida Naturalist 38(1): 29-30.

Case, R. M. 1978. **Interstate highway road-killed animals: a data source for biologists.** Wildlife Society Bulletin 6: 8-13.

Coleman, J. S. and S. A. Temple. 1996. **On the prowl.** Wisconsin Natural Resources; December issue.

Cooley, C. D. 1977. **Television tower casualties at Huntsville [Alabama]: fall, 1976.** Alabama Birdlife 25(3-4): 14-15.

Coues, E. 1876. **The destruction of birds by telegraph wire.** American Naturalist 10(12): 734-736.

Crawford, R. L. 1971. **Predation on birds killed at TV tower.** The Oriole December 1971: 33-35.

Crawford, R. L. and R. T. Engstrom. 2000. **Characteristics of avian mortality at a north Florida television tower: A 28-year experience.** Tallahassee, FL Tall Timbers Research Station.

Decker, D. 1987. **A limited survey of roadkills on the Warsaw-Hamilton blacktop.** Illinois Birds and Birding 3: 63-4.

Di Silvestro, R. 1996. **Poison in the Pampas: What's killing the Swainson's hawk?** International Wildlife 26(3): 38-43.

Dunn, E. H. 1993. **Bird mortality from striking residential windows in winter.** Journal of Field Ornithology 64(3): 302-309.

Dunthorn, A. A. and F. P. Errington. 1964. **Casualties among birds along a selected road in Wiltshire.** Bird Study 11: 168-182.

Edison Electric Institute. 2000. **The living grid: Evolving to meet the power needs of America.** Washington, DC: Energy Issues/News.

Erickson, W. P., M. D. Strickland, G. D. Johnson, and J. W. Kern. 2000a. **Examples of statistical methods to assess risk of impacts to birds from windplants.** In: Proceedings of the National Avian-Wind Power Planning Meeting III. National Wind Coordinating Committee, c/o RESOLVE, Inc., Washington, D.C.

Erickson W. P., G. D. Johnson, M. D. Strickland, and K. Kronner. 2000b. **Avian and bat mortality associated with the Vansycle wind project, Umatilla County, Oregon, 1999 study year.** Pendleton, OR: Technical report prepared for Umatilla County Department of Resource Services and Development.

Erickson, W. P., G. D. Johnson, M. D. Strickland, D. P. Young, Jr., K. J. Sernka, and R. E. Good. 2001. **Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States.** National Wind Coordinating Committee, c/o RESOLVE, Inc., Washington, D.C.

Esmoil, B. J. 1995. **Wildlife mortality associated with oil pits in Wyoming.** Prairie Naturalist 27(2).

Evans, B. 1998. **Telecommunications towers affect avian community.** Wave-Guide Information, Tower-Related Bird Kill Rates. 421 Titus Ave., Ithaca, NY 14850

Faanes, C. A. 1987. **Bird behavior and mortality in relation to powerlines in prairie habitats.** Fish and Wildlife Technical Report, No. 7. Washington, DC: Fish and Wildlife Service, U.S. Department of the Interior.

Federal Communications Commission (FCC). 2002. **Antenna structure registry database quarterly update.** Gettysburg, PA: July 2002; 1 p.

Finnis, R. G. 1960. **Road casualties among birds.** Bird Study 7: 21-32.

Flint, P. A., A. C. Fowler, and R. F. Rockwell. 1999. **Modeling bird mortality associated with the M/V Citrus oil spill off St. Paul Island, Alaska.** Ecological Modeling, 117: 261-267.

Gauthreaux, S. 1994. **The history of wind-related avian research in the U.S.A.** In: Proceedings of the National Avian-Windpower Planning Meeting. Washington, DC: National Wind Coordinating Committee c/o RESOLVE Inc.; 33-35

Harness, R. E. and K. R. Wilson. 2001. **Electric-utility structures associated with raptor electrocutions in rural areas.** Wildlife Society Bulletin 29: 612-623.

Hawrot, R. Y. and J. M. Hanowski. 1997. **Avian assessment document: avian population analysis for wind power generation regions--012.** NRRI Technical Report No. NRRI/TR-97-23. Duluth, MN: Center for Water and the Environment, Natural Resources Research Institute; 14p.

Hodson, N. L. 1962. **Some notes on the causes of bird road casualties.** Bird Study 9: 168-173.

Hodson, N. L. and D. W. Snow. 1965. **The road deaths enquiry, 1960-61.** Bird Study 9: 90-99.

Howell, J. A. 1997. **Bird mortality at rotor swept area equivalents, Altamont Pass and Montezuma Hills, California.** Transactions of the Western Section of The Wildlife Society 33: 24-29.

Hugues, B. 1996. **Barn Owl (*Tyto alba*) and Long-eared Owl (*Asio otus*) mortality along motorways in Bourgogne-Champagne: Report and Suggestions.** 2nd Owl Symposium; 58-61.

Hunt, W. G. 2002. **Golden Eagles in a perilous landscape: Predicting the effects of mitigation for energy-related mortality.** Report to the California Energy Commission, PIER Grant No. 500-97-4033 to the University of California, Santa Cruz, CA.

Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepherd, D. A. Shepherd, and S. A. Sarappo. 2002. **Collision mortality of local and migrant birds at a large-scale wind power development on Buffalo Ridge, Minnesota.** Wildlife Society Bulletin 30: 879-887.

Johnson, G. D., M. D. Strickland, W. P. Erickson, and D. P. Young, Jr. In press. **Use of data to develop mitigation measures for wind power development impacts to birds.** In: M. Ferrer, G. Janss, and M. de Lucas, editors. Birds and windpower. Spain: Quercus Press.

Johnston, D. W. and T. P. Haines. 1957. **Analysis of mass bird mortality in October, 1954.** The Auk 74: 447-458.

Kemper, C. 1996. **A study of bird mortality at a west central Wisconsin TV tower from 1957-1995.** The Passenger Pigeon 58: 219-235.

Kerlinger, P. 2000. **Avian mortality at communication towers: a review of recent literature, research, and methodology.** Unpublished report prepared for: The U.S. Fish and Wildlife Service, Office of Migratory Bird Management. Curry and Kerlinger, P.O. Box 453, Cape May Point, NJ 08212.

Klem, D., Jr. 1990. **Collisions between birds and windows: mortality and prevention.** Journal of Field Ornithology 61(1): 120-128.

Koops, F. B. J. 1987. **Collision victims of high-tension lines in the Netherlands and effects of marking.** KRMA Report 01282-MOB 86-3048.

Larkin, Ronald P. and Barbara A. Frase. 1988. **Circular paths of birds flying near a broadcasting tower in cloud.** Journal of Comparative Psychology 102: 90-93.

Loos, G. and P. Kerlinger. 1993. **Road mortality of Saw-whet and Screech-owls on the Cape May peninsula.** Journal of Raptor Research 27(4): 210-213.

Maehr, D. S., A. G. Spratt, and D. K. Voigts. 1983. **Bird casualties at a central Florida power plant.** Florida Field Naturalist 11(3): 45-68.

Maehr, D. S. and J. Q. Smith. 1988. **Bird casualties at a central Florida power plant: 1982-1986.** Florida Field Naturalist 16: 57-80.

Manville, A. 2000. **The ABCs of avoiding bird collisions at communication towers: the next steps.** In: Proceedings of the Avian Interactions Workshop, December 2, 1999, Charleston, SC. CA: Electric Power Research Institute; 15p.

Manville, M. This volume a. **Bird strikes and electrocutions at communication towers, power lines and wind turbines: State of the art and state of the science – Next steps toward mitigation.**

Manville, M. This volume b. **Seabird and waterbird bycatch in fishing gear: Next steps in dealing with a problem**

McCrary, M. D., R. L. McKernan, R. E. Landry, W. D. Wagner, and R. W. Schreiber. 1983. **Nocturnal avian migration assessment of the San Gorgonio wind resource study area, spring 1982.** Report prepared for: Research and Development, Southern California Edison Company, Rosemead, California; 121 p.

McCrary, M. D., R. L. McKernan, W. D. Wagner, and R. E. Landry. 1984. **Nocturnal avian migration assessment of the San Gorgonio wind resource study area, fall 1982.** Report prepared for: Research and Development, Southern California Edison Company, report #84-RD-11. Rosemead, California; 87p.

McCrary, M. D., R. L. McKernan, and R. W. Schreiber. 1986. **San Gorgonio wind resource area: Impacts of commercial wind turbine generators on birds, 1985 data report.** Report prepared for: Southern California Edison Company, Rosemead, California; 33p.

McClure, H. L. 1951. **An analysis of animal victims on Nebraska highways.** Journal of Wildlife Management 15(4): 410-420.

Mineau. P. 1988. **Avian mortality in agroecosystems: 1. the case against granule insecticides.** In: M. P Greaves, B. D. Smith, and P. W. Greig-Smith, editors. Field methods for the study of environmental effects of pesticides, proceedings of a symposium organized by the British Crop Protection Council, Churchill College, Cambridge, UK; 13-27.

Mineau, P. This volume. **Direct losses of birds to pesticides – Beginnings of a quantification.**

Morkill, A. E. and S. H. Anderson. 1991. **Effectiveness of marking powerlines to reduce Sandhill Crane collisions.** Wildlife Society Bulletin 19(4): 442-449.

Morrison, M. 2002. **Searcher bias and scavenging rates in bird/wind energy studies.** NREL/SR-500-30876. National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393.

Nehring, J. 2000. WSMV Tower study summary 1960-1997. http://www.towerkill.com/TNR/Tndata1a.html. Accessed 11/13/00.

Ogden, L. J. E. 1996. **Collision course: The hazards of lighted structures and windows to migrating birds.** Toronto, Ontario: World Wildlife Fund Canada and the Fatal Light Awareness Program; 46 p.

Orloff, S. and A. Flannery. 1992. **Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas, 1989-1991.** Final Report to Alameda, Contra Costa and Solano Counties and the California Energy Commission by Biosystems Analysis, Inc., Tiburon, CA. CEC Report No. P700-92-001.

Orloff, S. and A. Flannery. 1996. **A continued examination of avian mortality in the Altamont Pass Wind Resource Area**. Final Report to the California Energy Commission by Biosystems Analysis, Inc., Tiburon, CA. CEC Report No. P700-96-001CN.

Osborn, R. G., K. F. Higgins, R. E. Usgaard, C. D. Dieter, and R. G. Neiger. 2000. **Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota**. American Midland Naturalist 143: 41-52.

Overing, R. 1936. **The 1935 fall migration at the Washington Monument**. Wilson Bulletin 48: 222-224.

Pain, D. J. 1991. **Why are lead-poisoned waterfowl rarely seen?: The disappearance of waterfowl carcasses in the Camargue, France**. Wildfowl 42:118-122.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990. **Immediate impact of the Exxon Valdez oil spill on marine birds**. The Auk 107: 387-397.

Pimentel, D., A. Greiner, and T. Bashore. 1991. **Economic and environmental costs of pesticide use**. Archives of Environmental Contaminants and Toxicology 21: 84-90.

Remy, R. J., Jr. 1974. **Birmingham tower casualties – fall 1974**. Alabama Birdlife: Journal of the Alabama Ornithological Society 22(3-4): 9-10.

Remy, R. J., Jr. 1975. **Birmingham [Alabama] television tower casualties 1975**. Alabama Bird Life 23(3-4): 18-19.

Rosenberg, K. V. and P. J. Blancher. This volume. **Setting numerical population objectives for priority landbird species**.

Sargeant, A. B. 1981. **Road casualties of prairie nesting ducks**. Wildlife Society Bulletin 9: 65-69.

Sargeant, A. B. and J. E. Forbes. 1973. **Mortality among birds, mammals and certain snakes on 17 miles of Minnesota roads**. Loon 45: 4-7.

Spencer, K. G. 1965. **Avian casualties on railways**. Bird Study 12: 257.

Statistical Abstract of the United States. 1999. **U.S. Census Bureau**.

Stout, I. J. 1967. **The nature of nonhunting mortality in fledged North American waterfowl**. Virginia Polytechnic Institute, Blacksburg, Virginia; Master's thesis.

Taylor, W. K. and M. A. Kershner. 1986. **Migrant birds killed at the Vehicle Assembly Building (VAB), John F. Kennedy Space Center**. Journal of Field Ornithology 57: 142-154.

U. S. Bureau of Reclamation. 1984. **Status report on system verification units: wind-hydroelectric energy project, Wyoming**. Bureau of Reclamation, Wyoming.

Weaver, D. K. and R. St. Ores. 1974. **Trumpeter Swan mortality**. In: Proceedings and Papers of the Third Trumpeter Swan Society Conference, volume 3; 1973 September 18-20; Martin, South Dakota; 86-89.

Weir, R. D. 1976. **Annotated bibliography of bird kills at manmade obstacles: a review of the state of the art and solutions**. Canadian Wildlife Services, Ontario Region, Ottawa.

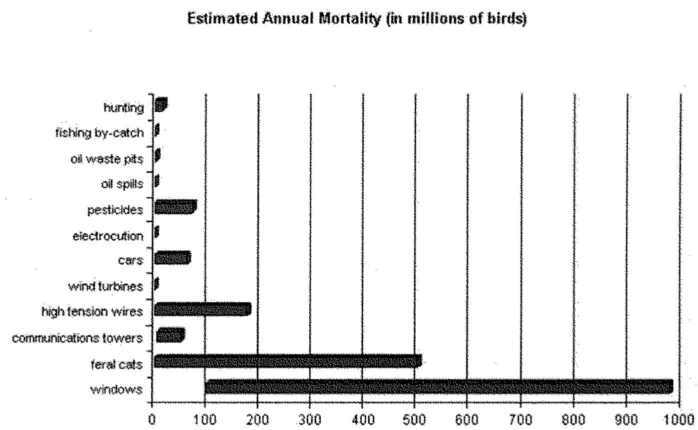
Willey, C. H. 1968. **The ecology, distribution, and abundance of the Mute Swan (*Cygnus olor*) in Rhode Island**. University of Rhode Island; Master's thesis.

Wobeser, G. and A. G. Wobeser. 1992. **Carcass disappearance and estimation of mortality in a simulated die-off of small birds**. Journal of Wildlife Diseases 28: 548-554.

Young, D. P. Jr., W. P. Erickson, R. E. Good, M. D. Strickland, and G. D. Johnson. 2003. **Avian and bat mortality associated with the initial phase of the Foote Creek Rim Windpower Project, Carbon County, Wyoming: November 1998 - June 2003**. Technical Report prepared by WEST, Inc. (2003 Central Ave, Cheyenne, Wyoming, 82001) for Pacificorp, Inc., SeaWest Wind Power, Inc. and Bureau of Land Management; 35 p.

posted January 15th, 2010; last edited November 18th, 2010 — David Sibley

Causes of Bird Mortality



A chart showing estimated numbers of birds killed annually by each of several different causes. Data from various sources.

This chart and the following text were prepared in 2003. Any updates would be welcome.

First, it should be stated that the single most significant threat to bird populations is habitat destruction, in all of its forms and with all of its causes. The various causes of mortality outlined below kill individual birds directly, and can certainly have an adverse effect on population size, but can actually have a beneficial effect in some cases. Studies of hunting have documented that in certain cases killing small numbers of birds can *improve* the health and survival of the remaining birds. As long as the habitat is intact, the population has the potential to replace the lost birds.

In simplest terms, habitat destruction reduces the population by reducing the available resources, denying birds the chance to reproduce, and effectively putting a cap on the population size.
The problems outlined below are serious threats and are implicated in the declines of many species. They should be addressed.

Collisions

Window strikes – estimated to kill 97 to 976 million birds/year – Millions of houses and buildings, with their billions of windows, pose a significant threat to birds. Birds see the natural habitat mirrored in the glass and fly directly into the window, causing injury and, in 50% or more of the cases, death. Simple steps can be taken to reduce the number of birds striking windows. Decals that stick to the glass are not very effective, but strips of tape on the outside of the glass, or strings or feathers hanging outside the window, each no more than 10 inches apart, are fairly effective. Decorative features like stained glass designs or window dividers can achieve the same result. Outside screens are very effective both to reduce the reflection and to cushion the impact. In short, anything that reduces or breaks up the window's reflection will reduce bird strikes. Lots of excellent info at FLAP (Fatal Light Awareness Program) ; follow the link to collision prevention and be sure to check out the "CollidEscape" film.

Communication towers – estimates of bird kills are impossible to make because of the lack of data, but totals could easily be over 5 million birds/year, and possibly as many as 50 million. Towers have proliferated in recent years, with an estimated 5000 new towers erected per year during the 1990s, mainly for the cell phone and digital TV industries. Any tall structure will kill birds by collision, and lighted towers attract birds at night. Theoretically cellphone towers are less dangerous than the taller structures, but there is no data either way, and the sheer number of cell phone towers may outweigh any other advantage. More info at FLAP (Fatal Light Awareness Program) and TOWERKILL .

High tension line collisions – may kill up to 174 million birds per year. This figure extrapolates from European studies to the millions of miles of aerial wires in North America. There are very few data in North America.

Electrocutions kill tens of thousands of birds per year. This occurs mainly when large birds such as raptors make contact between a live electrical wire and a ground such as a pole. The relatively small number of birds affected belies the significance of this threat, since species such as Golden Eagle are more susceptible. Large predators like eagles have smaller population sizes and lower reproduction rates than songbirds, so removing a few thousand birds from the population will have a much larger impact than removing the same number of, say, Savannah Sparrows. Studies byHawkWatch International revealed an electrocution rate of just under 1 bird per 100 poles per year, or 547 birds at 74,000 poles in Utah in 2001-2002. About 10% of the birds killed were Golden Eagles, 34% Ravens, and another 25%Buteos (Red-tailed, Swainson's and Ferruginous Hawks). Fortunately PacifiCorp, the owner of the poles, is committed to making changes to reduce electrocutions, and hopefully other regions will follow.

Cars may kill 60 million birds per year. Of over 8 million lane miles of roads in the US, 6.3 million, or over ¾, are in rural areas where most birds are presumably killed. There's not much we can do about this source of bird mortality short of changing our driving habits, but landscaping the roadside to discourage birds from congregating there is helpful. My own sense is that small cars with more aerodynamic designs hit fewer birds, while large boxy vans and trucks hit more birds, but I don't think this has been studied. By the way, 100 years ago there were fewer than 250 miles of paved roads in North America, all in urban centers.

Wind turbines may kill 33,000 birds per year, and, as in the case of electrocutions, these birds tend to be large and scarce (e.g. raptors). The recent surge of interest in wind power has heightened concerns about their effect on birds, and has led to at least the discussion of efforts by the wind power industry to design more benign windmills and to choose locations that are less "birdy". It's difficult for an environmentalist to come out against renewable energy like wind turbines, but as long as the electricity generated is considered a "supplement" to satisfy increasing demand, wind power will not really help the fight against global warming. Establishment of wind farms should go hand-in-hand with drastic cuts in electricity use, and there is a real need for more study of the relationship between birds and wind farms.

Poisoning

Pesticides may kill 72 million birds per year or possibly many more. The sub lethal effects of pesticides may also make the birds more susceptible to predators or unable to reproduce, essentially killing them. A New York study in 2000 found that common "over-the-counter" pesticides were responsible for more bird deaths there than West Nile Virus. More info about pesticides and birds can be found at The American Bird Conservancy, and BIRDSOURCE atCornell University. The Canadian Wildlife Service maintains a website with information about pesticides at http://www.cws-scf.ec.gc.ca/nwrc-cnrf/toxic/what_e.cfm

Oil spills kill hundreds of thousands of birds a year or more. Some of this occurs in dramatic large spills, but most probably occurs in thousands of small incidental spills that are never reported or documented.

Oil and wastewater pits may kill up to 2 million birds per year.

Lead poisoning – kills unknown numbers of birds each year, but Bellrose (many years ago) estimated that about 4% of the waterfowl population dies annually due to lead poisoning, and the California Condor recovery team stated that lead poisoning was the primary cause of the condor population decline over the last 50 years. This lead in the form of bullets and shot and fishing sinkers is ingested by the birds, ground up in the gizzard and absorbed by the body. More info is available from HawkWatch International. Alternative materials are now widely available and should be promoted. In Britain the use of lead fishing sinkers has been banned.

Pollution - Acid rain has been linked to calcium problems.

Predation

Hunting - as a point of reference the carefully-managed annual waterfowl hunt kills about 15 million birds a year in North America. This, of course, is balanced by extensive and well-funded management and conservation efforts so hunting is not a threat to the population of any North American bird, and conservation efforts led by hunters have been hugely beneficial to many species in addition to the ones being hunted.

Domestic and Feral Cats – may kill 500 million birds per year or more. More information can be found at The American Bird Conservancy. Predators, of course, account for the vast majority of bird deaths each year, and most of this predation is natural. Domestic cats are not natural predators, but kill many birds. It is worth noting that house cats have been blamed for the extinction of two species of small mammals in the southeastern United States, and feral cats continue to be a huge problem where they have been introduced on many oceanic islands.

By-catch – Tens to hundreds of thousands of seabirds are caught each year in nets and on hooks intended for fish. Although the total number is small this source of mortality is having a profound impact on a few species of birds.
See my newspaper column HERE about long-line fisheries and albatross. The BirdLife International site (an excellent source of global bird conservation information) has detailed information about the albatross declines here .

Disease

Disease – Unknown numbers. Disease is a major source of mortality for birds, and may be the underlying cause of death in many cases of predation. Most avian diseases are fairly specific, such as the conjunctivitis eye disease that hit House Finches hard in the eastern states. Botulism can be a serious problem in wetlands where water is drying up. The West Nile Virus has recently caused concern because it affects a wide range of species and has spread rapidly. TheHawaiian Islands have been particularly hard hit by avian disease, and offer a sobering example of the dangers of introduced diseases to naïve local bird populations; detailed info can be found here.

27 comments to Causes of Bird Mortality

Eric Luesebrink
August 6, 2010 at 12:33 PM · Reply

With regard to wind turbines, I don't think the description that "as in the case of electrocutions, these birds tend to be large and scarce (e.g. raptors)" is accurate. With the exception of the Altamont Pass in CA (where raptor deaths have occured but in much smaller numbers than quoted above) very few raptors or large birds have been killed by wind turbines. I would suggest you look up the work of Paul Kerlinger who has studied this issue for 20+ years.

Thanks,
Eric

bruce
September 2, 2010 at 12:55 PM · Reply

Domestic cats most certainly are predators. Turned loose from human captivity they will readily revert to feral and do quite well, assuming they have the natural tools. And cats have been "blamed" for many things, including the supernatural. But when a cat ventures out and raids a pheasant nest, it does so because that's what cats do. If one believes in a "Creator", then the cat has an absolute right to kill the pheasants. People kill them for entertainment in most all cases.

Robert
January 3, 2011 at 10:46 PM · Reply

Bruce, while many cats are able to survive in the wild after domestication, it is a myth to say that they all do so "readily". We have a serious problem in my area of people dumping cats because they believe this. The result is a large number of cats starving to death or living on garbage.

Chris
February 13, 2012 at 1:22 PM · Reply

Bruce,

Regardless of whether you are convinced of the existence of a "Creator" house cats were CREATED by Humans from a wild species that is native to Europe, Asia and Africa. Domestic cats and their wild ancestor, the Wild Cat (Felis silvestris) were never part of the North American fauna. It's unfortunate that you used another non-native species in your example. Feral cats as well as free-roaming pets kill large numbers of native birds, mammals and other small animals each year. You seem to imply that people killing pheasants for "entertainment" may be "wrong." A cat allowed to roam freely or released to fend for itself is no different than a human indiscriminently firing a shotgun while walking blindfolded through the forest.

Susan
June 18, 2013 at 8:16 AM · Reply

Cats, if hungry, do indeed kill to eat. But any well-fed cat will hunt and kill FOR THEIR PLEASURE– it is their nature to do so. We are talking domestic cats, NOT NATIVE, NOT part of nature.

Van
October 1, 2010 at 1:15 AM · Reply

Bruce, what does believing in a creator have to do with having a right to kill ??? Killing for entertainment? Huh?

Thanks for this overview, David!

Carole
March 26, 2011 at 11:12 PM · Reply

If one believes in a creator who created the various species, then one would necessary have to believe that the creator intended predators to kill. Indeed, many species have to kill to live. I don't think a cat could survive on a vegetarian diet. So either the cat kills or is fed animals that others have killed and made into cat food.

Linda
October 28, 2010 at 1:45 AM · Reply

The 'impacts' paper on the below web page estimates mortality of birds due to cat predation to be one billion.

http://www.abcbirds.org/abcprograms/policy/cats/tnr.html

Collision mortality updates:
http://www.abcbirds.org/abcprograms/policy/collisions/index.html

A variety of other threats are covered. ABC's website has been recently redone and updated.

Rich
January 18, 2011 at 7:08 AM · Reply

This article and many others only track birds killed unnaturally by external factors, such as cars or cats. Of course birds, like people and other creatures, have finite lifetimes. It would be interesting to know how many die of "normal" effects of aging, such as heart disease and cancer. That would make the number of "unnatural" deaths more significant.

Darwin26
March 30, 2011 at 4:47 AM · Reply

This sounds like the spineless 'above the law' spew of "that's what cats Do" impudent monsters …isn't that like telling the neighborhood if you don't like my unlicensed, unneutered, marauding predator in your yard thrill killing the birds that you've opened your yard up to, a personal sanctuary if you please, Tough S— 'Get used to it'. This is what the majority of predator Cats owners think and personally, they themselves are but impudent monsters – put here by a loving flying spagetti monster to Kill billions of birds for pleasure.
A few months ago i caught this marauding predator with 1 of my 5 Blue Jays who daily came to my feeder,in its mouth, it killed a chick-a-dee too and that mate was soo soo soo unhappy it cried all around me as i picked up the little torn up carcass, this feral cat was on a killing spree mostly sparrows and one Eurasian Ring-neck that i could see in my tiny little sanctuary thanks to predator lovers. No We won't get used to it.

Charles Holt
May 10, 2011 at 2:01 PM · Reply

Hello I am a ninth grade student in an iowa high school and my physical science teacher has givin me a new project. That is to wright the pros and cons of wind turbinds and make a debate in front of the class. During the debate the oppsing team brought up that wind turbinds kill birds but on this site it says that birds die more from windows than wind turbinds. so do you think that killing birds is a liable reason not to build wind turbinds?

Nick

May 10, 2011 at 2:08 PM · Reply

yes there should be no wind turbinds they kill valubal wild life and year apart familys

jack
July 22, 2011 at 2:44 PM · Reply

Charles,

From your post it is clear that you are smart enough to make up your own mind from the data available to you. Clearly emotional responses often indicate an opinion formed on the basis of events not related to the issue at hand.

No energy source has no impact on the environment. The challenge is to try to use energy sources that represent the best long-term compromises with the least impact and are sustainable. If birds are the only issue of importance (and in my opinion, this is one of several important issues regarding energy) then you ought to compare how many birds are killed or habitat destroyed by acid rain or the construction of other types of power plants. Those are just two examples.

Stay scientific. Let facts lead you. We need learned and calm consideration of our alternatives or we will never solve our problems. Your post gives me hope for our future.

Good luck with your investigation!

Getachew
October 1, 2011 at 9:23 AM · Reply

I am afried by what wind power is doing on birds.

Zepher
January 20, 2013 at 3:50 AM · Reply

Very little, especially compared to windows, if you notice the information above...

heidi
December 2, 2011 at 10:47 AM · Reply

Re: wind turbines and raptors, I'm not sure exactly why that assumption is being perpetuated – Altamont Pass was hell on raptors, but new turbine designs don't lure raptors in for perching... Instead they kill everything from warblers to ducks and beyond. I'm sure Altamont did the same, but raptors were the primary concern there. Raptors aren't the whole story for new turbine designs. Bats have it far worse than birds and that needs to be addressed far more seriously than it has been historically.

I'd like to see more of the 'bladeless' and vertical axis designs explored; 3 blade designs are hell on wildlife.

dv
December 30, 2011 at 8:32 PM · Reply

Based on slovacool, "Contextualizing avian mortality: a preliminary appraisal of bird and bat fatalities from wind, fossil-fuel, and nuclear electricity", which finds an average avian mortality of 0.3/GWh, if the entire US electrical base (3700 TWh/yr) were replaced with wind turbines, approximately 1.2 million birds would die each year from wind power. This is approximately 1/100 the minimum estimate for bird deaths from windows, and an estimated 10-fold decrease in bird fatalities relative to a coal-fired grid (based on the same paper).

I have tried to understand the fierce opposition to wind farms by some environmental groups. I suspect it is because they make easy targets. After all, they're suppose to be good for the environment, right?. When viewed in comparison to alternatives, they seem to be more environmentally friendly, and thus should probably not be opposed with such zeal. When looking to minimize bird deaths, it also seems that even minor efforts to reduce kills by feral cats, windows, and cars would completely dwarf any change in kill rate possible with turbines, even with vertical axis designs.

Barry
January 6, 2012 at 9:08 AM · Reply

I see these estimate from the wind lobby are still around. In NJ they erected 5 large wind turbines near Atlantic City on an island in an estuary. There local Audubon Study concludes that 74 birds and bat were killed per turbine per year. 4 Osprey(pop 800) and 1 peregrine Falcon(pop 30) were confirmed killed and they estimate there recovery rate is only 37% so more were likely killed. There are thousand planned so the NE should plan for the extinction of many raptors... here is the the study
http://www.ceoe.udel.edu/lewesturbine/documents/acua_quarterlyreport_fall09.pdf

Currently in California more Golden Eagles are killed by wind turbines than reproduced. The large more modern wind turbines actually are more in the flight path of large raptors and kill more. The SF Audubon has shown an increase in kills the better searches and larger turbines.

Barry
January 6, 2012 at 9:13 AM · Reply

How many Eagles are killed by windows? Feral cat killing Golden Eagles? I think the above estimate are a fraud places by wind turbine enthusiast. The EAgle protection act and the bird migration treaty both should be enforced against wind turbine companies, just like against oil companies. But the flow of subsidies to wind are just too great…the Gov of Maine went into the wind industry after setting up the laws to enrich himself.

Barry
January 6, 2012 at 12:10 PM · Reply

One last comment about the estimated BILLION birds hitting building…I have seen estimated that say we have 8-10 Billion birds in the USA…do you really believe that 10-15 percent of the bird population is wiped out every year?

Mike Barnard
May 17, 2012 at 3:54 PM · Reply

14 million fewer birds would die annually if all fossil fuel generation world-wide were replaced with wind turbines.

http://www.quora.com/Wind-Power/How-significant-is-bird-and-bat-mortality-due-to-wind-turbines/answer/Mike-Barnard

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Brian Peter
July 13, 2012 at 10:07 AM · Reply

I often wonder at these studies — do they ever ask questions of people
outside the study group ??
A classic case is the disappearance of song birds in our neighborhood,
The main reason is the growth in population of MAGPIES & CROWS
I have seven bird houses within my garden , all of them used to be occupied, but alas the magpies nesting in a neighbors garden has chased away our small birds.

Mike Barnard
August 15, 2012 at 1:44 PM · Reply

I redid the math: it's 70 MILLION BIRDS SAVED ANNUALLY if all fossil fuels were replaced with wind farms.

http://reneweconomy.com.au/2012/want-to-save-70-million-birds-a-year-build-more-wind-farms-18274

Walter Lamb
February 18, 2013 at 8:00 PM · Reply

I wonder what this chart would look like if it incorporated the results of the recent Smithsonian / USFWS study that claims that up to 3.7 billion and no fewer than 1.1 billion birds are killed by cats annually. It is clear that the authors of this study did no cross-checking of their math, so it would be interesting to work through some of the ramifications. For instance, on this chart, every single bird death from every anthropogenic cause and then some would have to be shifted to cats.

Tim Kirschner
May 16, 2013 at 6:28 PM · Reply

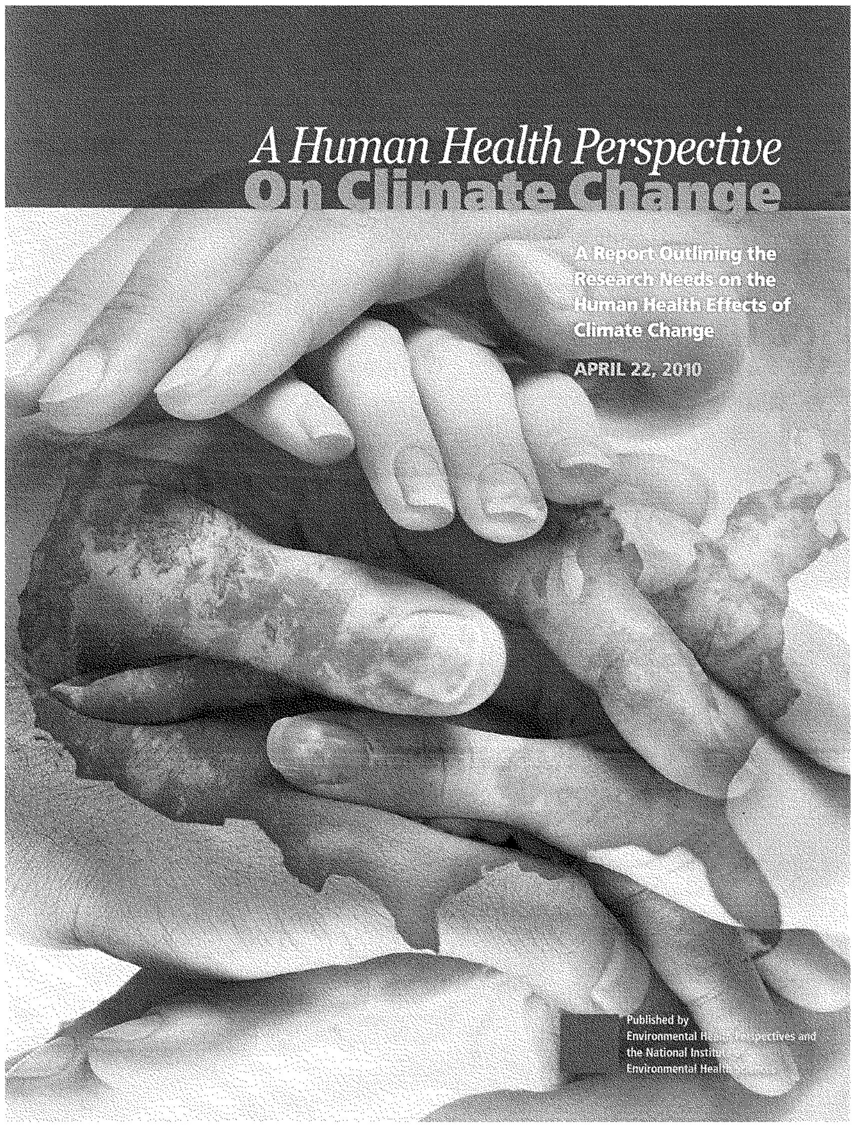
I am extremely familiar with birds. Do you know that hawks kill millions of non-agressive songbirds doves, and pigeons a year. Cooper Hawks alone according to the last study read, kill 7 million birds a year by themselves, this does not include any of the other species of Hawks, or owls. I see many hawks in very urban neighborhoods. If you wonder where your songbirds went, they either relocated due to pressure, or were killed by the hawks. My understanding is hawks are protected? Maybe it's time for revaluation of which species or raptor needs to be protected. My experience with turbines is the wind would have to push the birds int
O them, it's not something they would seek

Shedea
August 7, 2013 at 8:49 PM · Reply

Surely an engineer could design a strong, fine mesh guard that would protect birds and bats from the whirling blades? Obviously two drawbacks would be (a) some wind resistance, and (b) greater expense to produce. Perhaps the first problem could be offset by erecting more wind turbines. Then, with a greater demand for more turbines, they may become more affordable. If new safety standards could be introduced to the effect that all blades must be shielded, this would, in turn, generate more business for green energy industries. Even more so if a government grant towards research and development in this area could be obtained.

Bird Friendly
August 24, 2013 at 9:50 AM · Reply

There are already bladeless, energy efficient wind turbines out there.


A Human Health Perspective
On Climate Change
A Report Outlining the Research Needs on the Human Health Effects of Climate Change
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A Human Health Perspective On Climate Change

A Report Outlining the Research Needs on the Human Health Effects of Climate Change

The Interagency Working Group on Climate Change and Health[1]

APRIL 2010

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1 DISCLAIMER: The Interagency Working Group on Climate Change and Health (IWGCCH) is an ad hoc group formed by participating federal agencies and organizations at the invitation of the National Institute of Environmental Health Sciences (NIEHS), National Oceanic and Atmospheric Administration (NOAA), Centers for Disease Control and Prevention (CDC), and Environmental Protection Agency (EPA) following the January 2009 "Workshop on a Research Agenda for Managing the Health Risks of Climate Change," sponsored by the Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine. This report identifies gaps in knowledge of the consequences for human health of climate change, and suggests research to address them. The content, views, and perspectives presented in this report are solely those of the authors, and do not reflect the official views, policies, or implied endorsement of any of the individual participating federal agencies or organizations.

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Centers for Disease Control and Prevention

- National Center for Environmental Health

National Institutes of Health

- National Institute of Environmental Health Sciences
- Fogarty International Center
- Trans-NIH Working Group on Climate Change and Health

National Oceanic and Atmospheric Administration

Office of the Secretary, Department of Health and Human Services

U.S. Environmental Protection Agency

U.S. Department of Agriculture

U.S. Department of State

Executive Summary

The purpose of this paper is to identify research needs for all aspects of the research-to-decision making pathway that will help us understand and mitigate the health effects of climate change, as well as ensure that we choose the healthiest and most efficient approaches to climate change adaptation.

Climate change endangers human health, affecting all sectors of society, both domestically and globally. The environmental consequences of climate change, both those already observed and those that are anticipated, such as sea-level rise, changes in precipitation resulting in flooding and drought, heat waves, more intense hurricanes and storms, and degraded air quality, will affect human health both directly and indirectly. Addressing the effects of climate change on human health is especially challenging because both the surrounding environment and the decisions that people make influence health. For example, increases in the frequency and severity of regional heat waves—likely outcomes of climate change—have the potential to harm a lot of people. Certain adverse health effects can probably be avoided if decisions made prior to the heat waves result in such things as identification of vulnerable populations such as children and the elderly and ensured access to preventive measures such as air conditioning. This is a simplified illustration; in real-life situations a host of other factors also come into play in determining vulnerability including biological susceptibility, socioeconomic status, cultural competence, and the built environment. In a world of myriad "what if" scenarios surrounding climate change, it becomes very complicated to create wise health policies for the future because of the uncertainty of predicting environmental change and human decisions. The need for sound science on which to base such policies becomes more critical than ever.

Recognizing the complexity of this issue, an ad hoc Interagency Working Group on Climate Change and Health (IWGCCH)[2] assembled to develop a white paper on relevant federal research and science needs, including research on mitigation and adaptation strategies. Examples of mitigation and adaptation research needs are identified, but a comprehensive discussion of these issues is not included. These research and science needs broadly include basic and applied science, technological innovations and capacities, public health infrastructure, and communication and education. Consideration is also given to the potential structure of a federal climate change and health research agenda and the use of scientific research results for applications and decision making. The purpose of this paper is to identify research critical for understanding the impact of climate change on human health so that we can both mitigate and adapt to the environmental effects of climate change in the healthiest and most efficient ways. Although the group recognizes the global nature of climate change's impacts on human health, the primary focus of this paper is on the situation in the United States.

This report is organized around 11 broad human health categories likely to be affected by climate change.[3] Categories are arranged in alphabetical order, and no prioritization—for instance as to likelihood of occurrence, severity of effects, or depth of current knowledge—is implied. Each category is broken into sections that introduce the topic, explain its relationship to climate change, and identify the basic and applied research needs of that category, as well as crosscutting issues where relevant. Most investigations of climate change and health have relied on environmental and ecological effects to extrapolate potential human health impacts; the IWGCCH deliberately chose to emphasize the need for research on human health outcomes over environmental impacts for this reason: this approach highlights direct links between climate change and federal research priorities that are often disease- or outcome-specific, and a focus on human health outcomes enables a holistic approach to exploring climate change-related health impacts. We recognize that the health consequences identified in this document are not exhaustive, and that because so many climate change effects are prospective, some of the research needs enumerated may be speculative. As more information becomes available, new research needs may be identified and others rejected, but it is our intent that this report may serve as a baseline discussion from which agencies can proceed.

2 CDC, HHS/OS, EPA, NASA, NIEHS, NIH/Fogarty, NOAA, DOS, USDA, USGCRP

3 asthma, allergies, and airway diseases; cancer; cardiovascular disease and stroke; alterations in normal development; heat-related morbidity and mortality; mental health and stress disorders; neurological diseases and disorders; nutrition and food-borne illness; vectorborne and zoonotic disease; waterborne disease; weather-related morbidity and mortality

Highlights:

Asthma, Respiratory Allergies, and Airway Diseases—Respiratory allergies and diseases may become more prevalent because of increased human exposure to pollen (due to altered growing seasons), molds (from extreme or more frequent precipitation), air pollution and aerosolized marine toxins (due to increased temperature, coastal runoff, and humidity) and dust (from droughts). Mitigation and adaptation may significantly reduce these risks. Research should address the relationship between climate change and the composition of air pollutant mixtures (e.g., how altered pollen counts and other effects of climate change affect the severity of asthma) to produce models to identify populations at risk. Such tools support the use of science in understanding disease risks and as such, are an integral component of developing effective risk communication and targeting the messages to vulnerable populations.

Cancer—Many potential direct effects of climate change on cancer risk, such as increased duration and intensity of ultraviolet (UV) radiation, are well understood; however the potential impact of changes in climate on exposure pathways for chemicals and toxins requires further study. Science should investigate the effects of mitigation and adaptation measures on cancer incidence so that the best strategies can be developed and implemented; for example, research to inform understanding of the benefits of alternative fuels, new battery and voltaic cells, and other technologies, as well as any potential adverse risks from exposure to their components and wastes. Better understanding of climate change impacts on the capacity of ocean and coastal systems to provide cancer curative agents and other health-enhancing products is also needed.

Cardiovascular Disease and Stroke—Climate change may exacerbate existing cardiovascular disease by increasing heat stress, increasing the body burden of airborne particulates, and changing the distribution of zoonotic vectors that cause infectious diseases linked with cardiovascular disease. Science that addresses the cardiovascular effects of higher temperatures, heat waves, extreme weather, and changes in air quality on health is needed, and this new information should be applied to development of health risk assessment models, early warning systems, health communication strategies targeting vulnerable populations, land use decisions, and strategies to meet air quality goals related to climate change. In some areas, cardiovascular and stroke risks resulting from climate change could be offset by reductions in air pollution due to climate change mitigation.

Foodborne Diseases and Nutrition—Climate change may be associated with staple food shortages, malnutrition, and food contamination (of seafood from chemical contaminants, biotoxins, and pathogenic microbes, and of crops by pesticides). Science research needs in this area include better understanding of how changes in agriculture and fisheries may affect food availability and nutrition, better monitoring for disease-causing agents, and identification and mapping of complex food webs and sentinel species that may be vulnerable to climate change. This research could be used to prepare the public health and health care sectors for new illnesses, changing surveillance needs, and increased incidence of disease, as well as development of more effective outreach to affected communities.

Heat-Related Morbidity and Mortality—Heat-related illness and deaths are likely to increase in response to climate change but aggressive public health interventions such as heat wave response plans and health alert warning systems can minimize morbidity and mortality. Additional science should be focused on developing and expanding these tools in different geographic regions, specifically by defining environmental risk factors, identifying vulnerable populations, and developing effective risk communication and prevention strategies.

Human Developmental Effects—Two potential consequences of climate change would affect normal human development: malnutrition—particularly during the prenatal period and early childhood as a result of decreased food supplies, and exposure to toxic contaminants and biotoxins—resulting from extreme weather events, increased pesticide use for food production, and increases in harmful algal blooms in recreational areas. Research should examine the relationship between human development and adaptations to climate change, such as agriculture and fisheries changes that may affect food availability, increased pesticide use to control for expanding disease vector ranges, and prevention of leaching from toxic waste sites into floodwaters during extreme weather events, so that developmental consequences can be prevented.

Mental Health and Stress-Related Disorders—By causing or contributing to extreme weather events, climate change may result in geographic displacement of populations, damage to property, loss of loved ones, and chronic stress, all of which can negatively affect mental health. Research needs include identifying key mental health effects and vulnerable populations, and developing migration monitoring networks to help ensure the availability of appropriate health care support.

Neurological Diseases and Disorders—Climate change, as well as attempts to mitigate and adapt to it, may increase the number of neurological diseases and disorders in humans. Research in this area should focus on identifying vulnerable populations and understanding the mechanisms and effects of human exposure to neurological hazards such as biotoxins (from harmful algal blooms), metals (found in new battery technologies and compact fluorescent lights), and pesticides (used in response to changes in agriculture), as well as the potentially exacerbating effects of malnutrition and stress.

Vectorborne and Zoonotic Diseases—Disease risk may increase as a result of climate change due to related expansions in vector ranges, shortening of pathogen incubation periods, and disruption and relocation of large human populations. Research should enhance the existing pathogen/vector control infrastructure including vector and host identification; integrate human with terrestrial and aquatic animal health surveillance systems; incorporate ecological studies to provide better predictive models; and improve risk communication and prevention strategies.

Waterborne Diseases—Increases in water temperature, precipitation frequency and severity, evaporation-transpiration rates, and changes in coastal ecosystem health could increase the incidence of water contamination with harmful pathogens and chemicals, resulting in increased human exposure. Research should focus on understanding where changes in water flow will occur, how water will interact with sewage in surface and underground water supplies as well as drinking water distribution systems, what food sources may become contaminated, and how to better predict and prevent human exposure to waterborne and ocean-related pathogens and biotoxins.

Weather-Related Morbidity and Mortality—Increases in the incidence and intensity of extreme weather events such as hurricanes, floods, droughts, and wildfires may adversely affect people's health immediately during the event or later following the event. Research aimed at improving the capabilities of healthcare and emergency services to address disaster planning and management is needed to ensure that risks are understood and that optimal strategies are identified, communicated, and implemented.

In addition to the research needs identified in the individual research categories, there are crosscutting issues relevant to preventing or avoiding many of the potential health impacts of climate change including identifying susceptible, vulnerable, and displaced populations; enhancing public health and health care infrastructure; developing capacities and skills in modeling and prediction; and improving risk communication and public health education. Such research will lead to more effective early warning systems and greater public awareness of an individual's or community's health risk from climate change, which should translate into more successful mitigation and adaptation strategies. For example, health communications research is needed to properly implement health alert warning systems for extreme heat events and air pollution that especially affects people with existing conditions such as cardiovascular disease. Such a risk communication pilot project might demonstrate communication practices that are effective in multiple areas, and contribute to a comprehensive strategy for addressing multiple health risks simultaneously.

Other tools are needed and should be applied across multiple categories to close the knowledge gaps, including predictive models to improve forecasting and prevention, evaluations of the vulnerability of health care and public health systems and infrastructure, and health impact assessments. Trans-disciplinary development would help to ensure tools such as improved baseline monitoring that will be more widely applicable, and thus more efficient and cost effective than those currently available. In fact, many of the identified science needs will require trans-disciplinary responses. For example, to study how heat waves alter ambient air pollution and the resulting combined impact of heat and pollution on human illness and death, will require expertise in atmospheric chemistry, climate patterns, environmental health, epidemiology, medicine, and other science fields. Given the complexity of the science needs and the potential overlap of research questions across disciplines, promoting trans-disciplinary collaboration among and within federal agencies would be a logical approach and should be a high priority.

Recently, the National Research Council issued a report addressing how federal research and science could be improved to provide support for decision and policy making on climate change and human health.[4] Specifically, the report calls for a more complete catalogue of climate change health impacts, increasing the power of prediction tools, enhancing integration of climate observation networks with health impact surveillance tools, and improving interactions among stakeholders and decision makers. The IWGCCH approached this research needs assessment with these goals in mind. The next step will be for federal agencies to discuss the findings of this white paper with stakeholders, decision makers, and the public as they work to incorporate and prioritize appropriate research needs into their respective science agendas and collaborative research efforts.
A coordinated federal approach will bring the unique skills, capacities, and missions of the various agencies together to maximize the potential for discovery of new information and opportunities for success in providing key information to support responsive and effective decisions on climate change and health.

4 National Research Council (U.S.), Committee on Strategic Advice on the U.S. Climate Change Science Program., et al. 2009, Washington, D.C.: National Academies Press, xx, 254 p.

Introduction

Global climate change has become one of the most visible environmental concerns of the 21st century. From pictures of polar bears clinging to melting ice floes in Alaska to dried and cracked farmland stretching into the horizon in Africa, images of the ecological impacts of climate change have become part of our combined consciousness and inspire concern and discussion about what climate change ultimately will mean to our planet. But seldom are the effects of climate change expressed, either visually or otherwise, in terms of the real and potential costs in human lives and suffering. To date, most climate change research has focused on environmental effects and not health effects. It is clear that climate change endangers human health, but there is need to improve the science and knowledge base of how it occurs. One purpose of this document is to identify research gaps to increase the understanding of climate change and health. Expanding our understanding of the often indirect, long-term, and complex consequences of climate change for human health is a high priority and challenging research task.[5] In the developed world particularly, there is perhaps a greater perception of the ecological and environmental effects of climate change than of the human health implications. This may be due in part to the fact that images linking climate change and some already apparent wildlife and landscape effects are prevalent, and thereby, increase concern.

5 [illegible]

There is no doubt, however, that climate change is currently affecting public health through myriad environmental consequences, such as sea-level rise, changes in precipitation resulting in flooding and drought, heat waves, changes in intensity of hurricanes and storms, and degraded air quality, that are anticipated to continue into the foreseeable future. In a tally that included just four diseases (cardiovascular disease, malnutrition, diarrhea, and malaria) as well as floods, the World Health Organization (WHO) estimated 166,000 deaths and about 5.5 million disability-adjusted life years (DALYs, a measure of overall disease burden) were attributable to climate change in 2000.[6] To date, the majority of analyses on climate change and health have focused on diseases that predominantly affect people in the developing world, and therefore, are perceived as less relevant to more developed countries. However, as the recent pandemic of H1N1 virus has shown us, diseases do not respect international boundaries. Climate change can be a driver for disease migration, but even so, such diseases do not represent the broadest range of possible, or even likely, human health effects of climate change, nor do they reflect the likely co-benefits of mitigation and adaptation to climate change, some of which may have their greatest impact in the developed world.

For over 170 years, scientists have studied the complicated relationship between the weather, climate, and human health.[7] Since the first attempt at scientific consensus on climate change nearly four decades ago,[8] scientists have been examining whether climate is indeed changing as a result of human activity. However, the complicated relationships between climate change, the environment, and human health have not represented high priorities for scientific research in the United States, and there are abundant gaps in our understanding of these links.[9] Such gaps impair our ability to identify optimal strategies for mitigation and adaptation that will prevent illness and death in current human populations while simultaneously protecting the environment and health of future generations. The purpose of this report is to identify the major research areas that need to be further explored and understood, and to identify the scientific capacities that will be needed to adequately address the problems that arise at the nexus of climate, environment, and human health with the goal of informing federal agencies with a human health or related research mission as they approach these daunting challenges.[10] Research outcomes generated from the needs agenda outlined here would go a long way toward informing health decision making and addressing the challenges outlined in the National Research Council's report.[11].

Leaders including the Director, National Institute of Environmental Health Sciences (NIEHS); the Chief Scientist in the Office of the Science Advisor, U.S. Environmental Protection Agency (EPA); the Senior Scientist for Coastal Ecology, National Oceanic and Atmospheric Administration (NOAA); and the Director, National Center for Environmental Health, Centers for Disease Control and Prevention (CDC) initiated the development of this white paper in February 2009. The Interagency Working Group on Climate Change and Health (IWGCCH) was established with representation and participation from various federal agencies, institutes, and other organizations with an environmental health or public health mandate. (Participating groups are listed on the Working Group page of this document, pp. iii). The first activity of this ad hoc group was to review and distill the state of the science on the effects of climate change on human health from the many excellent reviews of climate change already published by groups including the Intergovernmental Panel on Climate Change, the World Health Organization, the U.S. Global Change Research Program, the National Research Council, and others. Most of these reports take a much broader view of the issue of climate change; however, the portions that are directly relevant to human health effects provided a critical baseline from which this working group could proceed to identify the research gaps and needs in this area.

This document does not attempt to be a comprehensive assessment of the risks associated with climate change and health or a strategic plan. Rather it seeks to build on the existing knowledge of the prior efforts, and extend this knowledge further by shifting the perspective on climate change effects from a largely ecological and meteorological base to one that focuses on the human health consequences of climate change, mitigation, and adaptation. Similarly, an aim of this report is to inform the federal government as it seeks to focus climate change research on understanding the interactions among the climate, human, and environmental systems and on supporting societal responses to climate change. In this way, it is responsive to the recommendations of some of these reports. The working group has drafted this document in consultation with subject matter experts at the various agencies, seeking their review and comment throughout the process to provide a concise, credible, and broad discussion.

6 Campbell-Lendrum, D., et al. Environmental Burden of Disease Series, ed. A. Prüss-Üstün, et al. 2003, Geneva: World Health Organization. 66
7 [illegible], F. 1835, Philadelphia: Carey, Lea & Blanchard. xx, [13]-534 p.
8 Study of Critical Environmental Problems., et al. 1970, Cambridge, Mass.,: MIT Press. xxv, 319 p.
9 Campbell-Lendrum, D. et al, The Lancet, 2009. 373(9676): p. 1663-1665.
10 Gamble, J.L., et al. 2008, Washington, D.C.: U.S. Climate Change Science Program. xx, 204 p.
11 National Research Council (U.S.). Committee on Strategic Advice on the U.S. Climate Change Science Program., et al. 2009, Washington, D.C.: National Academies Press. xiv, 254 p.

Figure 1 provides the conceptual framework used to develop this report. In addition to the direct effects of heat on humans, the major impacts of climate change on human health are through changes to the human environment such as rising oceans, changing weather patterns, and decreased availability of fresh water. Mitigation of climate change refers to actions being taken to reduce greenhouse gas emissions and to enhance the sinks that trap or remove carbon from the atmosphere to reduce the extent of global climate change. Adaptation refers to actions being taken to lessen the impact on health and the environment due to changes that cannot be prevented through mitigation. Appropriate mitigation and adaptation strategies will positively affect both climate change and the environment, and thereby positively affect human health. In addition, some adaptation activities will directly improve human health through changes in our public health and health care infrastructure. Gaps in our understanding of how human health, climate change, the environment, and mitigation and adaptation are linked are the focus of this report.

Figure 2 expands upon the conceptual framework in **Figure 1,** and provides a global view of the complex ecological networks that can be disrupted by climate change, the human health implications of such disruptions, and the targets of mitigation and adaptation. Many of these diseases[12] and disorders are not independently affected; any one disease is likely to have several drivers from the group of environmental consequences that result from climate change, and conversely, any particular environmental change could affect multiple disease categories. In addition, both positive and negative synergies will occur among various components of the system.

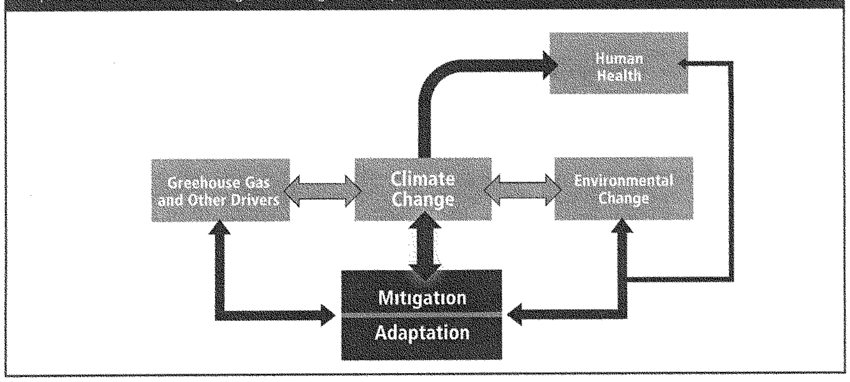
Climate change directly affects five components of the environment: water, air, weather, oceans, and ecosystems.[13] Changes in rainfall and other precipitation, changing temperatures, and melting of summer ice caps are already occurring and will create changes in the availability and quality of water across much of the planet over the next 30 years.[14] In the United States, water security, or the reliable availability of water for drinking, agriculture, manufacturing, and myriad other uses, is becoming a pressing issue. This is particularly true in the Western half of the country, where water shortages are exacerbated by reduced mountain snowpack due to warming, and in the South, where severe droughts have become a more frequent occurrence in recent years. Water quality is also affected in many regions, particularly coastal areas, due to extreme weather events

12 For simplicity, we will use disease to include the broad spectrum of human diseases, syndromes, ailments and conditions being described here.

13 Intergovernmental Panel on Climate Change. Working Group II. 2007. Cambridge: Cambridge University Press. ... 976 p; Karl, T, et al. 2009. New York: Cambridge University Press.

14 Intergovernmental Panel on Climate Change. Working Group II. 2007. Cambridge: Cambridge University Press. ... 976 p.

FIGURE 1 | Changes in greenhouse gas concentrations and other drivers change our global climate altering human health; mitigation alters climate and both mitigation and adaptation alter the human environment; the predominant impact on human health is through environmental changes as a result of climate change although there are direct impacts from both climate changes and mitigation/adaptation.

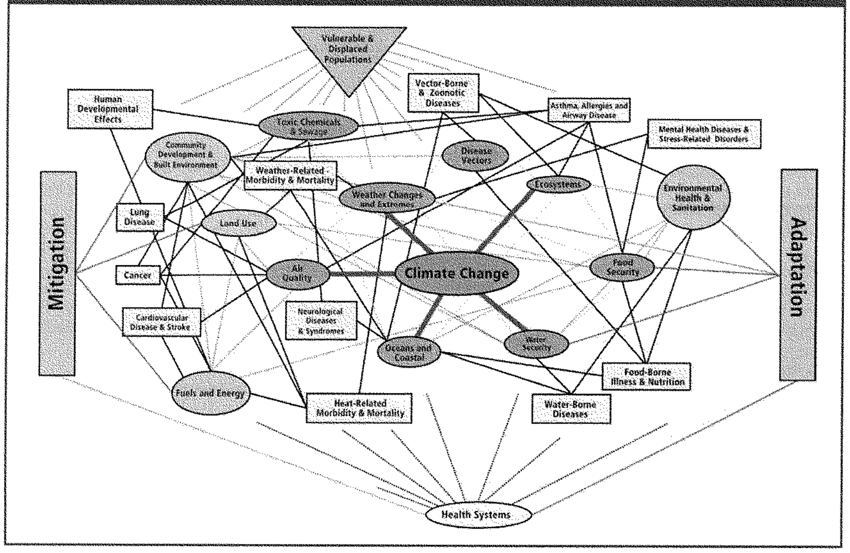


such as hurricanes and flooding. These same events, often associated with sea-level rise and increased storm surges, can heavily damage human communities and alter complex coastal ecosystems with consequences for both water and food quality and supply.

The complex atmospheric chemistry that governs air quality is modulated by heat, humidity, degree of ultraviolet (UV) radiation, and many other factors. Changes in any of these can directly reduce air quality, particularly in urban areas, by increasing air concentrations and human exposures to a variety of toxic air pollutants including chemicals, fungi, and aeroallergens. In many areas of the country, climate change and resulting weather events such as drought and wildfires will reduce general air quality and increase human exposure to a variety of pollutants, with resulting increases in asthma, cardiovascular disease, and other respiratory ailments.

Some of the human health effects will arise from extreme weather events that are expected to become more common in a warmer climate. For instance, more intense hurricanes and increases in flooding and wildfires may exacerbate a wide range of health effects resulting from the release of toxic chemicals from landfills, contamination of drinking water with raw sewage as a result of damage to water infrastructure, increased concentrations of air pollutants that are especially harmful to susceptible populations such as children, the elderly, and those with asthma or cardiovascular disease, and myriad other hazards associated with these events. Extreme heat

FIGURE 2 | Climate change has direct impacts on five aspects of the human environment (red lines, purple circles) that in turn impact additional environmental factors. These environmental changes then alter twelve separate aspects of human health (tan boxes). Mitigation and adaptation alter the human environment in order to address climate change and, in this way, alter human health. Finally, susceptible populations exist for all climate-targeted health points, and the health systems play an integral role in addressing the health concerns driven by climate change.



also directly increases the risk of injury, illness, and death, as well as indirectly by contributing to illnesses such as those associated with mental health and stress.[15]

Global climate change is visibly and profoundly affecting oceans, which in turn, affects human health. The warming of ocean waters contributes to increases in incidence and severity of toxic algal blooms, alterations in aquatic and estuarine food webs and seafood quality and availability, and effects on sentinel aquatic species[16]. High concentrations of carbon dioxide in the atmosphere increase the amount that is dissolved into the ocean, leading to acidification and disruption of ecosystems. As large portions of the world's populations, including those in the United States, live in coastal areas, and many depend on marine protein for daily subsistence, the consequences of perturbing delicate ocean and coastal systems will be far-reaching.

Climate changes including increased heat in certain arid and semi-arid parts of the United States can dramatically alter existing ecosystems, presenting new challenges to agricultural production and coastal ecosystems, with consequences for food quality and availability. Changes in plant habitat can result in reduced availability of grazing lands for livestock.[17] Climate changes also are directly associated with many pest habitats and disease vectors, and changes in temperature can extend or reorient habitats such that organisms are introduced to new geographic areas or life cycles are altered, requiring increases in pesticide use or use in new areas to achieve the same yields. Global warming is also causing shifts in the ranges of disease vectors that require specific environments to thrive (for example, Lyme disease),[18] and increasing the threat and incidence in humans of waterborne, vectorborne and zoonotic (those transferred from animals to humans) diseases.

No current mitigation strategy or technology can prevent the change in climate that has already occurred. At present, our ability to mitigate the magnitude of the climate changes that will occur over the next 100 years is limited by the current makeup of the atmosphere, as well as what we can prevent from entering and what we are able to remove from the atmosphere in the future. The major targets of climate change mitigation strategies include alternative fuels and energy conservation, changes in land use patterns, sustainable development of the built environment, and carbon capture and storage.[19] Switching from fossil fuels and other greenhouse gas-emitting energy sources to cleaner alternatives and using carbon capture and storage technologies will slow the rate at which we release greenhouse gases into the environment. Energy conservation and modifications in energy use will also reduce releases. Land use changes such as restricting the destruction of forests and replanting more trees will serve to increase natural carbon storage.

Actions to preserve other ecosystem services, such as flood control by protecting wetlands or vector control by conserving biodiversity, can also reduce the severity of climate change-related problems.[20] Finally, changes in building codes, transportation infrastructure, housing density, coastal development, and other urban planning strategies can reduce energy usage and thereby mitigate some portion of climate change. Through these changes in human activities and practices, we should be able to limit the magnitude of the changes to the planet's climate, and thus, reduce the negative impacts to human health. Though it is possible that some mitigation strategies may exacerbate known human health stressors or introduce unanticipated potential for human harm, many strategies will provide co-benefits, simultaneously reducing the negative effects of climate change while also reducing illness and death. For example, reducing harmful air pollutants generally decreases global warming but is also just more healthful to people.[21]

Recognizing that there are a broad set of issues related to both potential benefits and possible adverse effects on human health resulting from mitigation and adaptation strategies, the IWGCCH did not attempt to outline research needs for mitigation and adaption in a comprehensive manner in this report, nor provide a comprehensive overview of mitigation and adaptation approaches. These issues and their associated research needs will have to be evaluated in the context of the individual options and strategies. Instead, this report focuses on some of the broader mitigation and adaptation options that are currently under development that have the potential to provide great benefits to human health and proposes research needs that could inform decisions relating to them, and examples of mitigation and adaptation needs related to certain health consequences are included within each chapter.

Adapting to or coping with climate change will become necessary in the United States and around the world. Most adaptation strategies seek to change the human environment and decrease the potential for illness and death by helping to prevent some of the worst consequences of climate change. The primary environmental factors targeted for adaptation are water security and food security.

15 [illegible], et al., Environment International, 2009. [illegible] p. 977-986.
16 United States. Congress. Senate. Committee on Commerce Science and Transportation. 2005. Washington U.S. G.P.O. [illegible]
17 [illegible], P.L., et al., Environmental Science and Policy, 2009. 12(4) p. 373-377.
18 Estrada-Peña, A. Environ Health Perspect, 2002. 110(7): p. 635-40.
19 Haines, A., et al., Lancet, 2006. 367(9528): p. 2101-2109.
20 Corvalan, C., et al. 2005, (Geneva, Switzerland): World Health Organization. 53 p.
21 Smith, KR, et al., Lancet, 2009.

Given the likely changes that will occur in precipitation patterns, temperature, and extreme weather events, adapting the ways in which we store, treat, and use water will be key to avoiding changes in water security. Similarly, food sources—whether they be crops, livestock, marine, or freshwater—will be under greater stress in various parts of the United States, and as a nation we need to develop adaptation strategies to ensure our food security. Clean water and access to sufficient safe food are fundamental needs for human health, so successful adaptation methods that maintain and improve the availability of clean water and healthy food will be critical to avoiding some of the major health impacts of climate change. There is also a need for adaptation strategies focused on community development and the built environment, transportation, and public health infrastructure.[22]

Through these environmental changes, increases—and in some rare cases—decreases in adverse human health consequences are likely to occur. We have organized these health consequences into 11 broad categories for discussion (listed below). In this report, we provide for each category a brief synopsis of what is known about the relationship between climate change; mitigation, and adaptation; effects on the risk, incidence, severity, or characteristics of the specific diseases or disorders; the major research needs and questions that must be addressed; and in some cases, an indication of the specific skills and capacities that will be needed to facilitate the research. Because factors including urgency, likelihood of occurrence, numbers of people affected, severity of effects, and economic issues associated with each category are broad, difficult to quantify, and largely beyond the mandate of our individual agencies, we have deliberately chosen not to attempt a prioritization of the research needs, but rather seek to provide a body of knowledge to inform federal agencies, and the government as a whole, as agencies and other groups set their own priorities and agendas in this area. The scope of this analysis is largely confined to examining effects on the U.S. population, which is the primary constituency of the federal agencies, recognizing that most, if not all, of these issues are of global concern and consequence as well, and in the hopes that resulting gains from this information can be applied to global collaborations in the future. Similarly, although we attempt to provide some discussion of the training, capacities, technology, and infrastructure needs that will be required to address these critical research questions, it is within the context and for the purpose of identifying and applying those resources present or anticipated within our specific federal agencies.

Finally, the health consequence categories, although treated as individual topics, are not discrete, but rather are connected through the complicated systems within our planet and our own bodies. We have tried to draw out these connections wherever possible and when they are of major significance. We also have identified a number of crosscutting issues that are critical to this discussion including susceptible, vulnerable, and displaced populations; public heath and health care infrastructure; capacities and skills needed; and communication and education to increase awareness of climate change health effects.

Categories of human health consequences of climate change:

1. Asthma, Respiratory Allergies, and Airway Diseases
2. Cancer
3. Cardiovascular Disease and Stroke
4. Foodborne Diseases and Nutrition
5. Heat-Related Morbidity and Mortality
6. Human Developmental Effects
7. Mental Health and Stress-Related Disorders
8. Neurological Diseases and Disorders
9. Vectorborne and Zoonotic Diseases
10. Waterborne Diseases
11. Weather-Related Morbidity and Mortality

22 Haines, A, et al., Ibid 2006. 367(9528): p. 2101-2109

Crosscutting Issues for Climate Change and Health

In the process of identifying and characterizing research needs on the health implications of climate change for the 11 categories of consequences, it became evident that multiple crosscutting issues span all aspects of the research needs. In the sections below, we briefly summarize the major areas of overlap.

Susceptible, Vulnerable, and Displaced Populations. The World Health Organization defines "environment" as "all modifiable physical, chemical, and biological factors external to the human host, and all related behaviors that are critical to establishing and maintaining a healthy livable environment,"[23]. Within this definition, it is likely that the environment can affect most human diseases and illnesses. There are certain populations that are at increased risk from environmental factors that affect health, and such populations present unique concerns when considering the health risks from climate change. "Susceptibility" refers to intrinsic biological factors that can increase the health risk of an individual at a given exposure level. Examples of susceptibility factors that have been shown to increase individual health risks are certain genetic variants, life-stage such as childhood, and medical history such as a prior history of disease. "Vulnerability" refers to human populations at higher risk due to environmental or personal factors. For example, people living in mud brick houses in earthquake zones are much more vulnerable to injury from building collapse than those living in structures built with modern techniques and stronger materials. Populations living in poverty, substance abusers, and those with mental illness are at increased vulnerability to many of the environmental changes resulting from climate change. Another form of vulnerability is seen in displaced populations, who have been shown to be at higher risk of a number of diseases, including diarrheal and vectorborne diseases resulting from exposure to poor sanitation, as well as mental health illnesses due to increased acute and chronic stress.[24]

Populations with both susceptibility and vulnerability factors are referred to as "sensitive" populations. An example of a sensitive population would be certain members of the displaced population that evacuated New Orleans following Hurricane Katrina. Studies have shown that within this population, older people (susceptible) who were of low income (vulnerable) were the slowest to recover from the disaster.[25] Virtually every human disease is likely to have both susceptible and vulnerable populations associated with it. One key aspect to mitigating the effects of climate change is a better understanding of diseases and the unique risks of various exposed or affected populations so that strategies may be developed that take such risks into account and are tailored to address them.

In the case of diseases linked to climate change, a number of populations are particularly at risk. Children, pregnant women, and the elderly are generally more susceptible, especially for heat- and weather-related illness and death, vectorborne and zoonotic diseases, and waterborne and foodborne illnesses.[26] Also, children and some minority groups are very susceptible to asthma and allergies that may be exacerbated by climate change. Genetic links and markers that help to identify and define susceptible populations exist for many climate-related diseases.

Poverty generally makes people more vulnerable to many of the health effects of climate change, largely due to inadequate access to health care. Poverty also increases the risk that a population displaced by extreme weather events or environmental degradation will not easily recover, and as a result, will suffer much higher disease risks. The same is true for people who abuse drugs, those who suffer mental illness, and others who for various reasons are socially isolated For such populations, the effects of climate change such as temperature and weather extremes, disruptions in access to public services including health care and food assistance programs, and increased stress are all magnified by their preexisting conditions or situations. Outdoor workers and people living in coastal and riverine zones also are likely to experience increased vulnerability to climate-induced environmental changes resulting from flooding and extreme weather events.

Data to support a broad understanding of which populations will be most susceptible and vulnerable to diseases affected by climate change are generally lacking at this time; however, data are

23 Prüss-Üstün, A., et al. 2006. Geneva, Switzerland: World Health Organization. 104 p.
24 Myers, N. Philos Trans R Soc Lond B Biol Sci, 2002. 357(1420): p. 609-13.
25 Eisenman, DP, et al., Am J Public Health, 2007. 97 Suppl 1: p. S109-15.
26 Balbus, JM, et al., Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine, 2009. 51(1): p. 33-37.

available that identify vulnerable populations for some diseases with environmental causes or triggers that are likely to be altered by climate change. For example, reducing vehicle emissions may mean that populations living near freeways, who are at higher risk of cardiovascular disease, asthma, and spontaneous abortion, may see a reduction in incidence of these effects.[27] Expanding research on these diseases to incorporate effects of climate change will help to identify vulnerable populations, and also to develop the strategies needed to adapt to climate changes and avoid excess health risks. These research efforts, if they are to be effective, must involve a broad spectrum of research scientists from epidemiologists and physicians to environmental engineers and community planners. Such efforts also will require a broad-based, multi-agency federal program that builds on the strengths of each agency to develop an overall comprehensive research agenda.

Public Health and Health Care Infrastructure. The term "public health" describes the science of preventing disease, prolonging life, and promoting health and its application to society, communities, and groups. In contrast, "health care" primarily focuses on the treatment of illness and the protection of mental and physical well being in individuals through services provided by physicians and other health care professionals. Together, these two areas are tasked with the protection of the health of the people of the United States.

Public health agencies exist across the United States in most large cities, as well as at the county, state, and federal levels. Schools of public health and other training and research institutions add to the total public health infrastructure investment of the United States, which is very large and quite complex. The public health system will play a critical role in the prevention of human disease from climate change. As such, public health agencies should be deeply involved in researching, developing, and implementing adaptation strategies to climate change. There is a critical need for research to understand how climate change will alter our public health needs in the United States, and to design optimal strategies to meet those needs.[28]

The health care delivery infrastructure in the United States is even more diverse and complicated than the public health infrastructure (though there are multiple overlaps between the two systems). From family doctors in small towns to complex university research hospitals in large cities, health care professionals are the primary source of medical treatment, prenatal and pediatric care, and individual health protection and promotion for people in the United States. But this infrastructure is also vulnerable to climate change in a number of very important ways. Disasters can severely hinder the delivery of health care, with long-term impacts.[29] Changes in the numbers of patients and the spectrum of diseases with which they present could occur in some regions as the climate changes. The types of advice offered to patients with chronic conditions and the infrastructure to support them may need to be adapted to protect against climate-induced changes that may make these individuals more vulnerable. Currently there is limited research to guide these types of decisions.

The public health community is in the early stages of developing modeling skills and capacity in relation to climate change, particularly for combining climate models with ecological and other health outcome models for use in projecting disease dynamics under various climate scenarios. In order to understand these dynamics, a sustained surveillance infrastructure that integrates human and ecological health (terrestrial, marine, aquatic) is critical. While the public health community has developed considerable expertise in behavioral science and health education, this expertise has yet to be applied to the most trenchant issues related to climate change.

Sea-level rise, coastal erosion, and population displacement will create challenges for public health infrastructure that has been constructed over a period of hundreds of years. Disruption of coastal routes and harbors by sea-level rise will present additional challenges to health care delivery and food distribution. It is doubtful that transportation infrastructure will be able to adapt quickly enough to large population shifts that may be made in response to changes in rainfall patterns. Displaced populations will need sewer and water resources in new locations. The sewer and water resources in coastal locations may be threatened directly by sea-level rise.

Capacities and Skills Needed. Many of the existing skills used in public health and health care are well established and applicable to dealing with the health effects of climate change, but new skills will also be needed. Skills used in certain types of disease surveillance are well established. Less well established are the skills and methods needed to integrate current and future surveillance activities

27 Clougherty, JE, et al., Environ Health Perspect, 2009. 117(9): p. 1351-8; Green, RS, et al. Environ Health Perspect, 2009. 117(12): p. 1939-44

28 Bedsworth, L, Environmental Health Perspectives, 2009. 117(4): p. 617-623.

29 Rudowitz, R, et al. Health Aff (Millwood), 2006. 25(5): p. w393-406

and retrospective datasets with weather and climate information. Understanding of how to conceptualize and conduct epidemiological analysis using weather and climate as exposures is also preliminary. Methods and skill in combining spatial epidemiology with ecological approaches are also lacking. There is a strong need for the ability to translate vulnerability mapping and health impact assessments (HIAs) into behavioral changes and effective public health actions.

A greater emphasis must be placed on developing and maintaining interdisciplinary and inter-institutional collaborations, as well as on ensuring that established resources and expertise of all of the relevant disciplines, including climatology, modeling, environmental science, risk assessment, public health, and communications and education, are applied to these pressing problems. Many additional disciplines including ecology, social science, economics, geography, behavioral psychology, and others will need to play a vital role in climate and health decision making.

Communication and Education. Other areas where public health professionals may contribute robustly to efforts to address the impacts of climate change are in communication and education. Public health educators have a strong history of promoting health and wellness through educating individuals and communities about healthy behaviors and disease prevention or management. The same skills are critical to helping raise awareness of the potential impacts of climate change, and translating the scientific research and other technical data into credible and accessible information for the public to use in making informed decisions that will protect their health and the environment.

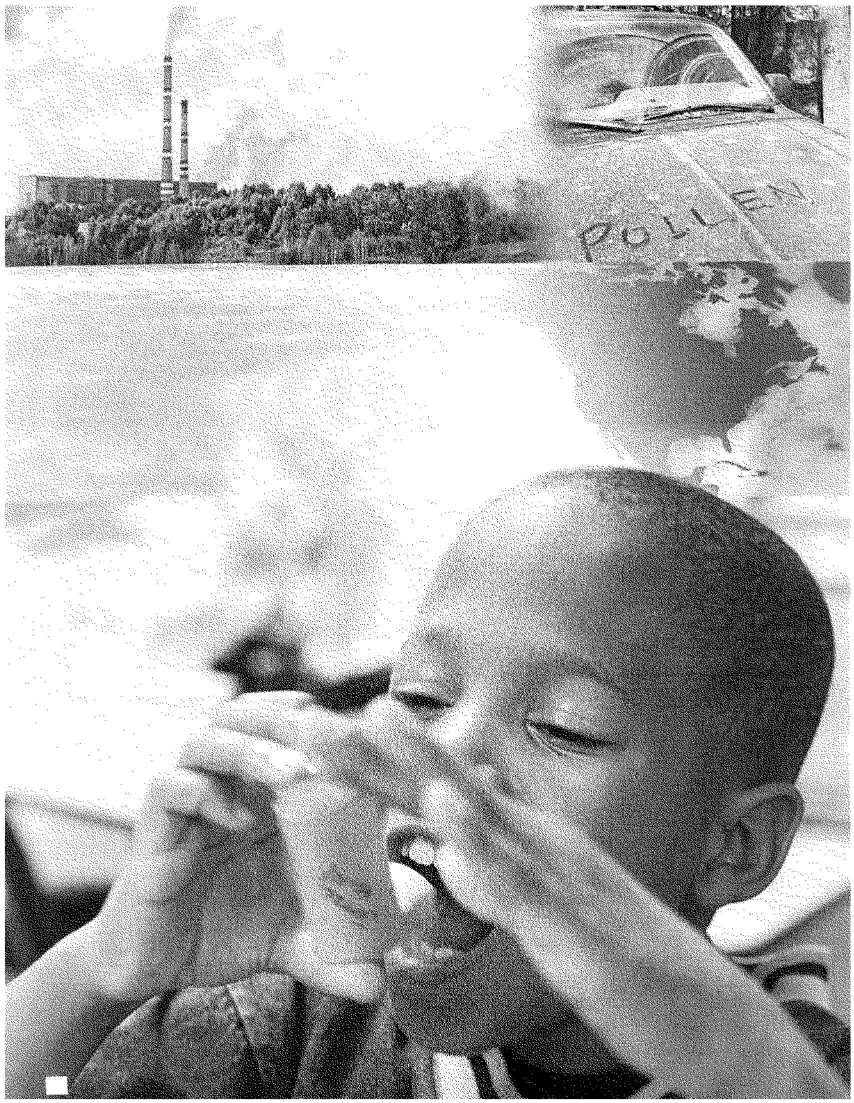
Recent studies show that the majority of those living in the United States now believe that climate change is a real and serious threat that is caused by human activity. However, research is still needed to determine how to effectively educate and organize the public to respond.[30] This is complicated by recent research showing that various audiences within the American public respond to the issue of climate change each in their own distinct way.[31] Research is needed that will aid climate change communicators and educators in adapting their messages and approaches to most appropriately and effectively reach and be assimilated by each individual audience.

30 Leiserowitz, A., et al., Climate change in the American mind: Americans' climate change beliefs, attitudes, policy preferences, and actions. 2009, Yale Project on Climate Change, School of Forestry and Environmental Sciences: New Haven, Connecticut. p. 55.

31 Maibach, E., et al., Global warming's six Americas 2009: An audience segmentation analysis. 2009, George Mason University Center for Climate Change Communication: Washington, DC. p. 140.

In addition to the general public, other audiences—each with their own culture and means of acquiring information—also require effective communication on issues of climate change. Stakeholders such as natural resource managers, policy makers, infrastructure planners, health care providers, and others also need access to credible and timely climate change information to inform their decision-making.

Protecting human health is an issue that crosses institutional, scientific, and political boundaries. In the United States, no single institution at the local, regional, or federal level can fully protect public health without cooperation from other institutions. In addition, no single scientific field is capable of accomplishing all aspects of the research needed to understand the human health consequences of global climate change; such an endeavor will require a broad-based, trans-disciplinary research portfolio. And in our global society, the highly integrated activities of individuals around the world mean that no one country can be solely responsible for addressing the health impacts of global climate change. Through the process of developing this white paper, it rapidly became clear that identifying research needs; mobilizing and creating the expertise, resources, tools, and technologies to address them; and translating these efforts into solutions that will enable human adaptation to our changing environment while protecting public health will require collaborations on an unprecedented scale. Such collaborations should build on the strengths and capacities of individual organizations in ways that maximize the efforts of the group toward these shared goals.


POLLEN

1

Asthma, Respiratory Allergies, and Airway Diseases

Allergic diseases, including asthma, hay fever, rhinitis, and atopic dermatitis, impact approximately 50 million individuals within the United States and are associated with significant health care costs and lost productivity.[32] In the early 1990s, the United States attributed health care costs of $11 billion to all respiratory disease with an estimated loss of 3 million workdays and 10 million schooldays.[33] Asthma is the second leading cause of chronic illness among children and is rapidly rising among children less than five years of age; however, the prevalence of asthma is highest among adults.[34] Incidence rates of asthma and other respiratory allergic diseases are often difficult to obtain; however rates of prevalence and disease exacerbation show a disproportionate trend along certain socioeconomic lines. Hospitalization rates, emergency department use, disability and death are often highest among children, African American and Hispanic populations, persons living in the inner city, and the poor.[35]

In recent decades, the world has seen a sharp rise in prevalence as well as severity of such respiratory diseases. The incidence of respiratory diseases grew markedly in the United States over the last several decades but has begun to plateau in recent years. Some experts speculate that the global rise in asthma was indirectly related to climate change.[36] Many respiratory allergic diseases are seasonal with climate sensitive components; climate change may increase the incidence and exacerbation of such allergic diseases. While some risk for respiratory disease can be clearly linked to climate change, for many others the risk attributable to climate change is unclear. Given the prevalence of these diseases and the significant disease burden imposed by asthma and respiratory allergic disease, further research into the impacts of climate change on these diseases should be a high priority.

Management of asthma and other respiratory allergic diseases relies on several factors including strict control of exacerbation triggers of the diseases. Although not all asthmatic episodes are triggered by environmental factors, a significant number are, including factors such as ambient air pollutants, allergens, stress, and a host of other environmental variables. As a result, changes to environment may adversely impact the severity of climate-sensitive diseases.

In addition to impacts on asthma and other allergic diseases, climate change has the potential to impact airway diseases by increasing ground level ozone and possibly fine particle concentrations. Breathing ozone can trigger a variety of reactions including chest pain, coughing, throat irritation, and congestion; and can worsen bronchitis, emphysema, and asthma. Exposure to ground-level ozone can also reduce lung function and inflame the linings of the lungs; repeated exposure may permanently scar lung tissue.[37] Fine particles (fewer than 2.5 micrometers in diameter, or $PM_{2.5}$) contain microscopic solids or liquid droplets that are so small that they can get deep into the lungs where they cause serious health problems. Numerous scientific studies have linked exposure to fine particle pollution to a variety of health problems including increased respiratory symptoms (irritation of the airways, coughing, difficulty breathing), decreased lung function, aggravated asthma, development of chronic bronchitis, irregular heartbeat, nonfatal heart attacks, and premature death in people with heart or lung disease.[38]

Impacts on Risk

Climate change will affect air quality through several pathways including production and allergenicity of aeroallergens such as pollen and mold spores and increases in regional ambient concentrations of ozone, fine particles, and dust. Some of these pollutants can directly cause respiratory disease or exacerbate respiratory disease in susceptible individuals.

Earlier flower blooming resulting from temperature increases and increased carbon dioxide (CO_2) concentrations affects timing of distribution of aeroallergens such as pollen through plant photosynthesis and metabolism.[39] There is also a possibility that certain aeroallergens may become more allergenic as temperatures and CO_2 concentrations increase.[40] Precipitation-affected aeroallergens such as mold spores also are of concern, as 5% of individuals are predicted to have some respiratory allergic airway symptoms from molds over their lifetime.[41]

32 Bytomski, JR, et al., Curr Sports Med Rep, 2003. 2(6): p. 320-4.
33 Smith, DH, et al., Am J Respir Crit Care Med, 1997. 156(3 Pt 1): p. 787-93; Weiss, KB, et al., N Engl J Med, 1992. 326(13): p. 862-6.
34 Benson, V, et al., Vital Health Stat 10, 1998(199): p. 1-428.
35 Mannino, DM, et al., MMWR CDC Surveill Summ, 1998. 47(1): p. 1-27.
36 D'Amato, G, et al., Clinical and Experimental Allergy, 2006. 30(8): p. 1264-1274.
37 [illegible], et al., Curr Opin Pulm Med, 2003. 9(2): p. 144-50.
38 Kreyling, WG, et al., J Aerosol Med, 2006. 19(1): p. 74-83.
39 Stitt, M, Plant Cell and Environment, 1991. 14(8): p. 741-762.
40 Confalonieri, U, et al. 2007, Cambridge: Cambridge University Press; Rogers, CA, et al., Environmental Health Perspectives, 2006. 114(6): p. 865-869; Shea, KM, et al., Journal of Allergy and Clinical Immunology, 2008. 122(3): p. 443-453; [illegible], et al., Nature, 2004. 427(6971): p. 214-216; Wan, SQ, et al., American Journal of Botany, 2002. 89(11): p. 1843-1846; Ziska, LH, et al., Global Change Biology, 2005. 11(10): p. 1798-1807.
41 Hardin, BD, et al., J Occup Environ Med, 2003. 45(5): p. 470-8.

In the presence of certain air emissions, the rate of ozone formation increases with higher temperatures and increased sunlight, and can also be affected by changes in storm tracks, humidity, and stability of the boundary layer (lowest part of the atmosphere).[42] Humidity and temperature also partly determine the formation of $PM_{2.5}$. Research studies associate fine particles with negative cardiovascular outcomes such as heart attacks, formation of deep vein blood clots, and increased mortality from several other causes.[43] These adverse health impacts intensify as temperatures rise.[44] Studies also link elevated exposure to ground-level ozone, $PM_{2.5}$, coarse thoracic PM, and aeroallergens to decreased lung function, aggravation of asthma, rhinitis, exacerbations of chronic obstructive pulmonary disease, hospitalizations for respiratory and cardiovascular diseases, and premature mortality.

Air pollution overcomes the mucosal barrier in lungs by inducing airway inflammation, which results in allergen-induced respiratory responses.[45] In addition, air pollutants such as $PM_{2.5}$ and ozone may alter the allergenicity of aeroallergens like pollen, thereby promoting further airway sensitization.[46] The triggers for such adverse respiratory responses vary and include climatic factors (meteorological events, rainfall patterns, and temperature anomalies), high levels of vehicle emissions, land-use patterns, variables in the built environment, geography, and distance from roadways.[47] Physiology also plays a significant role, as individuals with existing respiratory conditions are most vulnerable to disease exacerbations triggered by the environment.[48] The populations most vulnerable to the increased disease risks include children, pregnant women, persons of low socioeconomic status, persons situated near high traffic zones within urban centers, and those with preexisting respiratory and cardiovascular diseases.

Other airborne exposures are also likely to worsen with climate variability and change. Changes in the hydrologic cycle with increasingly variable precipitation and more frequent drought may also lead to a global increase of airborne dust, which, when coupled with anticipated stagnant air masses and increasingly strong inversion layers, will trap ozone and other airborne pollutants near the ground causing exacerbations of respiratory disease. Coarse thoracic PM (between 2.5 and 10 micrometers in diameter) is associated with increased risk of emergency department visits and hospitalizations for cardiovascular outcomes, especially among adults over 65 years of age.[49] Increased incidence of wildfires in some areas can also contribute to PM concentrations. In certain areas airborne dust serves as a carrier of specific diseases, such as coccidioidomycosis, or "valley fever," in the desert Southwest, the incidence of which has increased in recent years.[50] Prolonged drought will lead to more dust and particulate pollution while increased rainfall will cleanse the air but may create more mold and microbial pollution. In addition, drought, declining water quality, and increased temperatures contribute to the growth of harmful algal blooms that produce toxins that can be aerosolized and exacerbate asthma and respiratory diseases.[51]

Despite strong evidence of associations between a wide range of environmental variables impacted by climate and respiratory disease, the direct impacts of climate change on asthma, respiratory allergies, and airway diseases need further study to evaluate the fraction of respiratory disease risk that can be attributed to climate change and potentially mitigated or avoided.

Mitigation and Adaptation

Mitigation and adaptation strategies have the potential to both positively and negativel affect human health. Reduction of vehicle miles traveled will reduce ozone precursors, thereby reducing the ozone associated with myriad respiratory health effects. Alternative transportation options such as walking and bicycling will reduce toxic emissions while providing positive benefits for health such as increasing cardiovascular fitness and contributing to weight loss (although such activities also have the potential to increase exposure to harmful outdoor air pollutants, particularly in urban areas, simply by virtue of increased time spent outdoors)[52]. Mitigation of short-lived contaminant species that are both air pollutants and greenhouse gases is gaining momentum.[53] For example, controlling ozone or black carbon could bring short-term climate benefits and alleviate a fraction of the current health burden from these pollutants. Urban tree cover has been shown to reduce ambient concentrations of ozone, PM, and other pollutants.[54] Significant co-benefits of urban vegetation include shade, which reduces the heat-island effect and decreases energy required to cool buildings, and a concomitant reduction in greenhouse gas emissions.[55]

42 Houghton, JT, et al. 2001, Cambridge ; New York: Cambridge University Press. x, 881 p.

43 Bytomski, JR, et al., Curr Sports Med Rep. 2003. 2(6): p. 320-4; Vose, RS, et al., Nature, 2004. 427(6971): p. 213-214; Kaczorowski, A, et al., Archives of Internal Medicine, 2005. 165(9): p. 920-927; Confalonieri, U, et al., in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M Parry, et al., Editors. 2007, Cambridge University Press: Cambridge. p. 391-431; O'Neill, S, et al., Occupational and Environmental Medicine, 2007. 64(6): p. 373-379; Peters, A, et al., Circulation, 2001. 103(23): p. 2810-2815; Samoli, E, et al., Environmental Health Perspectives, 2008. 116(11): p. 1480-1486.

44 Chen, ZM, et al., Environmental Health Perspectives, 2008. 116(9): p. 1172-1178.

45 D'Amato, G, et al., Clinical and Experimental Allergy, 2008. 38(8): p. 1264-1274.

46 D'Amato, G, et al., Respiratory Medicine, 2001. 95(7): p. 606-611.

47 Shea, KM, et al., Journal of Allergy and Clinical Immunology, 2008. 122(3): p. 443-453.

48 D'Amato, G, et al., Clinical and Experimental Allergy, 2008. 38(8): p. 1264-1274.

49 Ballester, F, et al., Gac Sanit, 2006. 20 Suppl 1: p. 160-74; Le Tertre, A, et al., J Epidemiol Community Health, 2002. 56(10): p. 773-9; Zanobetti, A, et al., Environ Health Perspect, 2003. 111(9): p. 1188-93.

50 Komatsu, K, et al., Journal of the American Medical Association, 2003. 289(12): p. 1500-1502; Vugia, DJ, et al., Journal of the American Medical Association, 2009. 301(17): p. 1760-1762.

51 Abraham, WM, et al., Environmental Health Perspectives, 2005. 113(5): p. 632-637; Fleming, LE, et al., Chest, 2007. 131(1): p. 187-194.

52 Woodcock, J, et al., Lancet, 2009. 374(9705): p. 1930-43.

53 Smith, KR, et al., Ibid.

54 Bowler, [illegible], et al., Atmospheric Environment, 2007. 41: p. 8128-8139; Nowak, D, et al., Urban Forestry and Urban Greening, 2006. 4: p. 115-123.

55 Bolund, P, et al., Ecological Economics, 1999. 29: p. 293-301; McPherson, E, et al., Urban Ecosystems, 1997. 1: p. 49-61.

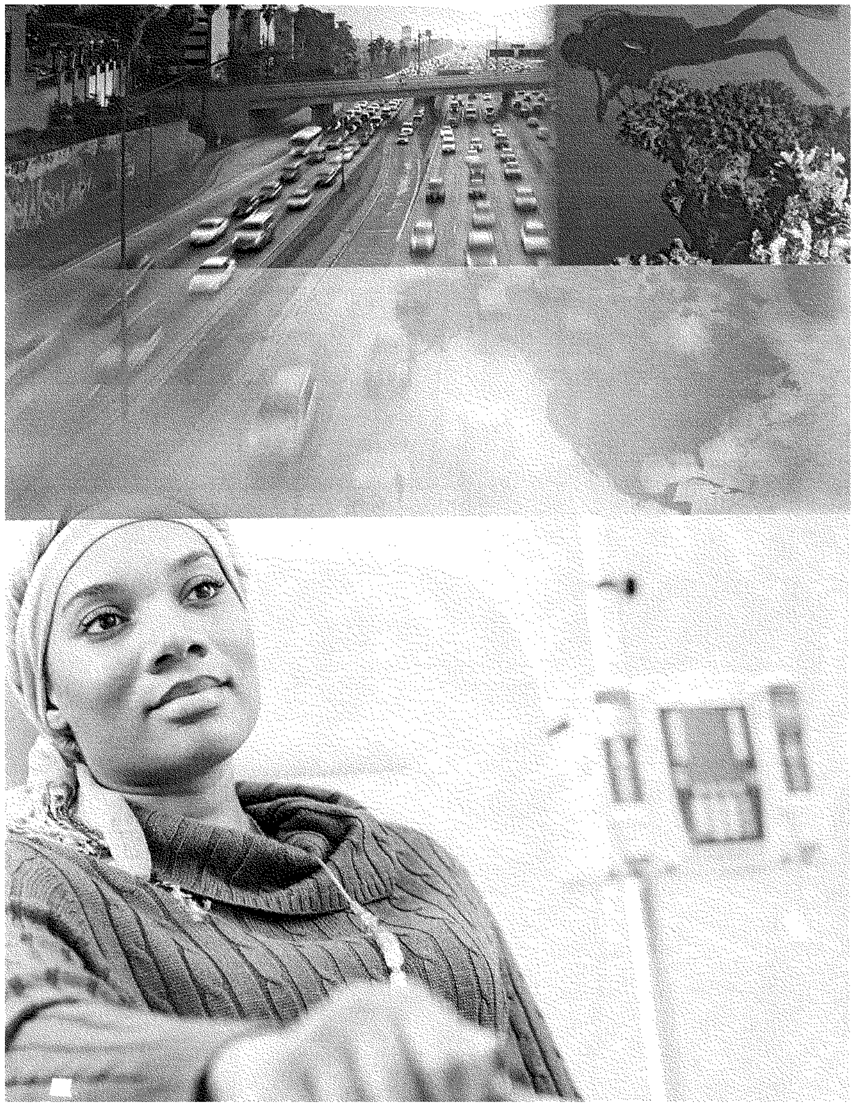
Adaptive measures such as increased use of air conditioning may alleviate some of the health effects associated with exposure to chronic or acute heat, but also can potentially result in higher greenhouse gas emissions and further declines in air quality, depending on the method of power generation. Health-based research to inform the use of novel fuel mixtures and electric vehicles will be important. Some impacts have been well characterized through life-cycle analyses, while others, particularly those related to novel fuels and energy sources, have yet to be assessed. Careful analyses of mitigation and adaptation co-benefits and tradeoffs are necessary so that appropriate strategies are adopted.

Research Needs

Climate change will likely amplify existing environmental stimulation of asthma, respiratory allergies, and airway disease, resulting in more severe and frequent disease exacerbations and an increase in the overall burden of these conditions. Thus, continued research on climate change's effect on alterations in the composition of aeroallergens and air pollutant mixtures and their consequent effects on health is essential. Research needs include:

- developing and validating real-time remote sensing and other *in situ* monitoring techniques to evaluate air quality, aeroallergens, aerosolized pathogens, dust burdens, and other climate-sensitive exposures directly linked to asthma and airway diseases
- understanding and modeling the impact of climate change on air quality, aeroallergens, and aerosolized marine toxins, and the resulting effects on asthma and airway diseases including in vulnerable populations
- applying modeling originally developed to assess health effects of air pollution and other ecological niche modeling to climate-sensitive diseases
- establishing climate-sensitive exposure metrics, with appropriate temporal and spatial dimensions, that are most strongly associated with asthma, allergy, and airway diseases
- identifying and mapping populations and communities at increased risk of climate-related respiratory disease, which will also help to identify populations at risk for other climate-related health impacts as many environmentally mediated diseases share common risk factors
- using epidemiological investigations to study the relationship between climate variables; altered production, distribution, and reactivity of pollen and marine toxins; changes in air pollutants; and the prevalence, severity, and onset of asthma exacerbations
- studying the health effects of airborne and indoor dust on asthma exacerbation, including changes in dust composition resulting from climate change
- understanding the acute and long-term impacts of wildfires on asthma and other respiratory diseases
- examining chemicals used in energy efficient technologies to ensure that they do not contribute to lung sensitization, asthma, or other respiratory diseases
- examining the relative risks for respiratory disease based on chemicals with lower global warming potential than existing greenhouse gases
- developing early warning systems for state and local governments and public and environmental health officials to anticipate and mitigate climate-related health impacts
- improving methods of identifying risks and communicating with vulnerable populations to reduce climate change impacts on all respiratory diseases
- developing decision support tools including health impact assessments (HIAs) of the burden of respiratory diseases attributable to climate change for help in identifying and selecting climate change and air quality mitigation and adaptation policies that will promote health benefits

Research needs also call for improvements in various capacities and skills. Air pollution modeling is well established and the health impacts of several species of particles and aeroallergens are reasonably well understood. However, the complex introduction of aeroallergens under a changing climate will require the expansion of scientific expertise to include botany and ecology in addition to meteorology and the built environment. Research will require the use of geographic information systems (GIS) and remote sensing expertise in new ways, as well as the application of novel vulnerability mapping techniques, early warning systems, and other public health tools. Spatial epidemiological methods will bring new power to ecological studies of air quality and public health. Identification and collection of integrated and appropriately scaled social, ecological, and epidemiological data are needed for effective monitoring and modeling. For health communications, novel strategies are required to identify vulnerable populations and develop communication strategies that will effectively reduce risk.



2 Cancer

Cancer refers to a group of diseases in which abnormal cells divide without control and are able to invade other tissues. There are more than 100 different types of cancer, and they are generally referred to by the organ or type of cell in which they arise (e.g. breast, prostate, colon). Cancer is the second leading cause of death in the United States after heart disease, killing more than half a million people every year.[56] Lung cancers, with about 220,000 new cases per year and about 160,000 deaths,[57] account for about 30% of overall deaths from cancer in the United States.[58] The main cause of lung cancer is smoking, especially cigarettes, but air pollution,[59] including indoor air pollution[60] and fine particulates,[61] also contributes to the burden of lung cancers.

There are potential impacts on cancer both directly from climate change and indirectly from climate change mitigation strategies. Climate change will result in higher ambient temperatures that may increase the transfer of volatile and semi-volatile compounds from water and wastewater into the atmosphere, and alter the distribution of contaminants to places more distant from the sources, changing subsequent human exposures.[62] Climate change is also expected to increase heavy precipitation and flooding events, which may increase the chance of toxic contamination leaks from storage facilities or runoff into water from land containing toxic pollutants. Very little is known about how such transfers will affect people's exposure to these chemicals—some of which are known carcinogens—and its ultimate impact on incidence of cancer.[63] More research is needed to determine the likelihood of this type of contamination, the geographical areas and populations most likely to be impacted, and the health outcomes that could result.

Although the exact mechanisms of cancer in humans and animals are not completely understood for all cancers, factors in cancer development include pathogens, environmental contaminants, age, and genetics. Given the challenges of understanding the causes of cancer, the links between climate change and cancer are a mixture of fact and supposition, and research is needed to fill in the gaps in what we know.

Impacts on Risks

One possible direct impact of climate change on cancer may be through increases in exposure to toxic chemicals that are known or suspected to cause cancer following heavy rainfall and by increased volatilization of chemicals under conditions of increased temperature. In the case of heavy rainfall or flooding, there may be an increase in leaching of toxic chemicals and heavy metals from storage sites and increased contamination of water with runoff containing persistent chemicals that are already in the environment. Marine animals, including mammals, also may suffer direct effects of cancer linked to sustained or chronic exposure to chemical contaminants in the marine environment, and thereby serve as indicators of similar risks to humans.[64] Climate impact studies on such model cancer populations may provide added dimensions to our understanding of the human impacts.

Another direct effect of climate change, depletion of stratospheric ozone, will result in increased ultraviolet (UV) radiation exposure. UV radiation exposure increases the risk of skin cancers and cataracts.[65] The incidence of typically nonlethal basal cell and squamous cell skin cancers is directly correlated to the amount of exposure to UV radiation. This effect is compounded by several other variables including temperature and exposure to other compounds that can amplify the carcinogenic potential of UV radiation.[66] Rising temperatures (such as occur at night versus day and in summer versus winter) are associated with increases in UV exposure. If increases in average or peak temperatures occur as a result of climate change, an increase in the incidence of non-melanoma skin cancers may occur.[67] Previous studies have shown that increased UV radiation exposure combined with certain polycyclic aromatic hydrocarbons (PAHs) can enhance

56 National Cancer Institute. What is cancer?. 2009 [cited 2009 July 21]; Available from: http://www.cancer.gov/cancertopics/what-is-cancer.
57 National Cancer Institute. Lung Cancer. 2009 [cited 2009 July 20]; Available from: http://www.cancer.gov/cancertopics/types/lung.
58 Centers for Disease Control and Prevention. Leading causes of death, 2006. 2009 [cited 2009 July 22]; Available from: http://www.cdc.gov/nchs/FASTATS/lcod.htm.
59 Beelen, R., et al., Epidemiology, 2008. 19(5): p. 702-10.
60 Ibid.
61 Krewski, D., et al., Res Rep Health Eff Inst, 2009(140): p. 5-114; discussion 115-36. Pope, C.A., 3rd, et al., JAMA, 2002. 287(9): p. 1132-41.
62 Macdonald, R.W., et al., Human and Ecological Risk Assessment, 2003. 9(3): p. 643-660.
63 Bates, B., et al., Climate change and water. 2008, Intergovernmental Panel on Climate Change: Geneva. p. 210.

64 McAloose, D., et al., Nat Rev Cancer, 2009. 9(7): p. 517-26.
65 Tucker, M.A., Hematol Oncol Clin North Am, 2009. 23(3): p. 383-95, vii.
66 Burke, K.E., et al., Toxicol Ind Health, 2009. 25(4-5): p. 219-24.
67 van der Leun, J.C., et al., Photochem Photobiol Sci, 2008. 7(6): p. 730-3.

the phototoxicity of these compounds and damage DNA.[68] However, it is also possible that increased exposure to UV radiation could elevate levels of circulating Vitamin D, which has been associated with a decreased risk for certain cancers such as colorectal cancer.[69] Increased UV radiation also could impact the human immune system and alter the body's ability to remove the earliest mutant cells that begin the cancer process, although it is unclear whether these changes would be beneficial or detrimental.[70]

Mitigation and Adaptation

In addition to direct impacts of climate change on cancer, the impact of mitigation strategies on cancer should also be considered. For instance, co-benefits of decreased greenhouse gas emissions and decreased cancer incidence may be attainable with energy efficient power generation and reduced emissions through lower vehicle miles traveled. These benefits could be realized through decreases in toxic outputs of fossil fuel-based power generation and transportation, including sulfur oxide and particulate matter (PM), which have been implicated in lung cancer.[71]

Decreases in greenhouse gas emissions are generally associated with decreases in cancers that occur due exposure to such pollutants. Increased energy efficiency will lead to reductions in emissions of sulfur dioxide, nitrous oxides, and PM, which should lead to reductions in rates of premature death including from certain cancers.[72] In most cases, these emission reductions will also result in subsequent reductions in ambient concentrations of ozone and secondary $PM_{2.5}$, which have been implicated in a variety of health effects including lung cancer. Reductions in other hazardous air pollutants, such as heavy metals from power generation and industrial processes that are known or suspected to cause cancer or other serious health effects, may also occur.

Several technologies currently being pursued to decrease greenhouse gas emissions may also help to reduce cancer incidence. For example, reducing greenhouse gas emissions from the transportation sector may be accomplished by reducing vehicle miles traveled through a variety of approaches such as high-density development, preservation of green space, and widespread use of mass transit. However, the impacts of some mitigation technologies on cancer have not been fully explored. For example, nanotechnology may be promising for mitigating climate change through its use in efficient hydrogen powered vehicles, enhanced and cheaper solar power technology, and the development of a new generation of batteries and supercapacitors, yet little is known about potential links to cancer and other health outcomes.

New technologies have been proposed to decrease our dependence on greenhouse gas-intensive power generation and fuel use. However, many of these have potential impacts on cancer that should be more fully investigated prior to being implemented. The widespread adoption of biofuels may have unintended consequences including possible increases or decreases in cancer due to a change in the level of existing pollutants or the creation and emissions of new air pollutants.[73] Also, barring changes in agricultural practices, there is potential for increased pesticide use for the growth of certain biofuels such as corn ethanol. Exposure to some legacy pesticides has been implicated for cancer in both adults and children,[74] leading to current efforts by the EPA to avoid this problem in new products.

Research is needed to understand if there are cancer implications from the use of electric vehicles, including the production and disposal of portable electric storage systems. Manufacturing of batteries for electric cars and photovoltaic (solar) power systems may have consequences including increased exposure to metals. The most common type of battery currently in use is the nickel-metal-hydride (NiMH) battery, with other types of batteries (lithium ion, lithium ion polymer, valve regulated lead acid, and nickel-cadmium) also under development for vehicle use. Increased use of NiMH batteries will necessarily require significant increases in nickel production and the impacts associated with nickel mining and refining. High-level nickel exposure is associated with increased cancer risk, respiratory disease, and birth defects; the same is true with certain other metals, especially cadmium and lead.

Increased production of solar cells also can lead to increased environmental risks.[75] For example, cadmium-tellurium (CdTe) compounds in photovoltaic systems and the potential for increased cadmium emissions from mining, refining, and the manufacture, utilization, and disposal of photovoltaic modules. Cadmium and cadmium compounds like CdTe are classified as known human carcinogens

68. Dong, J., et al., Chem Res Toxicol, 2005. 18(?): p. 595-[illegible]; Toyooka, T., et al., Environ Mol Mutagen, 2006. 47(1): p. 38-47
69. Garland, CF, et al., Ann Epidemiol, 2009. 19(7): p. 468-83
70. [illegible], A., et al., [illegible], 2004. [illegible]: p. 3-14.
71. Pope, CA, 3rd, et al., JAMA, 2002. 287(9): p. 1132-41
72. Woodcock, J., et al., Lancet, 2009. 374(9705): p. 1930-43; Haines, A., et al., Lancet, 2009; Wilkinson, P., et al., Lancet, 2009. 374(9705): p. 1917-29
73. Hill, J., et al., Proceedings of the National Academy of Sciences of the United States of America, 2009. 106(6): p. 2077-2082
74. Flower, K.B., et al., Environ Health Perspect, 2004. 112(5): p. 631-5; Kang, D., et al., Environ Res, 2008. 107(2): p. 271-6; [illegible], E., et al., Environ Health Perspect, 2006. 114(12): p. 1838-42
75. Fthenakis, V. in Practical handbook of photovoltaics: fundamentals and applications, T. Markvart, et al., Editors. 2003. Elsevier Advanced Technology: New York; Fthenakis, VM, et al., Environ Sci Technol, 2008. 42(6): p. 2168-74

by the National Toxicology Program and the International Agency for Research on Cancer and as probable human carcinogens by the EPA.[76] Acute exposure to CdTe can result in respiratory irritation and toxicity. Some of the other hazardous materials present in solar manufacturing include arsenic compounds, carbon tetra-chloride, hydrogen fluoride, hydrogen sulfide, lead, and selenium compounds,[77] many of which have been linked with multiple health effects, including cancer.

Production of hydrogen fuel cells will require significant increases in the total amount of platinum consumed worldwide, with a similar increase in mining and the environmental impacts associated with mining, processing, and transport. If hydrogen is used in a significant way as a transportation fuel, consideration must be given to the impacts of emissions from leaks during production, fueling, and operation. Increased hydrogen leaks could result in stratospheric ozone depletion by up to 20%,[78] which could lead to increased incidence of skin cancer.

For mitigation of climate change, nuclear power has been suggested as a possible alternative to coal-based power generation. Although the risks associated with direct exposure to radiation from nuclear power generation have been below accepted danger levels throughout the industry's history, the human health consequences over the full nuclear energy life cycle (production through waste disposal) may be of greater concern.[79]

Heatlth Impact Assessments (HIAs) are a useful emerging strategy for evaluating the health effects of novel policies and technologies at various scales, and have already been applied to several potential climate change mitigation strategies.[80] Given the widespread uncertainty regarding the potential health impacts, including cancer, of certain mitigation strategies, HIAs can be a valuable tool for evaluating possible health effects, especially when used in combination with other approaches to life-cycle assessment.

Research Needs

Many of the cancer risks resulting from the direct effects of climate change have been fairly well studied. The largest research gaps are in the materials and methods used for mitigation and adaptation, and their potential to increase or decrease cancer risks. Research needs include:

- utilizing animal cancer surveillance and investigations as sentinel biomedical models to better understand the environmental factors, mechanisms, and pathways of mammalian cancer risk
- developing and sustaining facilities and expertise to rapidly assess and monitor the threat of previously unrecognized toxins, carcinogens, and other bioactive molecules produced in response to stress on marine environments
- understanding the impact of increased heavy precipitation and flooding events on the risk of toxic contamination of the environment from storage facilities or runoff from land containing toxic chemicals, including the geographical areas, ecosystems, and populations most likely to be impacted and the health outcomes that could result
- understanding how climate changes such as changes in temperature and precipitation affect exposure to toxic chemicals including volatile and semi-volatile compounds and known or suspected human carcinogens
- elucidating the effects of ambient temperature on UV radiation-induced skin cancers, including the amplification of non-melanoma skin cancers
- evaluating the potential cancer risks through the entire life cycle of biofuel production, including risks from novel air pollutants and changes in agricultural practices that may increase exposures to pesticides, herbicides, and other environmental contaminants
- understanding cancer risks from the life cycle emissions of carcinogens and untested compounds associated with alternative energy and transportation technologies, particularly electricity storage systems and photovoltaic systems
- clarifying the life cycle cancer risks of nuclear energy radiation, including through occupational and environmental exposures
- developing mechanisms to conserve and explore marine and terrestrial biodiversity in environments likely to yield cancer cures and treatments
- characterizing and quantifying changes in cancer rates from implementation of specific greenhouse gas mitigation strategies, especially for existing fossil fuel-based energy production and use

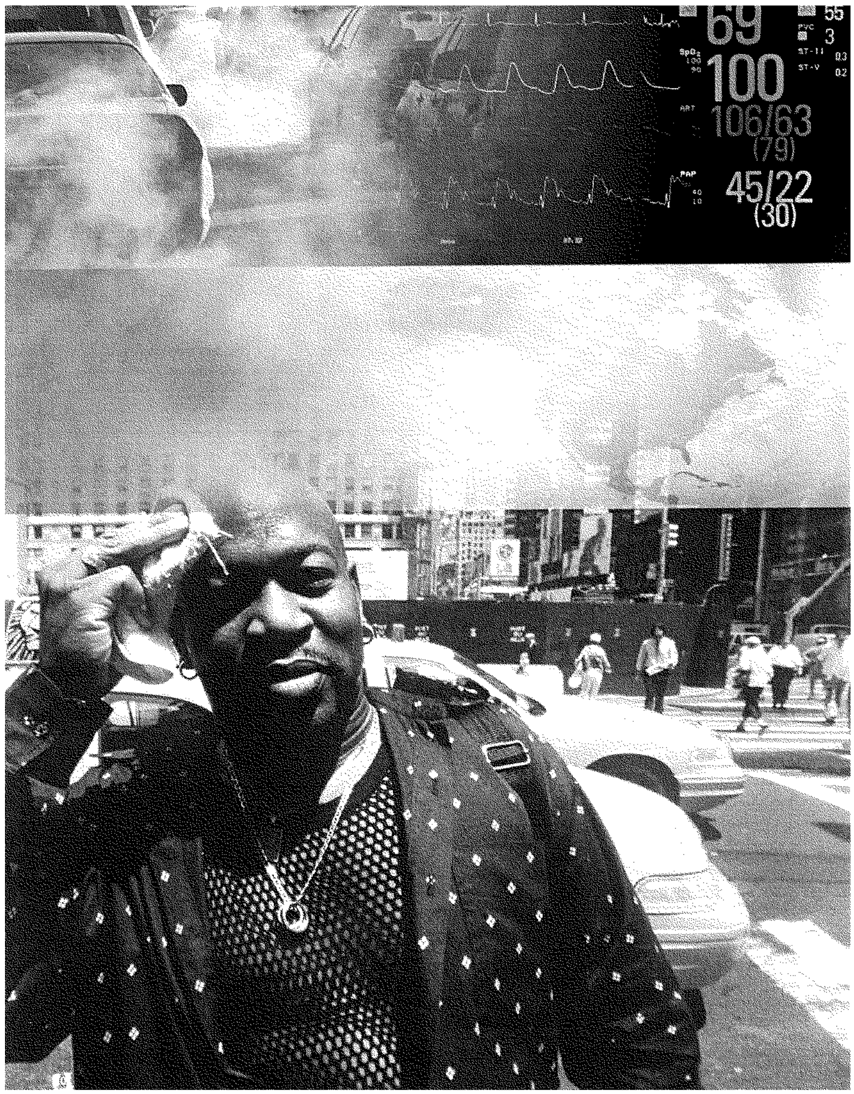
76 See [illegible], 2015[illegible], p. 1-A32.

77 Fthenakis, V. in Practical handbook of photovoltaics : fundamentals and applications, T. Markvart, et al., Editors. 2003, Elsevier Advanced Technology: New York

78 Tromp, TK, et al., Science, 2003. 300(5626): p. 1740-2

79 Massachusetts Institute of Technology. 2003, [Boston MA]: MIT. x, 170 p.

80 Patz, J. et al., Health impact assessment of global climate change: Expanding on comparative risk assessment approaches for policy making, in Annual Review of Public Health. 2008. p. 27-39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3 Cardiovascular Disease and Stroke

Cardiovascular disease refers to a class of diseases that pertain to the heart or blood vessels. Cardiovascular disease is the leading cause of death in the United States, with 631,636 deaths in 2006, the last year for which statistics are available. Stroke is the third leading cause, with 131,119 deaths in 2006.[81] Approximately 80 million Americans have some form of cardiovascular disease including hypertension, coronary artery disease, heart attack, or stroke.[82] Other cardiovascular diseases such as cardiac dysrhythmias (abnormal electrical activity in the heart), deep venous thrombosis (blood clots), and pulmonary embolism (blood clots in the lung) increase the numbers further. The American Heart Association and the National Heart, Lung, and Blood Institute together estimate that cardiovascular disease will be responsible for $475.3 billion in direct and indirect health care expenditures in 2009.[83] Altogether, this diverse set of conditions is a major driver of health care expenditures and disability.

There is evidence of climate sensitivity for several cardiovascular diseases, with both extreme cold and extreme heat directly affecting the incidence of hospital admissions for chest pain, acute coronary syndrome, stroke, and variations in cardiac dysrhythmias, though the reported magnitude of the exposure-outcome associations is variable.[84] Weather conditions such as extreme heat serve as stressors in individuals with pre-existing cardiovascular disease, and can directly precipitate exacerbations.[85] There is also evidence that heat amplifies the adverse impacts of ozone and particulates on cardiovascular disease. These pollutants are likely to be affected by climate change mitigation activities, and thus, likely reduce rates of cardiovascular morbidity and mortality. While the fraction of disease risk attributable to weather and associated environmental exposures is not known, given the prevalence of cardiovascular disease and the preventable nature of the exposures, further research into associations between weather, climate variability, long-term climate change, and cardiovascular disease is an immediate need.

81 Centers for Disease Control and Prevention. Leading causes of death, 2006. 2009 [cited 2009 July 22]; Available from: http://www.cdc.gov/nchs/FASTATS/lcod.htm.

82 American Heart Association. Cardiovascular disease statistics, 2006. 2009 [cited 2009 July 22]; Available from: http://www.americanheart.org/presenter.jhtml?identifier=4478.

83 American Heart Association. Cardiovascular disease cost, 2009. 2009 [cited 2009 July 22]; Available from: http://www.americanheart.org/presenter.jhtml?identifier=4475.

84 Basu, R., et al., Environmental Research, 2009. 109(5): p. 600-606; Kilbourne, EM, Am J Prev Med, 1999. 16(4): p. 359-60; McGeehin, MA, et al., Environ Health Perspect, 2001. 109 Suppl 2: p. 185-9; Piver, WT, et al., Environ Health Perspect, 1999. 107(11): p. 911-6; Ye, F, et al., Environ Health Perspect, 2001. 109(4): p. 355-9.

85 Fouillet, A., et al., International Archives of Occupational and Environmental Health, 2006. 80(1): p. 16-24; Wainwright, S. et al., American Journal of Epidemiology, 1994. 129(11): p. 549-549.

Impacts on Risk

Cardiovascular mortality associated with heat has been declining over time, presumably the result of increased air conditioning use; mortality associated with extreme cold has remained constant.[86] Cardiovascular hospital admissions increase with heat.[87,88] Dysrhythmias are primarily associated with extreme cold,[89] though associations with dysrhythmias and heat illness have been reported.[90] Stroke incidence increases with increasing temperature, as well.[91] For all direct associations between temperature and cardiovascular disease and stroke, elderly and isolated individuals are at greatest risk.

Indirect impacts of weather, weather variability, and climate changes on cardiovascular disease are many and varied. Associations between air quality, especially ozone and particulate burdens, and cardiovascular disease appear to be modified by weather and climate. Ozone, whose formation increases with temperature, increases cardiac effort and impairs pulmonary gas exchange.[92] Ozone concentrations modify the association between temperature and cardiovascular mortality,[93] and are also associated with acute myocardial infarction[94] (as discussed in the chapter on Asthma, Respiratory Allergies, and Airway Diseases). Particulate matter is associated with a variety of pathophysiological changes including systemic inflammation, deranged coagulation and thrombosis, blood vessel dysfunction and atherosclerotic disease, compromised heart function, deep venous thromboses,[95] and pulmonary embolism.[96] Increased burden of $PM_{2.5}$ is associated with increased hospital admissions and mortality from cardiovascular disease,[97] as well as ischemic heart disease.[98]

Other climate-related exposures are indirectly associated with incidence of cardiovascular disease and disease exacerbations.

86 Barnett, AG, Epidemiology, 2007. 18(3): p. 369-72.

87 Ebi, KL, et al., Int J Biometeorol, 2004. 49(1): p. 48-58; Mastrangelo, G., et al., International Journal of Cardiology, 2009. 105(3): p. 283-293. [illegible]

88 Schwartz, J. et al., Epidemiology, 2004. 15(6): p. 755-761.

89 Kysely, J. et al., BMC Public Health, 2009 Jan 19;9:19.

90 al-Harthi, SS, et al., Int J Cardiol, 1992. 37(2): p. 151-4.

91 Chang, CL, et al., Int J Biometeorol, 2004. 48(3): p. 45-58.

92 Gong, H. et al., American Journal of Respiratory and Critical Care Medicine, 1998. 158(2): p. 538-546.

93 Ren, C., et al., Occupational and Environmental Medicine, 2008. 65(4): p. 255-260.

94 Ruidavets, JB, et al., Circulation, 2005. 111(5): p. 563-569.

95 Baccarelli, A. et al., Archives of Internal Medicine, 2008. 168(9): p. 920-927.

96 Brook, RD, Clinical Science, 2008. 115(6): p. 175-187.

97 Jerrett, M., et al., New England Journal of Medicine, 2009. 360(11): p. 1085-1095.

98 Pope, CA, et al., Journal of the Air & Waste Management Association, 2006. 56(6): p. 709-742.

Extreme weather events affect cardiovascular health through several pathways. Directly, the stress of the event and anxiety over event recurrence are associated with myocardial infarction,[99] sudden cardiac death,[100] and development of stress-related cardiomyopathy.[101] Indirectly, displacement related to disasters is frequently associated with interruptions of medical care for chronic medical conditions,[102] putting populations with chronic cardiovascular conditions at risk for disease exacerbations.

Climate is also implicated in another indirect risk for cardiovascular disease: the incidence of certain vectorborne and zoonotic diseases (VBZD) with cardiovascular manifestations. One estimate holds that approximately 10% of strokes in the developing world are related to exposure to certain VBZD,[103] many of which are climate sensitive. In particular, Chagas disease is an important cause of stroke worldwide (although not in the United States); 20 million people globally have chronic Chagas, which is an independent risk factor for stroke in Latin America[104] and a leading cause of heart failure in South America.[105] There is some evidence of climate sensitivity for Chagas disease,[106] though the topic is little studied. In the United States, Lyme disease is a prevalent vectorborne disease that has cardiovascular manifestations,[107] though the incidence of such manifestations is much lower than that associated with Chagas disease.

There is little published literature on the projected direct and indirect impacts of climate change on cardiovascular disease incidence. Many of the studies coupling down-scaled climate projections with health outcomes have examined a particular exposure, such as heat or ozone, and projected mortality based on known associations, but do not make specific projections as to the incidence of cardiovascular morbidity and mortality. Insofar as climate change will bring increased ambient temperatures, increasingly variable weather, and increased extreme events, we can infer that climate change will likely have an overall adverse impact on the incidence of cardiovascular disease. Similarly, the impact of climate change on the incidence of cardiovascular complications from extreme weather events and certain VBZD is also likely to increase. However, the magnitude of these effects and the degree to which they can be lessened with adaptation efforts is unclear and warrants much further study.

Mitigation and Adaptation

The likely impacts of climate change mitigation activities on risk of cardiovascular disease and stroke depend primarily on emissions-associated energy production activities, particularly in the transportation sector. Some mitigation activities related to energy production, such as the increased use of wind, wave, solar, and nuclear sources of power generation, are likely to reduce cardiovascular disease risks by reducing particulate and other air pollution emissions.

Mitigation activities such as increasing the density of urban development, enhancing public transportation options, and encouraging alternatives to single occupancy vehicle use are likely to benefit cardiovascular fitness, reducing the overall burden of cardiovascular disease.[108] More research is needed, including economic analyses, to determine the most beneficial strategies to pursue. As with respiratory health risks, risks of cardiovascular disease and stroke may be reduced in urban populations through filtration of ambient pollutants by tree cover.[109] Co-benefits of tree cover include heat-island alleviation, reduced energy use to cool buildings, and consequent reductions in greenhouse gas emissions.[110]

Fuel mixtures each have different particulate and other criteria pollutant profiles, and variously reduce net greenhouse gas emissions.[111] Fuel mixtures associated with high emissions of particulates or other pollutants such as nitrous oxides and carbon monoxide will have adverse impacts on cardiovascular health,[112] as these pollutants are associated with incidence of cardiovascular hospital admissions among those with existing heart disease.[113] Preliminary analysis of certain biodiesel blends is promising[114] but more research is needed to fully characterize likely health impacts of large-scale mitigation activities related to transport fuels.[115] Some biodiesel blends appear to produce emissions with few negative health consequences.[116] While an association between PM exposure and increased risk of cardiovascular disease has been demonstrated, it is unclear which chemical constituents mediate this effect. More research is needed to better identify these pollutants, which in turn will help to predict the potential benefits of alternative combustible fuels.[117] Due to

99 Suzuki, S., et al., American Heart Journal, 1997. 134(5 Pt 1): p. 974-977.
100 Leor, J., et al., New England Journal of Medicine, 1996. 334(7): p. 413-419.
101 Watanabe, H., et al., Journal of the American Medical Association, 2005. 294(3): p. 305-307.
102 Krousel-Wood, MA, et al., American Journal of the Medical Sciences, 2008. 336(2): p. [illegible]
103 Carod-Artal, [illegible] 2007. [illegible]
104 Ibid.
105 [illegible], et al., [illegible], 2005. [illegible]
106 Carcavallo, RU, Memorias do Instituto Oswaldo Cruz, 1999. 94: p. 367-369.
107 [illegible], et al., American Heart Journal, 1991. 122(4 Pt 1): p. 1449-55.
108 Frumkin, H., et al., American Journal of Public Health, 2009. [illegible]
109 Nowak, D., et al., Atmospheric Environment, 2006. [illegible]; Tiwary, A., et al., Urban Forestry and Urban Greening, 2006. 4: p. 115-123.
110 [illegible], et al., [illegible] Economics, 1999. 29: p. 299-301; McPherson, E., et al., Urban Ecosystems, 1997. 1: p. 49-61.
111 Hill, J., et al., Proc Natl Acad Sci U S A, 2006. 103(30): p. 11206-10.
112 Hill, J., et al., Proceedings of the National Academy of Sciences of the United States of America, 2009. 106(6): p. 2077-2082.
113 [illegible], et al., Environmental Health Perspectives, 2002. 110(12): p. 1247-1252.
114 McCormick, RL, Inhalation Toxicology, 2007. 19(12): p. 1033-1039.
115 Swanson, KJ, et al., Environmental Health Perspectives, 2007. 115(4): p. 496-499.
116 McCormick, RL, Inhalation Toxicology, 2007. 19(12): p. 1033-1039.
117 Brook, RD, et al., Circulation, 2004. 109(21): p. 2655-71.

the unique electrophysiological properties associated with the very high heart rates of the rodents most commonly used in researching dysrhythmia, these biomedical models do not always closely replicate human conditions. In contrast, the rates and underlying physiology of fish hearts are closer to humans and, as such, fish models should be explored as tools for understanding and screening the effects of various transport fuels.[118]

Projecting the health impacts of adaptation activities, particularly the increased use of air conditioning to protect vulnerable populations from extreme heat, requires assumptions regarding how these activities will be powered. For instance, if significant additional electricity demand is met through increased fossil fuel combustion, then there is likely to be increased exposure to particulates and ozone as a result. However, these exposures may be partially offset by the protective effect of air conditioning. Most other adaptation activities are likely to have little direct impact on cardiovascular disease incidence.

Research Needs

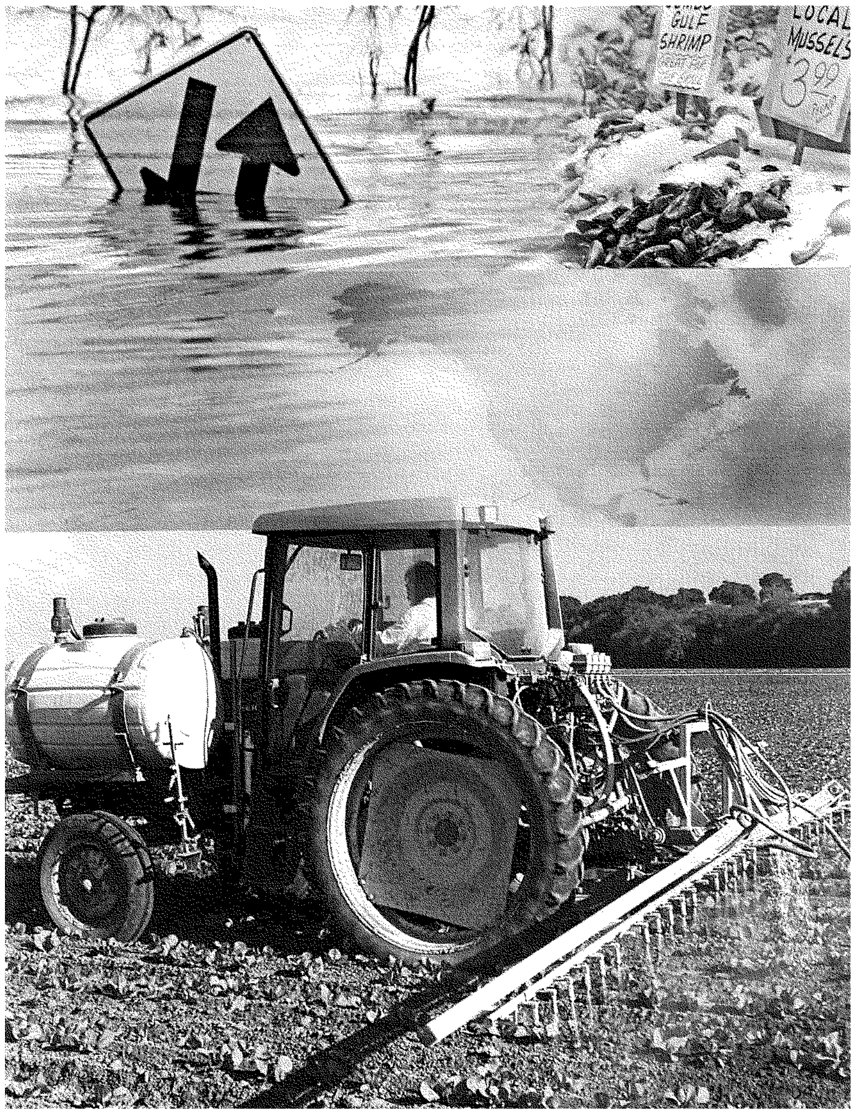
As noted, there are significant gaps in our understanding of climate change impacts on cardiovascular disease, particularly for morbidity, and there is virtually no research projecting future cardiovascular health impacts of climate change. Research needs include:

- increasing research on the incidence of cardiac dysrhythmias and associations with temperature and other environmental exposures
- enhancing research on the complex synergistic effect of temperature, weather variability, long-term climate change, and environmental exposures such as criteria air pollutants on the incidence of various cardiovascular disease outcomes
- intensifying investigation of the likely cardiovascular complications of VBZD prevalent in the United States and globally
- characterizing the multiple individual constituents of air pollution to better anticipate the health effects from switching the mix of pollutants in air through the use of alternative fuels
- studying strategies for incorporating cardiovascular disease outcomes in HIAs and integrated assessment climate models, including further characterization of exposure-outcome associations for cardiovascular morbidity in different geographic regions
- developing a national standard for heat-related mortality to facilitate epidemiologic study of mortality from heat and other co-morbid conditions[119]
- targeting research on early warning systems and health communications aimed at groups particularly at risk for adverse cardiovascular outcomes related to climate change
- identifying and quantifying the co-benefits to cardiovascular health of reducing our reliance on fossil fuel-based energy and changing emission scenarios
- characterizing both the potential health risks and benefits of novel fuels and other energy production activities being considered for large-scale adoption as part of a national mitigation strategy

Several cardiovascular disease research priorities dovetail with other areas. In particular, research into health impacts of increased temperature, extreme weather, and changes in air quality associated with climate change will inform research into cardiovascular health impacts. Similarly, research into early warning systems and integrated assessment models is transferable to other health outcomes associated with climate change, and research into the health impacts of potential mitigation and adaptation activities can be applied to other health outcomes sensitive to particulate and other emissions.

118 Milan, DJ, et al., Ibid.2009. 120(7): p. 553-9.

119 Wainwright, S. et al., American Journal of Epidemiology, 1994. 139(11): p. 540-549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SHRIMP
LOCAL
MUSSELS

4

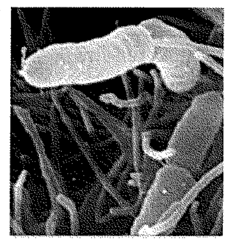
Foodborne Diseases and Nutrition

Nutrition is the sum of the processes by which humans and other living organisms take in food and use it for growth and nourishment. Along with clean air, water, and shelter, nutritious food is a basic necessity of life. Failure to obtain sufficient calories and an adequate mixture of macronutrients (calories, fat, proteins, carbohydrates), micronutrients (vitamins, minerals) and other bioactive components of food can result in illness and death. According to the United Nations Development Program, some 3.7 billion people worldwide are currently malnourished. While malnutrition and hunger are predominantly problems in the developing world, the United States and other developed countries still have significant populations affected by insufficient food resources and undernutrition.[120] Extreme weather events and changes in temperature and precipitation patterns can directly damage or destroy crops and other food supplies, as well as interrupt transport and distribution of food. This may happen seasonally, but is anticipated to become a more chronic problem under changing climate conditions. Indirectly, there is potential for harm from undernutrition or even famine resulting from damage to agricultural crops and related trade, economic, and social instability; diversion of staple crops for use in biofuels (corn for ethanol or other biofuels); changes in agricultural practices including those intended to mitigate or adapt to climate change; impaired ability to grow crops due to changing environmental conditions and water availability; and reduced availability and nutritional quality of protein from fisheries, aquaculture, and other marine-based foods.

In addition to being a source of essential nutrients, food can be a source of exposure for foodborne illness. Such illness results from ingesting food that is spoiled or contaminated with microbes, chemical residues such as pesticides, biotoxins, or other toxic substances. It is estimated that there are 38 million cases of foodborne illness in the United States each year, resulting in over 180,000 hospitalizations and 2,700 deaths.[121] Seafood contaminated with metals, biotoxins, toxicants, or pathogens; crops burdened with chemical pesticide residues or microbes; extreme shortages of staple foods; and malnutrition are among the possible effects of climate change on the production, quality, and availability of food.[122] The potential effects of climate change on foodborne illness, nutrition, and security are for the most part indirect

120 Nord, M., et al., Household food security in the United States, 2008, ER Service, Editor. November, 2009, US Department of Agriculture: Washington, DC.
121 Mead, PS, et al., Emerg Infect Dis, 1999. 5(5): p. 607-25.
122 Intergovernmental Panel on Climate Change. Working Group 3. 2007, Cambridge: Cambridge University Press. xi, 976 p.

RESEARCH HIGHLIGHT



Climate change may impact rates of foodborne illness through increased temperatures, which are associated with increased incidence of foodborne gastroenteritis. Several species of *Vibrio*, naturally occurring marine bacteria, are sensitive to changes in ocean temperature. *Vibrio paraheamolyticus* infects oysters and is the leading cause of Vibrio-associated gastroenteritis in the United States.[1] An outbreak in 2004 in Alaska has been linked to higher than normal ocean temperatures.[2] Other studies show a predictive relationship between sea surface temperature and *V. vulnificus* and *V. cholera*. Climate-driven changes in ocean temperature and coastal water quality are expected to increase the geographic range of these bacteria, and could be used to predict outbreaks. Increased temperatures also affect rates of other foodborne illnesses including campylobacteriosis and salmonellosis. A recent article examined the relationship between temperature and the weekly rates of several foodborne illnesses in England and Wales, including food poisoning, campylobacteriosis, and salmonellosis infections, and demonstrated this relationship. Research shows a significant correlation of these illnesses with ambient temperature at the time of illness and with the previous week's temperature.[3] Depending on the type of foodborne illness, for every degree centigrade rise in temperature, results showed 2.5–6% relative increase in the risk of foodborne illness. In the United States, good statistics on foodborne diseases are lacking, although estimates range from 6 million to 81 million illnesses and up to 9,000 deaths each year. Though current surveillance of foodborne illness in the United States is patchy and the burden of severe disease is not well known, further research may make it possible to translate these numbers into health impacts.

1 US Food and Drug Administration, Quantitative risk assessment on the public health impact of pathogenic *Vibrio parahaemolyticus* in raw oysters. 2005.
2 McLaughlin, JB, et al., N Engl J Med, 2005. 353(14): p. 1463-70.
3 Lake, IR, et al., Epidemiol Infect, 2009. 137: p. 1538-1547.

and, in the United States at least, may be moderate and unlikely except in the event of disruption of government regulatory programs. However, on a global scale they are huge in terms of numbers of people likely to be affected and consequent human suffering. The Intergovernmental Panel on Climate Change projected with high confidence an increase in malnutrition and consequent disorders, including those related to child growth and development, as a result of climate change.[123] Some of these effects are already being felt in the wake of extreme weather events such as droughts, flooding, and hurricanes, and as such present a fairly immediate concern. The World Health Organization estimated that in 2000, there were over 77,000 deaths from malnutrition and 47,000 deaths from diarrhea (many from foodborne exposures) due to climate change.[124]

Impacts on Risks

The U.S. Climate Change Science Program (CCSP) reported a likely increase in the spread of several foodborne pathogens due to climate change, depending on the pathogens' survival, persistence, habitat range, and transmission in a changing environment.[125] Drought has been shown to encourage crop pests such as aphids, locusts, and whiteflies, as well as the spread of the mold *Aspergillus flavus* that produces aflatoxin, a substance that may contribute to the development of liver cancer in people who eat contaminated corn and nuts. Agronomists are also concerned that climate change-based increases in a variety of blasts, rusts, blights, and rots will further devastate already stressed crops, and thereby exacerbate malnutrition, poverty, and the need for human migration. The spread of agricultural pests and weeds may lead to the need for greater use of some toxic chemical herbicides, fungicides, and insecticides,[126] resulting in potential immediate hazards to farm workers and their families,[127] as well as longer-term hazards to consumers, particularly children.[128]

The safety of agricultural crops and fisheries also may be threatened through contamination with metals, chemicals, and other toxicants that may be released into the environment as a result of extreme weather events, particularly flooding, drought, and wildfires, due to climate change.[129] Global changes in ocean currents and water mass distribution, along with changes in Arctic ice cover, length of melt season, hydrology, and precipitation patterns, will alter contaminant and pathogen pathways.[130] Contaminants include a wide range of chemicals and metals such as PCBs, PAHs, mercury, and cadmium; pharmaceuticals such as synthetic hormones, statins, and antibiotics; widely used industrial chemicals such as fire retardants, stain repellants, and non-stick coatings; and pesticides and herbicides for agricultural use and vector control for public health protection. The health effects of human exposure to these environmental agents via complex land and ocean food webs are not well documented or understood, but evidence from animal studies is showing that such compounds accumulate in foods at concentrations that may affect fetal development, immune function, and other biological processes. These agents often occur together and may act synergistically, producing potentially greater harm than a single agent.

Recent findings demonstrate that pathogens that can pose disease risks to humans occur widely in marine organisms and may be affected by climate change.[131] In one specific example, the CCSP noted the strong association between sea surface temperature and proliferation of many *Vibrio* bacteria species that occur naturally in the environment (including those that cause cholera), and suggested that rising temperatures would likely lead to increased occurrence of illness associated with *Vibrio* bacteria in the United States, especially seafood-borne disease associated with *V. vulnificus* and *V. parahaemolyticus*.[132] Rising temperatures and impacts on other environmental parameters such as ocean acidification may also lead to more virulent strains of existing pathogens and changes in their distribution, or the emergence of new pathogens.[133] Increased risks from animal-borne disease pathogens could be especially acute in human populations that are highly dependant on marine-based diets for subsistence and who live where environmental effects resulting from climate change are pronounced (for example in certain native populations in Alaska).[134] Increased acidity of water associated with climate change may alter environmental conditions leading to greater proliferation of microbes of a public health concern. This is a significant concern in molluscan shellfish, because ocean acidification may affect formation of their carbonate shells and immune responses, making them more vulnerable to microbial infection. The combined impact of potential contaminant-induced immune suppression and expanding ranges of disease-causing pathogens and biotoxins on food supply could be significant.

123 Ibid.
124 Campbell-Lendrum, D., et al. Environmental Burden of Disease Series, ed. A. Prüss-Üstün, et al. 2003, Geneva: World Health Organization. 66.
125 Gamble, JL, et al. 2009, Washington, D.C.: U.S. Climate Change Science Program. p. 204 p.
126 Gregory, PJ, et al., J Exp Bot, 2009. 60(10): p. 2827-38.
127 Lynch, SM, et al., Environ Res, 2009. 109(7): p. 860-8; Park, SK, et al., Int J Occup Environ Health, 2009. 15(3): p. 274-81; [illegible], JA, et al., Environ Health Perspect, 2009. 117(4): p. 593-6.
128 Eskenazi, B, et al., Basic Clin Pharmacol Toxicol, 2008. 102(2): p. 228-36; Rosas, LG, et al., Curr Opin Pediatr, 2008. 20(2): p. 191-7.
129 Ebi, K, et al., in Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, J. Gamble, et al., Editors. 2008, USEPA: Washington, D.C.

130 Ibid.
131 [illegible], SK, et al., Environmental Health: A Global Access Science Source, 2008. 7(Suppl 2): [illegible]
132 Ebi, K, et al. in Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, J. Gamble, et al., Editors. 2008, USEPA: Washington, D.C.
133 [illegible], MS, et al. 2003, Washington, D.C.: National Academies Press. xxxv, 367 p.
134 [illegible], et al., Nat Rev Microbiol, 2008. 6(7): p. 545-55.

Mitigation and Adaptation

In the long term, mitigation and adaptation decisions affecting food and nutrition including, for example, the diversion of staple crops for biofuel feedstock, the increased need for agricultural chemicals due to climate-related increases in pests and changes in pest habitats, and planning needs for the maintenance of food supply infrastructure and transport in the wake of extreme weather events are important factors to be considered in a strategic research plan for climate change and health. The benefits of biofuels, genetically modified organisms, new pesticides, and alternative energy on nutrition and foodborne illness must also be considered. All of these technologies have great potential to help humans mitigate and adapt to climate change, and each should be carefully evaluated to ensure that the best are implemented.

Health implications, both positive and negative, of changes in animal agriculture and aquaculture as a result of climate change mitigation and adaptation need to be identified and quantified. For example, climate change events such as drought and flooding can result in changes in animal feed quality and the use of marginal lands for animal grazing affects water and habitat quality. Better understanding is needed of effects of the use of new or increased herbicides and pesticides in response to changes in growing conditions caused by climate change, as well as potential health effects for both humans and animals of ingestion of crops that have been genetically modified to withstand stress conditions caused by climate change. The health implications of biomass-based energy and biofuels, including interactions between climate mitigation strategies affecting agricultural and energy policies and availability of food, must be a priority area of research.

Research Needs

New efforts are needed to combine current and anticipated advances in detection and warning systems for food, nutrition, and foodborne health threats with epidemiologic studies on the occurrence and severity of poor nutrition and foodborne disease in humans. This is especially needed for high-risk populations such as women, infants, and children, and people in resource-constrained settings. Research needs include:

- projecting impacts of climate change including increases in CO_2, temperature, drought, floods, and other extreme weather events, and changes in growing seasons on food production, availability, contamination, and nutritional value
- understanding and predicting potential ecosystem changes from climate change that may establish new foodborne pathogens, chemical contaminants, or biotoxins, as well as new pathways for human exposure
- assessing the impacts of climate change on outbreak incidence, geographic range, and growth cycles of insect pests and pathogens that can infect food crops and seafood, and cause human disease
- understanding the effects of changes in food safety due to climate change-related alterations in the accumulation and toxicity of foodborne contaminants, biotoxins, and pathogens
- understanding of changes in nutritional status associated with climate change that may increase individual susceptibility to the adverse health impacts of other environmental exposures such as chemicals and heavy metals
- improving surveillance of disease-causing agents (chemical contaminants, pathogens, toxins) in food animals, agricultural crops, and seafood, as well as monitoring of exposed human populations in order to improve estimates of disease related to contamination of the food supply
- identifying and characterizing aspects of food production and distribution systems that will reduce risk of contamination and disease and ensure sustainability under climate change scenarios
- understanding the effect of ocean acidification from climate change-related increases in air pollution on seafood quality and availability
- developing and implementing models linking climate change and other environmental data (such as land use, land cover, hydrology) to crops and seafood to improve prediction and risk assessment
- developing and implementing early warning systems to manage agriculture and fisheries risks related to climate change, including improved communications with domestic and international food security agencies


EMERGENCY

5 Heat-Related Morbidity and Mortality

As a result of anthropogenic climate change, global mean temperatures are rising, and are expected to continue to increase regardless of progress in reducing greenhouse emissions.[135] Global average temperatures are projected to increase between 1.8 and 4.0°C by end of this century.[136] Climate change is expected to raise overall temperature distribution and contribute to an increase in the frequency of extreme heat events, or heat waves.[137] Temperature, particularly temperature extremes, is associated with a wide range of health impacts.

The health outcomes of prolonged heat exposure include heat exhaustion, heat cramps, heat stroke, and death.[138] Extreme heat events cause more deaths annually in the United States than all other extreme weather events combined.[139] In the United States, an average of 688 persons succumb to heat-related death per year.[140] Prolonged exposure to heat may also result in additional illness and death by exacerbating preexisting chronic conditions such as various respiratory, cerebral, and cardiovascular diseases,[141] as well as increasing risk for patients taking psychotropic drug treatment for mental disorders,[142] due to the body's impaired ability to regulate temperature. Figures for these illnesses and deaths may be dramatically underestimated as disparities in health care make morbidity measurements difficult and heat is rarely identified as an official cause of death. Some public health response organizations are in the process of developing heat early warning systems for anticipated heat wave events and extended warm periods.

Varying age groups have been shown to be sensitive to all-cause mortality under excessive heat stress, including adults over 65, children, and infants under 1 year of age.[143] For type-specific mortality, sensitivity to death from respiratory disease has been demonstrated in the general population and in the elderly.[144] In general, risk of respiratory death due to heat stress is greater than that of cardiovascular effects. Sensitivity to cerebrovascular disease-related death has been reported in Europe.[145] More commonly, sensitivity to cardiovascular disease-related mortality associated with heat has been seen in the whole population, as well as among the elderly. Elevated hyperthermia death risk also has been seen among the elderly in the United States.[146] However, heat-related risks are not regionally or locally uniform; demographic shifts in the United States will produce concentrations of larger populations with higher mean age, and thereby, heightened vulnerability to excessive heat.[147]

Impacts on Risk

Both increased average temperatures and increasingly frequent and severe extreme heat events produce increased risks of heat-related illness and death that can be significant: the European heat wave of 2003 caused more than 35,000 excess deaths.[148] Human susceptibility to heat-related illness depends on several different factors, from physiologic adaptation to the local environment to socioeconomic status, and the impact of these changing exposures will depend on the vulnerability of exposed populations. As noted above, host factors such as age and the burden of other serious illnesses such as heart disease and diabetes that might exacerbate heat-related problems are important. In the United States, the number of individuals 65 years of age and older (who are more susceptible to heat effects) is expected to increase from 12.4% in 2000 to 20% in 2060.[149] Socioeconomic factors also determine vulnerability; economically disadvantaged and socially isolated people face higher burdens of death from heat.[150]

Cities and climate are co-evolving in a manner that will certainly amplify both the health effects of heat and the vulnerability of urban populations to heat-related deaths by magnifying the increased temperatures caused by climate change as compared to adjacent rural and suburban locales.[151,152] The urban built environment can

135 Houghton, JT, et al. 2001, Cambridge ; New York: Cambridge University Press. x, 881 p.
136 Intergovernmental Panel on Climate Change. Working Group II. 2007, Cambridge: Cambridge University Press. x, 976 p.
137 Meehl, GA, et al., Science, 2004. 305(5686): p. 994-7.
138 Ellis, FP, Trans R Soc Trop Med Hyg, 1976. 70(5-6): p. 402-11.; Kilbourne, EM, et al. JAMA, 1982. 247(24): p. 3332-6
139 Luber, G, et al., Am J Prev Med, 2008. 35(5): p. 429-35.
140 Mirchandani, H, et al., Journal of the American Medical Association, 1993. 270(7): p. 810-816
141 Kovats, RS, et al., Heat stress and public health: A critical review, in Annual Review of Public Health. 2008. p. 41-55
142 Davido, A, et al., Emerg Med J, 2006. 23(7): p. 515-8.
143 Bytomski, JR, et al., Curr Sports Med Rep, 2003. 2(6): p. 320-4; Piver, WT, et al., Environ Health Perspect, 1999. 107(11): p. 911-6; Ye, F, et al., Environ Health Perspect, 2001. 109(4): p. 355-9; Curriero, FC, et al., Am J Epidemiol, 2002. 155(1): p. 80-7; Davis, RE, et al., Environmental Health Perspectives, 2003. 111(14): p. 1712-1718; Gosling, SN, et al., Climatic Change, 2009. 92(3-4): p. 299-341.
144 Kovats, RS, et al., Heat stress and public health: A critical review, in Annual Review of Public Health. 2008. p. 41-55.

145 Gosling, SN, et al., Climatic Change, 2009. 92(3-4): p. 299-341.
146 Curriero, FC, et al., Am J Epidemiol, 2002. 155(1): p. 80-7.
147 Luber, G, et al., Am J Prev Med, 2008. 35(5): p. 429-35.
148 Vandentorren, S, et al., Am J Public Health, 2004. 94(9): p. 1518-20.
149 Wilmoth, JM, et al., Research on Aging, 2006. 28(3): p. 269-288.
150 Gosling, SN, et al., Climatic Change, 2009. 92(3-4): p. 299-341.
151 Brazel, AJ, et al., in Encyclopedia of World Climatology, JE Oliver, Editor. 2005, Springer: Dordrecht, The Netherlands. xx, 854 p.
152 Patz, JA, et al., Nature, 2005. 438(7066): p. 310-7.

both exacerbate and alleviate the effects of heat. For example, high concentrations of buildings in urban areas cause what is known as the urban heat island effect: generating as well as absorbing and releasing heat, resulting in urban centers that are several degrees warmer than surrounding areas. Expanding parks and green spaces and increasing the density of trees in and around cities can help to reduce this effect.[153] It is estimated that 60% of the global population will live in cities by 2030, greatly increasing the total human population exposed to extreme heat.[154]

Researchers comparing annual heat-related deaths for the city of Los Angeles in the 1990s to those projected for the mid- and late-21st century have concluded that heat-related deaths will increase, perhaps up to seven-fold.[155] Another study assessing 21 U.S. cities estimates that for most of the cities, summer deaths will increase dramatically and winter deaths will decrease slightly, even with acclimatization. This shift to higher summer heat-related deaths will likely outweigh the extra winter deaths averted.[156] Climate change is projected to increase the average number of summertime heat-related deaths, with the greatest increases occurring in mid-latitude major cities where summer climate variability is greatest. Noting that the number of current heat-related deaths in U.S. cities is considerable in spite of mortality displacement (reduced mortality in the months following a heat event due to increased early deaths of critically ill people who would have died in the near-term regardless) and the increased use of air conditioning, a substantial rise in weather-related deaths is the most likely direct health outcome of climate change.[157]

It is difficult to make valid projections of heat-related illness and death under varying climate change scenarios. A review of past changes in heat-related deaths found few significant relationships for any decade or demographic group, and suggested that improved medical care, air conditioning use, and other adaptation efforts were the causes of reduced death, stating that despite increasing stressful weather events, heat–related deaths are preventable, as evidenced by the decline of all-cause mortality during heat events over the past 35 years.[158] Overall, research suggests that under a climate change scenario using current anthropogenic emissions trends, there will be a small increase in the overall U.S. heat-related death rate by the end of the 21st century.[159] A standardized definition and methodology for identifying heat-related health outcomes is needed for surveillance and to evaluate temperature-related illness and death.

Mitigation and Adaptation

While climate change is likely to increase the burden of heat-related illness and death in the United States, many of these outcomes are preventable. With aggressive public health actions and widespread physiologic and behavioral adaptations such as robust heat early warning systems and other health communications, increased air conditioning use, decreased time spent outdoors, and increased wearing of sun-shielding clothing it will be possible to reduce overall rates of illness and death, though some of these measures may result in negative health consequences as well.[160]

Adaptation occurs through a range of physiological, behavioral, and technological mechanisms, and the slight reduction in heat-related deaths in the United States, despite warming trends, is likely a result of adaptation. In a report on acclimatization in elderly people over time, researchers showed both a declining risk of heat-related cardiovascular deaths until no excess risk remained and a steady risk of cold-related deaths.[161] This effect was observed in other populations as well: over four 10-year time periods in the 20th century in London, progressive reductions in temperature-related deaths (both cold and hot) were reported, despite an aging population.[162] Cities with cooler climates tend to experience more heat-related deaths than those with warmer climates because populations can acclimatize to some extent to heat and because populations in warmer climates are more likely to have access to air conditioning. Heat-related death rates declined significantly over four decades (the period of 1964–1998) in 19 of 28 U.S. metropolitan areas[163] although the trend seems to have leveled off since the 1990s.[164]

Although air conditioning may explain the reduced heat-related death risk, it also may be due to improved standards of living, better access to medical care, biophysical coping mechanisms, and infrastructural adaptations. Depending on methods of power generation and the air conditioning technology used, however,

153 Bolund, P. et al., Ecological Economics, 1999. 29: p. 293-301; McPherson, E. et al., Urban Ecosystems, 1997. 1: p. 49-61.
154 United Nations Department of Economic and Social Affairs Population Division World Urbanization Prospects: The 2005 Revision, P.D. United Nations Department of Economic and Social Affairs, Editor. 2006, United Nations Department of Economic and Social Affairs, Population Division: Geneva.
155 Hayhoe, K. et al., Proc Natl Acad Sci U S A, 2004. 101(34): p. 12422-7.
156 McMichael, A.J. et al., Lancet, 2006. 367(9513): p. 859-869.
157 Kalkstein, L.S. et al., Environ Health Perspect, 1997. 105(1): p. 84-93.
158 Davis, R.E. et al., Climate Research, 2002. 22(2): p. 175-184.
159 Deschenes, O. et al., Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US, in Center for the Study of Energy Markets Paper. 2007, Center for the Study of Energy Markets: Santa Barbara, CA. p. 61.
160 McGeehin, M.A. et al., Environ Health Perspect, 2001. 109 Suppl 2: p. 185-9.
161 Barnett, A.G., Epidemiology, 2007. 18(3): p. 369-72.
162 Carson, C. et al., Am J Epidemiol, 2006. 164(1): p. 77-84.
163 Davis, R.E. et al., Environmental Health Perspectives, 2003. 111(14): p. 1712-1718.
164 Sheridan, S.C. et al., Natural Hazards, 2009. 50(1): p. 145-160.

increased use of air conditioning may result in higher greenhouse gas emissions.[165] In addition, to the extent that power grids become overburdened during excessive heat events, resulting blackouts and brownouts could leave populations at increased risk of deaths.

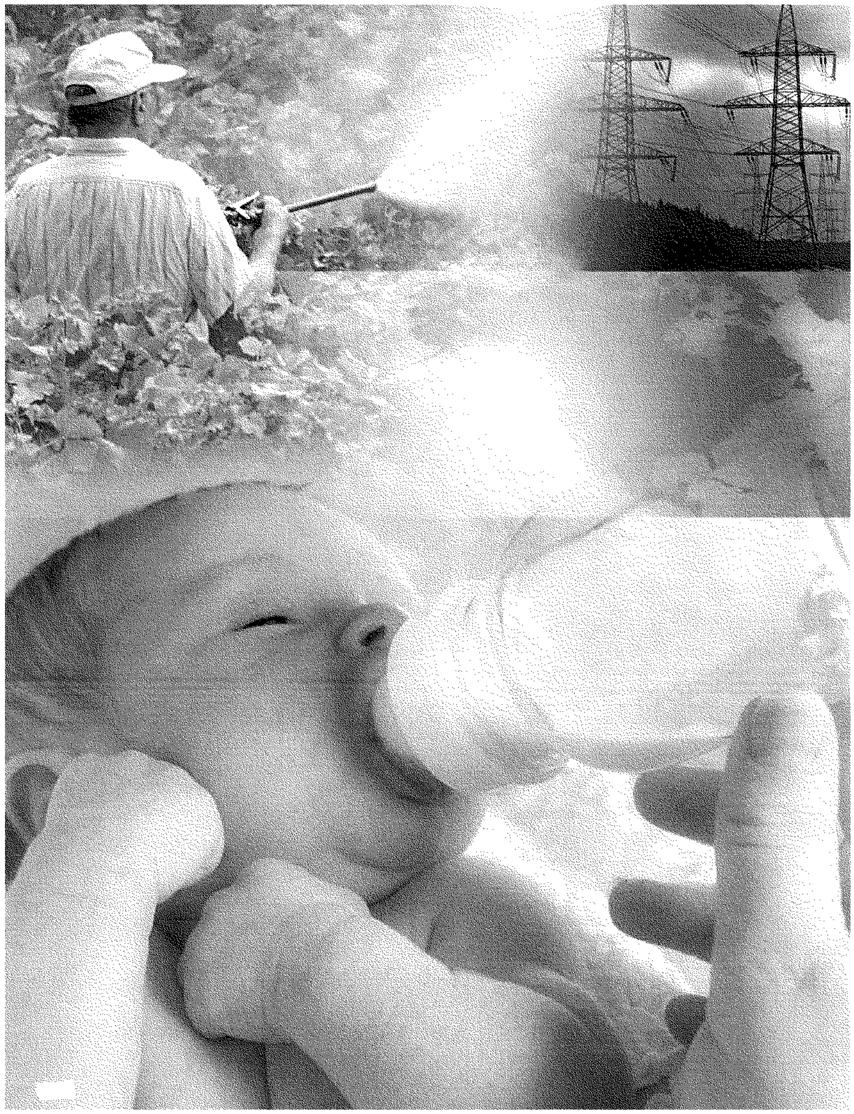
From a public health perspective, proactive heat wave response plans may prove to be a more sustainable adaptation strategy. Following a 2003 heat wave in Western Europe, France established a National Heat Plan incorporating several preventive measures aimed at reducing the risks related to high temperatures including a heat early warning system. During a lasting and severe heat wave in 2006, the excess death rate in France was much lower than expected given the high numbers of deaths three years earlier; research suggests that the decrease may have resulted from implementation of this plan.[166]

Research Needs

Research needs to improve understanding of heat-related illness and death, as well as impacts of heat mitigation and adaptation, include:

- developing and implementing a standard definition of heat-related health outcomes, as well as standard methodologies for surveillance of outcomes and evaluation of adaptations
- understanding risk factors for illness and death associated with both acute exposure to extreme heat events and long-term, chronic exposure to increased average temperatures, including how such exposure may alter human physiology (for example, by impacting the body's ability to metabolize and excrete harmful environmental toxicants)
- identifying which temperature-related metrics are most strongly related to increased hospitalization and mortality during heat waves
- quantifying the combined effects of exposure to heat waves and ambient air pollution on excessive illness and death
- conducting comparative analyses of heat-related death risks for application to national scale analyses
- determining attributes of communities, including regional and seasonal differences, that are more resilient or vulnerable to adverse health impacts from heat waves
- assessing the health benefits of the use of environmental design principles to reduce the high thermal mass of urban areas
- characterizing the likelihood and nature of multi-system failures, such as power grid failure, that could lead to significant morbidity and mortality during a heat wave
- enhancing the ability of current climate models to capture the observed frequency and intensity of heat waves across various timescales to support weather-climate predictions and use of heat early warning systems in decision making
- evaluating heat response plans, focusing on environmental risk factors, identification of high-risk populations, effective communications strategies, and rigorous methods for evaluating effectiveness on the local level

165 Yoshida, Y, Carbon Balance Manag, 2006. 1: p. 12
166 Fouillet, A. et al., Int J Epidemiol, 2008. 37(2): p. 309-17



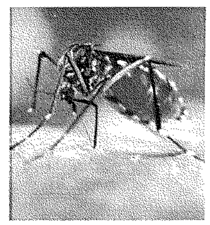
6 Human Developmental Effects

Most humans develop in a predictable fashion, growing from a fertilized egg to fetus, newborn, toddler, child, adolescent, and adult in a way that is fairly well understood. The environment can be a potent modifier of normal development and behavior. Environmental effects on development include subtle changes such as small reductions in IQ from exposure to lead,[167] changes in onset of puberty from exposure to endocrine disrupting chemicals,[168] birth defects such as cleft palate due to dioxin-like compounds,[169] and fetal loss through exposure-related spontaneous abortion.[170] According to the Centers for Disease Control and Prevention, about 3% of all children born in the United States have a birth defect, some of which can be attributed to environmental causes. Birth defects are a leading cause of death in children, accounting for almost 20% of all infant deaths. Babies born with birth defects also have a greater chance of illness and long-term disability than children without birth defects.[171] Some of these birth defects have been steadily increasing over the last 20 years, for example the rates of congenital heart defects have doubled,[172] suggesting a possible environmental linkage, although other explanations such as better reporting may also explain the rise.

Recent research into early functional programming has opened a new perspective on the developmental and early life origins of human disease.[173] Vulnerable periods during human development include preconception (gametogenesis), preimplantation, the fetal period, and early childhood. Environmental exposures during these periods can lead to functional deficits and developmental changes through several mechanisms including genetic mutations and epigenetic change. Some chemicals damage DNA directly, causing mutations in gametes or the developing fetus that can lead to later disease or conditions that increase disease risks such as obesity.[174] For example, toxins such as domoic acid, a biotoxin released from harmful algal blooms and taken up by seafood and

167 Stein, J., et al., J Dev Behav Pediatr, 2002. 23(1 Suppl): p. S13-22.
168 Rogan, WJ, et al., Int J Hyg Environ Health, 2007. 210(5): p. 659-67.
169 [illegible], et al., Birth Defects Res A Clin Mol Teratol, 2003. 67(12): p. 968-70.
170 [illegible], Regul Toxicol Pharmacol, 2004. 39(2): p. [illegible].
171 CDC, Birth Defects. 2008 [cited 2009 July 22]; Available from: http://www.cdc.gov/ncbddd/bd/.
172 Correa-Villasenor, A, et al., Birth Defects Res A Clin Mol Teratol, 2003. 67(9): p. 617-24.
173 [illegible], et al., Journal of Molecular Endocrinology, 2004. [illegible]
174 [illegible], et al., Semin Reprod Med, 2009. 27(5): p. 358-65.

RESEARCH HIGHLIGHT



Many of the chemicals that we use to control pests and improve crop yields can impact human development. Climate change will alter rainfall and temperature in various parts of the planet. In some cases, climate change will lead to changes in agricultural practices for crop yields that might increase pesticide use and thereby increase human exposures. Changes in the range of mosquitoes and other pests that can carry disease also may lead to an increase in the use of legacy pesticides (e.g. DDT). Malaria is rare in the United States, although the number of cases (imported or indigenous) have been increasing over the last decade in some locations.[1] The insecticide DDT is highly efficient for the control of mosquitoes that are capable of transmitting malaria to humans. Although withdrawn from use in the United States, DDT is still used as a desperate expedient to control mosquitoes in malaria-endemic areas around the world. DDT and its principal metabolite, DDE, are persistent in the environment and in humans. Research has shown that women whose mothers had high DDT levels in their blood when they were *in utero* have shortened menstrual cycles and a reduced chance of getting pregnant. A landmark study showed that for every 10 milligrams per liter of DDT in mother's serum, the probability of pregnancy for the daughter dropped by 32%.[2] Other pesticides also have been linked to similar decreases in fertility.[3] Later studies on similar exposures showed equivocal results on time-to-pregnancy, but suggested effects on fetal loss, child growth, and male reproductive development.[4]

1 WHO, Global Malaria Programme. 2008, Geneva: World Health Organization. xx, 190 p.
2 Cohn, BA, et al., Lancet, 2003. 361(9376): p. 2205-6.
3 Bretveld, N, et al., Curr Opin Obstet Gynecol, 2008. 20(3): p. 229-33.
4 Longnecker, MP, et al., Am J Epidemiol, 2002. 155(4): p. [illegible]; Law, DC, et al., Am J Epidemiol, 2005. 162(6): p. 523-32; Longnecker, MP, et al., Environ Res, 2005. 97(2): p. 127-33; [illegible], et al., Int J Epidemiol, 2006. 35(4): p. 853-8.

marine mammals, can bioaccumulate in amniotic fluid and alter fetal development.[175] Chemicals can also cause epigenetic changes that alter the way DNA is interpreted, leading to inheritable functional changes without changing DNA itself. These epigenetic changes could have consequences for many diseases and developmental changes.[176] For example, maternal undernutrition may act on the developing fetus to program the risks for adverse health outcomes such as cardiovascular disease, obesity, and metabolic syndrome in adult life. In this way, changes in maternal nutrition and *in utero* exposure to certain chemicals or biotoxins due to climate change may impact the health of future generations through epigenetic changes before conception and during pregnancy. Developmental changes can result in a lifetime of suffering and have significant societal costs in terms of resources, medical care, and lost productivity.[177]

Impacts on Risk

People at different stages of life can respond very differently to environmental changes. Some changes to the environment resulting from climate change could alter normal human development both in the womb and later in life. Foodborne illness and food insecurity, both likely outcomes of climate change [see chapter on Nutrition and Foodborne Diseases], may lead to malnutrition. While adult humans exposed to mild famine usually recover quite well when food again becomes plentiful, nutritional reductions to a fetus in the womb appear to have lasting effects throughout life.[178] Malnutrition and undernutrition in pregnant women are a global cause of low birth weight and other poor birth outcomes that are associated with later developmental deficits. Malnutrition is predominantly a problem in the developing world, but in the United States, one in six children still live in poverty,[179] and other developed countries also have substantial populations with insufficient food resources and undernutrition[180] that could be made worse by climate change. Climate change effects on food availability and nutritional content could have a marked, multigenerational effect on human development.[181]

Changes in patterns and concentrations of contaminants entering the marine environment due to climate change will impact seafood species, many of which provide a major source of protein to global populations. Such contaminants, particularly metals such as mercury and lead that accumulate in fish and seafood, are a special concern for human developmental effects.[182] Similarly, an increase in the use of herbicides and pesticides for agricultural purposes, as well as alterations in environmental degradation of such chemicals due to changes in climate, could result in increased exposures that would exceed safety guidelines and increase the risk of developmental changes.[183]

Other environmental exposures to pregnant women and to children that areassociated with climate change also present hazards to normal human development. For example, certain commercial chemicals present in storage sites or hazardous waste sites can alter human development. Flooding from extreme weather events and sea-level rise are likely to result in the release of some of these chemicals and heavy metals, most likely affecting drinking and recreational waters. Some of these, including mercury and lead, have known negative developmental effects.

And while more research is required, there is good reason for concern based on our current body of knowledge of certain toxic metals and persistent organic compounds. Of the metals likely to become more prevalent in human environments due to climate change, inorganic arsenic is of great concern because it is a potent human carcinogen, it alters the immune system, and it is a general poison that is lethal at certain doses. More than 100 million people worldwide are exposed to arsenic through groundwater contamination and industrial emissions. Both inorganic and methylated forms of arsenic have been shown to impede fetal development and increase spontaneous abortions.[184] Persistent organic compounds, even those no longer in use in many locales such as DDT and PCBs, could increase in some human environments and decrease in others as a result of flooding and extreme weather events due to climate change[185] Many of the Superfund toxic waste sites in the United States contain PCBs and dioxins that have been linked to cognitive deficits in children that continue throughout their lives. It is expected that every person on the planet carries some body burden of PCBs, but people living near contaminated sites have greater exposures and an increased risk of disease.[186] Dioxins, PCBs, asbestos, benzene, flame retardants, certain pesticides, and other chemicals are known to be immunotoxicants. Changes to the immune system during development can remain throughout life, possibly resulting in a reduced capacity to fight serious infection and an increased risk of several other diseases including cancer.

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179 Nord, M., et al., [illegible] Department of Agriculture, Washington, DC
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Climate change may alter the abundance and distribution of harmful algal blooms and their associated biotoxin accumulation in fish and seafood.[187] Currently there are over 100 known biotoxins associated with harmful algal blooms, and the biological effects of most are currently unknown; however, some have been shown to cross the placenta and affect the developing fetus.[188] It is partly for this reason though that fish species provide excellent biomedical models for developmental toxicity research, particularly the study of congenital heart defects. Such defects are notoriously difficult to study in standard rodent models due to the early dependency of mammalian embryos on circulatory function to provide oxygen. Because fish embryos are not dependent on early circulation for oxygen, fish models have made highly significant contributions to cardiac developmental studies in the past decade.[189]

Mitigation and Adaptation

In regions where water availability is a growing concern, there will be an increasing need to reuse water or seek alternate sources of water that may be of lower quality. This may result in new treatment options that may require the use of additional or more toxic chemicals.

Changes in energy source policies also could increase exposures to numerous airborne metal particulates, many of which, such as lead, have known adverse developmental impacts.[190] Given the large number of chemicals that are currently in commerce, the unknown degree to which climate change will alter human exposure to these compounds, and the lack of data on the developmental toxicity of most of these compounds, this is an area strongly in need of additional research.

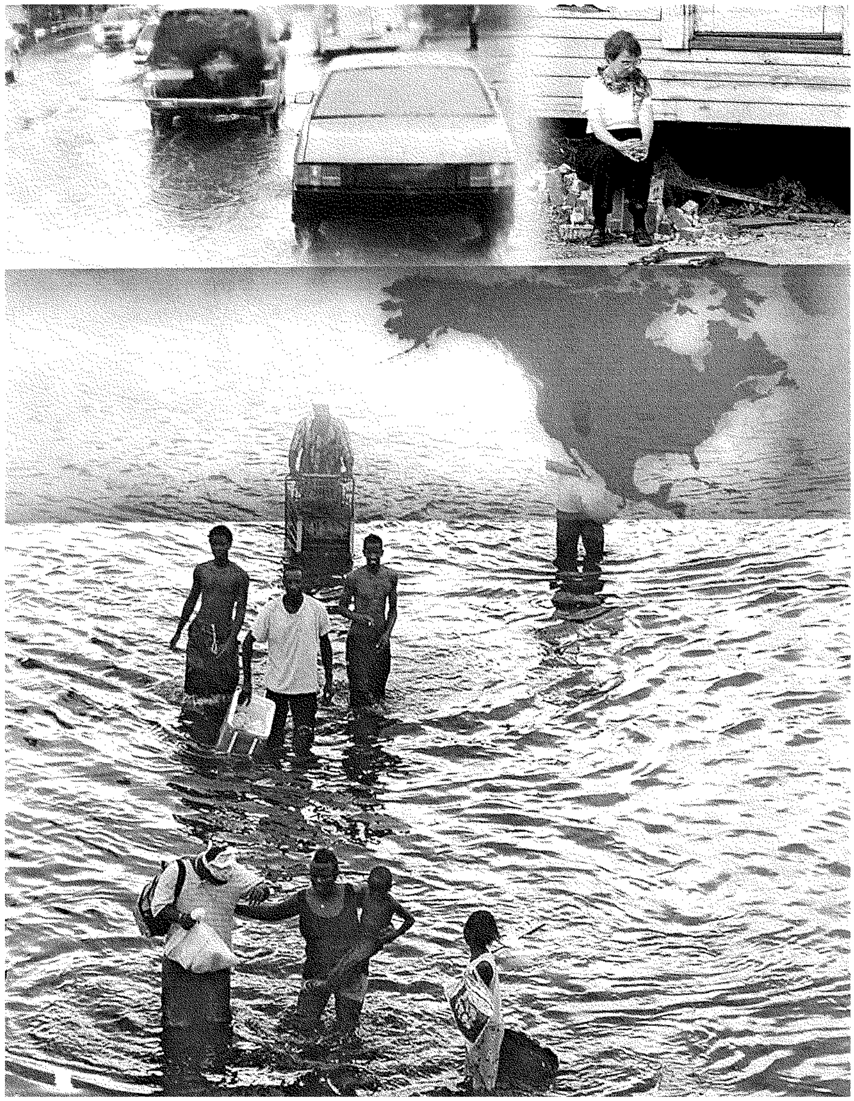
Access to prenatal health care and to early intervention services is critical in preventing and mitigating birth defects and impacts on human development. Following extreme weather events, such health care and services potentially may be disrupted for extended periods of time, increasing the risk of adverse long-term consequences for mothers, children, and society.

Research Needs

Research is needed to evaluate climate-related impacts at different life stages including direct and epigenetic effects (through exposures to mothers and fathers) that may be hazardous to human development. Such research could improve understanding of the long-term effects on human development and provide guidance on how mitigation and adaptation can reduce this health burden. Research needs include:

- understanding the effects of climate change-induced stress on human reproduction and development, including chronic and acute heat stress, and traumatic stress as a result of extreme weather events
- understanding how malnutrition may alter human development, how climate change may exacerbate such alterations, and how to develop effective strategies to minimize these impacts in vulnerable populations
- understanding the impacts of changes in weather patterns and ecosystems on the incidence, exposure, and distribution of chemical contaminants and biotoxins known to cause developmental disorders
- expanding the use of marine species as biomedical models and sentinels for understanding effects of contaminants and biotoxins on human reproduction and development
- understanding the implications of mitigation strategies, including changes in energy policies and new technologies, on the production, use, and storage of heavy metals and chemicals that are known to cause developmental disorders
- understanding how weather events affect access to health care and the implications of this for normal human development

187 [illegible], et al., Environmental Health Perspectives, 2006. [illegible] p. [illegible]-986.
188 Ibid.
189 Chen, Y., et al., Trends Cardiovasc Med, 2008. 18(4): p. 150-5.
190 Gohlke, J.M., et al., Environmental Health Perspectives, 2008. 116(6): p. A236-A237.



7 Mental Health and Stress-Related Disorders

Mental health disorders comprise a broad class of illnesses from mild disorders, such as social phobias and fear of speaking in public, to severe diseases including depression and suicidal ideation. Many mental health disorders can also lead to other chronic diseases and even death. Stress-related disorders derive from abnormal responses to acute or prolonged anxiety, and include diseases such as obsessive-compulsive disorder and post-traumatic stress disorder. It is estimated that 26.2% of Americans over the age of 18 suffer from a diagnosable mental health disorder in a given year; 9.5% suffer from mood disorders, and 6% suffer from serious mental illness.[191] However, mental health is an area of public health that is often a low research priority and one whose impacts on human and societal well being are typically underestimated, both within the United States and globally. It also is an area of public health in which disparities exist among socioeconomic groups in both access to and quality of care and treatment.[192]

Psychological impacts of climate change, ranging from mild stress responses to chronic stress or other mental health disorders, are generally indirect and have only recently been considered among the collection of health impacts of climate change.[193] Mental health concerns are among some of the most potentially devastating effects in terms of human suffering, and among the most difficult to quantify and address. A variety of psychological impacts can be associated with extreme weather and other climate related events. There has been significant research conducted depicting ways in which extreme weather events can lead to mental health disorders associated with loss, social disruption, and displacement, as well as cumulative effects from repeated exposure to natural disasters.[194] The effects of climate change impact the social, economic, and environmental determinants of mental health, with the most severe consequences being felt by communities who were already disadvantaged prior to the event.[195] Extreme weather events such as hurricanes, wildfires, and flooding, can create increased anxiety and emotional stress about the future,[196] as well as create added stress to vulnerable communities already experiencing social, economic, and environmental disruption. Individuals already vulnerable to mental health disease and stress-related disorders are likely to be at increased risk of exacerbated effects following extreme weather or other climate change events. Prolonged heat and cold events can create chronic stress situations that may initiate or exacerbate health problems in populations already suffering from mental disease and stress-related disorders. In addition, psychotropic drugs interfere with the body's ability to regulate temperature; individuals being treated with these drugs could be at increased risk of heat-related illness during extreme heat events.[197]

The severity of mental health impacts following an extreme climate event will depend on the degree to which there is sufficient coping and support capacity, both during and following the event.[198] During the recovery period following an extreme event, mental health problems and stress-related disorders can arise from geographic displacement, damage or loss of property, death or injury of loved ones, and the stress involved with recovery efforts.[199] The most common mental health conditions associated with extreme events range from acute traumatic stress to more chronic stress-related conditions such as post-traumatic stress disorder, complicated grief, depression, anxiety disorders, somatic complaints, poor concentration, sleep difficulties, sexual dysfunction, social avoidance, irritability, and drug or alcohol abuse.[200] The chronic stress-related conditions and disorders resulting from severe weather or other climate change-related events may lead to additional negative health effects. Studies have shown a negative relationship between stress and blood glucose levels, including influence on glycemic control among patients with type 2 diabetes.[201] Evidence has also shown that human response to repeated episodes of acute psychological stress or to chronic psychological stress may result in cardiovascular disease.[202] Although a direct cause and effect relationship has not yet been proven, some research has indicated a link between various psychological factors and an increased risk of developing

191 Kessler, RC, et al., Arch Gen Psychiatry, 2005. 62(6): p. 617-27.
192 Ibid.
193 Fritze, JG, et al., Int J Ment Health Syst, 2008. 2(1): p. 13.
194 Ibid.
195 Ibid.
196 Ibid.

197 Martin-Latry, K., et al., Eur Psychiatry, 2007. 22(6): p. 335-8.
198 Gosling, SM, et al., Philos Transact A Math Phys Eng Sci, 2007. 365(1860): p. 1511-25.
199 Ebi, K., et al., in Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, J Gamble, et al., Editors. 2008, USEPA: Washington, D.C.
200 Silove, D, et al., J Postgrad Med, 2006. 52(2): p. 121-5; Watson, PH, et al., JAMA, 2006. 296(5): p. 585-8.
201 Surwit, RS, et al., Diabetes Care, 2002. 25(1): p. 30-4.
202 Black, PH, et al., J Psychosom Res, 2002. 52(1): p. 1-23.

some forms of cancer, as well as the progression of cancer in those already presenting with the disease.[203]

Climate change has the potential to create sustained natural and humanitarian disasters beyond the scale of those we are experiencing today, which may exceed the capacity of our public health systems to cope with societal demands.[204] In the United States, this was demonstrated in 2005 by the devastating impact of Hurricane Katrina. Globally, climate change will continue to act as a threat to natural resources and ecosystem services that are already stressed, which may force the migration of large communities and create conditions leading to hostile political environments, conflict, and war.[205] The resources required to meet the psychological needs of those affected by extreme weather events, environmental conflicts, or other effects of climate change may be limited immediately following such an event,[206] or as people migrate in search of more stable natural environments.

Research on mental health service delivery following disaster events has only recently become a higher profile topic of scientific interest. Though some mental health diseases and stress-related disorders have been incorporated into the collection of health impacts of extreme weather and temperature events, numerous research gaps remain. More work is necessary to understand the effects of climate change and extreme weather events on mental health status, to determine how to mitigate these effects, and to overcome the barriers to utilization and delivery of mental health services following extreme weather events.

Impacts on Risks

The number of people killed by climatic, hydrological, and meteorological disasters in 2008 was the highest of the last decade, with 147,722 deaths reported worldwide.[207] In the United States, Hurricanes Katrina and Rita, which hit the Gulf Coast in 2005, were two of the most damaging hurricanes recorded in U.S. history, impacting more than 90,000 square miles and directly affecting more than 1.5 million people, including forcing 800,000 citizens to be relocated from their homes.[208] Scientific evidence supports that global warming will be accompanied by changes in the intensity, duration, and geographical extent of weather and climate extreme events; therefore, the threat to human health and well being from events such as hurricanes, wildfires, flooding, and tornadoes is likely to continue, and perhaps worsen.[209]

It is also highly likely that the long-term effects of climate change will displace significant numbers of people, many of whom are already vulnerable members of society. Extreme weather events, sea-level rise, destruction of local economies, resource scarcity, and associated conflict due to climate change are predicted to displace millions of people worldwide over the coming century.[210] The most commonly cited figure of projected population displacement from climate change is 200 million people worldwide by 2050.[211] Those with lower socio-economic standing are more likely to choose to relocate permanently following a devastating event, often due to limited resources to rebuild property and restore livelihood.[212] In addition, people will continue to experience place-based distress caused by the effects of climate change due to involuntary migration or the loss of connection to one's home environment, a phenomenon called "Solastalgia."[213]

The mental health impacts of environmentally displaced populations in conflict stricken areas have been well documented;[214] however, additional research is needed to better understand mental health impacts on such people as they relate to climate change and climate change-related migration. While there wil likely be some displacement of populations in the United States caused by the effects of climate change, this issue is anticipated to have far greater consequences on a global scale. The results of climate science research on sea-level rise, extreme events such as flooding and droughts, the impacts of climate change on natural resources, and other impacts caused by climate variability and change must be connected to social science research. This link to social sciences, including behavioral science research, will help to build an understanding of when, how, and where population shifts may occur, thereby increasing the likelihood that necessary mental health services and support can be made available where and when they are needed most.

203 Anand, SM., et al., Nat Rev Cancer, 2009. 9(4): p. 239-?.
204 The CNA Corporation, 2007. p. 68.
205 Kessler, R.C., et al., Arch Gen Psychiatry, 2005. 62(6): p. 917-22.
206 [illegible], SM., et al., Philos Transact A Math Phys Eng Sci, 2007. 365(1860): p. 1511-25.
207 International Federation of Red Cross and Red Crescent Societies, World Disaster Report 2009, in World Disaster Report, L. Knight, Editor. 2009, International Federation of Red Cross and Red Crescent Societies: Geneva. p. 243.
208 Department of Homeland Security. The First Year After Hurricane Katrina: What the Federal Government Did. 2009 [cited 2009 Nov 23]; Available from: www.dhs.gov/xfoia/archives/gc_1157649340100.shtm.
209 CCSP, Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research., T. Karl, et al., Editors. 2008, Department of Commerce, NOAA's National Climatic Data Center: Washington, DC, USA. p. 164.
210 Fritze, JG., et al., Int J Ment Health Syst, 2008. 2(1): p. 13.
211 Myers, N. Philos Trans R Soc Lond B Biol Sci, 2002. 357(1420): p. 609-13.
212 Hunter, LM., Population and Environment, 2005. 26(4): p. 273-302.
213 Albrecht, G., et al., Australas Psychiatry, 2007. 15: p. S95-S98.
214 Crowley, C., J Am Acad Nurse Pract, 2008. 21(6): p. 322-33; Mels, E., et al., Med Confl Surviv, 2008. 24(1): p. 3-15; [illegible], T., et al., J Arch Med [illegible], 2005. 17(2): p. 23-5; [illegible] M., et al., JAMA, 2002. 288(5): p. 611-21.

Mitigation and Adaptation

There is a need to fully understand what gaps currently exist in mental health infrastructure, resources, and services; how these gaps may be exacerbated due to climate change; and the resulting impacts on mental health status, both in the United States and worldwide. This information can then be incorporated into mitigation and adaptation strategies. The information can also be used to ensure adequate resources are allocated to enable services to prepare for and deal with the impending challenges associated with climate change including both extreme and chronic weather events and sea-level rise. In addition, much work needs to be done to help individuals better self-identify their mental health needs and to increase their awareness of the existence of mental health services in their communities. Work also needs to be done to eradicate the stigma associated with the need for mental health care so that individuals will seek out mental health services following extreme weather or other climate-related events.

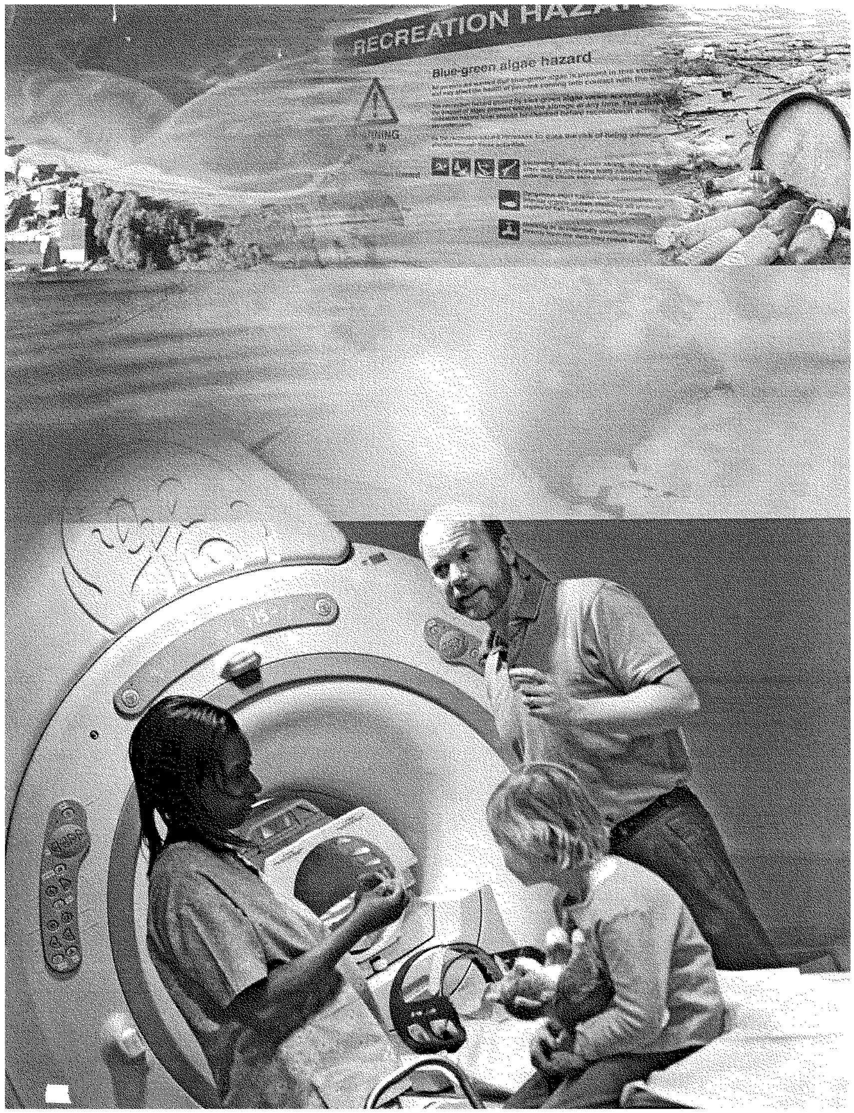
While some climate change adaptation measures may prevent the need for displacement and migration of communities, socioeconomically disadvantaged communities both within the United States and globally may not be able to effectively implement such adaptation measures. The effect may be social instability of the surrounding community, which will create additional stress and exacerbate the threat to overall mental health and well being.

Research Needs

Immediate research needs on the mental health implications of climate change[215] include:

- understanding of how psychological stress acts synergistically with other forms of environmental exposures to cause adverse mental health effects
- understanding the critical social and economic determinants for mental health and overall community well-being that might be altered by climate change
- identifying and incorporating key mental health outcomes in health impact assessments, both for U.S. populations and worldwide, under a range of climate change scenarios
- developing and implementing monitoring networks to help track the migration of environmentally displaced populations to assist with the provision of mental health care and services
- improving methods of identifying vulnerable mental health populations, and understanding the implications for these populations at the local and regional level
- identifying the most beneficial means of encouraging utilization of mental health services and delivering such services following extreme weather or other climate change events
- developing mental health promotion and communication programs related to proposed climate change mitigation and adaptation strategies

215 Fritze, JG, et al., Int J Ment Health Syst, 2008. 2(1): p. 13.


RECREATION
Blue-green algae hazard

8 Neurological Diseases and Disorders

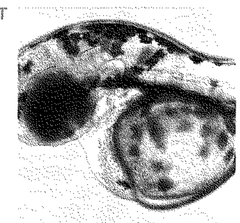
The United States has seen an increasing trend in the prevalence of neurological diseases and deficits.[216] Onset of diseases such as Alzheimer Disease (AD) and Parkinson Disease (PD) is occurring at earlier ages across the population. Environmental factors are suspected of playing a large role in both the onset and severity of these conditions, although there is a gap in our understanding of this role, especially in relation to genetics, aging, and other factors.[217] While some of these changes in neurological health likely are due to the aging of a large portion of the population, learning disabilities that affect children also are on the rise, and there are indicators that environmental factors may be involved including changes in climate that may exacerbate factors affecting the rates and severity of neurological conditions.[218,219] Neurological conditions generally carry high costs in terms of quality of life for both the sufferer and the caregiver and increased healthcare stresses on the economy and the workforce. The combination of these factors could affect a sizable portion of the U.S. population, and have significant impacts on productivity.

Factors affected by climate with particular implications for neurological functioning include malnutrition;[220] exposure to hazardous chemicals, biotoxins, and metals in air, food, and water;[221] and changes in pest management.[222] Understanding the role of climate in the incidence and progression of neurological conditions and how to prevent them is a critical need for public health and health care in the United States. Studies such as the National Children's Study[223] are an excellent opportunity to improve our understanding in this area.

Impacts on Risk

Numerous recent reports have described observed and anticipated detrimental effects of climate change on ocean health, resulting in increased risks to neurological health from ingestion of or

RESEARCH HIGHLIGHT



Harmful algal blooms (HABs) are increasing worldwide and global climate change is thought to play a significant role. Many HAB-related biotoxins cause significant neurotoxic effects in both animals and humans including permanent neurological impairment. The algae *Pseudo-nitzschia* spp. produce domoic acid, a potent neurotoxin that causes amnesiac shellfish poisoning in people. Blooms of this algae have been increasing off the California coast resulting in significant illness and death in marine animals. A decade of monitoring of health of California sea lions, a sentinel species for human health effects, indicates changes in the neurologic symptomatology and epidemiology of domoic acid toxicosis. Three separate clinical syndromes are now present in exposed animals: acute domoic acid toxicosis with seizure, permanent hippocampal atrophy, and death; a second novel neurological syndrome characterized by epilepsy associated with the chronic consequences of sub-lethal exposure to domoic acid; and a third syndrome associated with *in utero* exposures resulting in premature parturition, neonatal death, and significant neurotoxicity in the developing fetus resulting in seizure activity as the animal grows, as well as long-lasting impacts on memory and learning.[1] These observations indicate significant potential implications for human health effects, although their exact nature is not known and needs further study.

216 Steenland, K, et al., Alzheimer Dis Assoc Disord, 2009. 23(3): p. 165-70.
217 Bronstein, J, et al., Environmental Health Perspectives, 2009. 117(1): p. 117-121; Hendrie, HC, et al., Canadian Journal of Psychiatry-Revue Canadienne De Psychiatrie, 2004. 49(2): p. 92-99; Mayeux, R, Annals of Neurology, 2004. 55(2): p. 156-158.
218 Bronstein, J, et al., Environmental Health Perspectives, 2009. 117(1): p. 117-121; Mayeux, R, Annals of Neurology, 2004. 55(2): p. 156-158; Jones, E, et al., Lancet, 2009. 374(9690): p. 654-61.
219 Altevogt, BM, et al., Pediatrics, 2008. 121(6): p. 1225-1229.
220 Kar, BR, et al., Behav Brain Funct, 2008. 4: p. 31.
221 Kozma, C, Am J Med Genet A, 2005. 132(4): p. 441-4; Papanikolaou, NC, et al., Med Sci Monit, 2005. 11(10): p. RA329-36.
222 Mendola, AJ, et al., Epidemiology, 2007. 18(3): p. 312-20.
223 Landrigan, PJ, et al., Pediatrics, 2006. 118(5): p. 2175-86.

1 Goldstein, T, et al., Proceedings of the Royal Society B-Biological Sciences, 2008. 275(1632): p. 267-276; Ramsdell, JS and TS Zabka, Marine drugs, 2008. 6(2): p. 262-90.

exposure to neurotoxins in seafood and fresh and marine waters.[224] Neurotoxins produced by harmful algal blooms and other marine microorganisms can cause serious illness and death in humans. Under the correct conditions, harmful algal blooms produce potent neurotoxins that are often taken up and bioaccumulated in filter-feeding molluscan shellfish including oysters, clams, and mussels, as well as by certain marine and freshwater fish.[225] The most frequent human exposures are via consumption of seafood containing algal toxins, although some toxins may be present in freshwater sources of drinking water, and others may be aerosolized by surf breaking on beaches and then transported by winds to where they can cause respiratory distress in susceptible individuals who breathe them.[226] Because cooking or other means of food preparation do not kill seafood biotoxins, it is essential to identify contaminated seafood before it reaches consumers. Health effects including amnesia, diarrhea, numbness, liver damage, skin and eye irritation, respiratory paralysis, and PD- and AD-like symptoms may be severe, chronic, and even lead to death.[227] It has recently been reported that even a single low-level exposure to algal toxins can result in physiological changes indicative of neurodegeneration.[228] Work done on biotoxin-related neurologic disease in marine mammals indicates that domoic acid exposure can cause acute neurologic symptoms by crossing the placenta and accumulating in the amniotic fluid where it can impact neural development in the fetus, alter postnatal development, and lead to chronic illnesses such as epilepsy.[229,230,231] Climate change may alter the geographic range in which harmful algal bloom toxins appear, the frequency of toxin production, and the actual delivery of toxins (both increasing and decreasing in some cases) due to extreme weather.[232] Harmful algal blooms are increasing in frequency, intensity, and duration globally, partially as a result of climate change, although this link is poorly understood.[233] Nonetheless, it is clear that changes in precipitation and ocean temperatures, coupled with increased nutrient loading, may lead to earlier seasonal occurrence, as well as longer lasting and possibly more toxic harmful algal blooms.[234]

Emerging research suggests that exposure to a number of agents whose environmental presence may increase with climate change may have effects on neurological development and functioning. For example, exposure to pesticides and herbicides during specific developmental windows, in combination with other exposures later in life, could increase the risk of PD and other neurological diseases.[235] Exposure to heavy metals is known to exacerbate neurological deficits and learning disabilities in children,[236] and is suspected of being associated with both onset and exacerbation of AD[237] and PD. Evidence suggests that early-life occurrence of inflammation in the brain, as a consequence of either brain injury or exposure to infectious agents, also may play a role in the pathogenesis of PD.[238] In addition to conditions such as PD and AD, post-traumatic stress disorder (PTSD) is likely to have profound effects on the neurological functioning of populations exposed to the stress of extreme weather events, and the resulting dislocation and deprivation that may result from climate change.[239]

Mitigation and Adaptation

Mitigation to climate change may reduce our reliance on fossil fuels. This reduction in fossil fuel use will reduce the release of a number of neurotoxicants including arsenic, mercury, and other metals into the environment.[240] Simple actions that reduce the amount of energy needed, such as expanded use of compact fluorescent light bulbs, will reduce the amount of toxic metals emitted into the air by coal-fired power plants. However, additional mercury releases into the environment might occur due to breakage of these fluorescent bulbs or improper disposal, resulting in human exposures and potential neurological effects.[241] In more complicated mitigation strategies such as the expansion of the use of electric vehicles, heavy metals used in the batteries for such vehicles may present manufacturing and disposal challenges that will be of particular significance to the risk of neurological deficits.[242]

Adaptation efforts such as the increased use of pesticides to improve crop yield in areas with reduced farming capabilities may result in runoff of potentially neurotoxic pesticides into reservoirs and coasts used to capture water for human use, thereby increasing

224 National Research Council (U.S.). Committee on Ecological Impacts of Climate Change, 2008, Washington, D.C.: National Academies Press. xi, 57 p.; Sandifer, P., et al., Interagency oceans and human health research implementation plan: a prescription for the future. 2007, Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology: Washington, DC, USA.
225 Wang, D.Z., Marine Drugs, 2008. 6(2): p. 349-71.
226 Kirkpatrick, B., et al., Sci Total Environ, 2008. [illegible]
227 Wang, D.Z., Marine Drugs, 2008. 6(2): p. 349-71.
228 Lefebvre, KA, et al., Toxicol Sci, 2009. 107(1): p. 65-77.
229 Ramsdell, J.S., et al., Marine Drugs, 2008. 6(2): p. 262-90.
230 Brodie, EC, et al., Marine Mammal Science, 2006. 22(3): p. 700-707.
231 Maucher, JM, et al., Environmental Health Perspectives, 2007. 115(12): p. 1743-1746.
232 Moore, SK, et al., Environmental Health: A Global Access Science Source, 2008. 7(SUPPL. 2); Sandifer, P., et al., Interagency oceans and human health research implementation plan: a prescription for the future. 2007, Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology: Washington, DC, USA.
233 Moore, SK, et al., Environmental Health: A Global Access Science Source, 2008. 7(SUPPL. 2).
234 Paerl, HW, et al., Science, 2008. 320(5872): p. 57-8.

235 Costello, S., et al., Am J Epidemiol, 2009. 169(8): p. 919-26.
236 [illegible], Am J Med Genet B, 2005. [illegible]
237 [illegible], J Neurosci, 2009. [illegible]; Lovell, MA, J Alzheimers Dis, 2009. [illegible]; Mendez, CT, et al., Eur Arch Psychiatry Clin Neurosci, 2009. 259(1): p. 16-22; [illegible], Expert Rev Neurother 2009. 9(5): p. 631-?
238 Miller, DB, et al., Metabolism, 2008. 57 Suppl 2: p. S44-9.
239 [illegible], J Ayub Med Coll Abbottabad, 2005. 17(2): p. 23-6.
240 Gustin, MS, et al., J Air Waste Manag Assoc, 2004. 54(3): p. 320-30; [illegible], J Environ Monit, 2009. [illegible]; [illegible], Sci Total Environ, 2006. 368(1): p. 393-402.
241 Noyes, PD, et al., Environment International, 2009. 35(6): p. 971-986.
242 [illegible], Environmental Health Perspectives, 2009. 117(1): p. 117-121.

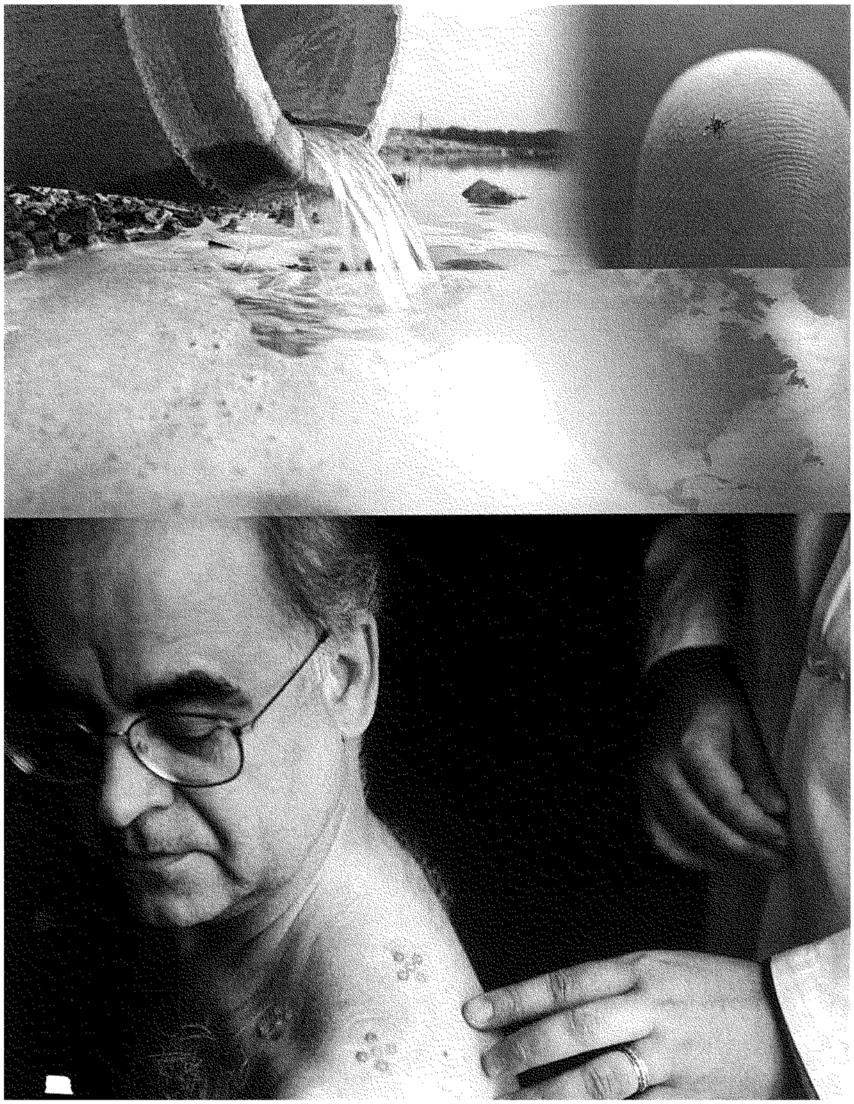
human exposures.[243] Alternately, recent research has shown multiple benefits on mental and neurological functioning as a result of increased exposure to natural and green space settings, particularly in urban areas.[244] Adaptation strategies that encourage and allow walkable cities and exercise, increases in green space and urban forestry, and improved green building methods that reduce the potential for exposure to chemicals such as arsenic and lead that leach from building materials could all contribute to reductions in neurological deficits. Numerous other mitigation and adaptation strategies may have both positive and negative health effects, most of which are poorly recognized or understood. Thus, any proposed mitigation and adaptation strategies will need to be carefully evaluated for both benefits and potential neurological effects.

Research Needs

More research is needed regarding the link between environmental exposures, the onset and severity of neurological diseases and disorders, and the relationship to climate change. Research needs include:

- identifying the factors that initiate harmful algal blooms and bacterial proliferations, focusing on the effects of temperature changes, shifts in rainfall patterns, and other climate-associated factors on their distribution, occurrence, and severity
- improving understanding of the mechanisms and pathways of acute and chronic exposures to harmful algal biotoxins and their impacts on fetal, postnatal, and adult development
- utilizing marine animal models to better understand the mechanisms and outcomes of exposure to harmful algal biotoxins individually and in conjunction with chemical exposures
- developing and validating strategies to inhibit the formation and severity of harmful algal blooms
- expanding research on the toxicity of chemicals known or suspected to cause neurological disorders, particularly pesticides, and on understanding how climate change may affect human exposure to such chemicals
- improving our understanding of the impact of increased heavy precipitation, ice melts, and flooding events on the risk of toxic contamination of the environment from storage-related issues or runoff, focusing on the likelihood of the event, the geographical areas and populations likely to be impacted, and the health outcomes that could result
- examining the neurological health benefits and costs of new climate change mitigation technologies, including research on the toxicity of new metals and metal compounds, including nanotechnologies, being used to improve battery performance for electric vehicles

243 Noyes, P.D. et al., Environment International, 2009. 35(6): p. 971-986.
244 Frumkin, H. et al. 2004. Washington, DC: Island Press. xx, 338 p.



9 Vectorborne and Zoonotic Diseases

Vectorborne and zoonotic diseases (VBZD) are infectious diseases whose transmission cycles involve animal hosts or vectors. Vectorborne diseases are those in which organisms, typically blood-feeding arthropods (insects, ticks, or mites) carry the pathogen from one host to another, generally with amplification (increased virulence) in the vector (for example, malaria). Zoonoses are diseases that can be transmitted from animals to humans by either contact with animals or by vectors that can carry zoonotic pathogens from animals to humans (for example, avian flu). Both domestic animals and wildlife, including marine mammals, fish, sea turtles, and seabirds may play roles in VBZD transmission by serving as zoonotic reservoirs for human pathogens or as means of interspecies transmission of pathogens. The epidemiology of VBZD in the United States has changed significantly over the past century, and many diseases that previously caused significant illness and death, including malaria,[245] dengue,[246] yellow fever,[247] and murine typhus,[248] are now rarely seen in this country. This dramatic change is a result of intentional programs to control vectors, vaccinate against disease, and detect and treat cases, with additional benefits from improvements in sanitation, development, and environmental modification. Examples of vectorborne diseases currently prevalent in the United States include Lyme disease[249] and ehrlichiosis, bacterial diseases that are transmitted primarily by ticks. Other important zoonoses in the United States, some of which are also vectorborne, include rabies,[250] Q fever,[251] anthrax, pathogenic *E. coli*, tularemia, hantavirus pulmonary syndrome,[252] and plague. Although VBZD currently are not a leading cause of morbidity or mortality in the United States, there is cause for some urgency on this issue. Our population is directly susceptible to the VBZD that circulate in warmer climates, and vulnerable as a result of global trade and travel. Our ability to respond to such threats on both a national and international level is currently limited.

Many vectorborne diseases that have been virtually eliminated from the industrialized world are still prevalent in developing countries. Globally, VBZD cause significant morbidity and mortality. For

245 Faust, E. In Malariology, a comprehensive survey of all aspects of this group of diseases from a global standpoint, MF Boyd, Editor. 1949, Saunders: Philadelphia. p. 2 v. (xxx, 1643 p.).
246 Adler, P. et al., American Entomologist, 2003. 49: p. 216-228.
247 Patz, JA, Jr., Am J Trop Med Hyg, 2004. 71(1): p. 2-16.
248 White, PC, Jr., JAMA, 1965. 193: p. 336-8.
249 Bacon, RM, et al., MMWR Surveill Summ, 2008. 57(10): p. 1-9.
250 Blanton, JD, et al., J Am Vet Med Assoc, 2006. 229(6): p. 884-97.
251 McQuiston, JH, et al., Am J Trop Med Hyg, 2006. 75(1): p. 36-40.
252 Douglass, R., et al., Vector Borne Zoonotic Dis, 2005. 5(2): p. 183-92.

RESEARCH HIGHLIGHT

Climate is one of several factors that influence the distribution of vectorborne and zoonotic diseases (VBZD) such as Lyme disease, Hantavirus, West Nile virus, and malaria. There is substantial concern that climate change will make certain environments more suitable for some VBZD, worsening their already significant global burden and potentially reintroducing some diseases into geographic areas where they had been previously eradicated. Recent public health experience with the outbreak and establishment of West Nile virus in the United States reveals the complexity of such epidemics, and the lack of preparedness required by public health officials to contain a national VBZD threat. Though unlikely, West Nile virus might have been contained when it emerged in New York City in 1999; however, delays of only a few weeks in recognizing the outbreak in birds and identifying the virus, combined with the absence of a robust mosquito abatement capability, allowed West Nile virus to spread quickly to surrounding areas. Relying on expertise from the mosquito abatement community, aerial spraying was applied fairly rapidly to combat mosquitoes in infected areas, but these efforts were not adequate to decrease populations of mosquitoes in time. From New York, the virus traveled across the entire United States, and by 2003, it had thoroughly established itself in the avian population. To date, individual mosquito abatement districts have been able to significantly protect their populations due to increased national funding combined with decades of experience in their local areas. However, underserved regions did not get significant protection despite efforts to identify them.

Resurgence of vectorborne disease as a result of climate change is also a major concern. Despite energetic interventions, the availability of drugs example, in 2006 there were 247 million cases of malaria and 881,000 malaria-related deaths worldwide.[253] The World Health Organization estimates that malaria is responsible for 2.9% of the world's total disability-adjusted life years (DALYs).[254] In the long term, climate change's potential to cause social upheaval and population displacement may provide opportunities for resurgence of certain VBZD in the United States, which has already seen some redistribution of vector species.[255] Disruption of economies, transportation routes, agriculture, and environmental services could result in large-scale population movements within and between countries, as well as a general decrease in what are now considered minimum standards of living.[256] A severe degradation of rural and urban climate and sanitation conditions could bring malaria, epidemic typhus, plague, and yellow fever to their former prominence.

Valid projections on likely impacts of climate change on VBZD are lacking, and a scientific consensus has yet to emerge. Even though we now have the technical knowledge to treat or vaccinate against many VBZD, in the absence of these technologies, some experts believe that population-level mortality from certain disease outbreaks could reach as high as 20–50%.[257] Ultimately, projections must be specific to location, altitude, ecosystem, and host or vector. Health impacts from changing distributions of VBZD are likely to unfold over the next several decades, and prevention and control activities must be developed and honed prior to significant vector range expansion in order to be most effective.

Emerging zoonotic disease outbreaks are increasing, with the majority of recent major human infectious disease outbreaks worldwide, as well as significant emerging diseases such as SARS, Nipah virus, and HIV/AIDS, originating in animals.[258] A recent report noted that the United States remains the world's largest importer of wildlife, both legal and illegal; these animals represent a potential source of zoonotic pathogen introduction into U.S. communities.[259] Interactions of wildlife with domestic animals and with people will likely increase in the United States due to changes to ecosystems and disease transmission resulting from both climate change and from adaptation and response strategies.

253 World Malaria Report 2008, Geneva: World Health Organization. xx, 190 p.
254 [illegible] 2004, Geneva: World Health Organization. xx, 190 p.
255 Carroll, R., Proc. of the Entomological Society of Washington, 2007. 109(1): p. 235-250.
256 Costello, A., et al., The Lancet, 2009. 373(9676): p. 1693-1733.
257 Greenwood, B.M., et al., Health Aff (Millwood), [illegible] p. 509-610.
258 Institute of Medicine (U.S.) Committee on Achieving Sustainable Global Capacity for Surveillance and Response to Emerging Diseases of Zoonotic Origin., et al., 2009, Washington, DC: National Academies Press. xxv, 312 p.
259 Pavlin, B.I., et al., Emerg Infect Dis, 2009. 15(11): p. 1721-6.

Impacts on Risks

VBZD ecology is complex, and weather and climate are among several factors that influence transmission cycles and human disease incidence.[260] Impacts in certain ecosystems are better understood; however, for others such as marine ecosystems, their role in VBZD has not been well characterized.[261] Changes in temperature and precipitation patterns affect VBZD directly through pathogen-host-vector interactions, and indirectly through ecosystem changes (humidity, soil moisture, water temperature, salinity, acidity) and species composition. Social and cultural behaviors also affect disease transmission. Many VBZD exhibit some degree of climate sensitivity, and ecological shifts associated with climate variability and long-term climate change are expected to impact the distribution and incidence of many of these diseases.[262] For instance, the range of Lyme disease is expected to expand northward as the range of the deer tick that transmits it expands.[263] In another example, the frequency of hantavirus pulmonary syndrome outbreaks, caused by human exposure to the virus in deer mice urine or feces, may change with increasingly variable rainfall in the desert Southwest, which affects the populations of deer mice and other rodents through changes in production of the pine nuts on which they feed.[264]

Similarly, certain VBZD may decrease in particular regions as habitats become less suitable for host or vector populations and for sustained disease transmission. Coastal and marine ecosystems will be particularly impacted by increasing temperatures, changes in precipitation patterns, sea-level rise, altered salinity, ocean acidification, and more frequent and intense extreme weather events. These changes will directly and indirectly affect ocean and coastal ecosystems by influencing community structure, biodiversity, and the growth, survival, persistence, distribution, transmission, and severity of disease-causing organisms, vectors, and reservoirs.[265] Also of concern for both terrestrial and aquatic/marine ecosystems is the loss of biodiversity (which underlies ecosystem services) that further exacerbates the impacts of climate change on vectors or animal reservoir populations. Such alterations in ecosystem functions may alter the emergence of VBZD in populations within the United States. With the loss of predators, insect vectors may increase, making necessary either chemical or mechanical controls.

260 [illegible], et al., Environmental Health Perspectives, 2006. 114(4): p. 608-614.
261 [illegible] de Magny, G., et al., [illegible], 2009. [illegible]
262 Gage, K.L., et al., Am J Prev Med, 2008. 35(5): p. 436-50.
263 [illegible], Environ Health Perspect, [illegible]
264 Douglass, R.J., et al., Vector Borne Zoonotic Dis, 2001. 1(2): p. 115-22; Costello, A., et al., The Lancet, 2009. 373(9676): p. 1693-1733; Shi, [illegible], et al., Environmental Health Perspectives, 2006. 114(8): p. 1218-1224.
265 [illegible], et al., Environmental Health Perspectives, 2004. 112(9): p. 979-985.

Projecting VBZD incidence is difficult given the complexity of VBZD transmission cycles, the variability of regional and local impacts of climate change, and the limited information currently available regarding the ecology of many VBZD. For instance, while malaria transmission increases with temperature and humidity, the decrease in disease incidence seen with prolonged drought may negate these effects. Human rural and urban development efforts, such as the creation of clean water sources for animal husbandry or swamp clearance to increase availability of land for human settlement, also have significant impacts on transmission dynamics that can offset climate impacts.

The incidence of VBZD in the United States will likely increase under anticipated climate change scenarios, for several reasons. The distribution of vectors currently restricted to warmer climates will expand into the United States. For example, the habitats of two potent mosquito vectors of malaria, *Anopheles albimanus* and *Anopheles pseudopunctipennis*, currently range as far north as northern Mexico, and would presumably expand northwards across the U.S.–Mexico border.[266] The extrinsic incubation period of pathogens in invertebrate vectors is highly dependent on ambient temperature. Since the lifespan of vector species is relatively constant, changes in the incubation period due to precipitation and temperature significantly alter the likelihood of transmission.[267] Also, large disruption and subsequent movement of human populations create conditions for wider distribution of pathogens and greater exposure to vector species.[268] And, climate change is already affecting the biodiversity of marine and terrestrial ecosystems, which in turn will alter the dynamics of predator–prey relationships, as well as vector and reservoir pathogen populations. This may alter the types and quality of subsistence animal foods, and present dependent communities with new pathogen risks.[269] The time scale of this threat will be continuous unless mitigating measures are taken. Economic and regulatory restrictions continue to slow the development and use of new modes of action against vectors.

RESEARCH HIGHLIGHT continued

for treatment, and vector control strategies supported by strong scientific understanding, malaria continues to be a severe problem in Africa and a persistent one in Asia and Latin America. Malaria could present a threatened return to its former importance in more temperate climates.[1] Korea provides a recent case study with respect to the more chronic, less fatal species of the parasite, *Plasmodium vivax*.[2] Malaria became a severe problem on the Korean peninsula during and following the Korean War in 1950–1953. A combination of case detection, treatment, and vector control reduced the number of cases and finally eliminated the parasite from South Korea by 1988.[3] The disease reemerged in 1993 and quickly became a problem in the military population by 1996, with cases of temperate-adapted parasites exported to the United States.[4] Subsequent studies of the vector mosquitoes revealed that a complex of multiple species, including a powerful vector, *Anopheles anthropophagus* that is prevalent in China, is responsible for the reemergence. This reemergence may have been exacerbated by increases in severe rainfall events and temperature, but this has not yet been definitively established.[5]

The story is different in sub-Saharan Africa, where malaria is responsible for a large proportion of the infant and childhood mortality.[6] Researchers have examined whether the wider distribution of malaria in highland regions is associated with climate change, and have performed quantitative predictions of the effects of various climate change scenarios on distribution of the disease.[7] Climate change induced increases in temperature may have several effects: increase the altitude at which malaria transmission is possible, intensify transmission at lower altitudes, and generally make greater demands on the efficacy of vector control efforts.

1 Faust, E. in Malariology, a comprehensive survey of all aspects of this group of diseases from a global standpoint, MF Boyd, Editor. 1949, Saunders: Philadelphia. p. 2 v. (xx, 1643 p.)
2 Ree, HI, Korean J Parasitol, 2000. 38(3): p. 119-38.
3 Paik, YH, et al., Jpn J Exp Med. 1988. 58(2): p. 55-66.
4 Feighner, BH, et al., Emerg Infect Dis. 1998. 4(2): p. 295-7.
5 Foley, DH, et al., J Med Entomol. 2009. 46(3): p. 680-92.
6 WHO. Global Malaria Programme. 2008, Geneva: World Health Organization. xx, 190 p.
7 Ebi, KL, et al., Climatic Change, 2005. 73(3): p. 375-393; Thomson, MC, et al., Trends in Parasitology, 2001. 17(9): p. 438-445; Zhou, G, et al., Trends Parasitol, 2005. 21(2): p. 54-6.

266 Rogers, DJ, et al., Science, 2000. 289(5485): p. 1763-6.
267 Shickman, D, et al., American Journal of Tropical Medicine and Hygiene, 2003. 69(2): p. 202-212.
268 Sowlie, A. in Rickettsial diseases of man, a symposium, FR Moulton, Editor. 1948, American Association for the Advancement of Science: Washington, D.C. p. 247 p.
269 Niemi, G, et al., Environmental Health Perspectives, 2004. 112(9): p. 979-986; Jentsch, A, et al., Comptes Rendus Geoscience, 2008. 340(9-10): p. 621-628.

Mitigation and Adaptation

Climate change mitigation includes activities to reduce greenhouse gas emissions such as decreased reliance on fossil fuels for energy generation and transport and changes in land use such as reducing deforestation and conversion of forested land to cropland. Strategies focused on alternative energy sources with lower greenhouse gas emission profiles, such as nuclear power, may influence local ecologies by increasing water demands, temperature, and currents.[270, 271] This, in turn, might alter the life cycles of certain disease vectors and animals that are part of VBZD transmission cycles. Increased reliance on hydroelectric power, which typically requires construction of dams, also may change local VBZD ecologies and alter transmission cycles. Mitigation activities focused on land use changes, particularly preservation of forests and wetlands, are likely to impact VBZD ecology and transmission cycles as well.[270] For example, changes to wetlands may affect mosquito burden in certain areas by altering breeding area size and potentially altering the incidence of malaria, dengue, or other mosquito-borne diseases.[271] Because the margins of disturbed ecosystems can be associated with outbreaks of zoonotic infections such as Ebola and Marburg viruses,[272] ecosystem preservation may also reduce the incidence of these VBZD. The net impact, either beneficial or detrimental, of these mitigations strategies on human health is difficult to determine, and more research is needed to elucidate these effects.

Climate change adaptation strategies include activities that provide early warning and reduce exposure to environmental hazards associated with climate change, and limit susceptibility in exposed populations. Some adaptation activities may impact VBZD or alter the potential for human exposure. For example, encouraging air conditioning use as an adaptation strategy against extreme heat may provide a co-benefit of reduced exposure to VBZD. The use of central air conditioning has been shown to be a protective factor against dengue infection in studies comparing dengue incidence on opposite sides of the U.S.-Mexico border.[273] Negative impacts of adaptation are also possible. For example, capture and storage of water runoff to adapt to increasingly sporadic rainfall might provide more suitable breeding habitat for mosquitoes, thereby increasing incidence of West Nile virus and other VBZD.

270 Attwood, SW, Journal of Molluscan Studies, 1995. 61: p. 29-42; Nay, EH, et al., Journal of the American Mosquito Control Association, 1996. 12(3): p. 421-428; Mason, DR, et al., Science of the Total Environment, 1998. 216(3): p. 193-207.

271 Vasconcelos, CH, et al., Igarss 2005: IEEE International Geoscience and Remote Sensing Symposium, Vols 1-8, Proceedings, 2005: p. 4561-4569, 4610; Yamamoto, M, et al., Tropical Medicine & International Health, 2005. 10(12): p. 1274-1285.

272 [illegible], R, Arch Virol Suppl, 1997. 13: p. 191-199.

273 Brunkard, JM, et al., Emerging Infectious Diseases, 2007. 13(10): p. 1477-1483; Reiter, P, et al., Emerging Infectious Diseases, 2003. 9(1): p. 86-89.

Research Needs

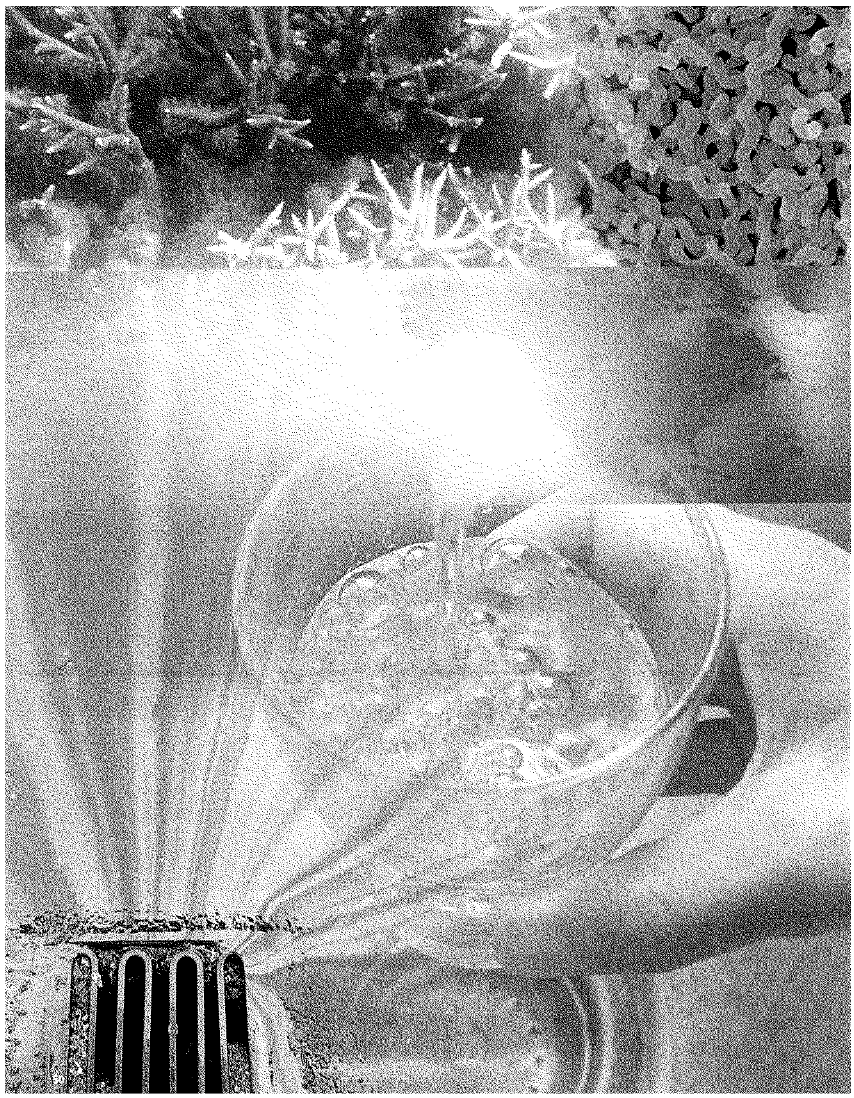
Given the potential for significant increases in the burden of VBZD as a result of climate change, public health preparation is required, and research needs include:

- understanding of VBZD transmission cycles and the impact of ecological management and disruption on VBZD transmission, including the impact of new and intensified selective pressures due to climate change
- developing methods to detect, quantify, characterize, and monitor potential VBZD transmission associated with changes in terrestrial, ocean, coastal, and Great Lakes environments
- developing and validating models of VBZD ecology that link established datasets of VBZD disease transmission, identify relevant climate-related patterns, and integrate downscaled climate projections of likely impacts
- understanding of secondary effects of climate change such as increased malnutrition, conflict, and population displacement on VBZD, and evaluation of the effectiveness of prevention strategies
- enhancing research on the effectiveness of novel personal disease prevention methods including vaccines, repellents, bed nets, chemoproprophylaxis, and others[274]
- developing new pesticides aimed at controlling disease vectors that combine the qualities of specificity (affecting only the target arthropods), adjustable persistence through formulation (chemically labile but persistent for useful periods), environmental safety (no bioaccumulation or effect on non-target organisms), low susceptibility to resistance (through either inherent physiology or effective resistance management techniques), and application to creative control strategies
- enhancing existing public health surveillance infrastructure to include longitudinal surveillance focused on the periphery of endemic areas to detect range expansion and on ports of entry (airports, seaports) where vectors may penetrate after long-distance travel
- enhancing existing animal health surveillance (both domestic animals and wildlife) and early detection of emerging diseases of animal origin with particular emphasis on increased human to wildlife contact

274 [illegible], D, et al. 2009, Oxford ; New York: Oxford University Press. xxx, 323 p., [8] p. of plates.

- developing early warning systems that integrate public and animal health surveillance, risk assessments, and mitigation and adaptation strategies related to VBZD transmission
- enhancing research on risk communication and prevention strategies related to VBZD outbreak response including evaluation of their effectiveness

The research needs identified for VBZD include crosscutting issues and opportunities for leveraging co-benefits. Enhanced surveillance capacity is transferable to other health categories. Deeper understanding of the ecology of VBZD will enable understanding of other ecosystems, and improve our ability to preserve ecosystem services and limit ecosystem mismanagement. Developing mathematical models of VBZD ecology and linking these models with downscaled climate projections will generate novel modeling methodologies, as well as new methods in spatial epidemiology and mapping, and enhance existing public health workforce capacity. Research into risk communication and prevention strategies for VBZD can be applied to other health risks, both climate-related and otherwise. Novel strategies for application of vector control will benefit public health and infrastructure development in general. Because vector abatement efforts require organization that reaches multiple levels (household, farm), such efforts will form an interactive customer base for the application of environmental tools such as spatial analysis and monitoring to other environmental services such as building code enforcement, water standards, and sanitation, as well as provide additional resources for gathering operational data on the status of populations.



10

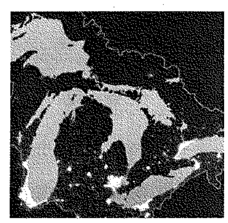
Waterborne Diseases

Waterborne diseases are caused by a wide variety of pathogenic microorganisms, biotoxins, and toxic contaminants found in the water we drink, clean with, play in, and are exposed to through other less direct pathways such as cooling systems. Waterborne microorganisms include protozoa that cause cryptosporidiosis, parasites that cause schistosomiasis, bacteria that cause cholera and legionellosis, viruses that cause viral gastroenteritis, amoebas that cause amoebic meningoencephalitis, and algae that cause neurotoxicity.[275] In the United States, the majority of waterborne disease is gastrointestinal, though waterborne pathogens affect most human organ systems and the epidemiology is dynamic. A recent shift has been seen in waterborne disease outbreaks from gastrointestinal toward respiratory infections such as that caused by *Legionella*, which lives in cooling ponds and is transmitted through air conditioning systems.[276] In addition to diarrheal disease, waterborne pathogens are implicated in other illnesses with immunologic, neurologic, hematologic, metabolic, pulmonary, ocular, renal and nutritional complications.[277] The World Health Organization estimates that 4.8% of the global burden of disease (as measured in disability-adjusted life years, or DALYs) and 3.7% of all mortality attributable to the environment is due to diarrheal disease.[278] Most of these diseases produce more serious symptoms and greater risk of death in children and pregnant women.[279]

For most waterborne pathogens in the United States, surveillance is spotty, diagnoses are not uniform, and our understanding of the impact of normal weather and climate variation on disease incidence, as well as illness and death burdens, is not firmly established. Impacts of any intensifying of climate events at local, regional, national, and global levels are a growing concern. Experts estimate that there is a high incidence of mild symptoms from waterborne pathogens and a relatively small, but not negligible mortality burden.[280]

275 Batterman, S., et al., Environ Health Perspect, 2009. 117(7): p. 1023-32.
276 Yoder, J., et al., MMWR Surveill Summ, 2008. 57(9): p. 39-62.
277 [illegible], P., J Water Health, 2006. 4 Suppl 1: p. 27-48.
278 Mathers, C., et al. 2008, Geneva, Switzerland: World Health Organization. vii, 146 p.
279 Ibid.
280 Craun, GF, et al. J Water Health, 2006. 4 Suppl 2: p. 101-19.

RESEARCH HIGHLIGHT



There is a clear association between increases in precipitation and outbreaks of waterborne disease, both domestically and globally. Climate change is expected to produce more frequent and severe extreme precipitation events worldwide. In the United States from 1948 to 1994, heavy rainfall correlated with more than half of the outbreaks of waterborne diseases.[1] Some of the largest outbreaks of waterborne disease in North America, particularly in the Great Lakes, have resulted after extreme rainfall events. For example, in May 2000, heavy rainfall in Walkerton, Ontario resulted in approximately 2,300 illnesses and seven deaths after the town's drinking water became contaminated with *E. coli* O157:H7 and *Campylobacter jejuni*.[2] There are 734 combined sewage and wastewater systems in and around the Great Lakes, with an estimated discharge of 850 billion gallons of untreated overflow water.[3] Using a suite of seven climate change models to project extreme precipitation events in the Great Lakes region, scientists have been able to estimate the potential impact of climate change on waterborne disease rates.[4] Their models predict more than 2.5 inches of rain in a single day will cause a combined sewer overflow into Lake Michigan, resulting in 50–100% more waterborne disease outbreaks in the region per year. Considering that the Great Lakes serves as the primary water source for over 40 million people and is surrounded by a number of large cities, both past events and these projections indicate a serious threat to public health in this region due to climate change alterations in the frequency of extreme precipitation.

1 Curriero, F.C., et al., Am J Public Health, 2001. 91(8): p. 1194-9.
2 Hrudey, S.E., et al., Water Science and Technology, 2003. 47(3): p. 7-14.
3 U.S. Environmental Protection Agency, Report to Congress: Impacts and Control of CSOs and SSOs. Office of Wastewater Management, 2004, US Environmental Protection Agency: Washington, DC.
4 Patz, J.A., et al., Am J Prev Med, 2008. 35(5): p. 451-8.

Globally, the impact of waterborne diarrheal disease is high and expected to climb with climate change. Improving domestic surveillance is a high priority, as this would enhance epidemiologic characterization of the drivers of epidemic disease. In particular, weather and climate-related drivers are not well understood. Waterborne disease outbreaks are highly correlated with extreme precipitation events,[281] but this correlation is based on limited research and needs further investigation and confirmation. Prevention and treatment strategies for waterborne disease are well established throughout the developed world; climate change is not likely to greatly impact the efficacy of these strategies in the United States. However, climate change is very likely to increase global diarrheal disease incidence, and changes in the hydrologic cycle including increases in the frequency and intensity of extreme weather events and droughts may greatly complicate already inadequate prevention efforts. Enhanced understanding and reinvigorated global prevention efforts are very important.

Ocean-related diseases are those associated with direct contact with marine waters (aerosolized in some cases) or sediments (including beach sands), ingestion of contaminated seafood, or exposure to zoonotics.[282] Pathogenic microorganisms (bacteria, viruses, protozoa, and fungi) that may occur naturally in ocean, coastal, and Great Lakes waters, or as a result of sewage pollution and runoff, are the primary etiologic agents.[283] Human exposure to these agents may result in a variety of infectious diseases including serious wound and skin infections, diarrhea, respiratory effects, and others.[284] Research has concluded that the antibiotic resistant methicillin resistant *Staphylococcus aureus* (MRSA) is persistent in both fresh and seawater and could become waterborne if released into these waters in sufficient quantities.[285] While this has yet to emerge as a significant public health concern, the potential for recreational exposure is significant, as people make nearly one billion trips to the beach annually in the United States alone. In contrast to diarrheal disease, there are few effective preventive strategies for marine-based environmental exposures beyond closing beaches to the public, and these areas need immediate additional research.

The effects of climate changes on the distribution and bioaccumulation of chemical contaminants in marine food webs are poorly understood and may be significant for vulnerable populations of humans and animals. The U.S. Climate Change Science Program (CCSP) reported a likely increase in the spread of waterborne pathogens depending on the pathogens' survival, persistence, habitat range, and transmission in a changing environment.[286] In one specific example, the CCSP noted the strong association between sea surface temperature and proliferation of many *Vibrio* species and suggested that rising temperatures would likely lead to increased occurrence of enteric disease associated with *Vibrio* bacteria (*V. cholerae, V. vulnificus,* and *V. parahaemolyticus)* in the United States, including the potential for the occurrence of cholera and wound infections. Further, recent findings demonstrate that pathogens that can pose disease risks to humans occur widely in marine vertebrates and regularly contaminate shellfish and aquacultured finfish.[287]

Impacts on Risk

Climate directly impacts the incidence of waterborne disease through effects on water temperature and precipitation frequency and intensity. These effects are pathogen and pollutant specific, and risks for human disease are markedly affected by local conditions, including regional water and sewage treatment capacities and practices. Domestic water treatment plants may be susceptible to climate change leading to human health risks. For example, droughts may cause problems with increased concentrations of effluent pathogens and overwhelm water treatment plants; aging water treatment plants are particularly at risk.[288] Urbanization of coastal regions may lead to additional nutrient, chemical, and pathogen loading in runoff.[289]

281 Curriero, FC, et al., Am J Public Health, 2001. 91(8): p. 1194-9.
282 Heaney, CD, et al., Am J Epidemiol, 2009. 170(2): p. 164-72.
283 Mok, L, et al., Environ Toxicol Chem, 2006. 25(12): p. 3110-7.
284 Stewart, JR, et al., Environ Health, 2008. 7 Suppl 2: p. S3.
285 Tolba, O, et al., Int J Hyg Environ Health, 2008. 211(3-4): p. 398-402.
286 Ebi, K, et al. in Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J. Gamble, et al., Editors. 2008. USEPA: Washington, D.C.
287 Moore, SK, et al., Environmental Health: A Global Access Science Source, 2008. 7(SUPPL. 2).
288 Fistermann, T, et al., Applied and Environmental Microbiology, 2002. 68(5): p. 2188-2192; Patz, JA, et al., Am J Prev Med, 2008. 35(5): p. 451-8; Semenza, HAL, et al., Water Science and Technology, 2007. 51(5): p. 53-59; Wiley, R, et al., Weather, 2005. 60(7): p. 206-211.
289 Dwight, RH, et al., American Journal of Public Health, 2004. 94(4): p. 565-567; Dwight, RH, et al., Water Environment Research, 2002. 74(1): p. 82-90; Semenza, JC, et al., Lancet Infectious Diseases, 2009. 9(6): p. 365-375.

Our understanding of weather and climate impacts on specific pathogens is incomplete. Climate also indirectly impacts waterborne disease through changes in ocean and coastal ecosystems including changes in pH, nutrient and contaminant runoff, salinity, and water security. These indirect impacts are likely to result in degradation of fresh water available for drinking, washing food, cooking, and irrigation, particularly in developing and emerging economies where much of the population still uses untreated surface water from rivers, streams, and other open sources for these needs. Even in countries that treat water, climate-induced changes in the frequency and intensity of extreme weather events could lead to damage or flooding of water and sewage treatment facilities, increasing the risk of waterborne diseases. Severe outbreaks of cholera, in particular, have been directly associated with flooding in Africa and India.[290] A rise in sea level, combined with increasingly severe weather events, is likely to make flooding events commonplace worldwide. A 40 cm rise in sea level is expected to increase the average annual numbers of people affected by coastal storm surges from less than 50 million at present to nearly 250 million by 2080.[291]

Several secondary impacts are also a concern. Ecosystem degradation from climate change will likely result in pressure on agricultural productivity, crop failure, malnutrition, starvation, increasing population displacement, and resource conflict, all of which are predisposing factors for increased human susceptibility and increased risk of waterborne disease transmission due to surface water contamination with human waste and increased contact with such waters through washing and consumption.[292,293]

Climate change may also affect the distribution and concentrations of chemical contaminants in coastal and ocean waters, for example through release of chemical contaminants previously bound up in polar ice sheets or sediments, through changes in volume and composition of runoff from coastal and watershed development, or through changes in coastal and ocean goods and services. Both naturally occurring and pollution-related ocean health threats will likely be exacerbated by climate change.[294] Other climate-related environmental changes may impact marine food webs as well, such as pesticide runoff, leaching of arsenic, fluoride, and nitrates from fertilizers, and lead contamination of drinking and recreational waters through excess rainfall and flooding.

Mitigation and Adaptation

Alternative energy production, carbon sequestration, and water reuse and recycling are some of the mitigation and adaptation options that could have the greatest implications for human health. As with all technologies, the costs and benefits of each will need to be carefully considered and the most beneficial implemented.

The potential impacts of different mitigation strategies for waterborne illness depend on the strategy. For instance, increased hydroelectric power generation will have significant impacts on local ecologies where dams are built, often resulting in increased or decreased incidence of waterborne disease, as was the case with schistosomiasis (increase) and haematobium infection (decrease) after construction of the Aswan Dam in Egypt.[295] Other modes of electric power generation, including nuclear, consume large quantities of water and have great potential environmental impacts ranging from increased water scarcity to discharge of warmed effluent into local surface water bodies. Shifting to wind and solar power, however, will reduce demand on surface waters and, therefore, limit impacts on local water ecosystems and potentially reduce risks of waterborne diseases. The impacts on waterborne pathogen ecology of other geoengineering mitigation strategies, such as carbon sequestration, have the potential to be substantial but are currently largely unknown.[296] Thorough health impact and environmental impact assessments are necessary prior to implementation and widespread adoption of any novel mitigation technology.

There is also significant potential for adaptation activities to impact the ecology of waterborne infectious disease. Certain adaptation strategies are likely to have a beneficial impact on water quality; for instance, protecting wetlands to reduce damage from severe storms.

290 Sidley, J, BMJ, 2008. 336(7642): p. 471; Sur, D, et al., Indian J Med Res, 2000. 112: p. 178-82.
291 [illegible], et al., Emerging Infectious Diseases, 2008. 15(9): p. [illegible].
292 [illegible], A, et al., American Journal of Tropical Medicine and Hygiene, [illegible].
293 [illegible], Ann. [illegible] Med, 2002. [illegible]: p. 33-41.
294 Sandifer, P, et al., Interagency oceans and human health research implementation plan: a prescription for the future. 2007, Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology: Washington, DC, USA.
295 Abdel-Wahab, MF, et al., Lancet, 1979. 2(8136): p. 242-4.
296 White, CM, et al., Energy & Fuels, 2005. 19(3): p. 659-724.

Under drought conditions, water reuse or the use of water sources that may be of lower quality is likely to increase.[297] Local water recycling and so-called grey-water reuse, as well as urban design strategies to increase green space and reduce runoff, may result in slower rates of water table depletion and reduce the impact of extreme precipitation events in urban areas where runoff is concentrated.

Other adaptation efforts may have both positive and negative effects. For instance, if the response to increasingly frequent and severe heat waves is widespread adoption of air conditioning, the associated increase in electricity demand will require additional power, which in turn could impact water availability and regional water ecology. In parts of the developing world, changing weather patterns and decreased food availability could lead to increased desertification, or at the least the need for more above-ground irrigation. If such projects are implemented in areas where parasitic diseases such as schistosomiasis are prevalent without close attention to potential ecosystem impacts, there may be changes in regional parasite transport and associated increases or decreases in human exposure.

Climate-induced changes to coastal ecosystems are poorly understood, especially with regard to ecosystem goods and services related to human health and well being, and ocean and coastal disease threats.[298] Interactions among climate change factors such as rising temperature, extreme weather events, inundation, ocean acidification, and changes in precipitation and runoff with coastal development, aquacultural practices, and other water use issues need to be studied.

Research Needs

The extent to which the United States is vulnerable to increased risk of waterborne diseases and ocean-related illness due to climate change has not been adequately addressed.[299] Research needs include:

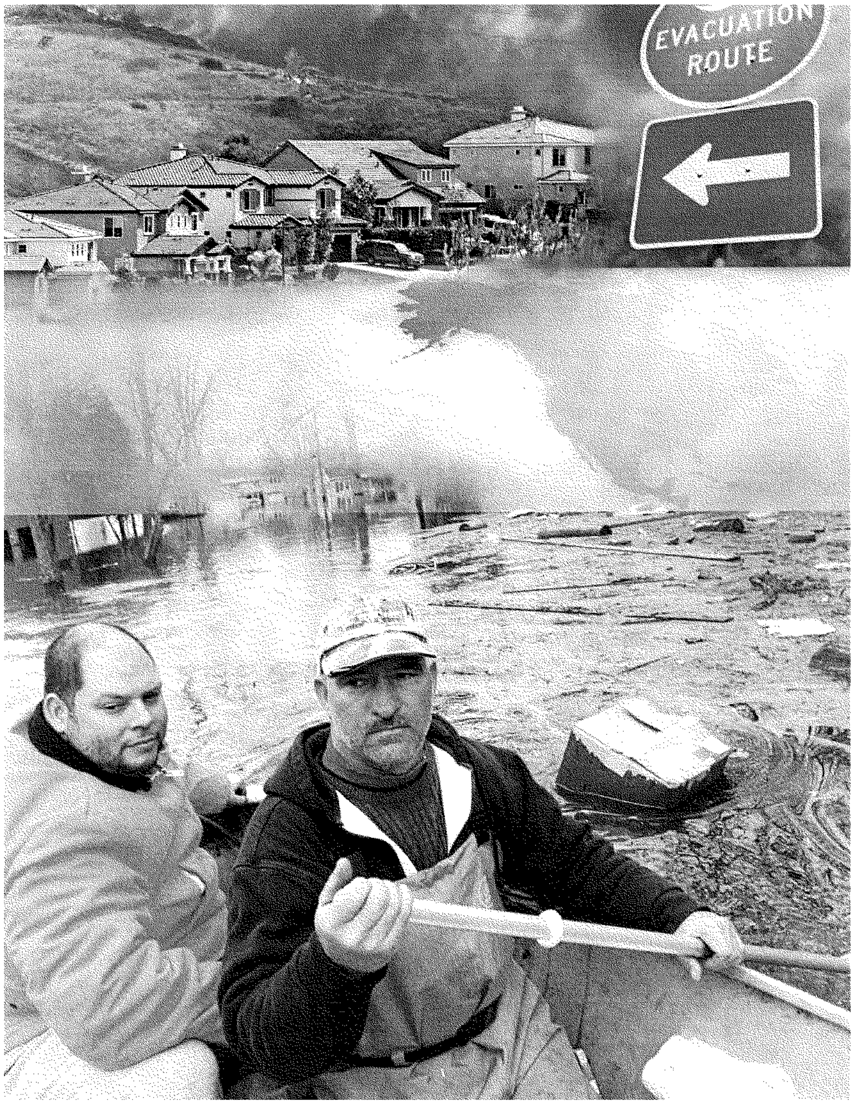
- understanding the likelihood and potential magnitude of waterborne disease outbreaks due to climate change including increases in the frequency and intensity of precipitation, temperature changes, extreme weather events, and storm surges
- researching the vulnerability of water systems to sewer overflow or flooding caused by extreme weather events, especially in water systems where there is already considerable water reuse; and examining the impacts of other water reuse and recycling strategies
- understanding how toxins, pathogens, and chemicals in land-based runoff and water overflow interact synergistically and with marine species, especially those important for human consumption, and the potential health risks of changing water quality
- developing means of identifying sentinel species for waterborne disease and understanding of how they may provide early warning of human health threats
- developing or improving vaccines, antibiotics and other preventive strategies to prevent and reduce the health consequences of waterborne disease on a global basis
- improving understanding of harmful algal blooms including their initiation, development, and termination, as well as the exact nature of the toxins associated with them

297 [illegible], et al., J Environ Qual, 2008. [illegible]

298 United States. Congress. Senate. Committee on Commerce Science and Transportation. 2005, Washington, U.S. G.P.O.

299 [illegible], et al., American Journal of Public Health, 2008. 98(3): p. 435-445; Ebi, K., et al. in Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J. Gamble, et al., Editors. 2008, USEPA: Washington, D.C.; Sandifer, P. et al., Interagency oceans and human health research implementation plan: a prescription for the future. 2007, Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology: Washington, DC, USA

- conducting epidemiologic studies on the occurrence and severity of ocean-related diseases among humans, especially high risk populations, in relation to climate change
- evaluating and monitoring exposures and health risks of chemical contaminants likely to be increasingly released and mobilized due to climate change
- improving methods to detect, quantify, and forecast ocean-related health threats including improved surveillance and monitoring of disease-causing agents in coastal waters; in marine organisms (especially seafood), aerosols, and sediments; and in exposed human populations
- assessing the capacity of the nation's public health infrastructure to detect and respond to increased waterborne disease incidence, and developing training and evaluation tools to address identified gaps


EVACUATION
ROUTE

11 Weather-Related Morbidity and Mortality

The United States experiences a variety of extreme weather events ranging from hurricanes and floods to blizzards and drought. Many of these events cause severe infrastructure damage and lead to significant morbidity and mortality. From 1940 to 2005, hurricanes caused approximately 4,300 deaths and flooding caused 7,000 deaths, primarily from injuries and drowning.[300] Climate change is expected to increase the frequency and intensity of some extreme weather events, including floods, droughts, and heat waves, though how these events will manifest on a regional level is uncertain.[301] The health impacts of these extreme weather events can be severe, and include both direct impacts such as death and mental health effects, and indirect impacts such as population displacement and waterborne disease outbreaks such as the 1993 Milwaukee cryptosporidium outbreak caused by flooding that sickened an estimated 400,000 people.[302,303]

The populations most at risk from such extreme events also are growing, particularly as a result of increased coastal development, as recent flooding events and hurricanes have shown. Sea-level rise associated with climate change will amplify the threat from storm surge associated with extreme weather events in coastal areas.[304] Other areas, such as the Southwest, are at risk for decreased agricultural productivity due to increased drought and possible compromise of potable water supplies due to flooding from heavy precipitation events.[305] Given the increased incidence of extreme weather events and the increasing number of people at risk, research in this area is an immediate and significant need. Preparation has a significant impact on outcomes of extreme weather events. Poor preparedness and response to Hurricane Katrina led to increased morbidity and mortality, as well as economic costs associated with recovery, which were estimated to be in excess of $150 billion.[306] By increasing research funding related to extreme weather events, increased preparedness levels could lower costs and minimize morbidity and mortality from future events.

Impacts on Risk

A changing climate coupled with changing demographics is expected to magnify the already significant adverse effects of extreme weather on public health. For example, the intensity and frequency of precipitation events in the United States have increased over the past 100 years in many locations.[307] In the Midwest and Northeastern United States, heavy rainfall events (defined as those in excess of 1 inch of rainfall) have increased by as much as 100%, and recent flooding events, such as the June 2008 flooding in the Midwest, have caused billions of dollars of damage and significant loss of life.[308] In line with this observed trend, there is a projected increase in intensity of precipitation events in some areas of the country, particularly in the Northeast, which has experienced a 67% increase in the amount of heavy precipitation events in the past 50 years.[309,310] Precipitation extremes also are expected to increase more than the mean. Regional variability appears to be increasing so that even though extreme precipitation events will become more common, some areas will concurrently experience drought, especially in the northeast and southwest.[311]

The intensity of extreme precipitation events is projected to increase with future warming.[312] This could limit the ability to capture and store water in reservoirs, leading to flash flooding events. Climate variability resulting from naturally occurring climate phenomena such as El Niño, La Niña, and global monsoons, are associated with extreme weather events around the globe.[313] El Niño and La Niña conditions lead to changes in the patterns of tropical rainfall

300 Ashley, ST, et al., Journal of Applied Meteorology and Climatology, 2008. 47(3): p. 805-818; National Weather Service, Summary of Natural Hazard Statistics for 2007 in the United States. 2007: Washington.

301 Greenough, G., et al., Environmental Health Perspectives, 2001. 109: p. 191-198; Trenberth, KE, et al., Bulletin of the American Meteorological Society, 2003. 84(9): p. 1205-+.

302 Mac Kenzie, WR, et al., N Engl J Med, 1994. 331(3): p. 161-7.

303 Greenough, G., et al., Environmental Health Perspectives, 2001. 109: p. 191-198; Mills, DM, Journal of Occupational and Environmental Medicine, 2009. 51(1): p. 26-32; Verger, P, et al., Journal of Exposure Analysis and Environmental Epidemiology, 2003. 13(6): p. 436-442.

304 Karl, T., et al., Weather and climate extremes in a changing climate regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands, in Synthesis and assessment product 3.3. 2008, U.S. Climate Change Science Program: Washington, DC. p. x, 162 p.

305 Ibid.

306 Burton, M., et al., Hurricane Katrina: Preliminary estimates of commercial and public sector damages. 2005, Center for Business and Economic Research, Marshall University: Huntington, WV.

307 Karl, T., et al. 2009, New York: Cambridge University Press; Kunkel, KE, Natural Hazards, 2003. 29(2): p. 291-305.

308 Black, N, Environmental Health Perspectives, 2008. 116(9): p. A390-+; Kunkel, KE, et al., Journal of Climate, 1999. 12(8): p. 2515-2527.

309 Kunkel, KE, Natural Hazards, 2003. 29(2): p. 291-305; Balling, RC, et al., Natural Hazards, 2003. 29(2): p. 103-112; Groisman, PY, et al., Climatic Change, 1999. 42(1): p. 243-283.

310 Meehl, G.A.e.S., T. F. and Collins, W. D. and Friedlingstein, A. T. and Gaye, A. T. and Gregory, J. M. and Kitoh, A. and Knutti, R. and Murphy, J. M. and Noda, A. and Raper, S. C. B. and Watterson, I. G. and Weaver, A. J. and Zhao, Z., in Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge ; New York. p. 747-845.

311 Christensen, JH, et al., Ibid; Hayhoe, K, et al., Climate Dynamics, 2007. 28(4): p. 381-407; Milly, PCD, et al., Nature, 2005. 438(7066): p. 347-350.

312 Meehl, G.A.e.S., T. F. and Collins, W. D. and Friedlingstein, A. T. and Gaye, A. T. and Gregory, J. M. and Kitoh, A. and Knutti, R. and Murphy, J. M. and Noda, A. and Raper, S. C. B. and Watterson, I. G. and Weaver, A. J. and Zhao, Z., in Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge ; New York. p. 747-845.

313 Karl, T., et al., Weather and climate extremes in a changing climate regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands, in Synthesis and assessment product 3.3. 2008, U.S. Climate Change Science Program: Washington, DC. p. x, 162 p.

and in the weather patterns in mid-latitudes, including changes in the frequency and intensity of weather extremes. El Niño is also projected to increase in both frequency and intensity as the climate warms, though there is uncertainty about the relative frequency of El Niño and La Niña in the future. Increased precipitation associated with stronger El Niño events would affect the Western United States, particularly California, the Pacific Northwest, and the Gulf Coast more than other regions of the country.[314]

Heavy precipitation events will be highly variable in magnitude, duration, and geographic location. Increased variability in weather and climate extremes is difficult to predict, and will impact the ability of human systems to manage for and adapt to heavy precipitation and flooding events. An observed divergence of precipitation patterns has lead to increased variability in the amount of precipitation per event, resulting in both extreme amounts of precipitation, as well as abnormally small precipitation events.[315] These effects have already been observed globally. A study in Germany found that winter storms from 1901 to 2000 showed an increasing trend of precipitation events both exceeding the 95th percentile and falling below the 5th percentile; while from 1956 to 2004 the Dongxiang River in China became increasingly likely to be at either extreme flood flow or abnormally low-flow.[316]

The current evidence is insufficient to determine if the frequency of tropical cyclones in the Atlantic Basin will change. The observed frequency of tropical cyclones in the Atlantic Basin has increased since the mid-1990s, though the numbers are not unprecedented and must be reconciled with active multi-decadal periods of the past, such as the 1950s and 1960s.[317] Increases in sea surface temperature and decreases in wind shear may lead to more intense Atlantic hurricanes, though some models also show a decrease in the number of intense hurricanes in the Atlantic Basin.

The spatial distribution of hurricanes also is likely to change, with storm surges becoming more damaging in areas unaccustomed to facing large hurricanes. The combination of sea-level rise with increasing storm intensity could lead to significant destruction of coastal infrastructure and more costly hurricanes.[318] In addition, flooding and coastal changes could lead to ecosystem changes such as loss of wetlands that could indirectly impact human health. Hurricane track forecasting and modeling methods have improved, and mortality rates for major storms have declined over time, but the combination of increased coastal population density, increased intensity of tropical storms, and sea-level rise will result in significantly increased risk going forward.[319]

Some models show that what were 20-year floods in 1860 in the United Kingdom are now 5-year floods; even greater impacts are expected in tropical regions.[320] In the United States, large floods are more frequent now than at the beginning of the 20th century.[321] Monsoon-related flooding results in damaged infrastructure, increased disease, and loss of life. During El Niño, areas includig Indonesia, southern Africa, northeastern Australia, and northeastern Brazil usually experience extensive periods of dry weather and warmer-than-average temperatures.[322] These conditions have historically resulted in a variety of adverse effects, such as mudslides, forest fires and resulting increased air pollution, mass migrations, and famines.[323]

Mitigation and Adaptation

Climate change mitigation includes activities that reduce greenhouse gas emissions. Important sources include land use changes, transport, energy production, and buildings. Some proposed mitigation strategies to reduce the occurrence of extreme weather events could impact human health. A reduction in personal automobile usage is one way to lower carbon emissions. However, a greater reliance on pubic transportation could either improve or reduce the ability to quickly evacuate a city prior to a severe weather event, depending on how it is managed. Mitigation activities related to land use may have other health impacts; anthropogenic reforestation, when combined with shifting weather patterns, could provide habitats for zoonotic and vectorborne diseases while reducing land available for agricultural uses. It is difficult to adequately evaluate the likely health impacts of various mitigation strategies, though Health Impact Assessments are proving a very useful public health tool for this purpose.

314 Ibid; Easterling, D.R., et al., Science, 2000. 289(5487): p. 2068-2074.

315 Jansson, A., et al., Comptes Rendus Geoscience, 2008. 340(9-10): p. 621-628; Christensen, J.H., et al., In Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge; New York. p. 747-845.

316 Zolina, O., et al., Theoretical and Applied Climatology, 2007. 90(1-4): p. 29-39; Wang, W., et al., Hydrology and Earth System Sciences, 2008. 12(1): p. 207-221.

317 Karl, T., et al., Weather and climate extremes in a changing climate regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands, in Synthesis and assessment product 3.3. 2008, U.S. Climate Change Science Program: Washington, DC. p. n. 162 p; Henderson-Sellers, A., et al., Bulletin of the American Meteorological Society, 1998. 79(1): p. 19-38; Knutson, T., et al., in Climate Extremes and Society. 2008, Cambridge University Press: Cambridge.

318 Meehl, G.A., et al., and Collins, W. D. and Friedlingstein, P. and Gaye, A. T. and Gregory, J. M. and Kitoh, A. and Knutti, R. and Murphy, J. M. and Noda, A. and Raper, S. C. B. and Watterson, I. G. and Weaver, A. J. and Zhao, Z., in Climate change 2007: the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge; New York. p. 747-845.

319 Rappaport, E.N., et al., Weather and Forecasting, 2009. 24(2): p. 395-419.

320 Allen, M.R., et al., Nature, 2002. 419(6903): p. 224-+.

321 Trenberth, K.E., et al., Bulletin of the American Meteorological Society, 2003. 84(9): p. 1205-+; Milly, P.C.D., et al., Nature, 2005. 438(7066): p. 347-350.

322 Karl, T., et al., Weather and climate extremes in a changing climate regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands, in Synthesis and assessment product 3.3. 2008, U.S. Climate Change Science Program: Washington, DC. p. n. 162 p.

323 Haines, A., Medecine Et Maladies Infectieuses, 1999. 29(5): p. 297-299.

There are several adaptation strategies for extreme weather events that have proven effective, including early warning systems, zoning and planning to avoid building in at-risk areas, reinforcing the built environment against hazardous weather events, and evacuation planning. While some strategies may be costly, they can be implemented over extended periods of time, defraying their costs. However, adaptation could be more difficult in some of the most heavily affected areas. For example, the population of many cities along the relatively high-risk U.S. Eastern seaboard has been growing in recent years and this growth is likely to continue. High population growth, typically associated with concentrations of critical infrastructure, in areas vulnerable to storm surges and sea-level rise will make adaptation difficult. Moreover, some adaptation activities intended to preserve existing infrastructure, such as building levees and other flood control measures, may have adverse ecological impacts and be prohibitively expensive. Alternatively, measures to fortify natural barriers to flooding and erosion and to buffer storm surge, such as wetlands and tidal marshes, will decrease the magnitude of adverse exposures and maintain associated ecosystem services such as food production and waste assimilation, thereby realizing potential co-benefits of climate change adaptation.

Research Needs

Due to the complexity of climate change and the health effects associated with climate variability and extreme weather, research needs in this area are diverse, and include:

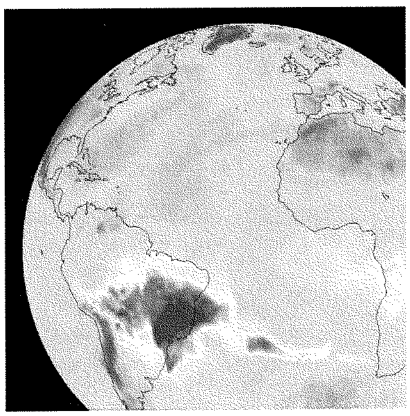
- exploring the impact of extreme precipitation events on waterborne disease, particularly cholera, and on the ecology of vectorborne and zoonotic disease
- improving understanding of extreme weather events associated with naturally occurring climate phenomena such as El Niño, La Niña, and monsoons, and their impacts on human health
- assessing the ability of health care systems to respond to extreme weather events and provide uninterrupted access to and delivery of health care services under a variety of scenarios
- improving understanding of how to anticipate and address food security and nutrition issues after extreme weather events, domestically and globally
- improving understanding of how to anticipate and address water quality and availability concerns associated with extreme weather events, domestically and globally
- developing strategies for linking health databases[324] with real-time monitoring and prospective assessment of weather, climate, geospatial, and exposure data[325] in order to better characterize the health impacts of extreme weather events
- improving the predictive power of probabilistic modeling of health effects of extreme events such as droughts, wildfires, and floods
- enhancing predictability, modeling, and ongoing assessment of the effects of climate variability and change (seasonal-to-interannual and decadal) on extreme events and correlation with short- and long-term health outcomes
- developing and validating downscaling techniques from global climate models to provide regional information for health early warning systems
- transitioning research advances into operational products and decision support tools for health early warning systems
- evaluating and improving the effectiveness of health alert warning systems and other health system risk communication tools such as evacuation protocols and National Disaster Management System activation, particularly for high-risk populations
- expanding research on prevention and preparedness for extreme weather events including development of disaster planning tools such as data and communication systems for public health and emergency care, including enhanced access to medical records and capabilities across hospitals on a regional level
- evaluating and developing new funding and reinsurance strategies and policies for disaster relief and rebuilding infrastructure

Weather related research intersects with several other areas of climate change research. Examples include waterborne and vectorborne illness following floods and hurricane storm surges, as well as post-traumatic stress disorder and related mental effects that can result from personal tragedy and displacement after extreme weather events. Studies of marine ecosystems and associated health impacts also overlap with extreme weather studies. Research in health communications and early warning systems is clearly applicable to periods proceeding and following weather disasters, as well as disaster preparedness and critical infrastructure development and protection

324 such as the databases maintained by the National Center for Health Statistics

325 such as the databases included in the Global Earth Observation System of Systems Initiative and those maintained by the US EPA and NOAA

Synthesis and Recommendations



There is abundant evidence that human activities are altering the earth's climate and that climate change will have significant health impacts both domestically and globally. While all of the changes associated with this process are not predetermined, the actions we take today will certainly help to shape our environment in the decades to come. Some degree of climate change is unavoidable, and we must adapt to its associated health effects; however, aggressive mitigation actions can significantly blunt the worst of the expected exposures. Still, there will be effects on the health of people in the United States, some of which are probably already underway. As great as the domestic risks to U.S. public health are, the global risks are even greater.

Climate change and health issues transcend national borders, and climate change health impacts in other countries are likely to affect health in the United States as well. Famine, drought, extreme weather events, and regional conflicts—all likely consequences of climate change—are some of the factors that increase the incidence and severity of disease, as well as contributing to other adverse health impacts, making it imperative to address climate change-related decision making at local, regional, national, and global levels. The complicated interplay of these and other factors must be considered in determining the scope and focus of both basic and applied research on climate change and health.

There are significant research needs to help direct adaptation activities and inform mitigation choices going forward. Such needs include integrating climate science with health science; integrating environmental, public health, and marine and wildlife surveillance; applying climate and meteorological observations to real-time public health issues; and down-scaling long-term climate models to estimate human exposure risks and burden of disease. Integrated data systems should incorporate a breadth of environmental parameters, as well as sociodemographic parameters such as population, income, and education.

Several overarching themes emerged during the creation of this document including: systems and complexity, risk communication and public health education, co-benefits of mitigation and adaptation strategies, and urgency and scope. These are discussed below.

Systems and Complexity. The complicated links between human and natural systems need to be better understood so public health agencies can develop evidence-based prevention strategies and the health care community can pursue secondary controls and respond to health incidents when prevention is not effective. Research on these links should focus not only on the direct health effects of climate change but also on the complex relationships between different exposure pathways and health risks. For example, people with compromised immune systems because of persistent organic pollutant exposure are likely to be at greater risk of infection and death from vectorborne, waterborne, and foodborne pathogens and disease. Similarly, people with respiratory illnesses such as asthma and chronic obstructive pulmonary disease are far more likely to suffer distress and hospitalization during extreme heat events, dust storms, or high pollen events than healthy people. Thus, the structure of basic research on health impacts should address the combined effects of multiple environmental changes and stressors, some caused by climate change and some by other factors, facilitating a robust public health and health care response.

Given the fundamental importance of ecosystems in climate change impacts and the significant roles that environmental factors play in human health, climate change and health research should also focus on the complex interplay between risk, location, and environmental conditions. Vulnerability and resilience to climate change health effects are both heavily determined by locality. A huge amount of diverse information will be needed at all governance levels (local, regional, national, global). Understanding local needs will be of greatest importance, given that effective adaptation strategies likely will not be universally applicable to all locations. However, there is also a need to identify common elements of strategies that may be generalized from one community to another. In addition, research is needed on how to identify common features of locales that will help identify them as having similar responses to climate change, how to determine and develop optimal strategies for interventions, and how to develop and implement communication tools that will effectively help communities respond to their particular situation.

Risk Communication and Public Health Education. Knowledge is one of the most strategic tools in reducing health problems in any environment; it allows us to understand what is harmful, why, and possibly how to avoid such harm. Research is critical, but knowledge that is not effectively communicated to appropriate audiences is wasted. Knowledge of the health impacts associated with climate change will have limited value without effective communication and education strategies to increase public awareness and understanding of the specific risks involved and the complexity of the issues. Communication with particularly vulnerable individuals and populations, as well as with health care professionals and public health officials tasked with protecting communities, is itself deserving of further research. For example, public health agencies already warn people with pulmonary diseases to avoid lengthy exposure outdoors on days of high ozone. Such warning systems might be more effective if delivered through multiple channels and tailored to individual health risks. Warnings on other harmful environmental exposures such as high pollen concentrations and extreme heat events should be expanded in geographic scope. For at-risk patients, warnings could be integrated into hospital and clinic discharge instructions or distributed with medications to more effectively prevent exacerbations of environmentally sensitive disease. Public health professionals need to be highly vigilant for opportunities to increase the range and impact of early warning systems on vulnerable populations. As our health care system is increasingly integrated and preventive health activities become more robust, there will be ever more opportunities to prevent adverse health effects associated with harmful environmental exposures. Risk communication efforts need to be culturally sensitive to provide appropriate and effective guidance, and potential interventions require testing and evaluation before they are implemented.

Mitigation and Adaptation. Considerable discussion currently focuses on identifying mitigation strategies that balance the economic costs of emission reductions (both direct mitigation costs and costs associated with loss of productivity) with the costs of environmental degradation from continuing business as usual. Examples of mitigation technologies include electric cars, alternative fuels, and green urban development. Cost-benefit evaluations typically express costs in economic terms rather than in terms of human morbidity and mortality, though these health impacts can be substantial. Many mitigation and adaptation strategies reach across health endpoints and may be both beneficial and problematic for a wide array of diseases.

Climate change health impacts are complicated and not always intuitive or unidirectional. For example, reducing reliance on fossil fuels in the transportation sector will substantially reduce CO_2 emissions, which over time will reduce the effects of climate change on human health. Thus, consideration of the costs of emissions reductions should include reduced health cost due to effective mitigation. Failing to mitigate also carries additional health consequences beyond those associated with climate change itself. For example, reducing vehicular emissions improves air quality, which may lessen incidences of effects such as airway diseases and irritations, cardiovascular disease, and cancer. However, further research, including life cycle analyses of batteries and other technologies, and human exposure to novel emission mixtures, is needed to avoid unintended negative consequences. If we choose not to reduce greenhouse gas emissions from transportation, levels of air pollution generated by vehicles will remain high and the cardiovascular, respiratory, and cancer morbidity and mortality associated with vehicular air pollution will continue and probably increase. This example illustrates the importance of understanding the potential co-benefits of climate change mitigation efforts so that optimal strategies can be implemented. Basic research on health and environmental factors and implementation research to develop new models and paradigms for burden-of-disease calculations are needed to allow for a careful use of health and economic cost indicators in the same evaluation. Health impact assessments are an important tool for evaluating the health impacts, both positive and negative, of possible mitigation strategies prior to widespread implementation.

Similarly, there is considerable need for study of broader adaptation issues that will affect many different groups. Examples of adaptation include use of air conditioning, weather alerts, and increased numbers of medical facilities. Of key interest are the health effects of adaptation practices in food, water, and chemical use. For example, regional water shortages will cause a greater intensity of recycling and reuse of water, with resulting increases in risks of human exposure to waterborne pollutants and pathogens. The genetic modification of plants to withstand altered environments and use less water could introduce changes in the allergenicity or toxicity of foods that are currently considered harmless. And use of pesticides whose residues may be harmful to both current and future generations may increase as a way of adapting to the effects of increasing temperatures and changing precipitation patterns that affect crop yields. Other adaptation efforts may have important health co-benefits that need to be identified. For example, adaptation efforts focusing on urban design, such as increasing urban albedo through green roofs, increasing urban tree cover, reducing the size of the urban heat island through compact development, and decreasing impervious surface runoff through use of permeable paving surfaces have been shown to have multiple co-benefits.

By no means a comprehensive list, the strategies discussed above illustrate the diversity in mitigation and adaptation possibilities, and it should be noted that many new ideas and options are being developed. As with all emerging technologies, it is important to holistically examine their effects on health, both positive and negative, so that the best options for society can be identified and adopted.

Scope and Urgency. The necessary research on climate change health impacts, the health effects of mitigation, and development of appropriate adaptation strategies will not occur spontaneously and cannot occur in isolation. To be successful, an overarching research program needs to be integrated, focused, interdisciplinary, supported, and sustainable, yet flexible enough to adjust to new information and broad enough to cover the very diverse components described in this document. The effort must also be multinational, multiagency, and multidisciplinary, bringing together the strengths of all partners. The effort also must promote user-driven research that closely aligns future research directions with the needs of decision makers by facilitating multi-directional dialogue among information producers, providers, and end users. This research will require capacity building in a number of areas, especially in climate sciences and disease and ecosystem surveillance necessary to support the health sciences as they grapple with these issues. Finally, both the efforts and the outcomes need to be evaluated using clear metrics that are linked to assessment questions and outcome indicators to ensure they are valid, effective, and achieve the desired goals.

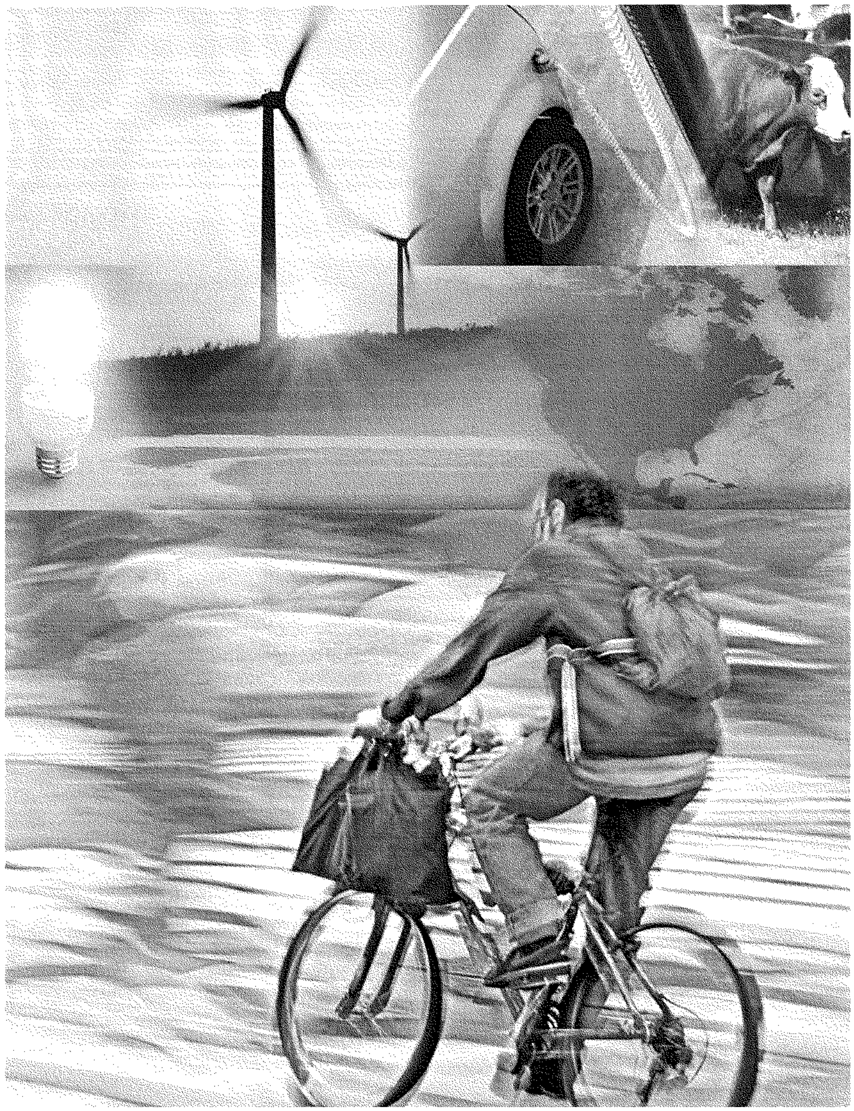
Natural systems adapt to environmental changes or they fail. Climate change threatens many of the natural and built systems that protect and preserve our nation's health. The infrastructure that we have put in place to protect health and provide well being in the United States is extremely diverse and includes hospitals, clinics, public health agencies, trained personnel, roads and transportation systems, the electrical grid, water treatment systems, and many other components. Threats to these systems from climate change range from damage to natural and built physical infrastructure to damage to intangible organizational structures (human and social capital) that are required to maintain resilience to environmental threats. Climate change could have grave impacts on public health systems if they are not appropriately strengthened. Research into the vulnerability of these systems will be critical to identifying areas most in need of attention, avoiding mistakes, limiting human suffering, and ultimately saving lives.

Summary Statement

Humans have successfully adapted to environmental change over time, from evolving natural physiological responses to the use of science, technology, and knowledge to improve our lives and advance our health. From the dawn of the industrial age, people have made great strides in improving health, and enjoy a markedly improved quality of life. However, these improvements have come at a cost that must now be understood and addressed. Climate change will force humans to negotiate with their changing environment as never before to find ways to reshape it both for short-term protection and long-term alleviation of health consequences.

There is no doubt that we have the capacity to find ways to avoid many of the worst health effects of climate change, and indeed, given the universality and potential magnitude of such effects, we have an ethical imperative to do so. The research needs described in this document should guide the process, helping us to develop the proper tools and make informed choices that will ultimately result in better health and better lives for the citizens of the United States and of the world.

Interagency Working Group on Climate Change and Health



Bibliography

Aagaard-Tillery, K.M., et al., *Developmental origins of disease and determinants of chromatin structure: maternal diet modifies the primate fetal epigenome.* Journal of Molecular Endocrinology, 2008. **41**(2): p. 91-102.

Abdel-Wahab, M.F., et al., *Changing pattern of schistosomiasis in Egypt 1935—79.* Lancet, 1979. **2**(8136): p. 242-4.

Abraham, W.M., et al., *Effects of inhaled brevetoxins in allergic airways: toxin-allergen interactions and pharmacologic intervention.* Environmental Health Perspectives, 2005. **113**(5): p. 632-637.

Adler, P. and W. Wills, *The history of arthropod-borne human disease in South Carolina.* American Entomologist, 2003. **49**: p. 216-228.

Ahn, Y.H., et al., *Application of satellite infrared data for mapping of thermal plume contamination in coastal ecosystem of Korea.* Marine Environmental Research, 2006. **61**(2): p. 186-201.

al-Harthi, S.S., et al., *Non-invasive evaluation of cardiac abnormalities in heat stroke pilgrims.* Int J Cardiol, 1992. **37**(2): p. 151-4.

Albrecht, G., et al., *Solastalgia: the distress caused by environmental change.* Australasian Psychiatry, 2007. **15**: p. S95-S98.

Allen, M.R. and W.J. Ingram, *Constraints on future changes in climate and the hydrologic cycle.* Nature, 2002. **419**(6903): p. 224-+.

Altevogt, B.M., S.L. Hanson, and A.I. Leshner, *Autism and the environment: Challenges and opportunities for research.* Pediatrics, 2008. **121**(6): p. 1225-1229.

American Heart Association. *Cardiovascular disease cost, 2009.* 2009 [cited 2009 July 22]; Available from: http://www.americanheart.org/presenter.jhtml?identifier=4475.

American Heart Association. *Cardiovascular disease statistics, 2006.* 2009 [cited 2009 July 22]; Available from: http://www.americanheart.org/presenter.jhtml?identifier=4478.

Antoni, M.H., et al., *The influence of bio-behavioural factors on tumour biology: pathways and mechanisms.* Nat Rev Cancer, 2006. **6**(3): p. 240-8.

Ashley, S.T. and W.S. Ashley, *Flood fatalities in the United States.* Journal of Applied Meteorology and Climatology, 2008. **47**(3): p. 805-818.

Attwood, S.W., *A Demographic-Analysis of Y-Neotricula Aperta (Gastropoda, Pomatiopsidae) Populations in Thailand and Southern Laos, in Relation to the Transmission of Schistosomiasis.* Journal of Molluscan Studies, 1995. **61**: p. 29-42.

Baccarelli, A., et al., *Exposure to particulate air pollution and risk of deep vein thrombosis.* Archives of Internal Medicine, 2008. **168**(9): p. 920-927.

Bacon, R.M., K.J. Kugeler, and P.S. Mead, *Surveillance for Lyme disease--United States, 1992-2006.* MMWR Surveill Summ, 2008. **57**(10): p. 1-9.

Balbus, J.M. and C. Malina, *Identifying vulnerable subpopulations for climate change health effects in the United States.* Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine, 2009. **51**(1): p. 33-37.

Ballester, F., J. Diaz, and J.M. Moreno, *[Climatic change and public health: scenarios after the coming into force of the Kyoto Protocol.].* Gac Sanit, 2006. **20 Suppl 1**: p. 160-74.

Balling, R.C. and R.S. Cerveny, *Compilation and discussion of trends in severe storms in the United States: Popular perception v. climate reality.* Natural Hazards, 2003. **29**(2): p. 103-112.

Barnett, A.G., *Temperature and cardiovascular deaths in the US elderly: changes over time.* Epidemiology, 2007. **18**(3): p. 369-72.

Bassil, K.L., et al., *Temporal and spatial variation of heat-related illness using 911 medical dispatch data.* Environmental Research, 2009. **109**(5): p. 600-606.

Bates, B., et al., *Climate change and water.* 2008, Intergovernmental Panel on Climate Change: Geneva. p. 210.

Batterman, S., et al., *Sustainable control of water-related infectious diseases: a review and proposal for interdisciplinary health-based systems research.* Environ Health Perspect, 2009. **117**(7): p. 1023-32.

Bedsworth, L., *Preparing for climate change: A perspective from local public health officers in California.* Environmental Health Perspectives, 2009. **117**(4): p. 617-623.

Beelen, R., et al., *Long-term exposure to traffic-related air pollution and lung cancer risk.* Epidemiology, 2008. **19**(5): p. 702-10.

Benson, V. and M.A. Marano, *Current estimates from the National Health Interview Survey, 1995.* Vital Health Stat 10, 1998. **190**. p. 1-428.

Black, H., *Unnatural disaster—Human factors in the Mississippi floods.* Environmental Health Perspectives, 2008. **116**(9): p. A390-+.

Black, P.H. and L.D. Garbutt, *Stress, inflammation and cardiovascular disease.* J Psychosom Res, 2002. **52**(1): p. 1-23.

Blanton, J.D., et al., *Rabies surveillance in the United States during 2007.* J Am Vet Med Assoc, 2008. **233**(6): p. 884-97.

Bocchi, E.A., et al., *Cardiomyopathy, adult valve disease and heart failure in South America.* Heart, 2009. **95**(3): p. 181-189.

Bolund, P. and S. Hunhammer, *Ecosystem services in urban areas.* Ecological Economics, 1999. **29**: p. 293-301.

Booth, S. and D. Zeller, *Mercury, food webs, and marine mammals: implications of diet and climate change for human health.* Environ Health Perspect, 2005. **113**(5): p. 521-6.

Bowker, G., et al., *The effects of roadside structures on the transport and dispersion of ultrafine particles from highways.* Atmospheric Environment, 2007. **41**: p. 8128-8139.

Boxall, A.B.A., et al., *Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture.* Environmental Health Perspectives, 2009. **117**(4): p. 508-514.

Brazel, A.J. and D. Quattrochi, *Urban Climates*, in *Encyclopedia of world climatology*, J.E. Oliver, Editor. 2005, Springer: Dordrecht, The Netherlands. p. xx, 854 p.

Brodie, E.C., et al., *Domoic acid causes reproductive failure in california sea lions (Zalophus californianus).* Marine Mammal Science, 2006. **22**(3): p. 700-707.

Bronstein, J., et al., *Meeting Report: Consensus Statement-Parkinson's Disease and the Environment: Collaborative on Health and the Environment and Parkinson's Action Network (CHE PAN) Conference 26-28 June 2007.* Environmental Health Perspectives, 2009. **117**(1): p. 117-121.

Brook, R.D., *Cardiovascular effects of air pollution.* Clinical Science, 2008. **115**(6): p. 175-187.

Brook, R.D., et al., *Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association.* Circulation, 2004. **109**(21): p. 2655-71.

Brunkard, J.M., et al., *Dengue fever seroprevalence and risk factors, Texas-Mexico border, 2004.* Emerging Infectious Diseases, 2007. **13**(10): p. 1477-1483.

Bukowski, J.A., *Review of the epidemiological evidence relating toluene to reproductive outcomes.* Regul Toxicol Pharmacol, 2001. **33**(2): p. 147-56.

Burke, K.E. and H. Wei, *Synergistic damage by UVA radiation and pollutants.* Toxicol Ind Health, 2009. **25**(4-5): p. 219-24.

Burton, M. and M. Hicks, *Hurricane Katrina: Preliminary estimates of commercial and public sector damages.* 2005, Center for Business and Economic Research, Marshall University: Huntington, WV.

Bytomski, J.R. and D.L. Squire, *Heat illness in children.* Curr Sports Med Rep, 2003. **2**(6): p. 320-4.

Campbell-Lendrum, D., et al., *Health and climate change: a roadmap for applied research.* The Lancet, 2009. **373**(9676): p. 1663-1665.

Campbell-Lendrum, D., R. Woodruff, and WHO, *Climate Change: quantifying the health impactat national and local levels.* Environmental Burden of Disease Series, ed. A. Pruss-Ustun and C. Corvalan. 2007, Geneva: World Health Organization. 66.

Carcavallo, R.U., *Climatic factors related to Chagas disease transmission.* Memorias Do Instituto Oswaldo Cruz, 1999. **94**: p. 367-369.

Carod-Artal, F.J., *Strokes caused by infection in the tropics.* Revista De Neurologia, 2007. **44**(12): p. 755-763.

Carroll, J.F., *A note on the occurrence of the lone star tick, Amblyomma americaoum in the greater Baltimore-Washington area.* Proc. of the Entomological Society of Washington, 2007. **109**(1): p. 253-256.

Carson, C., et al., *Declining vulnerability to temperature-related mortality in London over the 20th century.* Am J Epidemiol, 2006. **164**(1): p. 77-84.

Cassassa, G., et al., *Assessment of observed changes and responses in natural and managed systems.* 2007, Cambridge: Cambridge University Press.

CCSP, *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.*, T. Karl, et al., Editors. 2008, Department of Commerce, NOAA's National Climatic Data Center: Washington, DC, USA. p. 164.

CDC. *Birth Defects.* 2009 [cited 2009 July 22]; Available from: http://www.cdc.gov/ncbddd/bd/.

Centers for Disease Control and Prevention. *Leading causes of death, 2006.* 2009 [cited 2009 July 22]; Available from: http://www.cdc.gov/nchs/FASTATS/lcod.htm.

Chico, T.J., P.W. Ingham, and D.C. Crossman, *Modeling cardiovascular disease in the zebrafish.* Trends Cardiovasc Med, 2008. **18**(4): p. 150-5.

Christensen, J.H., et al., *Regional Climate Projections*, in *Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, Intergovernmental Panel on Climate Change., and Intergovernmental Panel on Climate Change. Working Group I., Editors. 2007, Cambridge University Press: Cambridge ; New York. p. 747-845.

Clougherty, J.E. and L.D. Kubzansky, *A framework for examining social stress and susceptibility to air pollution in respiratory health.* Environ Health Perspect, 2009. **117**(9): p. 1351-8.

Cohn, B.A., et al., *DDT and DDE exposure in mothers and time to pregnancy in daughters.* Lancet, 2003. **361**(9376): p. 2205-6.

Confalonieri, U., et al., *Human Health*, in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. Parry, et al., Editors. 2007, Cambridge University Press: Cambridge. p. 391-431.

Constantin de Magny, G. and R.R. Colwell, *Cholera and climate: a demonstrated relationship.* Trans Am Clin Climatol Assoc, 2009. **120**: p. 119-28.

Correa-Villaseñor A., et al., *The Metropolitan Atlanta Congenital Defects Program: 35 years of birth defects surveillance at the Centers for Disease Control and Prevention.* Birth Defects Res A Clin Mol Teratol, 2003. **67**(9): p. 617-24.

Corvalán, C., et al., *Ecosystems and human well-being : health synthesis.* 2005, [Geneva, Switzerland]: World Health Organization. 53 p.

Corwin, D.L. and S.A. Bradford, *Environmental impacts and sustainability of degraded water reuse.* J Environ Qual, 2008. **37**(5 Suppl): p. S1-7.

Costello, A., et al., *Managing the health effects of climate change. Lancet and University College London Institute for Global Health Commission.* The Lancet, 2009. **373**(9676): p. 1693-1733.

Costello, S., et al., *Parkinson's disease and residential exposure to maneb and paraquat from agricultural applications in the central valley of California.* Am J Epidemiol, 2009. **169**(8): p. 919-26.

Cox, J. and M. Krajden, *Cardiovascular Manifestations of Lyme-Disease.* American Heart Journal, 1991. **122**(5): p. 1449-1455.

Craun, G.F. and R.L. Calderon, *Observational epidemiologic studies of endemic waterborne risks: cohort, case-control, time-series, and ecologic studies.* J Water Health, 2006. **4 Suppl 2**: p. 101-19.

Crowley, C., *The mental health needs of refugee children: a review of literature and implications for nurse practitioners.* J Am Acad Nurse Pract, 2009. **21**(6): p. 322-31.

Curriero, F.C., et al., *Temperature and mortality in 11 cities of the eastern United States.* Am J Epidemiol, 2002. **155**(1): p. 80-7.

Curriero, F.C., *et al.*, *The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994*. Am J Public Health, 2001. **91**(8): p. 1194-9.

D'Amato G. and L. Cecchi, *Effects of climate change on environmental factors in respiratory allergic diseases*. Clinical and Experimental Allergy, 2008. **38**(8): p. 1264-1274.

D'Amato G., *et al.*, *The role of outdoor air pollution and climatic changes on the rising trends in respiratory allergy*. Respiratory Medicine, 2001. **95**(7): p. 606-611.

Davido, A., *et al.*, *Risk factors for heat related death during the August 2003 heat wave in Paris, France, in patients evaluated at the emergency department of the Hopital Europeen Georges Pompidou*. Emerg Med J, 2006. **23**(7): p. 515-8.

Davis, R.E., *et al.*, *Changing heat-related mortality in the United States*. Environmental Health Perspectives, 2003. **111**(14): p. 1712-1718.

Davis, R.E., *et al.*, *Decadal changes in heat-related human mortality in the eastern United States*. Climate Research, 2002. **22**(2): p. 175-184.

Department of Homeland Security. *The First Year After Hurricane Katrina: What the Federal Government Did*. . 2009 [cited 2009 July 22]; Available from: www.dhs.gov/xfoia/archives/gc_1157649340100.shtm.

Deschenes, O. and M. Greenstone, *Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US*, in *Center for the Study of Energy Markets Paper*. 2007, Center for the Study of Energy Markets: Santa Barbara, CA. p. 61.

Diaz, J.H., *The influence of global warming on natural disasters and their public health outcomes*. Am J Disaster Med, 2007. **2**(1): p. 33-42.

Dong, S., *et al.*, *UVA-Induced DNA single-strand cleavage by 1-hydroxypyrene and formation of covalent adducts between DNA and 1-hydroxypyrene*. Chem Res Toxicol, 2000. **13**(7): p. 585-93.

Douglass, R.J., C.H. Calisher, and K.C. Bradley, *State-by-state incidences of hantavirus pulmonary syndrome in the United States, 1993-2004*. Vector Borne Zoonotic Dis, 2005. **5**(2): p. 189-92.

Dunglison, R., *On the influence of atmosphere and locality; change of air and climate; seasons; food; clothing; bathing; exercise; sleep; corporeal and intellectual pursuits, &c. &c. on human health; constituting elements of hygiene*. 1835, Philadelphia,: Carey, Lea & Blanchard. xi, [13]-514 p.

Dwight, R.H., *et al.*, *Health effects associated with recreational coastal water use: Urban versus rural California*. American Journal of Public Health, 2004. **94**(4): p. 565-567.

Dwight, R.H., *et al.*, *Association of urban runoff with coastal water quality in Orange County, California*. Water Environment Research, 2002. **74**(1): p. 82-90.

Easterling, D.R., *et al.*, *Climate extremes: Observations, modeling, and impacts*. Science, 2000. **289**(5487): p. 2068-2074.

Ebi, K., *et al.*, *Effects of Global Change on Human Health*, in *Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, J. Gamble, *et al.*, Editors. 2008, USEPA: Washington, D. C.

Ebi, K.L., *et al.*, *Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983-1998*. Int J Biometeorol, 2004. **49**(1): p. 48-58.

Ebi, K.L., *et al.*, *Climate suitability for stable malaria transmission in Zimbabwe under different climate change scenarios*. Climatic Change, 2005. **73**(3): p. 375-393.

Ebi, K.L., *et al.*, *Climate change and human health impacts in the United States: An update on the results of the U.S. National Assessment*. Environmental Health Perspectives, 2006. **114**(9): p. 1318-1324.

Eisenman, D.P., *et al.*, *Disaster planning and risk communication with vulnerable communities: lessons from Hurricane Katrina*. Am J Public Health, 2007. **97 Suppl 1**: p. S109-15.

Ellis, F.P., *Heat illness. I. Epidemiology*. Trans R Soc Trop Med Hyg, 1976. **70**(5-6): p. 402-11.

Ericksen, P.J., J.S.I. Ingram, and D.M. Liverman, *Food security and global environmental change: emerging challenges*. Environmental Science and Policy, 2009. **12**(4): p. 373-377.

Eskenazi, B., *et al.*, *Pesticide toxicity and the developing brain*. Basic Clin Pharmacol Toxicol, 2008. **102**(2): p. 228-36.

Estrada-Peña A., *Increasing habitat suitability in the United States for the tick that transmits Lyme disease: a remote sensing approach*. Environ Health Perspect, 2002. **110**(7): p. 635-40.

Faust, E., *Malaria Incidence in North America*, in *Malariology; a comprehensive survey of all aspects of this group of diseases from a global standpoint*, M.F. Boyd, Editor. 1949, Saunders: Philadelphia,. p. 2 v. (xxi, 1643 p.).

Feighner, B.H., *et al.*, *Reemergence of Plasmodium vivax malaria in the republic of Korea*. Emerg Infect Dis, 1998. **4**(2): p. 295-7.

Fleming, L.E., *et al.*, *Aerosolized red-tide toxins (brevetoxins) and asthma*. Chest, 2007. **131**(1): p. 187-194.

Flower, K.B., *et al.*, *Cancer risk and parental pesticide application in children of Agricultural Health Study participants*. Environ Health Perspect, 2004. **112**(5): p. 631-5.

Foley, D.H., *et al.*, *Geographic distribution and ecology of potential malaria vectors in the Republic of Korea*. J Med Entomol, 2009. **46**(3): p. 680-92.

Ford, T.E., *et al.*, *Using Satellite Images of Environmental Changes to Predict Infectious Disease Outbreaks*. Emerging Infectious Diseases, 2009. **15**(9): p. 1341-1346.

Fouillet, A., *et al.*, *Excess mortality related to the August 2003 heat wave in France*. International Archives of Occupational and Environmental Health, 2006. **80**(1): p. 16-24.

Fouillet, A., *et al.*, *Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave*. Int J Epidemiol, 2008. **37**(2): p. 309-17.

Franzblau, A., *et al.*, *Residences with anomalous soil concentrations of dioxin-like compounds in two communities in Michigan, USA: A case study*. Chemosphere, 2009. **74**(3): p. 395-403.

Fritze, J.G., *et al.*, *Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing*. Int J Ment Health Syst, 2008. **2**(1): p. 13.

Frumkin, H., L.D. Frank, and R. Jackson, *Urban sprawl and public health : designing, planning, and building for healthy communities*. 2004, Washington, DC: Island Press. xxi, 338 p.

Frumkin, H., *et al.*, *Climate change: The public health response*. American Journal of Public Health, 2008. **98**(3): p. 435-445.

Fthenakis, V., *Overview of potential hazards*, in *Practical handbook of photovoltaics : fundamentals and applications*, T. Markvart and L. Castañer, Editors. 2003, Elsevier Advanced Technology: New York.

Fthenakis, V.M., H.C. Kim, and E. Alsema, *Emissions from photovoltaic life cycles*. Environ Sci Technol, 2008. **42**(6): p. 2168-74.

Gage, K.L., *et al.*, *Climate and vectorborne diseases*. Am J Prev Med, 2008. **35**(5): p. 436-50.

Gamble, J.L. and K.L. Ebi, *Analyses of the effects of global change on human health and welfare and human systems : final report, synthesis and assessment product 4.6 : report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. 2008, Washington, D.C.: U.S. Climate Change Science Program. ix, 204 p.

Garland, C.F., *et al.*, *Vitamin D for cancer prevention: global perspective*. Ann Epidemiol, 2009. **19**(7): p. 468-83.

Gohlke, J.M., S.H. Hrynkow, and C.J. Portier, *Health, economy, and environment: Sustainable energy choices for a nation*. Environmental Health Perspectives, 2008. **116**(6): p. A236-A237.

Gong, H., *et al.*, *Cardiovascular effects of ozone exposure in human volunteers*. American Journal of Respiratory and Critical Care Medicine, 1998. **158**(2): p. 538-546.

Gosling, S.N., *et al.*, *Associations between elevated atmospheric temperature and human mortality: A critical review of the literature*. Climatic Change, 2009. **92**(3-4): p. 299-341.

Gosse, P., *Twenty-five years of research in hydroecology at the EDF research & development division*. Houille Blanche-Revue Internationale De L Eau, 1999. **54**(3-4): p. 95-102.

Green, R.S., *et al.*, *Residential exposure to traffic and spontaneous abortion*. Environ Health Perspect, 2009. **117**(12): p. 1939-44.

Greenough, G., *et al.*, *The potential impacts of climate variability and change on health impacts of extreme weather events in the United States*. Environmental Health Perspectives, 2001. **109**: p. 191-198.

Gregory, P.J., *et al.*, *Integrating pests and pathogens into the climate change/food security debate*. J Exp Bot, 2009. **60**(10): p. 2827-38.

Groisman, P.Y., *et al.*, *Changes in the probability of heavy precipitation: Important indicators of climatic change*. Climatic Change, 1999. **42**(1): p. 243-283.

Gustin, M.S. and K. Ladwig, *An assessment of the significance of mercury release from coal fly ash*. J Air Waste Manag Assoc, 2004. **54**(3): p. 320-30.

Haines, A., *et al.*, *Climate change and human health: impacts, vulnerability, and mitigation*. Lancet, 2006. **367**(9528): p. 2101-2109.

Haines, A., *et al.*, *Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers*. Lancet, 2009.

Handal, A.J., *et al.*, *Neurobehavioral development in children with potential exposure to pesticides*. Epidemiology, 2007. **18**(3): p. 312-20.

Hardin, B.D., B.J. Kelman, and A. Saxon, *Adverse human health effects associated with molds in the indoor environment*. J Occup Environ Med, 2003. **45**(5): p. 470-8.

Hayhoe, K., *et al.*, *Emissions pathways, climate change, and impacts on California*. Proc Natl Acad Sci U S A, 2004. **101**(34): p. 12422-7.

Hayhoe, K., *et al.*, *Past and future changes in climate and hydrological indicators in the US Northeast*. Climate Dynamics, 2007. **28**(4): p. 381-407.

Heaney, C.D., *et al.*, *Contact with beach sand among beachgoers and risk of illness*. Am J Epidemiol, 2009. **170**(2): p. 164-72.

Henderson-Sellers, A., *et al.*, *Tropical cyclones and global climate change: A post-IPCC assessment*. Bulletin of the American Meteorological Society, 1998. **79**(1): p. 19-38.

Hendrie, H.C., *et al.*, *Alzheimer's disease, genes, and environment: The value of international studies*. Canadian Journal of Psychiatry-Revue Canadienne De Psychiatrie, 2004. **49**(2): p. 92-99.

Hill, J., *et al.*, *Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels*. Proc Natl Acad Sci U S A, 2006. **103**(30): p. 11206-10.

Hill, J., *et al.*, *Climate change and health costs of air emissions from biofuels and gasoline*. Proceedings of the National Academy of Sciences of the United States of America, 2009. **106**(6): p. 2077-2082.

Hollifield, M., *et al.*, *Measuring trauma and health status in refugees: a critical review*. Jama, 2002. **288**(5): p. 611-21.

Houghton, J.T. and Intergovernmental Panel on Climate Change. Working Group I., *Climate change 2001 : the scientific basis : contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change*. 2001, Cambridge ; New York: Cambridge University Press. x, 881 p.

Hrudey, S.E., *et al.*, *A fatal waterborne disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the developed world*. Water Science and Technology, 2003. **47**(3): p. 7-14.

Hunter, L.M., *Migration and environmental hazards*. Population and Environment, 2005. **26**(4): p. 273-302.

Institute of Medicine (U.S.). Committee on Achieving Sustainable Global Capacity for Surveillance and Response to Emerging Diseases of Zoonotic Origin. and G. Keusch, *Sustaining global surveillance and response to emerging zoonotic diseases*. 2009, Washington, DC: National Academies Press. xxv, 312 p.

Intergovernmental Panel on Climate Change. Working Group II., *Climate change 2007 : impacts, adaptation and vulnerability : contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. 2007, Cambridge: Cambridge University Press. ix, 976 p.

International Federation of Red Cross and Red Crescent Societies, *World Disaster Report 2009*, in *World Disaster Report*, L. Knight, Editor. 2009, International Federation of Red Cross and Red Crescent Societies: Geneva. p. 210.

Ito, S., T. Yokoyama, and K. Asakura, *Emissions of mercury and other trace elements from coal-fired power plants in Japan*. Sci Total Environ, 2006. **368**(1): p. 397-402.

Jentsch, A. and C. Beierkuhnlein, *Research frontiers in climate change: Effects of extreme meteorological events on ecosystems*. Comptes Rendus Geoscience, 2008. **340**(9-10): p. 621-628.

Jerrett, M., *et al.*, *Long-Term Ozone Exposure and Mortality*. New England Journal of Medicine, 2009. **360**(11): p. 1085-1095.

Jones, L., *et al.*, *Severe mental disorders in complex emergencies.* Lancet, 2009. **374**(9690): p. 654-61.

Kalkstein, L.S. and J.S. Greene, *An evaluation of climatelmortality relationships in large U.S. cities and the possible impacts of a climate change.* Environ Health Perspect, 1997. **105**(1): p. 84-93.

Kang, D., *et al.*, *Cancer incidence among pesticide applicators exposed to trifluralin in the Agricultural Health Study.* Environ Res, 2008. **107**(2): p. 271-6.

Kar, B.R., S.L. Rao, and B.A. Chandramouli, *Cognitive development in children with chronic protein energy malnutrition.* Behav Brain Funct, 2008. **4**: p. 31.

Karl, T., J. Melilo, and T. Peterson, *Global Climate ChangeImpacts in the United States.* 2009, New York: Cambridge University Press.

Karl, T., *et al.*, *Weather and climate extremes in a changing climate regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, in *Synthesis and assessment product 3.3.* 2008, U.S. Climate Change Science Program: Washington, DC. p. x, 162 p.

Kay, B.H., *et al.*, *Alphavirus infection in mosquitoes at the Ross River reservoir, north Queensland, 1990-1993.* Journal of the American Mosquito Control Association, 1996. **12**(3): p. 421-428.

Kessler, R.C., *et al.*, *Prevalence, severity, and comorbidity of 12-month DSM-IV disorders in the National Comorbidity Survey Replication.* Arch Gen Psychiatry, 2005. **62**(6): p. 617-27.

Kilbourne, E.M., *The spectrum of illness during heat waves.* Am J Prev Med, 1999. **16**(4): p. 359-60.

Kilbourne, E.M., *et al.*, *Risk factors for heatstroke. A case-control study.* JAMA, 1982. **247**(24): p. 3332-6.

Kim, Y.S., H.G. Choi, and K.W. Nam, *Seasonal variations of marine algal community in the vicinity of Uljin nuclear power plant, Korea.* Journal of Environmental Biology, 2008. **29**(4): p. 493-499.

Kirkpatrick, B., *et al.*, *Florida red tide and human health: a pilot beach conditions reporting system to minimize human exposure.* Sci Total Environ, 2008. **402**(1): p. 1-8.

Kistermann, T., *et al.*, *Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff.* . Applied and Environmental Microbiology, 2002. **68**(5): p. 2188-2197.

Knutson, T. and R. Tuleya, *ropical cyclones and climate change: revisiting recent studies at GFDL*, in *Culture Extremes and Society.* 2008, Cambridge University Press: Cambridge.

Komatsu, K., *et al.*, *Increase in coccidioidomycosis - Arizona,1998-2001 (Reprinted from MMWR, vol 52, pg 109, 2003).* Journal of the American Medical Association, 2003. **289**(12): p. 1500-1502.

Kotermanski, S.E. and J.W. Johnson, *Mg2+ imparts NMDA receptor subtype selectivity to the Alzheimer's drug memantine.* J Neurosci, 2009. **29**(9): p. 2774-9.

Kovats, R.S. and S. Hajat, *Heat stress and public health: A critical review*, in *Annual Review of Public Health.* 2008. p. 41-55.

Kozma, C., *Neonatal toxicity and transient neurodevelopmental deficits following prenatal exposure to lithium: Another clinical report and a review of the literature.* Am J Med Genet A, 2005. **132**(4): p. 441-4.

Krewski, D., *et al.*, *Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality.* Res Rep Health Eff Inst, 2009(140): p. 5-114; discussion 115-36.

Kreyling, W.G., M. Semmler-Behnke, and W. Moller, *Ultrafine particle-lung interactions: does size matter?* J Aerosol Med, 2006. **19**(1): p. 74-83.

Krousel-Wood, M.A., *et al.*, *Medication adherence in older clinic patients with hypertension after Hurricane Katrina: Implications for clinical practice and disaster management.* American Journal of the Medical Sciences, 2008. **336**(2): p. 99-104.

Kunkel, K.E., *North American trends in extreme precipitation.* Natural Hazards, 2003. **29**(2): p. 291-305.

Kunkel, K.E., K. Andsager, and D.R. Easterling, *Long-term trends in extreme precipitation events over the conterminous United States and Canada.* Journal of Climate, 1999. **12**(8): p. 2515-2527.

Kysely, J., *et al.*, *Excess cardiovascular mortality associated with cold spells in the Czech Republic.* BMC Public Health, 2009 Jan 15;**9**:19.

Lake, I.R., *et al.*, *A re-evaluation of the impact of temperature and climate change on foodborne illness.* Epidemiol Infect, 2009. **137**, p. 1538–1547.

Landrigan, P.J., *et al.*, *The National Children's Study: a 21-year prospective study of 100,000 American children.* Pediatrics, 2006. **118**(5): p. 2173-86.

Law, D.C., *et al.*, *Maternal serum levels of polychlorinated biphenyls and 1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene (DDE) and time to pregnancy.* Am J Epidemiol, 2005. **162**(6): p. 523-32.

Le Tertre, A., *et al.*, *Short-term effects of particulate air pollution on cardiovascular diseases in eight European cities.* J Epidemiol Community Health, 2002. **56**(10): p. 773-9.

Lefebvre, K.A., *et al.*, *Gene expression profiles in zebrafish brain after acute exposure to domoic acid at symptomatic and asymptomatic doses.* Toxicol Sci, 2009. **107**(1): p. 65-77.

LeGuenno, B., *Haemorrhagic fevers and ecological perturbations.* Arch Virol Suppl, 1997. **13**: p. 191-9.

Leiserowitz, A., E. Maibach, and C. Roser-Renouf, *Climate change in the American mind: Americans' climate change beliefs, attitudes, policy preferences, and actions.* 2009, Yale Project on Climate Change, Scool of Forestry and Environmental Sciences: New Haven, Connecticut. p. 56.

Leor, J., W.K. Poole, and R.A. Kloner, *Sudden cardiac death triggered by an earthquake.* New England Journal of Medicine, 1996. **334**(7): p. 413-419.

Longnecker, M.P., *et al.*, *Maternal serum level of 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene and risk of cryptorchidism, hypospadias, and polythelia among male offspring.* Am J Epidemiol, 2002. **155**(4): p. 313-22.

Longnecker, M.P., *et al.*, *Maternal serum level of the DDT metabolite DDE in relation to fetal loss in previous pregnancies.* Environ Res, 2005. **97**(2): p. 127-33.

Lovell, M.A., *A potential role for alterations of zinc and zinc transport proteins in the progression of Alzheimer's disease.* J Alzheimers Dis, 2009. **16**(3): p. 471-83.

Luber, G. and M. McGeehin, *Climate change and extreme heat events.* Am J Prev Med, 2008. **35**(5): p. 429-35.

Lynch, S.M., *et al.*, *Cancer incidence among pesticide applicators exposed to butylate in the Agricultural Health Study (AHS).* Environ Res, 2009. **109**(7): p. 860-8.

Mac Kenzie, W.R., *et al.*, *A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply.* N Engl J Med, 1994. **331**(3): p. 161-7.

Macdonald, R.W., T. Harner, and J. Fyfe, *Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data.* Sci Total Environ, 2005. **342**(1-3): p. 5-86.

Macdonald, R.W., *et al.*, *How will global climate change affect risks from long-range transport of persistent organic pollutants?* Human and Ecological Risk Assessment, 2003. **9**(3): p. 643-660.

Mahajan, R., *et al.*, *Fonofos exposure and cancer incidence in the agricultural health study.* Environ Health Perspect, 2006. **114**(12): p. 1838-42.

Maibach, E., C. Roser-Renouf, and A. Leiserowitz, *Global warming's six Americas 2009: An audience segmentation analysis.* 2009, George Mason University Center for Climate Change Communication: Washington, DC. p. 140.

Mann, J.K., *et al.*, *Air pollution and hospital admissions for ischemic heart disease in persons with congestive heart failure or arrhythmia.* Environmental Health Perspectives, 2002. **110**(12): p. 1247-1252.

Mannino, D.M., *et al.*, *Surveillance for asthma—United States, 1960-1995.* MMWR CDC Surveill Summ, 1998. **47**(1): p. 1-27.

Martin-Latry, K., *et al.*, *Psychotropic drugs use and risk of heat-related hospitalisation.* Eur Psychiatry, 2007. **22**(6): p. 335-8.

Massachusetts Institute of Technology., *The Future of nuclear power : an interdisciplinary MIT Study.* 2003, [Boston MA]: MIT. x, 170 p.

Maszle, D.R., *et al.*, *Hydrological studies of schistosomiasis transport in Sichuan Province, China.* Science of the Total Environment, 1998. **216**(3): p. 193-203.

Mathers, C., *et al.*, *The global burden of disease : 2004 update.* 2008, Geneva, Switzerland: World Health Organization. vii, 146 p.

Mathers, J.C., *Early nutrition: Impact on epigenetics.* Nutrigenomics - Opportunities in Asia, 2007. **60**: p. 42-48.

Maucher, J.M. and J.S. Ramsdell, *Maternal-fetal transfer of domoic acid in rats at two gestational time points.* Environmental Health Perspectives, 2007. **115**(12): p. 1743-1746.

Mayeux, R., *Dissecting the relative influences of genes and the environment in Alzheimer's disease.* Annals of Neurology, 2004. **55**(2): p. 156-158.

McAloose, D. and A.L. Newton, *Wildlife cancer: a conservation perspective.* Nat Rev Cancer, 2009. **9**(7): p. 517-26.

McCormick, R.L., *The impact of biodiesel on pollutant emissions and public health.* Inhalation Toxicology, 2007. **19**(12): p. 1033-1039.

McGeehin, M.A. and M. Mirabelli, *The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States.* Environ Health Perspect, 2001. **109 Suppl 2**: p. 185-9.

McLaughlin, J.B., *et al.*, *Outbreak of Vibrio parahaemolyticus gastroenteritis associated with Alaskan oysters.* N Engl J Med, 2005. **353**(14): p. 1463-70.

McMichael, A.J., R.E. Woodruff, and S. Hales, *Climate change and human health: Present and future risks.* Lancet, 2006. **367**(9513): p. 859-869.

McPherson, E., *et al.*, *Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project.* . Urban Ecosystems, 1997. **1**: p. 49-61.

McQuiston, J.H., *et al.*, *National surveillance and the epidemiology of human Q fever in the United States, 1978-2004.* Am J Trop Med Hyg, 2006. **75**(1): p. 36-40.

Mead, P.S., *et al.*, *Food-related illness and death in the United States.* Emerg Infect Dis, 1999. **5**(5): p. 607-25.

Meehl, G.A. and C. Tebaldi, *More intense, more frequent, and longer lasting heat waves in the 21st century.* Science, 2004. **305**(5686): p. 994-7.

Meehl, G.A.a.S., T. F. and Collins, W. D. and Friedlingstein, A. T. and Gaye, A. T. and Gregory, J. M. and Kitoh, A. and Knutti, R. and Murphy, J. M. and Noda, A. and Raper, S. C. B. and Watterson, I. G. and Weaver, A. J. and Zhao, Z., *Global CLimate Projections*, in *Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, Intergovernmental Panel on Climate Change., and Intergovernmental Panel on Climate Change. Working Group I., Editors. 2007, Cambridge University Press: Cambridge ; New York. p. 747-845.

Meinhardt, P.L., *Recognizing waterborne disease and the health effects of water contamination: a review of the challenges facing the medical community in the United States.* J Water Health, 2006. **4 Suppl 1**: p. 27-34.

Mendes, C.T., *et al.*, *Lithium reduces Gsk3b mRNA levels: implications for Alzheimer Disease.* Eur Arch Psychiatry Clin Neurosci, 2009. **259**(1): p. 16-22.

Merchandani, H., *et al.*, *Heat-Related Deaths - United-States, 1993 (Reprinted from Mmwr, Vol 42, 558-560, 1993).* ournal of the American Medical Association, 1993. **270**(7): p. 810-810.

Milan, D.J., *et al.*, *Drug-sensitized zebrafish screen identifies multiple genes, including GINS3, as regulators of myocardial repolarization.* Circulation, 2009. **120**(7): p. 553-9.

Miller, D.B. and J.P. O'Callaghan, *Do early-life insults contribute to the late-life development of Parkinson and Alzheimer diseases?* Metabolism, 2008. **57 Suppl 2**: p. S44-9.

Mills, D.M., *Climate Change, Extreme Weather Events, and US Health Impacts: What Can We Say?* Journal of Occupational and Environmental Medicine, 2009. **51**(1): p. 26-32.

Mills, E., *et al.*, *Prevalence of mental disorders and torture among Bhutanese refugees in Nepal: a systemic review and its policy implications.* Med Confl Surviv, 2008. **24**(1): p. 5-15.

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia, *Global pattern of trends in streamflow and water availability in a changing climate.* Nature, 2005. **438**(7066): p. 347-350.

Moore, S.K., *et al.*, *Impacts of climate variability and future climate change on harmful algal blooms and human health.* Environmental Health: A Global Access Science Source, 2008. **7**(SUPPL. 2).

Morabito, M., *et al.*, *Relationships between weather and myocardial infarction: A biometeorological approach.* International Journal of Cardiology, 2005. **105**(3): p. 288-293.

Mos, L., *et al.*, *Chemical and biological pollution contribute to the immunological profiles of free-ranging harbor seals.* Environ Toxicol Chem, 2006. **25**(12): p. 3110-7.

Myers, N., *Environmental refugees: a growing phenomenon of the 21st century.* Philos Trans R Soc Lond B Biol Sci, 2002. **357**(1420): p. 609-13.

Naeem, F., *et al.*, *Psychiatric morbidity among Afghan refugees in Peshawar, Pakistan.* J Ayub Med Coll Abbottabad, 2005. **17**(2): p. 23-5.

Narukawa, T., *et al.*, *Investigation on chemical species of arsenic, selenium and antimony in fly ash from coal fuel thermal power stations.* J Environ Monit, 2005. **7**(12): p. 1342-8.

National Cancer Institute. *Lung Cancer.* 2009 [cited 2009 July 26]; Available from: http://www.cancer.gov/cancertopics/types/lung.

National Cancer Institute. *What is cancer?* 2009 [cited 2009 July 21]; Available from: http://www.cancer.gov/cancertopics/what-is-cancer.

National Research Council (U.S.). Committee on Ecological impacts of Climate Change., *Ecological impacts of climate change.* 2008, Washington, D.C.: National Academies Press. xii, 57 p.

National Research Council (U.S.). Committee On Health, E., And Other External Costs And, Benefits Of Energy Production And Consumption., and National Research Council (U.S.). Board on environmental studies and toxicology., *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use.* Board on Environmental Studies and Toxicology special report. 2009, Washington, D.C.: Board on Environmental Studies and Toxicology.

National Research Council (U.S.). Committee on Strategic Advice on the U.S. Climate Change Science Program., *et al.*, *Restructuring federal climate research to meet the challenges of climate change.* 2009, Washington, D.C.: National Academies Press. xii, 254 p.

National Weather Service, *Summary of Natural Hazard Statistics for 2007 in the United States.* 2007: Washington.

Niemi, G., *et al.*, *Rationale for a new generation of indicators for coastal waters.* Environmental Health Perspectives, 2004. **112**(9): p. 979-986.

Nord, M., M. Andrews, and S. Carlson, *Hosehold food security in the United States, 2008*, E.R. Service, Editor. November, 2009, US Department of Agriculture: Washington, DC.

Nowak, D., D. Crane, and J. Stevens, *Air pollution removal by urban trees and shrubs in the United States.* Urban Forestry and Urban Greening, 2006. **4**: p. 115-123.

Noyes, P.D., *et al.*, *The toxicology of climate change: Environmental contaminants in a warming world.* Environment International, 2009. **35**(6): p. 971-986.

NTP Report on Carcinogens. Rep Carcinog, 2005(11).

O'Neill MS., *et al.*, *Air pollution and inflammation in type 2 diabetes: a mechanism for susceptibility.* Occupational and Environmental Medicine, 2007. **64**(6): p. 373-379.

Orenstein, W.A., *et al.*, *Immunizations in the United States: success, structure, and stress.* Health Aff (Millwood), 2005. **24**(3): p. 599-610.

Paerl, H.W. and J. Huisman, *Climate. Blooms like it hot.* Science, 2008. **320**(5872): p. 57-8.

Paik, Y.H., H.I. Ree, and J.C. Shim, *Malaria in Korea.* Jpn J Exp Med, 1988. **58**(2): p. 55-66.

Papanikolaou, N.C., *et al.*, *Lead toxicity update. A brief review.* Med Sci Monit, 2005. **11**(10): p. RA329-36.

Park, S.K., *et al.*, *Cancer incidence among paraquat exposed applicators in the agricultural health study: prospective cohort study.* Int J Occup Environ Health, 2009. **15**(3): p. 274-81.

Patz, J., *et al.*, *Health impact assessment of global climate change: Expanding on comparative risk assessment approaches for policy making*, in *Annual Review of Public Health*. 2008. p. 27-39.

Patz, J.A., *et al.*, *Impact of regional climate change on human health.* Nature, 2005. **438**(7066): p. 310-7.

Patz, J.A., *et al.*, *Climate change and waterborne disease risk in the Great Lakes region of the U.S.* Am J Prev Med, 2008. **35**(5): p. 451-8.

Pavlin, B.I., L.M. Schloegel, and P. Daszak, *Risk of importing zoonotic diseases through wildlife trade, United States.* Emerg Infect Dis, 2009. **15**(11): p. 1721-6.

Peters, A., *et al.*, *Increased particulate air pollution and the triggering of myocardial infarction.* Circulation, 2001. **103**(23): p. 2810-2815.

Petri, W.A., Jr., *America in the world: 100 years of tropical medicine and hygiene.* Am J Trop Med Hyg, 2004. **71**(1): p. 2-16.

Piver, W.T., *et al.*, *Temperature and air pollution as risk factors for heat stroke in Tokyo, July and August 1980-1995.* Environ Health Perspect, 1999. **107**(11): p. 911-6.

Planton, S., *Global warming and El Nino: a review of the current knowledge.* Medecine Et Maladies Infectieuses, 1999. **29**(5): p. 267-276.

Pope, C.A., 3rd, *et al.*, *Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution.* JAMA, 2002. **287**(9): p. 1132-41.

Pope, C.A. and D.W. Dockery, *Health effects of fine particulate air pollution: Lines that connect.* Journal of the Air & Waste Management Association, 2006. **56**(6): p. 709-742.

Potapova, M. and P. Snoeijs, *The natural life cycle in wild populations of Diatoma moniliformis (Bacillariophyceae) and its disruption in an aberrant environment.* Journal of Phycology, 1997. **33**(6): p. 924-937.

Pradat, P., *et al.*, *First trimester exposure to corticosteroids and oral clefts.* Birth Defects Res A Clin Mol Teratol, 2003. **67**(12): p. 968-70.

Prüss-Üstün, A., C. Corvalán, and World Health Organization., *Preventing disease through healthy environments : towards an estimate of the environmental burden of disease.* 2006, Geneva, Switzerland: World Health Organization. 104 p.

Qian Z, *et al.*, *High temperatures enhanced acute mortality effects of ambient particle pollution in the "Oven" city of Wuhan, China.* Environmental Health Perspectives, 2008. **116**(9): p. 1172-1178.

Quinn, J.F., *et al.*, *Copper in Alzheimer's disease: too much or too little?* Expert Rev Neurother, 2009. **9**(5): p. 631-7.

Ramsdell, J.S. and T.S. Zabka, *In utero domoic acid toxicity: a fetal basis to adult disease in the California sea lion (Zalophus californianus).* Marine Drugs, 2008. **6**(2): p. 262-90.

Rappaport, E.N., *et al.*, *Advances and Challenges at the National Hurricane Center.* Weather and Forecasting, 2009. **24**(2): p. 395-419.

Ree, H.I., *Unstable vivax malaria in Korea.* Korean J Parasitol, 2000. **38**(3): p. 119-38.

Reiter, P., *et al.*, *Texas lifestyle limits transmission of dengue virus.* Emerging Infectious Diseases, 2003. **9**(1): p. 86-89.

Ren, C., *et al.*, *Ozone modifies associations between temperature and cardiovascular mortality: analysis of the NMMAPS data.* Occupational and Environmental Medicine, 2008. **65**(4): p. 255-260.

Ribas-Fitó N., *et al.*, *Prenatal exposure to 1,1-dichloro-2,2-bis (p-chlorophenyl)ethylene (p,p'-DDE) in relation to child growth.* Int J Epidemiol, 2006. **35**(4): p. 853-8.

Roeleveld, N. and R. Bretveld, *The impact of pesticides on male fertility.* Curr Opin Obstet Gynecol, 2008. **20**(3): p. 229-33.

Rogan, W.J. and N.B. Ragan, *Some evidence of effects of environmental chemicals on the endocrine system in children.* Int J Hyg Environ Health, 2007. **210**(5): p. 659-67.

Rogers, C.A., *et al.*, *Interaction of the onset of spring and elevated atmospheric CO2 on ragweed (Ambrosia artemisiifolia L.) pollen production.* Environmental Health Perspectives, 2006. **114**(6): p. 865-869.

Rogers, D.J. and S.E. Randolph, *The global spread of malaria in a future, warmer world.* Science, 2000. **289**(5485): p. 1763-6.

Rosas, L.G. and B. Eskenazi, *Pesticides and child neurodevelopment.* Curr Opin Pediatr, 2008. **20**(2): p. 191-7.

Rudowitz, R., D. Rowland, and A. Shartzer, *Health care in New Orleans before and after Hurricane Katrina.* Health Aff (Millwood), 2006. **25**(5): p. w393-406.

Ruidavets, J.B., *et al.*, *Ozone air pollution is associated with acute myocardial infarction.* Circulation, 2005. **111**(5): p. 563-569.

Rusiecki, J.A., *et al.*, *Cancer incidence among pesticide applicators exposed to permethrin in the Agricultural Health Study.* Environ Health Perspect, 2009. **117**(4): p. 581-6.

Samoli, E., *et al.*, *Acute Effects of Ambient Particulate Matter on Mortality in Europe and North America: Results from the APHENA Study.* Environmental Health Perspectives, 2008. **116**(11): p. 1480-1486.

Sandifer, P., *et al.*, *Interagency oceans and human health research implementation plan: a prescription for the future.* 2007, Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology: Washington, DC, USA.

Schwartz, J., J.M. Samet, and J.A. Patz, *Hospital admissions for heart disease - The effects of temperature and humidity.* Epidemiology, 2004. **15**(6): p. 755-761.

Scoville, A., *Epidemic typhus fever in Japan and Korea*, in *Rickettsial diseases of man; a symposium*, F.R. Moulton, Editor. 1948, American Association for the Advancement of Science.: Washington, D.C.,. p. 247 p.

Semenza, J.C. and B. Menne, *Climate change and infectious diseases in Europe.* Lancet Infectious Diseases, 2009. **9**(6): p. 365-375.

Senhorst, H.A.J. and J.J.G. Zwolsman, *Climate change and effects on water quality: a first impression.* Water Science and Technology, 2005. **51**(5): p. 53-59.

Shea, K.M., *et al.*, *Climate change and allergic disease.* Journal of Allergy and Clinical Immunology, 2008. **122**(3): p. 443-453.

Sheridan, S.C., A.J. Kalkstein, and L.S. Kalkstein, *Trends in heat-related mortality in the United States, 1975-2004.* Natural Hazards, 2009. **50**(1): p. 145-160.

Shultz, A., *et al.*, *Cholera Outbreak in Kenyan Refugee Camp: Risk Factors for Illness and Importance of Sanitation.* American Journal of Tropical Medicine and Hygiene, 2009. **80**(4): p. 640-645.

Sidley, P., *Floods in southern Africa result in cholera outbreak and displacement.* BMJ, 2008. **336**(7642): p. 471.

Silove, D. and Z. Steel, *Understanding community psychosocial needs after disasters: implications for mental health services.* J Postgrad Med, 2006. **52**(2): p. 121-5.

Sleijffers, A., *et al.*, *Ultraviolet light and resistance to infectious diseases.* J Immunotoxicol, 2004. **1**(1): p. 3-14.

Smith, D.H., *et al.*, *A national estimate of the economic costs of asthma.* Am J Respir Crit Care Med, 1997. **156**(3 Pt 1): p. 787-93.

Smith, K.R., *et al.*, *Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants.* Lancet, 2009.

Smolinski, M.S., *et al.*, *Microbial threats to health ; emergence, detection, and response.* 2003, Washington, D.C.: National Academies Press. xxviii, 367 p.

Sokurenko, E.V., R. Gomulkiewicz, and D.E. Dykhuizen, *Source-sink dynamics of virulence evolution.* Nat Rev Microbiol, 2006. **4**(7): p. 548-55.

Steenland, K., *et al.*, *Recent trends in Alzheimer disease mortality in the United States, 1999 to 2004.* Alzheimer Dis Assoc Disord, 2009. **23**(2): p. 165-70.

Stein, J., *et al.*, *In harm's way: toxic threats to child development.* J Dev Behav Pediatr, 2002. **23**(1 Suppl): p. S13-22.

Stewart, J.R., *et al.*, *The coastal environment and human health: microbial indicators, pathogens, sentinels and reservoirs.* Environ Health, 2008. **7 Suppl 2**: p. S3.

Stitt, M., *Rising Co2 Levels and Their Potential Significance for Carbon Flow in Photosynthetic Cells.* Plant Cell and Environment, 1991. **14**(8): p. 741-762.

Strickman, D., S.P. Frances, and M. Debboun, *Prevention of bug bites, stings, and disease.* 2009, Oxford ; New York: Oxford University Press. xviii, 323 p., [8] p. of plates.

Strickman, D. and P. Kittayapong, *Dengue and its vectors in Thailand: Calculated transmission risk from total pupal counts of Aedes aegypti and association of wing-length measurements with aspects of the larval habitat.* American Journal of Tropical Medicine and Hygiene, 2003. **68**(2): p. 209-217.

Study of Critical Environmental Problems. and Massachusetts Institute of Technology., *Man's impact on the global environment; assessment and recommendations for action; report or the Study of Critical Environmental Problems (SCEP).* 1970, Cambridge, Mass.,: MIT Press. xxii, 319 p.

Sur, D., *et al.*, *Severe cholera outbreak following floods in a northern district of West Bengal.* Indian J Med Res, 2000. **112**: p. 178-82.

Surwit, R.S., *et al.*, *Stress management improves long-term glycemic control in type 2 diabetes.* Diabetes Care, 2002. **25**(1): p. 30-4.

Suzuki, S., *et al.*, *Hanshin-Awaji earthquake as a trigger for acute myocardial infarction.* American Heart Journal, 1997. **134**(5): p. 974-977.

Swanson, K.J., M.C. Madden, and A.J. Ghio, *Biodiesel exhaust: The need for health effects research.* Environmental Health Perspectives, 2007. **115**(4): p. 496-499.

Tapsell, S.M., *et al.*, *Vulnerability to flooding: health and social dimensions.* Philos Transact A Math Phys Eng Sci, 2002. **360**(1796): p. 1511-25.

The CNA Corporation, *National Security and the Threat of Climate Change.* 2007: p. 68.

Thomson, M.C. and S.J. Connor, *The development of malaria early warning systems for Africa.* Trends in Parasitology, 2001. **17**(9): p. 438-445.

Tofail, F., *et al.*, *Effect of Arsenic Exposure during Pregnancy on Infant Development at 7 Months in Rural Matlab, Bangladesh.* Environmental Health Perspectives, 2009. **117**(2): p. 288-293.

Tolba, O., *et al.*, *Survival of epidemic strains of healthcare (HA-MRSA) and community-associated (CA-MRSA) meticillin-resistant Staphylococcus aureus (MRSA) in river-, sea- and swimming pool water.* Int J Hyg Environ Health, 2008. **211**(3-4): p. 398-402.

Toyooka, T., *et al.*, *Coexposure to benzo[a]pyrene and UVA induces DNA damage: first proof of double-strand breaks in a cell-free system.* Environ Mol Mutagen, 2006. **47**(1): p. 38-47.

Trenberth, K.E., *et al.*, *The changing character of precipitation.* Bulletin of the American Meteorological Society, 2003. **84**(9): p. 1205-+.

Tromel, S. and C.D. Schonwiese, *Probability change of extreme precipitation observed from 1901 to 2000 in Germany.* Theoretical and Applied Climatology, 2007. **87**(1-4): p. 29-39.

Tromp, T.K., *et al.*, *Potential environmental impact of a hydrogen economy on the stratosphere.* Science, 2003. **300**(5626): p. 1740-2.

Tucker, M.A., *Melanoma epidemiology.* Hematol Oncol Clin North Am, 2009. **23**(3): p. 383-95, vii.

United Nations Department of Economic and Social Affairs Population Division *World Urbanization Prospects: The 2005 Revision*, P.D. United Nations Department of Economic and Social Affairs, Editor. 2006, United Nations Department of Economic and Social Affairs, Population Division: Geneva.

United States. Congress. Senate. Committee on Commerce Science and Transportation., *Oceans and Human Health Act: report of the Committee on Commerce, Science, and Transportation on S. 1218.* 2003, Washington: U.S. G.P.O. ii. 8 p.

US Environmental Protection Agency, *Report to Congress: impacts and control of CSOs and SSOs. Office of Wastewater Management.* 2004, US Environmental Protection Agency,: Washington, DC.

US Food and Drug Administration, *Quantitative risk assessment on the public health impact of pathogenic Vibrio parahaemolyticus in raw oysters.* 2005.

Uysal, N. and R.M. Schapira, *Effects of ozone on lung function and lung diseases.* Curr Opin Pulm Med, 2003. **9**(2): p. 144-50.

van der Leun, J.C., R.D. Piacentini, and F.R. de Gruijl, *Climate change and human skin cancer.* Photochem Photobiol Sci, 2008. **7**(6): p. 730-3.

Vandentorren, S., *et al.*, *Mortality in 13 French cities during the August 2003 heat wave.* Am J Public Health, 2004. **94**(9): p. 1518-20.

Vasconcelos, C.H. and E. Novo, *Influence of recipitation, deforestation and Tucurui reservoir operation on malaria incidence rates in southeast Para, Brazil.* Igarss 2003: Ieee International Geoscience and Remote Sensing Symposium, Vols I - Vii, Proceedings, 2003: p. 4567-4569

Verger, P., *et al.*, *Assessment of exposure to a flood disaster in a mental-health study.* Journal of Exposure Analysis and Environmental Epidemiology, 2003. **13**(6): p. 436-442.

Vose, R.S., *et al.*, *Climate - Impact of land-use change on climate.* Nature, 2004. **427**(6971): p. 213-214.

Vugla, D.J., *et al.*, *Increase in Coccidioidomycosis-California, 2000-2007 (Reprinted from MMWR, vol 58, pg 105-109, 2009).* Journal of the American Medical Association, 2009. **301**(17): p. 1760-1762.

Wadhwa, P.D., *et al.*, *Developmental origins of health and disease: brief history of the approach and current focus on epigenetic mechanisms.* Semin Reprod Med, 2009. **27**(5): p. 358-68.

Wainwright, S., S. Buchanan, and H. Mainzer, *Cardiovascular Mortality - the Hidden Peril of Heat Waves.* American Journal of Epidemiology, 1994. **139**(11): p. S49-S49.

Wan, S.Q., *et al.*, *Response of an allergenic species Ambrosia psilostachya (Asteraceae), to experimental warming and clipping: Implications for public health.* American Journal of Botany, 2002. **89**(11): p. 1843-1846.

Wang, D.Z., *Neurotoxins from marine dinoflagellates: a brief review.* Marine Drugs, 2008. **6**(2): p. 349-71.

Wang, W., *et al.*, *Detecting changes in extreme precipitation and extreme streamflow in the Dongjiang River Basin in southern China.* Hydrology and Earth System Sciences, 2008. **12**(1): p. 207-221.

Watanabe, H., *et al.*, *Impact of earthquakes on Takotsubo cardiomyopathy.* Journal of the American Medical Association, 2005. **294**(3): p. 305-307.

Weisler, R.H., J.G.t. Barbee, and M.H. Townsend, *Mental health and recovery in the Gulf Coast after Hurricanes Katrina and Rita.* JAMA, 2006. **296**(5): p. 585-8.

Weiss, K.B., P.J. Gergen, and T.A. Hodgson, *An economic evaluation of asthma in the United States.* N Engl J Med, 1992. **326**(13): p. 862-6.

White, C.M., *et al.*, *Sequestration of carbon dioxide in coal with enhanced coalbed methane recovery - A review.* Energy & Fuels, 2005. **19**(3): p. 659-724.

White, P.C., Jr., *Murine Typhus in Fulton County, Georgia.* Mil Med, 1965. **130**: p. 386-8.

WHO, *Monitoring Antimalarial Drug Resistance.* 2002, Geneva: World Health Organization. xx, 190 p.

WHO. Global Malaria Programme., *World malaria report, 2008.* 2008, Geneva: World Health Organization. xx, 190 p.

Wilby, R., M. Hedger, and H. Orr, *Climate change impacts and adaptation: A science agenda for the Environment Agency of England and Wales.* Weather, Volume 60. Issue 7. p. 206-211.

Wilkinson, P., *et al.*, *Public health benefits of strategies to reduce greenhouse-gas emissions: household energy.* Lancet, 2009. **374**(9705): p. 1917-29.

Wilmoth, J.M. and C.F. Longino, *Demographic trends that will shape US policy in the twenty-first century.* Research on Aging, 2006. **28**(3): p. 269-288.

Woodcock, J., *et al.*, *Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport.* Lancet, 2009. **374**(9705): p. 1930-43.

Ye, F., *et al.*, *Effects of temperature and air pollutants on cardiovascular and respiratory diseases for males and females older than 65 years of age in Tokyo, July and August 1980-1995.* Environ Health Perspect, 2001. **109**(4): p. 355-9.

Yoder, J., *et al.*, *Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking--United States, 2005-2006.* MMWR Surveill Summ, 2008. **57**(9): p. 39-62.

Yohannes, M., *et al.*, *Can source reduction of mosquito larval habitat reduce malaria transmission in Tigray, Ethiopia?* Tropical Medicine & International Health, 2005. **10**(12): p. 1274-1285.

Yoshida, Y., *Development of air conditioning technologies to reduce CO2 emissions in the commercial sector.* Carbon Balance Manag, 2006. **1**: p. 12.

Zanobetti, A., *et al.*, *The temporal pattern of respiratory and heart disease mortality in response to air pollution.* Environ Health Perspect, 2003. **111**(9): p. 1188-93.

Zhou, G., *et al.*, *Climate variability and malaria epidemics in the highlands of East Africa.* Trends Parasitol, 2005. **21**(2): p. 54-6.

Ziska, L.H., *et al.*, *Alterations in the production and concentration of selected alkaloids as a function of rising atmospheric carbon dioxide and air temperature: implications for ethno-pharmacology.* Global Change Biology, 2005. **11**(10): p. 1798-1807.

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United States Senate
Environment and Public Works Committee

Minority Report

Critical Thinking on Climate Change

Questions to Consider Before Taking Regulatory Action and Implementing Economic Policies

July 18, 2013

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U.S. Senate Environment and Public Works Committee (Minority)

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INTRODUCTION

The climate has always and will always be changing, and that is unquestionable. What is in question is the amount of influence human activity has on climate patterns, and this report is intended to provide an opportunity to think critically and review some of the more important global warming predictions made over the last several decades.

For more than thirty years, a litany of predictions and claims have been made about what impact anthropogenic (human-caused) greenhouse gases (GHGs) would be on the earth's climate, and on plant and animal life directly. Much of the concern that has been raised—and which continues to be raised—focuses on carbon dioxide (CO_2) emissions, an otherwise naturally occurring gas that makes the process of photosynthesis and life on earth possible. Over nearly four decades, numerous predictions have had adequate time to come to fruition, providing an opportunity to analyze and compare them to today's statistics.

There is little doubt that affordable reliable energy is one of the greatest equalizers in our society. Our use of fossil energy has established a standard of living in the United States that provides families of any income level the ability to heat and cool their home, drive to work or their children to school, or even visit far away family members. In fact, the National Academy of Engineering dubbed electrification "the greatest engineering achievement of the 20th Century."[1] Inevitably, the use and production of this energy releases some CO_2 into our atmosphere.

The use of fossil energy has increased and expanded internationally, and GHG emissions are anticipated to continue to grow in developing nations such as China and India. This report posits that as the developing world has greatly expanded its use of fossil energy and CO_2 emissions have increased, then the predictions and claims regarding human influence on climate patterns should be apparent and easily proven. It is important to keep in mind that many of the predictions and claims analyzed in this report were made prior to China surpassing the United States in 2011 as the largest global GHG emitter. Accordingly, if things are "worse than predicted" as many climate activists and politicians have recently asserted, impacts should prove themselves out as worse than the predictions and claims reviewed in this report.

> *"In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual."*[2] - Galileo Galilei, Italian physicist, mathematician, astronomer, and philosopher

> *"The truth may be puzzling. It may take some work to grapple with. It may be counterintuitive. It may contradict deeply held prejudices. It may not be consonant with what we desperately want to be true. But our preferences do not determine what's true."*[3] - Carl Sagan, American astronomer and scientist

[1] *The Greatest Achievements of the 20th Century*, NAT'L ACADEMY OF ENGINEERING, (Dec. 3, 2004), http://www.mae.ncsu.edu/eischen/courses/mae415/docs/GreatestEngineeringAchievements.pdf.
[2] FRANCOIS ARAGO, BIOGRAPHIES OF DISTINGUISHED SCIENTIFIC MEN 365 (Baden Powell, Robert Grant, and William Fairbairn trans.) (1859).
[3] Carl Sagan, *Wonder and Skepticism*, 19 SKEPTICAL ENQUIRER 1(Jan.-Feb. 1995).

I. CLIMATE MODELS: THE 15-YEAR HIATUS IN WARMING

"An experiment is a question which science poses to Nature and a measurement is the recording of Nature's answer." [4] Max Planck, German physicist

Predictions:

"Most of the climate models...now project that average global temperatures will rise somewhere from 3 to 8 degrees Fahrenheit toward the middle of next century.... A range as high as 14.4 degrees and 18 degrees cannot be ruled out."[5] *New York Times*, January 17, 1989

"Using computer models, researchers concluded that global warming would raise average annual temperatures nationwide two degrees by 2010."[6] *Associated Press*, May 15, 1989.

"Children just aren't going to know what snow is." [7] Dr. David Viner, senior research scientist at the climatic research unit (CRU) of the University of East Anglia, interviewed by the *UK Independent*, March 20, 2000.

"The entire north polar ice cap will be gone in 5 years." [8] Former Vice President Al Gore, December 13, 2008.

Claims:

"The climate is heating up far faster than scientists had predicted, spurred by sharp increases in greenhouse gas emissions from developing countries like China and India." [9] *Reuters*, February 14, 2009

"The temperature around the globe is increasing faster than was predicted even 10 years ago." [10] President Barack Obama, November 14, 2012

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[4] MAX PLANCK, SCIENTIFIC AUTOBIOGRAPHY AND OTHER PAPERS (1968).
[5] Philip Shabecoff, *Global Warming: Experts Ponder Bewildering Feedback Effects*, N.Y. TIMES, Jan. 17, 1989, http://www.nytimes.com/1989/01/17/science/global-warming-experts-ponder-bewildering-feedback-effects.html?pagewanted=all&src=pm.
[6] Kirk Myers, *Arctic Ocean warming, icebergs growing scarce, Washington Post reports*, THE EXAMINER, Mar. 2, 2010, http://www.examiner.com/article/arctic-ocean-warming-icebergs-growing-scarce-washington-post-reports (*quoting* Associated Press).
[7] Charles Onians, *Snowfalls are now just a thing of the past*, THE INDEPENDENT, Mar. 20, 2000, http://www.independent.co.uk/environment/snowfalls-are-now-just-a-thing-of-the-past-724017.html.
[8] Charles J. Hanley, *Gore: Polar Ice May Vanish in 5 Years*, HUFFINGTON POST, Dec. 14, 2009, http://www.huffingtonpost.com/2009/12/14/gore-polar-ice-may-vanish_n_391632.html.
[9] Julie Steenhuysen, *Global warming seen worse than predicted*, REUTERS, Feb. 14, 2009, http://www.reuters.com/article/2009/02/14/us-climate-idUSTRE51D29E20090214.
[10] *Transcript of President Obama's News Conference*, N.Y. TIMES, Nov. 14, 2012, http://www.nytimes.com/2012/11/14/us/politics/running-transcript-of-president-obamas-press-conference.html?pagewanted=10&_r=2&src=twr.

The Latest Science:

The predictions seem unlikely to come true, and the claims contradict the data, as noted by entities generally supportive of the Administration's climate change policies. For instance, *The Economist* recently explained that "temperatures have not really risen over the past ten years"[11] and that "[o]ver the past 15 years air temperatures at the Earth's surface have been flat."[12] Last month, *BBC News* reported, "Since 1998, there has been an unexplained 'standstill' in the heating of the Earth's atmosphere."[13]

Furthering the concern that past climate models have not proven true, Professor Judith Curry, chair of the School of Earth and Atmospheric Sciences at Georgia Institute of Technology in Atlanta, stated on June 14, 2013, "Attention in the public debate seems to be moving away from the 15-17 year 'pause' to the cooling since 2002."[14] She further stated, "This period since 2002 is scientifically interesting, since it coincides with the 'climate shift' circa 2001/2002 posited by Tsonis and others.[15] This shift and the subsequent slight cooling trend provide a rationale for inferring a slight cooling trend over the next decade or so, rather than a flat trend from the 15 year 'pause.'"[16]

Importantly, the U.S. Environmental Protection Agency (EPA) has essentially ignored Members of Congress who asked for EPA data supporting the President's claims about global temperature predictions. For example, on December 4, 2012, Senator Sessions wrote former Administrator Jackson:

> The actual temperature data show no significant change in global temperatures over the past decade and certainly less warming than the climate change models predicted. At an August 1, 2012, hearing before the Senate Committee on Environment and Public Works...climatologist Dr. John Christy of the University of Alabama-Huntsville offered testimony demonstrating that the IPCC climate models, which have been relied upon by alarmists, vastly over-stated the degree of warming in comparison to actual temperature data observed by advanced satellites. Dr. Christy's chart...demonstrates that the IPCC models, on average, predicted a significant amount of warming that has not actually occurred. In fact, contrary to the President's assertion, the chart shows that global average temperatures have not increased at all over the past decade, and certainly less than was predicted 10 years ago.
>
> The President's assertion also conflicts with the views of many other scientists and experts. In an editorial published earlier this year in the Wall Street Journal, scientists and engineers from MIT, Princeton, Cambridge, and other leading

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[11] *Apocalypse perhaps a little later*, ECONOMIST, Mar. 30, 2013, http://www.economist.com/news/leaders/21574490-climate-change-may-be-happening-more-slowly-scientists-thought-world-still-needs.
[12] *Climate Science: A Sensitive Matter*, ECONOMIST, Mar. 30, 2013, http://www.economist.com/news/science-and-technology/21574461-climate-may-be-heating-up-less-response-greenhouse-gas-emissions.
[13] Matt McGrath, *Climate slowdown means extreme rates of warming 'not as likely'*, BBC NEWS, (May 19, 2013, 1: 31 PM), http://www.bbc.co.uk/news/science-environment-22567023.
[14] Judith Curry, *Week in Review*, CLIMATE ETC., (June 14, 2013), http://judithcurry.com/2013/06/14/week-in-review-3/.
[15] Bill Osmulski, *UW-Milwaukee Professor Predicts 50 Years of Global Cooling*, MACIVER INSTITUTE (Jan. 13, 2010, 2:59 PM), http://www.maciverinstitute.com/2010/01/uw-milwaukee-professor-predicts-50-years-of-global-cooling/.
[16] *Id.*

> institutions explained that 'perhaps the most inconvenient fact is the lack of global warming for well over 10 years now' and that there has been a 'smaller-than-predicted warming over the 22 years since the U.N.'s Intergovernmental Panel on Climate Change (IPCC) began issuing projections.' Additionally, the lead author of the 2007 IPCC climate report stated in an email that 'we can't account for the lack of warming at the moment...'
>
> As policymakers consider proposals aimed at addressing concerns about rising temperatures predicted by the IPCC climate models, a critical question is whether the planet is warming to the extent predicted by these models. The data suggest to me that the planet is not warming to the extent predicted 10 years ago.[17]

To shed light on this issue, Senator Sessions asked EPA to "provide the best available data that EPA would rely upon to support the President's assertion,"[18] along with an EPA-prepared chart comparing "actual global average temperature increases since 1979 (when satellite temperature data became available) versus the latest IPCC predictions..."[19]

Gina McCarthy, nominee to be EPA Administrator, responded to Senator Sessions in a letter dated February 14, 2013, by asserting that "there are multiple lines of evidence that clearly demonstrate that average global temperatures are rising,"[20] yet she did not provide any of the requested data relating to average global temperatures. Instead, the letter seems to dodge Senator Sessions' data request by claiming that "only looking at 10 years of a single dataset cannot provide a full picture of climate change trends, and should also not be the sole test by which to judge the usefulness of climate models in either simulating past climates or projecting further climate change."[21]

The lack of responsiveness on these points was raised at McCarthy's April 11, 2013 nomination hearing when Senator Sessions presented the following chart which demonstrates global temperatures have not increased over the last decade and certainly not to the extent predicted by the climate models:

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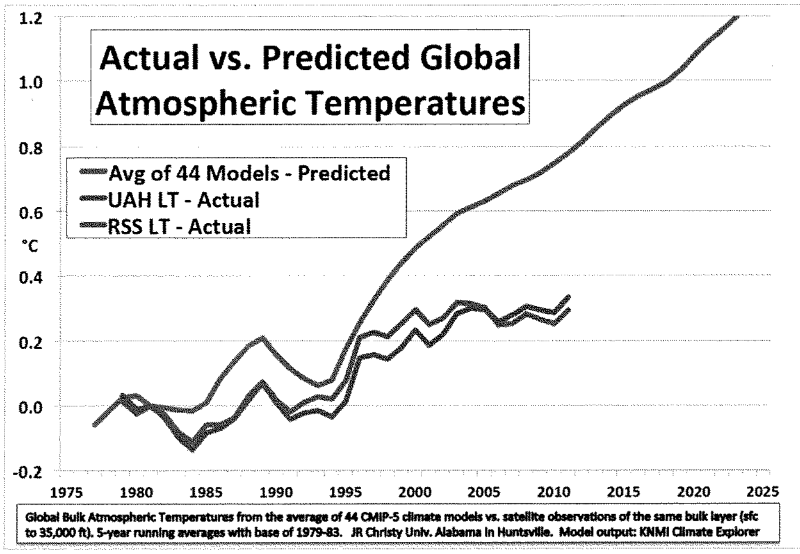
[17] Letter from Sen. Jeff Sessions to Lisa Jackson, EPA Adm'r, (Dec. 4, 2012) (on file with author).
[18] Letter from Sen. Jeff Sessions et al. to Gina McCarthy, EPA Asst. Adm'r Office of Air & Radiation, (June 24, 2013) (on file with author).
[19] *Id.*
[20] *Id.*
[21] *Id.*



In his questions for the record, Senator Sessions once again requested the data from McCarthy: "Will you provide me with data showing actual global average temperatures since 1979 versus IPCC predictions, as was requested in my letter?" [22]

On April 30, 2013, the EPA responded to Senator Sessions. Yet, instead of providing the requested analysis including a chart showing official predictions versus actual global temperatures, the Agency simply stated that "EPA has not produced its own analysis, but we expect a definitive comparison in the forthcoming [International Panel on Climate Change] Fifth Assessment Report."[23] Unlike EPA, the IPCC is an international body outside the jurisdiction and oversight of the United States Congress. Moreover, EPA is the entity of the United States government that is seeking sweeping regulations on the basis that GHGs are increasing global temperatures. EPA's reliance on the IPCC is not only a violation of the Data Quality Act,[24] but also violates the Agency's own internal policy.[25]

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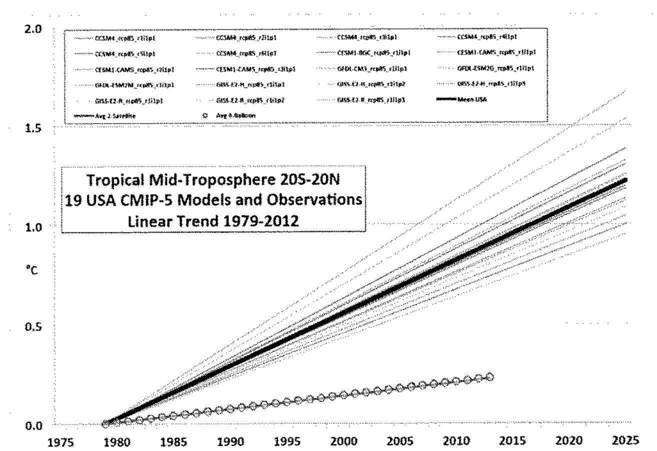
[22] *Hearing on the Nomination of Gina McCarthy to be Administrator of the U.S. Environmental Protection Agency*, 113th Cong. (2013), http://www.epw.senate.gov/public/index.cfm?FuseAction=Hearings.Hearing&Hearing_ID=d71fd4b6-ce77-3a98-46a0-fb02b0cae0ed.

[23] *Id.*

[24] The DQA directs the Office of Management and Budget (OMB) to issue government-wide guidelines that "provide policy and procedural guidance to Federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by Federal agencies." *See* Data Quality Act §515, 42 U.S.C. §502-504.

[25] Peer Review Advisory Grp., *Addendum to: Guidance for Evaluating the Quality of Scientific and Technical Information*, EPA'S SCI. AND TECH. POLICY COUNCIL (Dec. 2012), http://www.epa.gov/spc/pdfs/assess3.pdf.

To support the President's claim that the temperature around the globe is increasing faster than was predicted even 10 years ago, EPA referred to a short paper by Stefan Rahmstorf[26] published in an online journal whose editor-in-chief also happens to be the "coordinating lead author"[27] for the IPCC—during the time the IPCC published the climate models vastly over-predicting global temperature increases. It is remarkable that EPA—without first conducting its own analysis—would endorse that paper's finding that "global temperature continues to increase in good agreement with the best estimates of the IPCC,"[28] a view that appears to be contrary to the actual current data and facts. This is shown by a comprehensive comparison of climate models used by the IPCC, which is reflected in the following chart:[29]



The American public should be deeply troubled to learn that EPA is actively working to increase energy prices based on predicted global temperature increases without first undertaking efforts to determine if temperatures are actually increasing to the extent predicted by the climate models they are using. This refusal to provide reasonable data requested by Members of Congress comes on the heels of the EPA Inspector General's highly critical report investigating EPA's review of external data for the GHGs endangerment finding.[30]

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[26] Stefan Rahmstorf et al., *Comparing climate projections to observations up to 2011*, 7 ENVTL. RES. LETTERS 044035 (2012), *available at* http://iopscience.iop.org/1748-9326/7/4/044035/pdf/1748-9326_7_4_044035.pdf; It is also noteworthy that this paper was published on November 27, 2012—almost two weeks after the President stated that "the temperature around the globe is increasing faster than was predicted even 10 years ago." *Transcript of President Obama's News Conference*, N.Y. TIMES, Nov. 14, 2012, http://www.nytimes.com/2012/11/14/us/politics/running-transcript-of-president-obamas-press-conference.html?pagewanted=10&_r=2&src=twr.

[27] Dr. Daniel M. Kammen's Personal Website. BERKELEY.EDU, http://kammen.berkeley.edu// (last visited July 16, 2013).

[28] Stefan Rahmstorf et al., *Comparing climate projections to observations up to 2011*, 7 ENVTL. RES. LETTERS 044035 (2012), *available at* http://iopscience.iop.org/1748-9326/7/4/044035/pdf/1748-9326_7_4_044035.pdf.

[29] Dr. John Christy, *Tropical Mid-Troposphere 20S-20N*, (June 4, 2013), http://www.drroyspencer.com/wp-content/uploads/CMIP5-19-USA-models-vs-obs-20N-20S-MT.png.

[30] ENVTL. PROT. AGENCY, OFFICE OF INSPECTOR GEN., REPORT NO. 11-P-0702, PROCEDURAL REVIEW OF EPA'S GREENHOUSE GASES ENDANGERMENT FINDING DATA QUALITY PROCESSES (2011), *available at* http://www.epa.gov/oig/reports/2011/20110926-11-P-0702.pdf.

Congress continues to wait for the federal agency's supporting data and analysis the President cited which shows actual global average temperatures since 1979 versus IPCC predictions, as was requested in Senator Sessions' December 2012 letter and again during McCarthy's nomination hearing to lead the Agency.

Questions for Critical Thinking:

1. If the computer models and predictions have been inaccurate, why is our federal government relying on these models to take unilateral action?

2. If global warming has been "worse than predicted," why won't the federal government provide the data supporting this claim?

3. As it continues to be recognized that the Earth has not warmed for the past 15 years, will we see the term "global warming" abandoned and replaced in its entirety by "climate change?"

4. Given that many of these models predicted warming trends well before China surpassed the United States as the largest GHG emitter, and given the fact that emissions continue to grow at a pace beyond what was originally incorporated into the models, shouldn't the warming be far worse than what was predicted in the worst case scenarios rather than well below predictions?

II. SEA LEVEL RISE: IT'S MEASURED IN MILLIMETERS, NOT FEET

> *"Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more science than a heap of stones a house."* Jules Henri Poincaré, French mathematician, theoretical physicist, engineer, and philosopher of science

Predictions:

> In 1989, Noel Brown, then-Director of the United Nations Environment Program (UNEP) New York office, warned of a "10-year window of opportunity to solve" global warming. "A senior U.N. environmental official says entire nations could be wiped off the face of the Earth by rising sea levels if the global warming trend is not reversed by the year 2000. Coastal flooding and crop failures would create an exodus of 'eco-refugees,' threatening political chaos."[31] *Miami Herald*, July 5, 1989

> By the year 2100 "global mean sea level will rise 15 to 95 centimeters."[32] *New York Times*, December 1, 1997

[31] *Gore's Really Inconvenient Timing- 'Consensus' On Man-Made Global Warming Collapses in 2008*, REPUBLICAN ENV'T AND PUB WORKS COMM., July 18, 2008, http://www.epw.senate.gov/public/index.cfm?FuseAction=Minority.Blogs&ContentRecord_id=37ae6e96-802a-23ad-4c8a-edf6d8150789.
[32] *Id.*

> "Rising sea levels, desertification and shrinking freshwater supplies will create up to 50 million environmental refugees by the end of the decade, experts warn today." [33] *UK Guardian*, October 11, 2005

> "The last time the world was three degrees warmer than today – which is what we expect later this century – sea levels were 25m higher (75 feet). So that is what we can look forward to if we don't act soon. None of the current climate and ice models predict this. But I prefer the evidence from the Earth's history and my own eyes. I think sea-level rise is going to be the big issue soon, more even than warming itself." [34] James Hansen, climate activist and adjunct professor at Columbia University, February 17, 2006

Claims:

> "The newer analyses that have been done since the IPCC report came out, indicate that the upper limit for the year 2100 is probably between 1 and 2 meters, and those are the numbers that I now quote, because they are the latest science." [35] John Holdren, White House Science Advisor, February 12, 2009

> "Sea level could rise more than six feet by the end of the century," and "could continue rising a foot each decade after that." [36] Jeff Goodell for *Rolling Stone*, June 20, 2013

The Latest Science:

Both the predictions and claims are highly inconsistent with the latest science. In fact, the United Nations has already made their 2005 prediction disappear.[37] According to the National Oceanic and Atmospheric Administration (NOAA), data indicates that sea levels rose only 1.1 - 1.3 mm/year from 2005-2012.[38] Citing NOAA directly, the "numbers represent the globally averaged changes in sea level and have magnitudes on the order of millimeters per year." [39] Accordingly, at the current rate of sea level rise, it would take approximately 25,000 years (around the year 27013) for the oceans to reach Hansen's 2006 prediction levels rather than something "we expect" to reach by the year 2100. [40]

During his 2009 confirmation hearing, Dr. John Holdren, the present White House science advisor, retracted from his prior claim that sea levels could rise "13 feet" and instead revised

[33] David Adam, *50m environmental refugees by end of decade, UN warns*, THE GUARDIAN, Oct. 11, 2005, http://www.guardian.co.uk/environment/2005/oct/12/naturaldisasters.climatechange1.
[34] Jim Hansen, *Climate change: On the edge*, THE INDEPENDENT, Feb. 17, 2006, http://www.independent.co.uk/environment/climate-change-on-the-edge-466818.html.
[35] *Hearing before the Comm. On Commerce, Science, and Trans.*, 111th Cong., (2009) (statement of John Holdren, White House Science Advisor).
[36] Jeff Goodell, *Goodbye, Miami*, ROLLING STONE, June 20, 2013, http://www.rollingstone.com/politics/news/why-the-city-of-miami-is-doomed-to-drown-20130620.
[37] Anthony Watts, *The UN "disappears" 50 million climate refugees, then botches the disappointing attempt*, WATTSUPWITHTHAT BLOG (Apr. 15, 2011), http://wattsupwiththat.com/2011/04/15/the-un-disappears-50-million-climate-refugees-then-botches-the-disappearing-attempt/.
[38] U.S. DEP'T OF COMMERCE, NAT'L OCEANIC AND ATMOSPHERIC ADMIN. THE BUDGET OF RECENT GLOBAL SEA LEVEL RISE 2005-2012 (2012).
[39] *Id.*
[40] *Id.*

down his own predictions to match the lower numbers from the IPCC 2007 report. The following is an excerpt from the February 12, 2009, hearing:

> *Senator Vitter*: Final question: In 2006, obviously pretty recently, in an article, "The War on Hot Air," you suggested that global sea levels could rise by 13 feet by the end of this century. And in contrast to that, the IPCC's 2007 report put their estimate at between 7 and 25 inches. So their top line was 25 inches, about 2 feet. What explains the disparity?
>
> *Dr. Holdren*: My statement was based on articles in the journals *Science* and *Nature*, peer reviewed publications by some of the world's leading specialists in studying ice, who had concluded that twice in the last 19,000 years, in natural warming periods of similar pace to the warming period that we're experiencing now, in large part because of human activities, sea level went up by as much as 2 to 5 meters per century.
>
> *Senator Vitter*: The bottom line: Do you think the better worst-case estimate is 25 inches or 13 feet?
>
> *Dr. Holdren*: The newer analyses that have been done since the IPCC report came out indicate that the upper limit for the year 2100 is probably between 1 and 2 meters, and those are the numbers that I now quote, because they are the latest science. [41]

A further review of the science shows that the rate of sea level change has been found to be larger in the early part of last century (2.03 ± 0.35 mm/yr 1904–1953), in comparison with the latter part (1.45 ± 0.34 mm/yr 1954–2003).[42] When compared to NOAA's data on sea level rise from 2005-2012, the 1.1 – 1.3 mm/year rate is below the rate from 1954-2003, indicating that the rate of sea level rise continues to decline. Analysis from a recent peer-reviewed study had findings consistent with the following:[43]

> Although the mean rate of change of global mean sea level is found to be greater in the first half of the twentieth century, the two rates are consistent with being the same at the 95% confidence level, given their individual standard errors. However, a greater rate of rise in the early part of the record is consistent with previous analyses of tide gauge records which suggested a general deceleration in sea level rise during the 20th century [*Woodworth*, 1990; *Douglas*, 1992; *Jevrejeva et al.*, 2006]. A twentieth century deceleration is consistent with the work of *Church and White* [2006] who, although finding evidence for a post-1870 acceleration based on an EOF reconstruction of global sea level, found that much of the overall acceleration occurred in the first half of the 20th century. *Church and White* [2006] suggested that the greater rate of sea level rise observed in the first half of last century was due to reduced volcanic emissions (and hence also lower variability in sea level) during the 1930s to 1960s. This idea is supported by results from the HadCM3 model which suggest that the simulated global

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[41] *Hearing before the Comm. On Commerce, Science, and Trans.*, 111th Cong., (2009) (statement of John Holdren, White House Science Advisor).
[42] S.J. Holgate, *On the decadal rates of sea level change during the twentieth century*, 34 GEOPHYSICAL. RES. LETTERS L01602 (2007), *available at* http://onlinelibrary.wiley.com/doi/10.1029/2006GL028492/abstract.
[43] *Id.*

mean sea level did not accelerate through the twentieth century due to the offsetting of anthropogenic warming by reduced natural forcing [*Gregory et al.*, 2006].[44]

In short, the peer-reviewed scientific evidence can be summed up as follows:

- Sea level rise was greater in the first half of the twentieth century;
- There has been a decline in sea level rise in the latter half of the twentieth century; and
- NOAA's latest data indicates that the rate of sea level rise is less than half that predicted by the IPCC.

<u>Questions for Critical Thinking</u>:

1. If the present rate of sea level rise would put the world on pace to see an increase of less than 7 inches by the end of the century, then where are the data sets the IPCC and other advocates use to come up with estimates that are in feet and/or meters?
2. What science did Al Gore use to come to the conclusion that the oceans would rise 20 feet or more?
3. What exactly is meant by the statement in the scientific literature "is consistent with previous analyses of tide gauge records which suggested a general deceleration in sea level rise during the 20th century?"[45]
4. If empirical evidence indicates that the rate of sea level rise is decreasing, how does the IPCC claim that there definitively is a strong correlation between sea level rise and CO_2 concentrations in the atmosphere? Doesn't the science tend to indicate that there is a lack of correlation?

III. EXTREME WEATHER: HURRICANES, DROUGHTS, HEAT WAVES, AND WILDFIRES

"When the number of factors coming into play in a phenomenological complex is too large scientific method in most cases fails. One need only think of the weather, in which case the prediction even for a few days ahead is impossible."[46] Albert Einstein, German physicist

[44] *Id.*
[45] S.J. Holgate, *On the decadal rates of sea level change during the twentieth century*, 34 GEOPHYSICAL RES. LETTERS L01602 (2007), *available at* http://onlinelibrary.wiley.com/doi/10.1029/2006GL028492/abstract.
[46] *Science, Philosophy and Religion, A Symposium*, published by the *Conference on Science, Philosophy and Religion in Their Relation to the Democratic Way of Life, Inc.*, New York (1941); later published in *Out of My Later Years* (1950).

Predictions:

> "Increasingly, it is being recognized that other climatic factors, including changes in rainfall patterns and the frequency and intensity of hurricanes, cyclones and wildfire, may have far greater consequences than a rise in temperature."[47] *New York Times*, August 17, 1993
>
> "Global warming is likely to produce a significant increase in the intensity and rainfall of hurricanes in coming decades, according to the most comprehensive computer analysis done so far."[48] *New York Times*, September 30, 2004
>
> "From heat waves to storms to floods to fires to massive glacial melts, the global climate seems to be crashing around us."[49] *TIME*, March 26, 2006

Claims:

> "At the same time, we must be very clear. Hurricane Sandy is a wake-up call for all Americans that we must act to reverse global warming. While scientists do not attribute this storm or any single weather disturbance to global warming, it is increasingly clear that global warming is fueling more extreme weather disturbances."[50] Senator Bernie Sanders, November 1, 2012
>
> "Heat waves, droughts, wildfires, and floods – all are now more frequent and intense."[51] President Obama, February 12, 2013
>
> "The effects of climate change, driven by carbon pollution, hit Americans harder each year. Extreme weather events like hurricanes, wildfires and droughts are growing ever more frequent and severe."[52] Senator Sheldon Whitehouse, June 19, 2013

The Latest Science:

Wildfires have not increased:

"Historical analysis of wildfires around the world shows that since 1950 their numbers have decreased globally by 15%. Estimates published in the Proceedings of the National Academy of Sciences show that even with global warming proceeding uninterrupted, the level of wildfires will continue to decline until around midcentury and won't resume on the level of 1950—the worst for fire—before the end of the century."[53]

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[47] *Dangers to Forests Seen From Warming*, N.Y. TIMES, Aug. 17, 1993, http://www.nytimes.com/1993/08/17/science/dangers-to-forests-seen-from-warming.html.

[48] Andrew C. Revkin, *Global Warming is Expected to Raise Hurricane Intensity*, N.Y. TIMES, Sept. 30, 2004, http://www.nytimes.com/learning/students/pop/articles/30hurricane_LN.html.

[49] Jeffrey Kluger, *Earth at the Tipping Point: Global Warming Heats Up*, TIME, Mar. 26, 2006, http://www.time.com/time/magazine/article/0,9171,1176980,00.html.

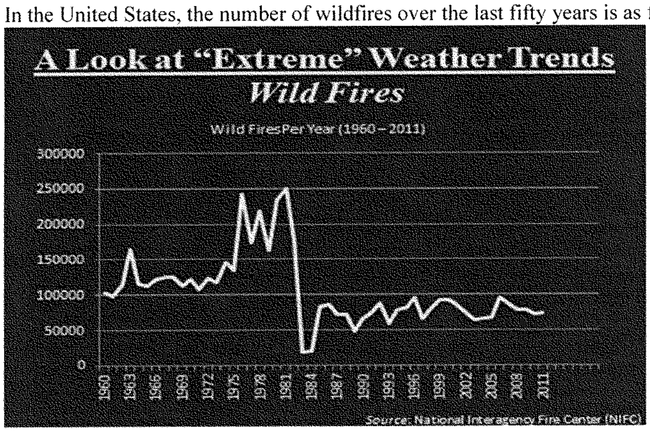
[50] Press Release, Office of Sen. Bernie Sanders, Global Warming and Hurricane Sandy (Nov. 1, 2012) http://www.sanders.senate.gov/newsroom/news/?id=ad66348a-d6cc-4d43-8241-c5f2bffaf633.

[51] President Barack Obama, State of the Union Address (Feb. 12, 2013).

[52] Sen. Sheldon Whitehouse, *The Price of Ignoring Climate Change*, REUTERS, June 19, 2013.

[53] Bjorn Lomborg, *Climate-Change Misdirection*, WALL STREET J., Jan. 23, 2013, http://online.wsj.com/article/SB10001424127887323485704578258172660564886.html.

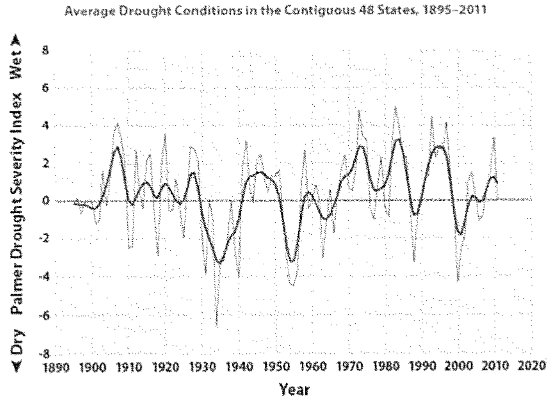
In the United States, the number of wildfires over the last fifty years is as follows:



Droughts have not increased:

"The world has not seen a general increase in drought. A study published in *Nature* in November shows globally that 'there has been little change in drought over the past 60 years.' The U.N. Climate Panel in 2012 concluded: 'Some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia.'"[54]

Average Drought Conditions in the Contiguous 48 States, 1895–2011



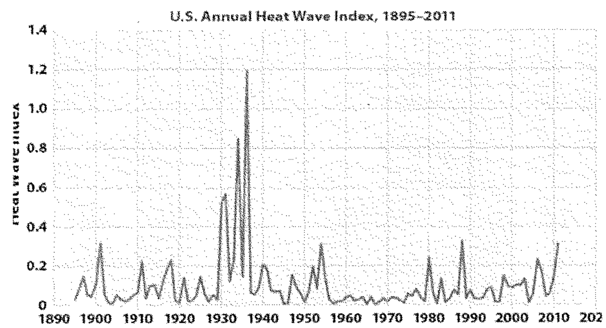
Data source: NOAA (National Oceanic and Atmospheric Administration). 2012. National Climatic Data Center. Accessed January 2012. www.ncdc.noaa.gov/oa/ncdc.html.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

[54] *Id.*

Heat waves have not increased:

"The "Dust Bowl" years of 1930-36 brought some of the hottest summers on record to the United States, especially across the Plains, Upper Midwest and Great Lake States. For the Upper Mississippi River Valley, the first few weeks of July 1936 provided the hottest temperatures of that period, including many all-time record highs. The string of hot, dry days was also deadly. Nationally, around 5000 deaths were associated with the heat wave. In La Crosse, WI, there were 14 consecutive days (July 5th-18th) where the high temperature was 90 degrees or greater, and 9 days that were at or above 100. Six record July temperatures set during this time still stand, including the hottest day on record with 108 on the 14th. The average high temperature for La Crosse during this stretch of extreme heat was 101."[55]



Hurricane activity has not increased:

According to Dr. Bjorn Lomborg, Director of Copenhagen Consensus Center and Adjunct Professor at Copenhagen Business School, "As for one of the favorites of alarmism, hurricanes in recent years don't indicate that storms are getting worse. Measured by total energy (Accumulated Cyclone Energy), hurricane activity is at a low not encountered since the 1970s. The U.S. is currently experiencing the longest absence of severe landfall hurricanes in over a century—the last Category 3 or stronger storm was Wilma, more than seven years ago."[56]

"While it's hardly mentioned in the media, the U.S. is currently in an extended and intense hurricane 'drought.'"[57]

The source of the following three graphs is Professor Roger Pielke, Jr., in his July 18, 2013, testimony before the Senate EPW Committee:

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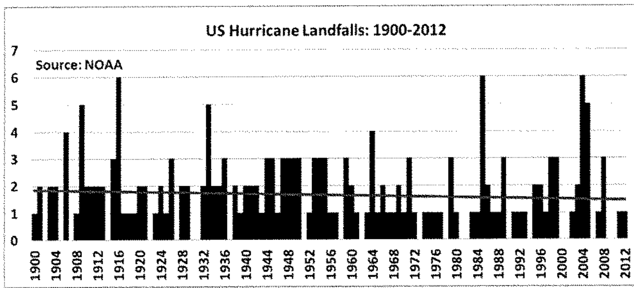
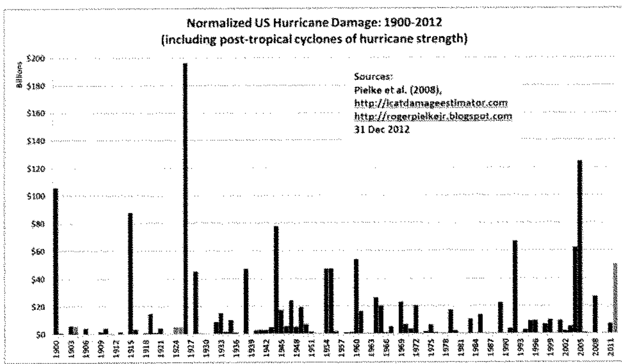
[55] *The Heatwave of July 1936*, Nat'l Oceanic & Atmospheric Admin. Nat'l Weather Serv. Weather Forecast Office, http://www.crh.noaa.gov/arx/events/heatwave36.php.
[56] Bjorn Lomborg, *Climate-Change Misdirection*, WALL STREET J., Jan. 23, 2013, http://online.wsj.com/article/SB10001424127887323485704578258172660564886.html.
[57] Roger Pielke, *Hurricanes and Human Choice*, WALL STREET J., Oct. 31, 2012, http://online.wsj.com/article/SB10001424052970204840504578089413659452702.html.



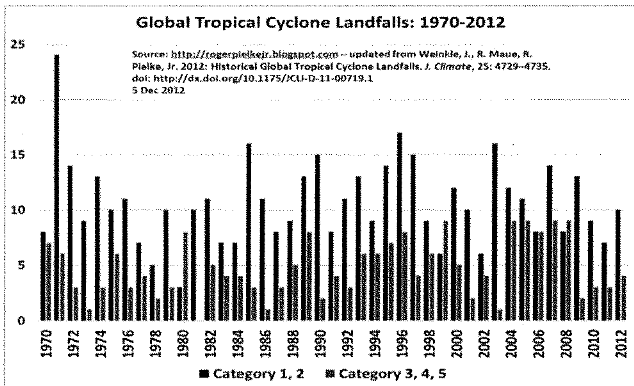
Number of landfalling U.S. hurricanes from 1900-2012. The red line shows the linear trend, exhibiting a decrease from about 2 to 1.5 landfalls per year since 1900. Source: NOAA.[58]



Normalized U.S. hurricane damage 1900-2012, estimated total damage if each past hurricane season occurred with 2012 levels of development. After Pielke et al. 2008.[59] Note that the figure includes "Superstorm" Sandy (2012) in gray and placeholders for the three other post-tropical cyclones of hurricanes which made landfall in 1904, 1924 and 1925.

[58] *Chronological List of All Hurricanes: 1851-2012*, Nat'l Oceanic & Atmospheric Admin. Hurricane Research Div., http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html.

[59] Roger A. Pielke, Jr. et al., *Normalized Hurricane Damages in the United States: 1900-2005*, 9(1) Natural Hazards Rev. 29-42 (2008). The data is updated to 2012 values using the ICAT Damage Estimator. ICAT Damage Estimator, http://www.icatdamageestimator.com.



Global tropical cyclone (called hurricanes in the North Atlantic) landfalls, 1970-2012, after Weinkle et al. 2012.[60]

<u>Questions for Critical Thinking</u>:

1. When we are unable to predict extreme weather events, and empirical evidence does not show that extreme weather events are increasing, why would some scientists/activists claim that extreme weather events are the product of human activity?

2. Did extreme weather events begin with the advent of the internal combustion engine, or does historical and geological evidence exist indicating extreme weather events have been occurring for hundreds, thousands, or even millions of years?

3. What is the level of confidence that extreme weather events won't decrease in a warming climate? Is there evidence that colder climates can be harsher?

IV. CLIMATE REGULATION: WHAT IS IT REALLY ABOUT?

> *"If you once forfeit the confidence of your fellow citizens, you can never regain their respect and esteem. It is true that you may fool all of the people some of the time; you can even fool some of the people all of the time; but you can't fool all of the people all of the time."* Abraham Lincoln, 16th President of the United States[61]

The following is a list of claims made by key activists and political officials in the climate science community:

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[60] Jessica Weinkle et al., *Historical Global Tropical Cyclone Landfalls*, 25 J. CLIMATE 4729-4735 (2012), *available at* http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00719.1.

[61] President Abraham Lincoln, Speech at Clinton, IL (Sept. 8, 1854).

- Stephen Schneider, who authored *The Genesis Strategy*, a 1976 book warning that global cooling risks posed a threat to humanity, later changed that view 180 degrees when he served as a lead author for important parts of three sequential IPCC reports. In an article published in *Discover*, he said: "On the one hand, as scientists we are ethically bound to the scientific method, on the other hand, we are not just scientists, but human beings as well. And like most people, we'd like to see the world a better place, which in this context translates into our working to reduce the risk of potentially disastrous climatic change. To do that, we need to get some broad-based support, to capture the public's imagination. That, of course, entails getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of the doubts we might have. Each of us has to decide what the right balance is between being effective and being honest."[62]

- In 1988, the former Canadian Minister of the Environment told editors and reporters of the *Calgary Herald*, "No matter if the science of global warming is all phony...climate change [provides] the greatest opportunity to bring about justice and equality in the world."[63]

- Maurice Strong, who organized the first U.N. Earth Climate Summit (1992) in Rio de Janeiro, Brazil, expressed his true position on climate issues: "We may get to the point where the only way of saving the world will be for industrialized civilization to collapse."[64]

- Former U.S. Senator Timothy Wirth (D-CO), and former U.S. Undersecretary of State for global issues, likely agreed with Maurice Strong at the same Rio Climate Summit when he stated: "We have got to ride the global warming issue. Even if the theory of global warming is wrong, we will be doing the right thing in terms of economic policy and environmental policy."[65]

- Also at the Rio conference, then-Deputy Assistant of State Richard Benedick, who headed the policy divisions of the U.S. State Department, stated: "A global warming treaty [such as the Kyoto Protocol] must be implemented even if there is no scientific evidence to back the [enhanced] greenhouse effect."[66]

- Speaking at the 2000 U.N. Conference on Climate Change in the Hague, former President Jacques Chirac of France explained why the IPCC's climate initiative supported a key Western European Kyoto Protocol objective: "For the first time, humanity is instituting a genuine instrument of global governance, one that should find a place within the World Environmental Organization which France and the European Union would like to see established."[67]

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[62] STEPHEN H. SCHNEIDER & LYNNE E. MESIROW, The GENESIS STRATEGY: CLIMATE AND GLOBAL SURVIVAL (1976).
[63] Larry Bell, *Global Warming Alarmism: When Science IS Fiction*, FORBES, May 29, 2012, http://www.forbes.com/sites/larrybell/2012/05/29/global-warming-alarmism-when-science-is-fiction/2/.
[64] LARRY BELL, CLIMATE OF CORRUPTION: POLITICS AND POWER BEHIND THE GLOBAL WARMING HOAX 226 (2011).
[65] Larry Bell, *In Their Own Words: Climate Alarmists Debunk Their 'Science'*, FORBES, Feb. 5, 2013, http://www.forbes.com/sites/larrybell/2013/02/05/in-their-own-words-climate-alarmists-debunk-their-science/.
[66] *Id.*
[67] *Id.*

- On November 14, 2010, Ottmar Edenhofer, a U.N. IPCC Official, stated, "First of all, developed countries have basically expropriated the atmosphere of the world community. But one must say clearly that we redistribute de facto the world's wealth by climate policy. Obviously, the owners of coal and oil will not be enthusiastic about this. One has to free oneself from the illusion that international climate policy is environmental policy. This has almost nothing to do with environmental policy anymore...."[68]

Just something to ponder:

- As Greenpeace co-founder Patrick Moore observed on Fox Business News in January 2011, "We do not have any scientific proof that we are the cause of the global warming that has occurred in the last 200 years....The alarmism is driving us through scare tactics to adopt energy policies that are going to create a huge amount of energy poverty among the poor people. It's not good for people and it's not good for the environment.... In a warmer world we can produce more food."[69]

- "The World Bank board of directors could today endorse a sweeping new energy policy that for the first time restricts financing for new coal plants in poor countries, bank officials confirmed." Lisa Friedman, *E&E* reporter, July 16, 2013[70]

V. THE SCIENCE IS SETTLED: THE GOVERNMENT CAN'T CONTROL CLIMATE

> *"Any physical theory is always provisional, in the sense that it is only a hypothesis: you can never prove it. No matter how many times the results of experiments agree with some theory, you can never be sure that the next time the result will not contradict the theory. On the other hand, you can disprove a theory by finding even a single observation that disagrees with the predictions of the theory."* Stephen Hawking, English theoretical physicist, cosmologist, author and Director of Research at the Centre for Theoretical Cosmology within the University of Cambridge[71]

Claim:

"Humanity is sitting on a time bomb. If the vast majority of the world's scientists are right, we have just ten years to avert a major catastrophe that could send our entire planet's climate system into a tail-spin of epic destruction involving extreme weather, floods, droughts, epidemics and killer heat waves beyond anything we have ever experienced—a catastrophe of our own making." Al Gore[72]

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[68] *The Science is Settled: U.N. Official Admits Climate Policy is About Wealth Redistribution and Not Global Warming*, MOTOR CITY TIMES, Nov. 18, 2010.
[69] Larry Bell, *In Their Own Words: Climate Alarmists Debunk Their 'Science'*, FORBES, Feb. 5, 2013, http://www.forbes.com/sites/larrybell/2013/02/05/in-their-own-words-climate-alarmists-debunk-their-science/.
[70] Lisa Friedman, *World Bank Approves Landmark Coal Restrictions*, E & E PUBL'G, July 17, 2013.
[71] STEPHEN HAWKING, A BRIEF HISTORY OF TIME: FROM THE BIG BANG TO BLACK HOLES 10 (1988).
[72] Documentary, AN INCONVENIENT TRUTH (2006).

Can our government and the U.N. control these factors:

- Solar Radiation: "Variations in the amount of solar radiation reaching the Earth are thought to influence climate, but the extent of this influence on timescales of millennia to decades is unclear. A number of climate records show correlations between solar cycles and climate, but the absolute changes in solar intensity over the range of decades to millennia are small and the influence of solar flux on climate is not well established."[73]

- Cosmic Rays: "The second type of mechanisms is indirect, through the solar modulation of the cosmic ray flux and the effect that the latter may have on the climate. Cosmic rays are high energy particles (primarily protons) which appear to originate from supernova remnants (the leftovers from the explosive death of massive stars). A possible climatic link through cosmic rays was first suggested by Edward Ney already in 1959. It was well known that the solar wind decreases the flux of these high energy particles and that these particles are the primary source of ionization in the troposphere (which is the lower part of the atmosphere). Ney proposed that the changing levels of ionization can play some climatic role."[74]

- Supernovae: "The hypothesis that a high GCR flux should coincide with cold conditions on the Earth is borne out by comparing the general geological record of climate over the past 510 million years with the fluctuating local SN rates. Surprisingly a simple combination of tectonics (long-term changes in sea level) and astrophysical activity (SN rates) largely accounts for the observed variations in marine biodiversity over the past 510 Myr."[75]

- Ocean Currents: "Understanding the processes that drive sea-ice formation and advancement can help scientists predict the future extent of Arctic ice coverage — an essential factor in detecting climate fluctuations and change. But existing models vary in their predictions for how sea ice will evolve."[76]

Summary Thought:

- Given the dynamic nature of our climate and the factors well outside of human control (many of which are not listed above), including lack of technology to govern these factors, is it possible to control and stop climate change through government regulations?

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[73] U. Neff, et al., *Strong Coherence between Solar Variability and the Monsoon in Oman between 9 and 6 kyr ago*, 411 NATURE J. 290-293 (2001).

[74] Nir Shaviv, *20th Century Global Warming "There is Nothing New Under the Sun"*, Racah Inst. of Physics, Hebrew Univ. of Jerusalem (June 2010), *available at* http://www.sciencebits.com/NothingNewUnderTheSun-I.

[75] Henrik Svensmark, *Evidence of Nearby Supernovae Affecting Life on Earth*, 423 MONTHLY NOTICES OF ROYAL ASTRONOMICAL SOC'Y 1234-1253 (Apr. 2012).

[76] Jennifer Chu, *Ocean Currents Play a Role in Predicting Extent of Arctic Sea Ice*, Mass. Inst. of Tech. News, Nov. 21, 2012, http://web.mit.edu/newsoffice/2012/ocean-currents-and-sea-ice-1121.html.

VI. SUMMARY: POINTS ON U.S. UNILATERAL REGULATION

- On December 7, 2009, the EPA expanded its regulation over air quality through an endangerment finding, determining that GHGs harm public health. This has become a cornerstone of the Obama Administration's regulatory agenda.

- However, EPA's Inspector General released a report in September 2011, "Procedural Review of EPA's Greenhouse Gases Endangerment Finding Data Quality Processes,"[77] revealing that the scientific assessment underpinning the EPA's endangerment finding for GHGs was inadequate and in violation of the Agency's own peer review procedures.

- According to the EPA's own website, total GHG emissions have only risen 1% in the U.S. since 2005,[78] while levels in China, India, and Russia have combined to rise more than 6%.[79] China is responsible for two-thirds of that number.

- China has surpassed the United States as the world's largest producer of CO_2.[80] They emit more CO_2 than the U.S. and Canada combined, and India is now the world's third biggest emitter of CO_2 - pushing Russia into fourth place. Simultaneously, U.S. CO_2 levels have been steadily declining.[81]

- According to a recent report from the World Resources Institute, there are plans to build nearly 1,200 coal-fired power plants in 59 different countries, totaling over 1.4 million megawatts. China and India alone account for 76 % of the proposals.[82] China now burns more coal than all countries combined, and India will surpass the United States as the world's second-largest consumer of coal by 2017.[83]

- Future emissions will come overwhelmingly from the developing world, and the most significant emitters (China, India, and Russia) do not ascribe to international GHG reduction agreements. Regardless, the Obama Administration maintains that it is in our best interest to regulate CO_2 domestically.

- Senator Joe Manchin (D-WV) had this to say about EPA's approach to climate and energy: "You know my concerns about the EPA not having an all-in energy policy. If we're talking about climate change and we're talking about the world consuming 8 billion

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[77] ENVTL. PROT. AGENCY, OFFICE OF INSPECTOR GEN., REPORT NO. 11-P-0702, PROCEDURAL REVIEW OF EPA'S GREENHOUSE GASES ENDANGERMENT FINDING DATA QUALITY PROCESSES (2011), *available at* http://www.epa.gov/oig/reports/2011/20110926-11-P-0702.pdf.

[78] *Global Greenhouse Gas Emissions Data*, U.S. Envtl. Prot. Agency, http://www.epa.gov/climatechange/ghgemissions/global.html.

[79] *Canada's Emissions Trends*, Env't Canada (2011) http://www.ec.gc.ca/doc/publications/cc/COM1374/ec-com1374-en-es.htm.

[80] *World Carbon Dioxide Emissions Data by Country: China Speeds Ahead of the Rest*, THE GUARDIAN DATA BLOG, http://www.guardian.co.uk/news/datablog/2011/jan/31/world-carbon-dioxide-emissions-country-data-co2.

[81] *Id.*

[82] Ailun Yang & Yiyun Cui, *Global Coal Risk Assessment: Data Analysis and Market Research*, (World Res. Inst., Working Paper, Nov. 2012), *available at* http://pdf.wri.org/global_coal_risk_assessment.pdf.

[83] Brad Plumer, *China Now Burning as much Coal as the Rest of the World*, WASH. POST, (Jan. 29, 2013), http://www.washingtonpost.com/blogs/wonkblog/wp/2013/01/29/china-is-burning-nearly-as-much-coal-as-the-rest-of-the-world-combined/.

tons of coal and the United States of America consuming less than 1 billion tons of coal, what's their proposal for cleaning up the environment on a global market?"[84]

- Even former EPA Administrator Lisa Jackson confirms that only having the United States regulate carbon will not have any impact on worldwide carbon levels. She testified at the July 7, 2009, EPW hearing, "Moving America toward a Clean Energy Economy and Reducing Global Warming Pollution: Legislative Tools," "I believe the central parts of the [EPA] chart are that U.S. action alone will not impact world CO_2 levels."[85]

- Regardless of her admission, EPA perseveres in moving forward with regulations targeting GHG emissions while justifying these rules as being beneficial to the economy, as well as public health and welfare. However, in February 2013, the U.S. Chamber of Commerce released a study examining dozens of air pollution rules dating from the 1990s. It reveals flawed analyses that do not take into account economy-wide impacts or negative impacts of the rules, raising significant concerns with the underlying economic modeling EPA utilizes.[86]

- President Obama's "green jobs" movement represents the epitome of failed government based on the false belief that U.S action alone is sound policy. Estimates from the National Renewable Energy Laboratory show that the government spent about $9 billion on green jobs and created just 910 new, long-term jobs. This means taxpayers spent $9.8 million per job.[87]

- The EU Emissions Trading Scheme (ETS) has cost their consumers $287 billion for "almost zero impact" on cutting carbon emissions, according to a 2011 UBS study. [88]

- Imposing a carbon tax on corporations and private business, which ultimately impacts consumers, is no wiser than unilateral regulation. In November 2012, the Congressional Budget Office released a study noting a carbon tax would "impose a larger burden, relative to income, on low-income households than on high-income households."[89] Furthermore, there exists zero evidence that carbon trading schemes in the EU, much less the United States, are having any impact on climate nor are they resulting in positive economic impacts or job creation in those regions.

- In late February 2013, the National Association of Manufacturers (NAM) released a study demonstrating the devastating effects a carbon tax would have on the economy,

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[84] Jason Plautz, *Former McCarthy Skeptic Signals 2nd-round Battle over Nomination*, ENV'T & ENERGY DAILY, March 5, 2013, http://www.eenews.net/EEDaily/2013/03/05/1.
[85] Hearing before the S. Comm. on Env't & Public Works, 111th Cong. (2009) (statement of Lisa Jackson, former EPA Administrator).
[86] *See generally* IMPACTS OF REGULATIONS ON EMPLOYMENT: EXAMINING EPA'S OFT-REPEATED CLAIMS THAT REGULATIONS CREATE JOBS, U.S. CHAMBER OF COMMERCE (Feb. 2013), *available at* http://www.uschamber.com/sites/default/files/reports/020360_ETRA_Briefing_NERA_Study_final.pdf.
[87] David Horowitz & Jacob Laksin, *Obama's Green Jobs Bust*, THE DAILY CALLER, July 10, 2012, http://dailycaller.com/2012/07/10/obamas-green-jobs-bust/.
[88] Sid Maher, *Europe's $287bn Carbon 'Waste': UBS Report*, THE AUSTRALIAN, Nov. 23, 2011, http://www.theaustralian.com.au/national-affairs/europes-287bn-carbon-waste-ubs-report/story-fn59niix-1226203068972.
[89] Terry Dinan, *Offsetting a Carbon Tax's Costs on Low-Income Households* (Cong. Budget Office, Working Paper No. 16, 2012), *available at* http://www.cbo.gov/sites/default/files/cbofiles/attachments/11-13LowIncomeOptions.pdf.

including manufacturing output falling up to 15 percent, millions of jobs lost, and approximately a $1 trillion reduction in economic growth.[90] Unilateral regulatory action by the EPA is set to similarly undermine our national economy.

"The energy of the mind is the essence of life."[91] Aristotle, Greek philosopher and polymath, a student of Plato and teacher of Alexander the Great

[90] ECONOMIC OUTCOME OF A U.S. CARBON TAX, NERA ECONOMIC CONSULTING (Feb. 26, 2013) http://www.nam.org/~/media/64FDD87B13C44C3E8E95CC805E4E5952.ashx?utm_source=nam&utm_medium=alias&utm_campaign=CarbonTax+Full+Report.

[91] *See The Power of the Mind: Quotes to Get You Thinking*, PSYCHOLOGY TODAY (Jan. 4, 2012) http://www.psychologytoday.com/blog/high-octane-women/201201/the-power-the-mind-quotes-get-you-thinking.

Drought and Global Climate Change: An Analysis of Statements by Roger Pielke Jr
John P. Holdren, 28 February 2014

Introduction

In the question and answer period following my February 25 testimony on the Administration's Climate Action Plan before the Oversight Subcommittee of the U.S. Senate's Committee on Environment and Public Works, Senator Jeff Sessions (R-AL) suggested that I had misled the American people with comments I made to reporters on February 13, linking recent severe droughts in the American West to global climate change. To support this proposition, Senator Sessions quoted from testimony before the Environment and Public Works Committee the previous July by Dr. Roger Pielke, Jr., a University of Colorado political scientist. Specifically, the Senator read the following passages from Dr. Pielke's written testimony:

> *It is misleading, and just plain incorrect, to claim that disasters associated with hurricanes, tornadoes, floods or droughts have increased on climate timescales either in the United States or globally.*
>
> *Drought has "for the most part, become shorter, less, frequent, and cover a smaller portion of the U.S. over the last century". Globally, "there has been little change in drought over the past 60 years."*

Footnotes in the testimony attribute the two statements in quotation marks within the second passage to the US Climate Change Science Program's 2008 report on extremes in North America and a 2012 paper by Sheffield *et al.* in the journal Nature, respectively.

I replied that the indicated comments by Dr. Pielke, and similar ones attributed by Senator Sessions to Dr. Roy Spencer of the University of Alabama, were not representative of mainstream views on this topic in the climate-science community; and I promised to provide for the record a more complete response with relevant scientific references.

Dr. Pielke also commented directly, in a number of tweets on February 14 and thereafter, on my February 13 statements to reporters about the California drought, and he elaborated on the tweets for a blog post on The Daily Caller site (also on February 14). In what follows, I will address the relevant statements in those venues, as well. He argued there, specifically, that my statements on drought "directly contradicted scientific reports", and in support of that assertion, he offered the same statements from his July testimony that were quoted by Senator Sessions (see above). He also added this:

> *The United Nations Intergovernmental Panel on Climate Change found that there is "not enough evidence at present to suggest more than low confidence in a global-scale observed trend in drought."*

In the rest of this response, I will show, first, that the indicated quote from the US Climate Change Science Program (CCSP) about U.S. droughts is missing a crucial adjacent sentence in the CCSP report, which supports my position about drought in the American West. I will also show that Dr. Pielke's statements about global drought trends, while irrelevant to my comments about drought in California and the Colorado River Basin, are seriously misleading, as well, concerning what is actually in the UN Panel's latest report and what is in the current scientific literature.

Drought trends in the American West

My comments to reporters on February 13, to which Dr. Pielke referred in his February 14 tweet and to which Senator Sessions referred in the February 25 hearing, were provided just ahead of President Obama's visit to the drought-stricken California Central Valley and were explicitly about the drought situation in California and elsewhere in the West.

That being so, any reference to the CCSP 2008 report in this context should include not just the sentence highlighted in Dr. Pielke's testimony but also the sentence that follows immediately in the relevant passage from that document and which relates specifically to the American West. Here are the two sentences in their entirety (http://downloads.globalchange.gov/sap/sap3-3/Brochure-CCSP-3-3.pdf):

> *Similarly, long-term trends (1925-2003) of hydrologic droughts based on model derived soil moisture and runoff show that droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the U.S. over the last century (Andreadis and Lettenmaier, 2006). The main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends (Groisman et al., 2004; Andreadis and Lettenmaier, 2006).*

Linking Drought to Climate Change

In my recent comments about observed and projected increases in drought in the American West, I mentioned four relatively well understood mechanisms by which climate change can play a role in drought. (I have always been careful to note that, scientifically, we cannot say that climate change caused a particular drought, but only that it is expected to increase the frequency, intensity, and duration of drought in some regions—and that such changes are being observed.)

The four mechanisms are:

1. In a warming world, a larger fraction of total precipitation falls in downpours, which means a larger fraction is lost to storm runoff (as opposed to being absorbed in soil).
2. In mountain regions that are warming, as most are, a larger fraction of precipitation falls as rain rather than as snow, which means lower stream flows in spring and summer.
3. What snowpack there is melts earlier in a warming world, further reducing flows later in the year.
4. Where temperatures are higher, losses of water from soil and reservoirs due to evaporation are likewise higher than they would otherwise be.

Regarding the first mechanism, the 2013 report of the IPCC's Working Group I, *The Science Basis* (http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf, p 110), deems it "likely" (probability greater than 66%) that an increase in heavy precipitation events is already detectable in observational records since 1950 for more land areas than not, and that further changes in this direction are "likely over many land areas" in the early 21st century and "very likely over most of the mid-latitude land masses" by the late 21st century The second, third, and fourth mechanisms reflect elementary physics and are hardly subject to dispute (but see also additional references provided at the end of this comment).

As I have also noted in recent public comments, additional mechanisms have been identified by which changes in atmospheric circulation patterns that may be a result of global warming could be affecting droughts in the American West. There are some measurements and some analyses suggesting that these mechanisms are operating, but the evidence is less than conclusive, and some respectable analysts attribute the indicated circulation changes to natural variability. The uncertainty about these mechanisms should not be allowed to become a distraction obscuring the more robust understandings about climate change and regional drought summarized above.

Global Drought Patterns

Drought is by nature a regional phenomenon. In a world that is warming on the average, there will be more evaporation and therefore more precipitation; that is, a warming world will also get wetter, on the average. In speaking of global trends in drought, then, the meaningful questions are (a) whether the frequency, intensity, and duration of droughts are changing in most or all of the regions historically prone to drought and (b) whether the total area prone to drought is changing.

Any careful reading of the 2013 IPCC report and other recent scientific literature about on the subject reveals that droughts have been worsening in some regions in recent decades while lessening in other regions, and that the IPCC's "low confidence" about a global trend relates mainly to the question of total area prone to drought and a lack of sufficient measurements to settle it. Here is the key passage from the Technical Summary from IPCC WGI's 2013 report (http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf, p 112):

> *Compelling arguments both for and against significant increases in the land area affected by drought and/or dryness since the mid-20th century have resulted in a low confidence assessment of observed and attributable large-scale trends. This is due primarily to a lack and quality of direct observations, dependencies of inferred trends on the index choice, geographical inconsistencies in the trends and difficulties in distinguishing decadal scale variability from long term trends.*

The table that accompanies the above passage from the IPCC's report—captioned "Extreme weather and climate events: global-scale assessment of recent observed changes, human contribution to the changes, and projected further changes for the early (2016-2035) and late (2081-2100) 21st century"—has the following entries for "Increases in intensity and/or duration of drought": under changes observed since 1950, "low confidence on a global scale, likely changes in some regions" [emphasis added]; and under projected changes for the late 21st century, "likely (medium confidence) on a regional to global scale".

Dr. Pielke's citation of a 2012 paper from Nature by Sheffield *et al.*, entitled "Little change in global drought over the past 60 years", is likewise misleading. That paper's abstract begins as follows:

> *Drought is expected to increase in frequency and severity in the future as a result of climate change, mainly as a consequence of decreases in regional precipitation but also because of increasing evaporation driven by global warming*[1-3]*. Previous assessments of historic changes in drought over the late twentieth and early twenty-first centuries indicate that this may already be happening globally. In particular, calculations of the Palmer Drought Severity Index (PDSI) show a decrease in moisture globally since the 1970s with a commensurate increase in the area of drought that is attributed, in part, to global warming*[4-5]*.*

The paper goes on to argue that the PDSI, which has been relied upon for drought characterization since the 1960s, is too simple a measure and may (the authors' word) have led to overestimation of global drought trends in previous climate-change assessments—including the IPCC's previous (2007) assessment, which found that "More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics."

The authors argue for use of a more complex index of drought, which, however, requires more data and more sophisticated models to apply. Their application of it with the available data shows a smaller global drought trend than calculated using the usual PDSI, but they conclude that better data are needed. The conclusion of the Sheffield *et al.* paper has proven controversial, with some critics pointing to the inadequacy of existing observations to support the more complex index and others arguing that a more rigorous application of the new approach leads to results similar to those previously obtained using the PDSI.

A measure of the differences of view on the topic is available in a paper entitled "Increasing drought under global warming in observations and models", published in Nature Climate Change at about the same time as Sheffield et al. by a leading drought expert at the National Center for Climate Research, Dr. Aiguo Dai. Dr. Dai's abstract begins and ends as follows:

> *Historical records of precipitation, streamflow, and drought indices all show increased aridity since 1950 over many land areas[1,2]. Analyses of model-simulated soil moisture[3,4], drought indices[1,5,6], and precipitation minus evaporation[7] suggest increased risk of drought in the twenty-first century. ... I conclude that the observed global aridity changes up to 2010 are consistent with model predictions, which suggest severe and widespread droughts in the next 30-90 years over many land areas resulting from either decreased precipitation and/or increased evaporation.*

The disagreement between the Sheffield et al. and Dai camps appears to have been responsible for the IPCC's downgrading to "low confidence", in its 2013 report, the assessment of an upward trend in global drought in its 2007 Fourth Assessment and its 2012 Special Report on Extreme Events (http://www.ipcc-wg2.gov/SREX/) .

Interestingly, a number of senior parties to the debate—including Drs. Sheffield and Dai—have recently collaborated on a co-authored paper, published in the January 2014 issue of Nature Climate Change, entitled "Global warming and changes in drought". In this new paper, the authors identify the reasons for their previous disagreements; agree on the need for additional data to better separate natural variability from human-caused trends; and agree on the following closing paragraph (quoted here in full):

> *Changes in the global water cycle in response to the warming over the twenty-first century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will probably increase, although there may be regional exceptions. Climate change is adding heat to the climate system and on land much of that heat goes into drying. A natural drought should therefore set in quicker, become more intense, and may last longer. Droughts may be more extensive as a result. Indeed, human-induced warming effects accumulate on land during periods of drought because the 'air conditioning effects' of water are absent. Climate change may not manufacture droughts, but it could exacerbate them and it will probably expand their domain in the subtropical dry zone.*

Additional References (with particularly relevant direct quotes in italics)

Christopher R. Schwalm *et al.*, Reduction of carbon uptake during turn of the century drought in western North America, Nature Geoscience, vol. 5, August 2012, pp 551-556.

> *The severity and incidence of climatic extremes, including drought, have increased as a result of climate warming. ... The turn of the century drought in western North America was the most severe drought over the past 800 years, significantly reducing the modest carbon sink normally present in this region. Projections indicate that drought events of this length and severity will be commonplace through the end of the twenty-first century.*

Gregory T. Pederson *et al.*, The unusual nature of recent snowpack declines in the North American Cordillera, Science, vol. 333, 15 July 2011, pp 332-335.

> *Over the past millennium, late 20th century snowpack reductions are almost unprecedented in magnitude across the northern Rocky Mountains and in their north-south synchrony across the cordillera. Both the snowpack declines and their synchrony result from unparalleled springtime warming that is due to positive reinforcement of the anthropogenic warming by decadal variability. The increasing role of warming on large-scale snowpack variability and trends foreshadows fundamental impacts on streamflow and water supplies across the western United States.*

Gregory T. Pederson et al., Regional patterns and proximal causes of the recent snowpack decline in the Rocky Mountains, US, Geophysical Research Letters, vol. 40, 16 May 2013, pp 1811-1816.

> *The post-1980 synchronous snow decline reduced snow cover at low to middle elevations by ~20% and partly explains earlier and reduced streamflow and both longer and more active fire seasons. Climatologies of Rocky Mountain snowpack are shown to be seasonally and regionally complex, with Pacific decadal variability positively reinforcing the anthropogenic warming trend.*

Michael Wehner et al., Projections of future drought in the continental United States and Mexico, Journal of Hydrometeorology, vol. 12, December 2011, pp 1359-1377.

> *All models, regardless of their ability to simulate the base-period drought statistics, project significant future increases in drought frequency, severity, and extent over the course of the 21st century under the SRES A1B emissions scenario. Using all 19 models, the average state in the last decade of the twenty-first century is projected under the SRES A1B forcing scenario to be conditions currently considered severe drought (PDSI<-3) over much of the continental United States and extreme drought (PDSI<-4) over much of Mexico.*

D. R. Cayan *et al.*, Future dryness in the southwest US and the hydrology of the early 21st century drought, Proceedings of the National Academy of Sciences, vol. 107, December 14, 2010, pp 21271-21276.

> *Although the recent drought may have significant contributions from natural variability, it is notable that hydrological changes in the region over the last 50 years cannot be fully explained by natural variability, and instead show the signature of anthropogenic climate change.*

E. P. Maurer *et al.*, Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada, Journal of Geophysical Research, vol. 112, 2007, doi:10.1029/2006JD08088.

> *The warming experienced in recent decades has caused measurable shifts toward earlier streamflow timing in California. Under future warming, further shifts in streamflow timing are projected for the rivers draining the western Sierra Nevada, including the four considered in this study. These shifts and their projected increases through the end of the 21st century will have dramatic impacts on California's managed water system.*

H. G. Hidalgo *et al.*, Detection and attribution of streamflow timing changes to climate change in the western United States, Journal of Climate, vol. 22, issue 13, 2009, pp 3838-3855, doi: 10.1175/2009JCLI2740.1.

> *The advance in streamflow timing in the western United States appears to arise, to some measure, from anthropogenic warming. Thus the observed changes appear to be the early phase of changes expected under climate change. This finding presages grave consequences for the water supply, water management, and ecology of the region. In particular, more winter and spring flooding and drier summers are expected as well as less winter snow (more rain) and earlier snowmelt.*

COMMENTARY:

Overestimated global warming over the past 20 years

John C. Fyfe, Nathan P. Gillett and Francis W. Zwiers

Recent observed global warming is significantly less than that simulated by climate models. This difference might be explained by some combination of errors in external forcing, model response and internal climate variability.

Global mean surface temperature over the past 20 years (1993–2012) rose at a rate of 0.14 ± 0.06 °C per decade (95% confidence interval)[1]. This rate of warming is significantly slower than that simulated by the climate models participating in Phase 5 of the Coupled Model Intercomparison Project (CMIP5). To illustrate this, we considered trends in global mean surface temperature computed from 117 simulations of the climate by 37 CMIP5 models (see Supplementary Information). These models generally simulate natural variability — including that associated with the El Niño–Southern Oscillation and explosive volcanic eruptions — as well as estimate the combined response of climate to changes in greenhouse gas concentrations, aerosol abundance (of sulphate, black carbon and organic carbon, for example), ozone concentrations (tropospheric and stratospheric), land use (for example, deforestation) and solar variability. By averaging simulated temperatures only at locations where corresponding observations exist, we find an average simulated rise in global mean surface temperature of 0.30 ± 0.02 °C per decade (using 95% confidence intervals on the model average). The observed rate of warming given above is less than half of this simulated rate, and only a few simulations provide warming trends within the range of observational uncertainty (Fig. 1a).

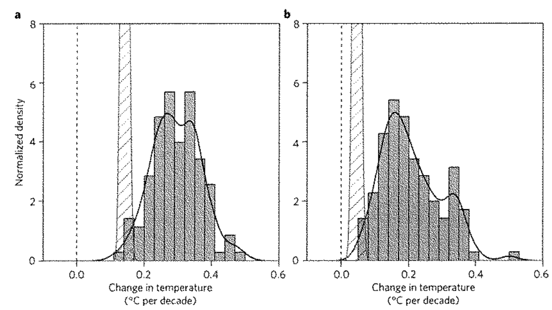

Figure 1 | Trends in global mean surface temperature. **a**, 1993–2012. **b**, 1998–2012. Histograms of observed trends (red hatching) are from 100 reconstructions of the HadCRUT4 dataset[1]. Histograms of model trends (grey bars) are based on 117 simulations of the models, and black curves are smoothed versions of the model trends. The ranges of observed trends reflect observational uncertainty, whereas the ranges of model trends reflect forcing uncertainty, as well as differences in individual model responses to external forcings and uncertainty arising from internal climate variability.

The inconsistency between observed and simulated global warming is even more striking for temperature trends computed over the past fifteen years (1998–2012). For this period, the observed trend of 0.05 ± 0.08 °C per decade is more than four times smaller than the average simulated trend of 0.21 ± 0.03 °C per decade (Fig. 1b). It is worth noting that the observed trend over this period — not significantly different from zero — suggests a temporary 'hiatus' in global warming[2–4]. The divergence between observed and CMIP5-simulated global warming begins in the early 1990s, as can be seen when comparing observed and simulated running trends from 1970–2012 (Fig. 2a and 2b for 20-year and 15-year running trends, respectively).

The evidence, therefore, indicates that the current generation of climate models (when run as a group, with the CMIP5 prescribed forcings) do not reproduce the observed global warming over the past 20 years, or the slowdown in global warming over the past fifteen years. This interpretation is supported by statistical tests of the null hypothesis that the observed and model mean trends are equal, assuming that either: (1) the models are exchangeable with each other (that is, the 'truth plus error' view); or (2) the models are exchangeable with each other and with the observations (see Supplementary Information). Differences between observed and simulated 20-year trends have p values (Supplementary Information) that drop to close to zero by 1993–2012 under assumption (1) and to 0.04 under assumption (2) (Fig. 2c). Here we note that the smaller the p value is, the stronger the evidence against the null hypothesis. On this basis, the rarity of the 1993–2012 trend difference under assumption (1) is obvious. Under assumption (2), this implies that such an inconsistency is only expected to occur by chance once in 500 years, if

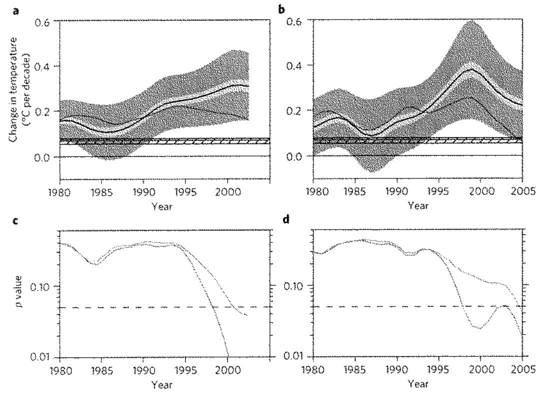

Figure 2 | Global mean surface temperature trends and *p* values. **a**,**b**, 20-year (**a**) and 15-year (**b**) running trends. Black curves are ensemble-averaged trends over the 37 sets of model simulations. Dark-grey shading indicates the 2.5–97.5% ranges of the simulated estimates. Light-grey shading shows the 95% uncertainty ranges of the ensemble means, derived by dividing the 2.5–97.5% ranges by the square root of the number of models. Red curves are the observed trends averaged over 100 realizations and the horizontal red lines show the observed 1900–2012 trends averaged over 100 realizations. Black cross-hatchings are the 95% uncertainty ranges for simulated 1900–2012 ensemble mean trends. Note that the observed and simulated long-term trends are very similar to one another, and are smaller than the short-term trends. **c**,**d**, 20-year (**c**) and 15-year (**d**) *p* values on trend differences between the simulations and observations for assumption (1) (purple curves), or assumption (2) (green curves). The horizontal dashed lines indicate the threshold below which we reject the null hypothesis.

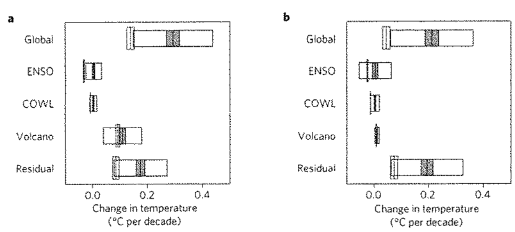

Figure 3 | Trends in global mean surface temperature and in associated natural and residual time series. **a**, 1993–2012. **b**, 1998–2012. The 2.5–97.5% ranges for observed estimates are shown by the red boxes. The 2.5–97.5% ranges for simulated estimates are represented by the open black boxes, with the 95% ranges on ensemble mean trends indicated by grey shading. The estimated natural signals shown are associated with the El Niño-Southern Oscillation (ENSO), dynamically induced atmospheric variability (cold ocean-warm Earth; COWL) and major explosive volcanic eruptions (Volcano). Trends in global mean surface temperature without these estimated natural signals are shown at the bottom (Residual).

20-year periods are considered statistically independent. Similar results apply to trends for 1998–2012 (Fig. 2d). In conclusion, we reject the null hypothesis that the observed and model mean trends are equal at the 10% level.

One possible explanation for the discrepancy is that forced and internal variation might combine differently in observations than in models. For example, the forced trends in models are modulated up and down by simulated sequences of ENSO events, which are not expected to coincide with the observed sequence of such events. For this reason the moderating influence on global warming that arises from the decay of the 1998 El Niño event does not occur in the models at that time. Thus we employ here an established technique to estimate the impact of ENSO on global mean temperature, and to incorporate the effects of dynamically induced atmospheric variability and major explosive volcanic eruptions[5,6]. Although these three natural variations account for some differences between simulated and observed global warming, these differences do not substantively change our conclusion that observed and simulated global warming are not in agreement over the past two decades (Fig. 3). Another source of internal climate variability that may contribute to the inconsistency is the Atlantic multidecadal oscillation[7] (AMO). However, this is difficult to assess as the observed and simulated variations in global temperature that are associated with the AMO seem to be dominated by a large and concurrent signal of presumed anthropogenic origin (Supplementary Fig. S1). It is worth noting that in any case the AMO has not driven cooling over the past 20 years.

Another possible driver of the difference between observed and simulated global warming is increasing stratospheric aerosol concentrations. Results from several independent datasets show that stratospheric aerosol abundance has increased since the late 1990s, owing to a series of comparatively small tropical volcanic eruptions[8]. Although none of the CMIP5 simulations take this into account, two independent sets of model simulations estimate that increasing stratospheric aerosols have had a surface cooling impact of about 0.07 °C per decade since 1998[8,9]. If the CMIP5 models had accounted for increasing stratospheric aerosol, and had responded with the same surface cooling impact, the simulations and observations would be in closer agreement. Other factors that contribute to the discrepancy could include a missing decrease in stratospheric water vapour[10] (whose processes are not well represented in current climate models), errors in aerosol forcing in the CMIP5 models, a bias in the prescribed solar irradiance trend, the possibility that the transient climate sensitivity of the CMIP5 models could be on average too high[11,12] or a possible unusual episode of internal climate variability not considered above[13,14]. Ultimately the causes of this inconsistency will only be understood after careful comparison of simulated internal climate variability and climate model forcings with observations from the past two decades, and by waiting to see how global temperature responds over the coming decades. ❐

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References

1. Morice, C. P., Kennedy, J. J., Rayner, N. A. & Jones, P. D. *J. Geophys. Res.* **117**, D08101 (2012).
2. Easterling, D. R. & Wehner, M. F. *Geophys. Res. Lett.* **36**, L08706 (2009).
3. Knight, J. *et al. Bull. Am. Meteorol. Soc.* **90**, S75–S79 (2009).
4. Fyfe, J. C. *et al. Geophys. Res. Lett.* **38**, L22801 (2011).
5. Thompson, W. J., Wallace, J. M., Jones, P. D. & Kennedy, J. J. *J. Clim.* **22**, 6120–6141 (2009).
6. Fyfe, J. C., Gillett, N. P. & Thompson, D. W. J. *Geophys. Res. Lett.* **37**, L16802 (2010).
7. Schlesinger, M. E. & Ramankutty, N. *Nature* **367**, 723–726 (1994).
8. Solomon, S. *et al. Science* **333**, 866–870 (2011).
9. Fyfe, J. C., von Salzen, K., Cole, J. N. S., Gillett, N. P. & Vernier, J-P. *Geophys. Res. Lett.* **40**, 584–588 (2013).
10. Solomon, S. *et al. Science* **327**, 1219–1223 (2010).
11. Stott, P., Good, P., Jones, G., Gillett, N. & Hawkins, E. *Environ. Res. Lett.* **8**, 014024 (2013).
12. Otto, A. *et al. Nature Geosci.* **6**, 415–416 (2013).
13. Meehl, G. A., Arblaster, J. M., Fasullo, J. T., Hu, A. & Trenberth, K. E. *Nature Clim. Change* **1**, 360–364 (2011).
14. Guemas, V., Doblas-Reyes, F. J., Andreu-Burillo, I. & Asif, M. *Nature Clim. Change* **3**, 649–653 (2013).

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Author Contributions

J.C.F. helped to carry out the analysis and wrote the initial draft. N.P.G. and F.W.Z. helped with the analysis and edited the manuscript.

Additional information

Supplementary information is available in the online version of the paper.

COMMENTARY:

Uncertainty analysis in climate change assessments

Richard W. Katz, Peter F. Craigmile, Peter Guttorp, Murali Haran, Bruno Sansó and Michael L. Stein

Use of state-of-the-art statistical methods could substantially improve the quantification of uncertainty in assessments of climate change.

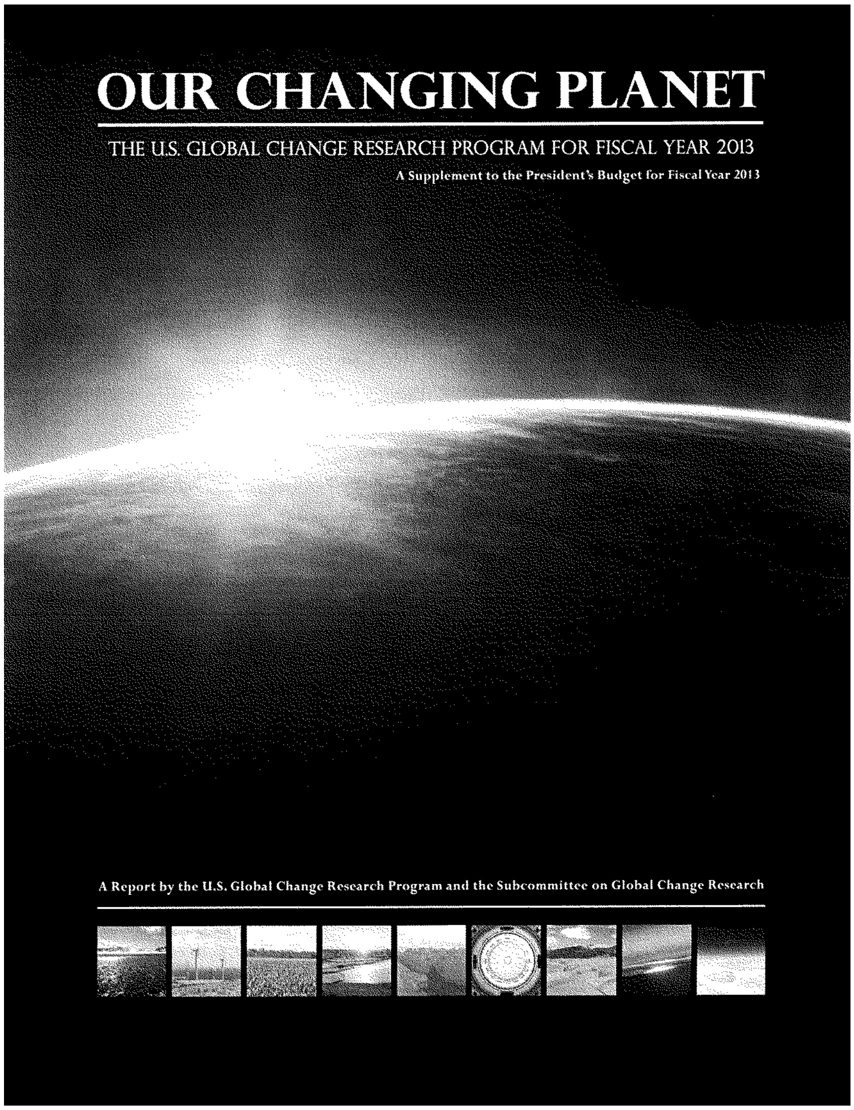
Because the climate system is so complex, involving nonlinear coupling of the atmosphere and ocean, there will always be uncertainties in assessments and projections of climate change. This makes it hard to predict how the intensity of tropical cyclones will change as the climate warms, the rate of sea-level rise over the next century or the prevalence and severity of future droughts and floods, to give just a few well-known examples. Indeed, much of the disagreement about the policy implications of climate change revolves around a lack of certainty. The forthcoming Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) and the US National Climate Assessment Report will not adequately address this issue. Worse still, prevailing techniques for quantifying the uncertainties that are inherent in observed climate trends and projections of climate change are out of date by well over a decade. Modern statistical methods and models could improve this situation dramatically.

Uncertainty quantification is a critical component in the description and attribution of climate change. In some circumstances, uncertainty can increase when previously neglected sources of uncertainty are recognized and accounted for (Fig. 1 shows how uncertainty can increase for projections of sea-level rise). In other circumstances, more rigorous quantification may result in a decrease in the apparent level of uncertainty, in part because of more efficient use of the available information. For example, despite much effort over recent decades, the uncertainty in the estimated climate sensitivity (that is, the long-term response of global mean temperature to a doubling of the CO_2 concentration in the atmosphere) has not noticeably decreased[1]. Nevertheless, policymakers need more accurate uncertainty estimates to make better decisions[2].

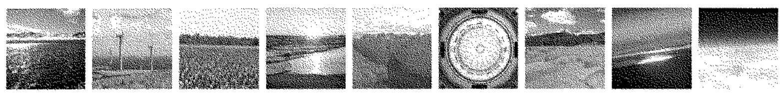
Detailed guidance provided to authors of the IPCC AR5 and the US National Climate Assessment Report emphasizes the use of consistent terminology for describing uncertainty for risk communication. This includes a formal definition of terms such as 'likely' or 'unlikely' but, oddly, little advice is given about what statistical techniques should be adopted for uncertainty analysis[3,4]. At the least, more effort could be made to encourage authors to make use of modern techniques.

Historically, several compelling examples exist in which the development and application of innovative statistical methods resulted in breakthroughs in the understanding of the climate system (for example, Sir Gilbert Walker's research in the early twentieth century related to the El Niño–Southern Oscillation phenomenon[5]). We anticipate that similar success stories can be achieved for quantification of uncertainty in climate change.

Although climate observations and climate model output have different sources of error, both exhibit substantial spatial and temporal dependence. Hierarchical statistical models can capture these features in a more realistic manner[6]. These models adopt a 'divide and conquer' approach, breaking the problem into several layers of conceptually and computationally simpler conditional statistical models. The combination of these components produces an unconditional statistical model, whose structure can be quite complex and realistic.


OUR CHANGING PLANET
THE U.S. GLOBAL CHANGE RESEARCH PROGRAM FOR FISCAL YEAR 2013
A Supplement to the President's Budget for Fiscal Year 2013
A Report by the U.S. Global Change Research Program and the Subcommittee on Global Change Research

OUR CHANGING PLANET



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EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

February, 2013

Members of Congress:

On behalf of the National Science and Technology Council, I am pleased to transmit *Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year (FY) 2013.* The U.S. Global Change Research Program (USGCRP) coordinates scientific research across 13 Federal departments and agencies whose missions include understanding changes in the global environment and their implications for society. In accordance with the Global Change Research Act of 1990 (GCRA) the enclosed report summarizes USGCRP's recent achievements, current status, future priorities, and FY 2013 budget information.

Notably, in April 2012, USGCRP released the *National Global Change Research Plan 2012 – 2021: A Strategic Plan for the U.S. Global Change Research Program.* The Plan sets four strategic goals for USGCRP to achieve over the next decade: (1) advance science; (2) inform decisions; (3) conduct sustained assessments; and (4) communicate and educate. It also reinforces the importance of partnerships that leverage Federal investments and foster broad use of Program results.

Implementation of this Plan will build upon USGCRP's strengths in integrated observation, modeling, information services, and science to serve societal needs. It will also fully address the GCRA mandate to "*understand, assess, predict, and respond to human-induced and natural processes of global change.*"

This *Our Changing Planet* report summarizes USGCRP's significant progress toward achieving its strategic goals and building a knowledge base that effectively informs human responses to global change. I appreciate the close cooperation of the participating agencies and look forward to continuing to work with members of the Congress on advancing this essential National program.

Sincerely,

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

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PHOTOGRAPHY CREDITS
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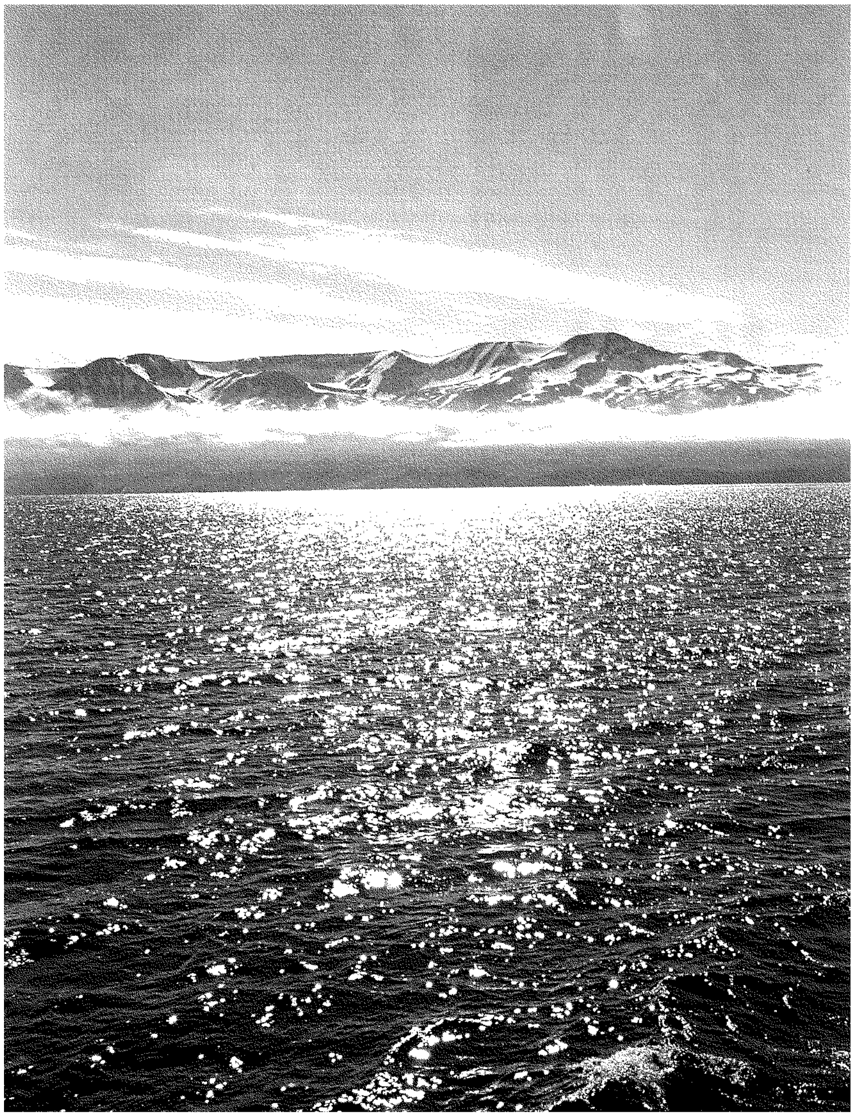
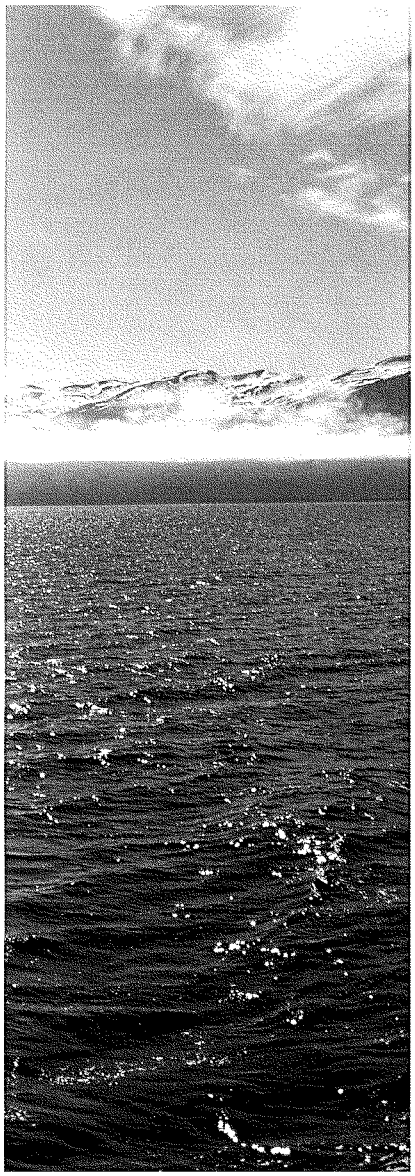




1. INTRODUCTION

"We're aiming to ensure that any response to global change is a response informed by sound science."

— Thomas R. Armstrong, Executive Director of the U.S. Global Change Research Program, April 2012

Global change is happening now. Increases in population, industrialization, and human activities have altered the world's climate, oceans, land, ice cover, and ecosystems. In the United States, climate change has already resulted in more frequent heat waves, extreme precipitation, wildfires, and water scarcity.

These are serious challenges that directly affect American families, communities, and jobs. The only way to respond effectively is with a sound understanding of the changes underway, the threats and opportunities they present, and how they will change over time. The United States Congress recognized this urgent need in 1990 by mandating a Federal interagency program to *"assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."*

The U.S. Global Change Research Program (USGCRP) is designed to fulfill that mandate by coordinating the Federal Government's $2.6 billion annual investment in global change research—the largest such investment in the world (Figure 1).

Figure 1. USGCRP's Vision and Mission.

Vision – *A nation, globally engaged and guided by science, meeting the challenges of climate and global change*

Mission – *To build a knowledge base that informs human responses to climate and global change through coordinated and integrated Federal programs of research, education, communication, and decision support*

The science portfolio managed by USGCRP spans systems and scales from atoms, to ecosystems, to the entire planet, and includes changes being wrought by human behaviors as well as by larger forces. It incorporates nearly all forms of scientific work, including laboratory experiments, field research, computer modeling, scientific assessment, and observations of Earth from land, air, sea, and space. This vast body of work is carried out by 13 Federal agencies, each with its own mission and areas of expertise (Figure 2).

USGCRP provides both a skeletal framework for and connective tissue between these member agencies so that, together, they produce effective, efficient, and holistic results. This is accomplished in a variety of ways—by developing joint research priorities, enabling knowledge and capacity transfer between agencies, minimizing redundancy across projects, and leveraging distributed Federal resources—an especially important task during austere budget times.

Figure 2. USGCRP Member Agencies and Departments.

- Department of Agriculture
- Department of Commerce
- Department of Defense
- Department of Energy
- Department of Health and Human Services
- Department of the Interior
- Department of State
- Department of Transportation
- Environmental Protection Agency
- National Aeronautics and Space Administration
- National Science Foundation
- Smithsonian Institution
- United States Agency for International Development

Science activities enabled by USGCRP include:

- Observations of the Earth, including satellite observations that allow scientists to monitor global change and understand climate processes;
- Development, testing, and application of sophisticated models—the principal tools scientists use to predict future climate;
- Assessments of the current climate and climate change impacts in the United States by synthesizing available scientific information from peer-reviewed literature and other credible sources;
- Sharing of information to support specific adaptation and response needs, in part through increased engagement between those researching global change and those affected by it; and
- Communication of scientific findings to diverse audiences, including the public, members of the Congress, and the global research community.

For more than two decades, USGCRP has supported the Federal global change research enterprise to create a high-performance science portfolio that today provides taxpayers substantial returns on their investment—including major advances in our knowledge of Earth's past and present climate, improved climate change projections for the future, and a better understanding of our vulnerabilities to the impacts of global change. These benefits extend far beyond pure science into domains that are directly relevant to the day-to-day lives of Americans and others around the world. They support weather forecasting, water and land resource management, agricultural crop production, and many other functions that impact lives, livelihoods, and communities.

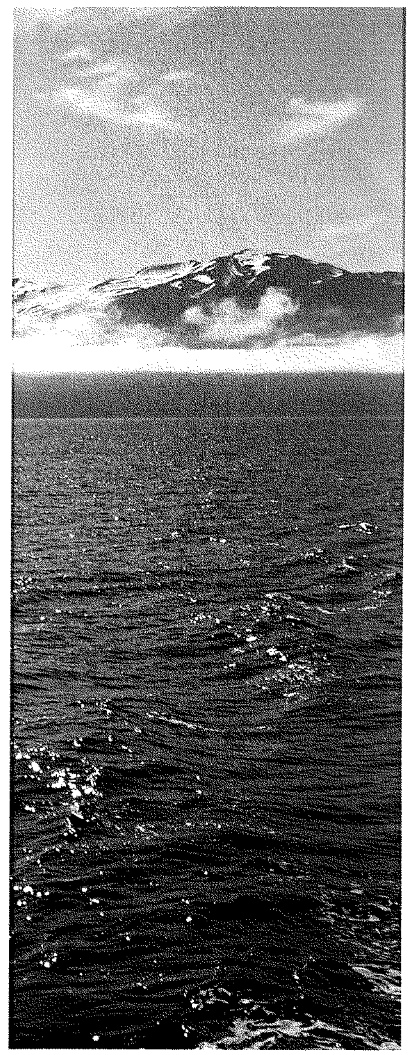
Today, USGCRP continues to advance fundamental scientific understanding of global change. But recognizing that global change and its consequences are happening already, it is also focusing more than ever on a new priority: ensuring that its science is as immediately decision-relevant as possible.

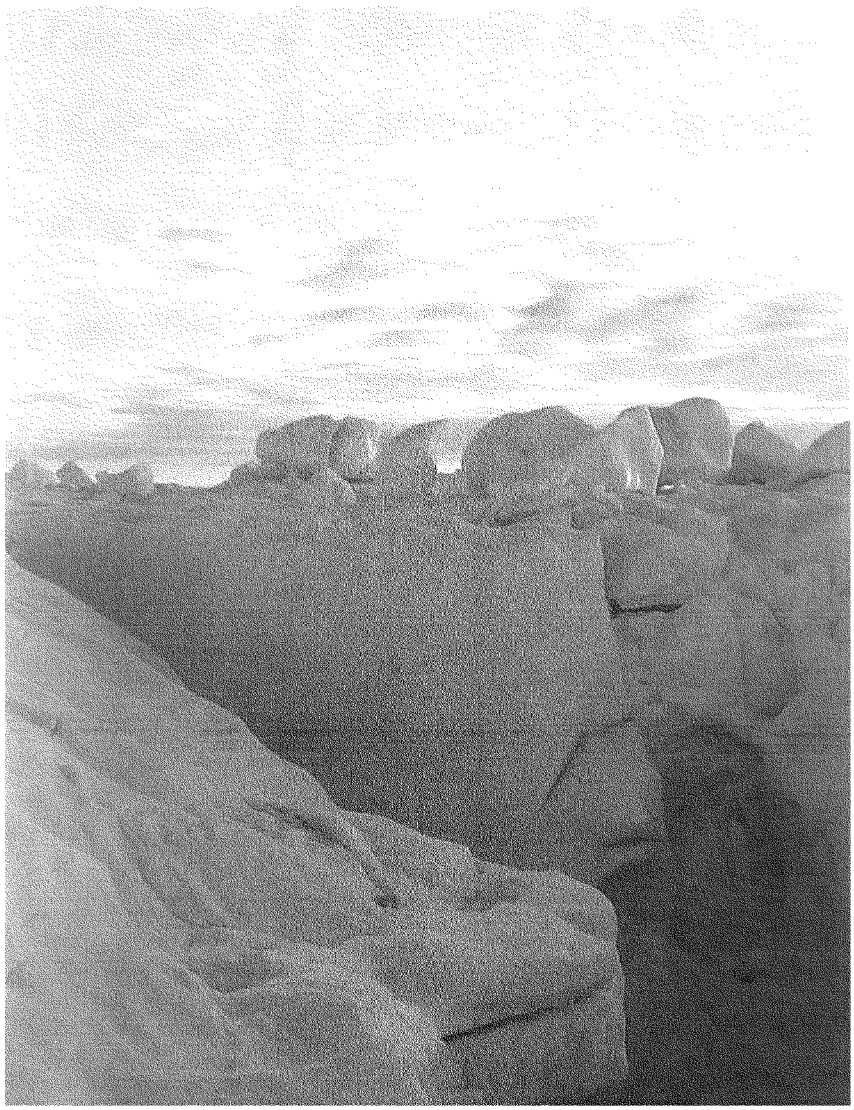
A new Research Plan for 2012-2021 lays out clear goals and objectives to achieve this ambitious new emphasis, including the expansion of stakeholder participation in all stages of the scientific process, and dissemination of results and information to broad audiences, including the public.

A substantial amount of work is underway at USGCRP to achieve this vision—with many notable successes already achieved. Highlights of this recent work and its benefits to the Nation are presented to members of the Congress and the public in this *Our Changing Planet* report.

"What we're doing—at a fundamental level—is working to prepare the Nation and the world for the future."

— Thomas Karl, Chair of the National Science and Technology Committee's Subcommittee on Global Change Research, April 2012





2. FY 2012 & RECENT ACCOMPLISHMENTS

2.1 NEW DECADAL RESEARCH PLAN

Today's rate of global change far exceeds anything documented in human history. Decision makers at every level of government, across every geographic region, and in every economic sector are demanding clear information about global change in order to plan, prepare, adapt, and respond. Because of USGCRP's legacy of major contributions to climate change science, the breadth of expertise encompassed by its member agencies, and its broad, ongoing engagement with decision makers, the Program is highly qualified to address this growing demand for information.

In April 2012, USGCRP released a new research plan that describes in detail how the Program will fulfill this role and its Congressional mandate over the next decade (Figure 3). The Plan, entitled *The National Global Change Research Plan 2012-2021: A Strategic Plan for the U.S. Global Change Research Program*, lays out specific goals and objectives to generate and disseminate scientific knowledge that is readily available and directly useful to decision makers and citizens (Figure 4).

Figure 3. Cover image of the National Global Change Research Plan 2012–2021.

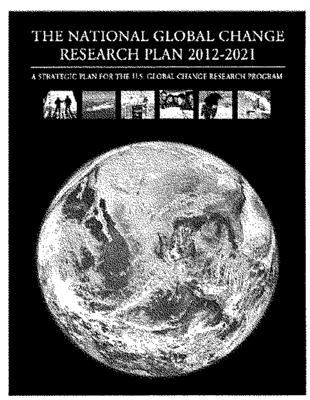


Figure 4. New Decadal National Global Change Research Plan Goals and Objectives.

GOAL 1. ADVANCE SCIENCE: Advance scientific knowledge of the integrated natural and human components of the Earth system.

Objective 1.1. Earth System Understanding: Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among them, to improve knowledge of the causes and consequences of global change.

Objective 1.2. Science for Adaptation and Mitigation: Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change.

Objective 1.3. Integrated Observations: Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales to gain fundamental scientific understanding and monitor important variations and trends.

Objective 1.4. Integrated Modeling: Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among them, to represent more comprehensively and predict more realistically global change processes.

Objective 1.5. Information Management and Sharing: Advance the capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

GOAL 2. INFORM DECISIONS: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

Objective 2.1. Inform Adaptation Decisions: Improve the deployment and accessibility of science to inform adaptation decisions.

Objective 2.2. Inform Mitigation Decisions: Improve the deployment and accessibility of science to inform decisions on mitigation and the mitigation-adaptation interface.

Objective 2.3. Enhance Global Change Information: Develop the tools and scientific basis to enable an integrated system of global change information, informed by sustained, relevant, and timely data to support decision making.

GOAL 3. CONDUCT SUSTAINED ASSESSMENTS: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Objective 3.1. Scientific Integration: Integrate emerging scientific understanding of the integrated Earth system into assessments and identify critical gaps and limitations in scientific understanding.

Objective 3.2. Ongoing Capacity: Strengthen and evolve ongoing capacity to conduct assessments with accessible, transparent, and consistent processes and broad participation of stakeholders across regions and sectors.

Objective 3.3. Inform Responses: Inform responses to global change with accurate, authoritative, and timely information that is accessible to multiple audiences in multiple formats.

Objective 3.4. Evaluate Progress: Ensure ongoing evaluation of assessment processes and products, and incorporate the findings into an adaptive response for systemic improvement.

GOAL 4. COMMUNICATE AND EDUCATE: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

Objective 4.1. Strengthen Communication and Education Research: Strengthen the effectiveness of global change communication and education research to enhance practices.

Objective 4.2. Reach Diverse Audiences: Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions.

Objective 4.3. Increase Engagement: Establish effective and sustained engagement to enable a responsive and wholly integrated Program.

Objective 4.4. Cultivate Scientific Workforce: Cultivate a capable, diverse scientific workforce that is knowledgeable about global change.

USGCRP's new strategic goals are:

(1) Advance Science;

(2) Inform Decisions;

(3) Conduct Sustained Assessments; and

(4) Communicate and Educate.

To achieve these goals, USGCRP must leverage the strengths of its member agencies; improve coordination across the breadth of Federal activities; foster more effective collaboration among researchers in the natural and social sciences; and conduct more robust dialogues with decision makers and diverse audiences. It is estimated that full implementation of these objectives will take 10 years.

In FY 2012, in addition to setting a practical new course for research into the future, USGCRP also made significant progress in science, assessment, decision support, and communication to serve the Nation. These accomplishments are presented in the following sections and categorized according to their alignment with USGCRP's new strategic goals and other crosscutting priorities.

2.2 ADVANCE SCIENCE

Goal 1—Advance Science: *Advance scientific knowledge of the integrated natural and human components of the Earth system.*

Improving scientific understanding of the Earth system and its interactions with human society will remain at the core of USGCRP programs and activities. USGCRP will continue to *advance science* in the areas of *integrated Earth observation, multidisciplinary scientific understanding of Earth systems, and integrated Earth system modeling*, among others.

INTEGRATED EARTH OBSERVATIONS: Observations across all of Earth's domains – atmospheric, oceanic, and terrestrial – improve understanding of how Earth systems operate and how they respond to human activities. Satellite observations of changes to the Greenland ice sheet, for example, help scientists document the effects of human-induced global change on the high-latitude environment.

By definition, observations expose processes and impacts that have already occurred, or are ongoing. But they also underpin our ability to predict future behavior. For example, observations are used to test and evaluate models that predict future long-term global change, and to inform short-term weather forecasts, among other critical tasks.

No single technology can provide all of the observations needed to perform these functions. That is why complementary instruments are used in concert on the ground, at sea, in aircraft, and on satellites to obtain observational data. The United States has capabilities across all of these domains and produces both domestic observations and contributions to international observation efforts on an ongoing basis.

But despite their vast utility, our Nation's observational capabilities are at serious risk of decline. As has been widely documented, more than half of all United States and international satellite sensors are past their intended operational life spans. A large number of other United States observation instruments suffer the same status. Loss of aging instruments and inability to fully incorporate successor instruments into missions planned for the future have left the Nation at considerable risk for gaps in continuous observations of Earth from space. Such gaps are not only problematic in real time; they also make it challenging (or even impossible) to connect data streams from successive instruments—leaving the observations we *do* obtain vulnerable to greater uncertainty. Similar declines in ground-based monitoring networks are also hampering the Nation's ability to assess global change trends and prepare for the future.

As demand for reliable information grows, the Nation will be faced with increasing pressure to maintain existing capabilities and develop new observation systems that are better integrated and incorporate additional variables such as socioeconomic behavior. Building such integrated observational capacity is essential to advancing science, enhancing the Nation's resilience, and remaining globally competitive.

MULTIDISCIPLINARY SCIENTIFIC UNDERSTANDING OF EARTH SYSTEMS: Just as no single observational instrument can capture all information about a changing Earth system, no single scientific discipline or research method can address the full range of questions related to global change. Physical, geological, chemical, biological, ecological, social, behavioral, and economic processes interact with each other in various ways—with changes to one system inevitably affecting many others. Understanding the full picture of complex interactions requires diverse expertise, capabilities, and scientific approaches—ranging from controlled laboratory experimentation and field research campaigns, to modeling of complex multivariate systems and analyzing data trends across vast scales of time and space.

It is the job of scientists to stitch together insights that emerge from these various lines of inquiry, identify gaps or weaknesses in collective understanding, and seek new ways to address them. This iterative process is what ultimately leads to discovery and progress.

INTEGRATED EARTH SYSTEM MODELING: Models help scientists understand the behavior of Earth systems that sometimes interact in surprising ways. Models also allow scientists to predict the future behavior of systems, including how they will respond to human influences over time.

The earliest climate models incorporated atmosphere and land-surface components. Over time, additional components that we now know are critical pieces of the climate system—such as oceans and sea ice—began to be incorporated. More recently, climate models have been expanded to include detailed representations of ice sheets, atmospheric chemistry, biogeochemical cycles, and more. Scientists are continuously testing, evaluating, and improving these components so that models simulate Earth systems as accurately as possible.

Despite these major advances, challenges remain. More work is needed to improve the spatial resolution of models, improve representation of climate and weather extremes in models, quantify uncertainty in model results, and incorporate new socioeconomic components.

RECENT HIGHLIGHTS: ADVANCE SCIENCE

The following section highlights USGCRP interagency activities and research results in key areas of study including extreme weather, oceans, the cryosphere, climate modeling, and many others. While not comprehensive, these results demonstrate the breadth, depth, and national significance of USGCRP-enabled work—which has resulted in important scientific advances, new discoveries, and enhanced research capabilities.

In the United States, Weather Extremes Surge, Agencies Study Possible Links to Climate Change

In 2011 and 2012, the United States experienced an unusual number of extreme weather and climate events. A major national need for authoritative scientific information about extreme events continues to be filled by the National Oceanic and Atmospheric Administration (NOAA), the United States Department of Agriculture (USDA), and other USGCRP agencies. Much of what is known about these events—including their present character and historical context—derives from data collected and reported by USGCRP agencies. Examples include:

- In 2011, the United States experienced a record-breaking 14 weather disasters producing insured losses of more than $1B each. The previous record was nine, set in 2008.[1]
- The average temperature for the contiguous United States during July 2012 was the hottest for any month on record (since 1895).[2]
- In the United States, the 12-month period ending July 31, 2012 was the warmest since recordkeeping began in 1895[3] and NOAA announced in December 2012 that 2012 was poised to go down in the record books as the hottest since 1895.
- During July 2012, 2.01 million acres were burned by wildfires in the United States —the 4th largest extent on record. In the same month, 9,869 fires burned—the 5th highest number on record for July over the past dozen years.[4]

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[1] Billion Dollar Weather/Climate Disasters. National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/billions/

[2] State of the Climate: July 2012. National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/sotc/2012/7

[3] State of the Climate: July 2012. National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/sotc/2012/7

[4] State of the Climate: July 2012. National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/sotc/2012/7

- 62.9 percent of the contiguous United States experienced moderate to exceptional drought at the end of July 2012. The maximum value of 63.9 percent reached on July 24 set a record for the 13-year history of the United States Drought Monitor—which is maintained by NOAA, USDA, and other partners.[5]

In addition to tracking, analyzing, and reporting extreme weather as it occurs, USGCRP agencies have also begun to study extreme weather trends and possible links to climate change. A 2012 statistical analysis by NASA scientists, for example, showed that some recent extreme summer heat waves, including the intense heat that afflicted the U.S. Midwest in the summer of 2012, were almost certainly the consequence of global warming.[6]

At NOAA, scientists contributed to a report on the state of available science for connecting specific recent weather events to broader climate processes. They concluded that while much work remains to be done to improve this "attribution science"—including improving climate models and collecting better observational data—there is already some existing potential to make such connections and, with more targeted scientific research, this ability will likely improve over time.[7]

At High Latitudes, Climate Change Unlocks Hidden Carbon Stores

High latitude ecosystems are among the most vulnerable to global change, and impacts on these ecosystems can have global consequences. Research shows, for example, that changes in fire intensity in high latitude ecosystems have resulted in large releases of carbon previously locked up in tundra soils. Other research has shown that melting permafrost at high latitudes is causing both gradual and abrupt releases of carbon dioxide (CO_2) and methane—two greenhouse gases (GHG) that contribute significantly to global warming.[8]

USGCRP research is providing novel insights about the stores of carbon locked up in these high-latitude ecosystems. For

Figure 5. The Anaktuvuk River fire on the north slope of Alaska in 2007. Climate change has increased fire frequency and intensity in the arctic tundra, resulting in a fundamental change in the carbon balance in high latitude ecosystems. Photo credit: Alaska Fire Service

example, a recent study by scientists at the Department of Interior's (DOI) United States Geological Survey (USGS) and university researchers shows that a substantial amount of organic carbon on Alaskan glaciers comes from atmospheric deposition of particles associated with fossil fuel burning. Prior research suggested that the primary source was ancient soil, plants, and other organic materials from forests and peat lands that were overrun by glaciers thousands of years ago. The finding suggests that a large portion of organic carbon – which can speed the melting of ice and snow by absorbing rather than reflecting solar radiation – found on glaciers can be traced to human activity.

In another USGS-led effort, scientists conducted a landmark airborne survey of permafrost in the Yukon Flats of Alaska that yielded some of the most detailed, data-rich maps of permafrost ever generated. Though permafrost—frozen ground that remains at or below water's freezing point for at least two years—accounts for only 0.022 percent of all water on Earth, it covers more than 20 percent of exposed land at Earth's northern high latitudes and is likely to play an important role in climate dynamics.

For example, as temperatures rise, permafrost thaws, making the massive stores of carbon locked up in permafrost increasingly available for release into the atmosphere, where they contribute to further warming. Changes in permafrost can also impact ground stability, affecting infrastructure such as roads, home foundations, water treatment facilities, and industrial sites.

USGCRP continues to coordinate a wide range of other high-latitude ecosystem research efforts across the Federal government, including: work supported by the National Science

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4 State of the Climate: July 2012. National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/sotc/2012/7
5 U.S. Drought Monitor: July 2012. National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Agriculture, et al. http://droughtmonitor.unl.edu/monitor.html
6 Hansen et al. 2012: Perception of Climate Change. Proceedings of the National Academy of Sciences. 10.1073/pnas.1205276109
7 Peterson et al. 2012: Explaining Extreme Events of 2012 from a Climate Perspective. American Meteorological Society
8 Schuur, E.A.G., B. Abbott, and the Permafrost Carbon Network. 2011: High risk of permafrost thaw: Northern soils will release huge amounts of carbon in a warmer world. *Nature* 480: 32-33.

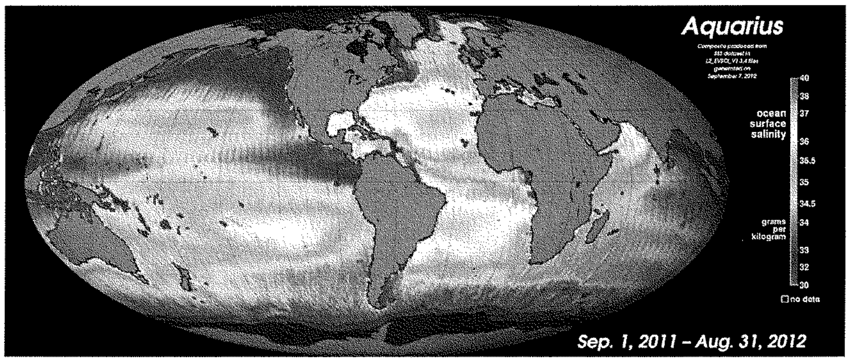


Figure 6. Aquarius-derived Sea Surface Salinity (SSS) Map. Source: NASA

Foundation (NSF) to study long-term patterns of change in organic carbon and CO_2 in Alaska; airborne campaigns by the National Aeronautics and Space Administration's (NASA) to collect detailed measurements of greenhouse gases in the Alaskan Arctic; and the Department of Energy's (DOE) development of a new high-resolution model of changing Arctic ecosystems.

Unprecedented Ocean Observations from Sea and Space

For more than a century, information about sea surface salinity has been collected from ship-based observations, surface buoys, and, more recently, profiling floats. Two new NASA efforts—the Aquarius mission and the Salinity Processes in the Upper Ocean Regional Study (SPURS) field campaign— will complement this sometimes-sparse data record by providing new observations of the complex interactions between evaporation, precipitation, and ocean circulation worldwide.

These observations are important because regional variations in ocean salinity can influence the ocean's ability to absorb, transport, and store heat, freshwater, and CO_2, and, therefore, drive further changes in atmospheric circulation and the hydrologic cycle.

NASA's Aquarius mission was launched in 2011 in partnership with the Space Agency of Argentina – Comisión Nacional de Actividades Espaciales – and is the first satellite mission specifically focused on producing global observations of sea surface salinity. It will deliver monthly salinity maps with an estimated accuracy of 0.2 practical salinity units (psu) – equivalent to detecting a single "pinch" of salt (1/8th of a teaspoon) in one gallon of water.

The SPURS field campaign will closely monitor the saltiest region of the Earth's oceans – the subtropical North Atlantic gyre – to provide a 3D view of processes that drive changes in salinity distribution. Beginning in September 2012, NASA, NSF, NOAA, and European partner agencies have been deploying instruments on floats, ships, moored buoys, underwater gliders, and an autonomous underwater vehicle to capture this detailed view of ocean processes (Figure 7).

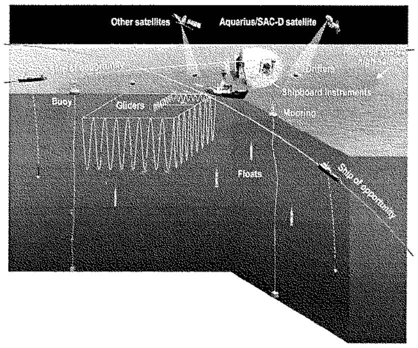
Particle Pollution Linked to Clouds and Climate

USGCRP scientists are studying airborne particles and their interactions with climate systems to support global change-related decision making in urban environments and elsewhere.

A recent DOE-funded study by the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change has delivered a novel global-scale air quality model. The new model includes, for the first time, the air pollution contributions of urban-scale aerosols—airborne suspensions of tiny particles or droplets, such as dusts, mist, or fumes.[9] Historically, aerosol processes have not been included in

[9] Cohen, J.B., Prinn, R.G., and C. Wang. 2011. The impact of detailed urban-scale processing on the composition, distribution, and radiative forcing of anthropogenic aerosols. *Geophysical Research Letters* 38, L10808.

Figure 7. Schematic of the SPURS observational strategy. A combination of instrumentation generates high-resolution measurements of the upper ocean.



global models because of the very high computation demands required to do so. The new system has already begun to be used by modelers to simulate the effects of cities on global aerosol chemistry and physics.

In 2010, USGCRP agencies led a field study in cooperation with the California Air Resources Board (CARB) and other partners to investigate emissions and atmospheric processes over California and the eastern Pacific coastal region. The study, called CalNex, examined the opportunities and trade-offs faced by decision makers at the nexus of air quality and climate change. Results show that California's clean-fuel regulations and voluntary actions taken by shipping companies have substantially reduced air pollution caused by near-shore ships. Research results show that these voluntary actions reduce emissions of sulfur dioxide, soot, and other pollutants that impact both human health and climate by as much as 90 percent.[10] The results suggest that California's new regulations are working as intended—information that may help other regions to decide whether to adopt similar strategies.

DOE-funded scientists used measurements from a 2008 field campaign in conjunction with a weather research and forecasting model to examine the indirect effects of aerosols on two cloud regimes in Southeast China.[11] The scientists sought to better understand the effect of aerosols on cloud formation and precipitation—one of the least understood aspects of our climate system. They found that changes in the concentration of nuclei around which clouds form (i.e., aerosols) can significantly change the timing of storms, the rate and distribution of precipitation, and the height of deep convective clouds—and are thus important variables to include in regional and global climate simulations.

New Climate Models are Better Performing, Higher-Resolution

Modeling centers affiliated with USGCRP agencies continue to lead in developing, evaluating, and applying climate models, as well increasing the accessibility of model output to diverse user communities.

USGCRP agencies are playing key roles in Phase 5 of the Coupled Model Intercomparison Project (CMIP5)—a major international effort to evaluate and improve climate models. CMIP5 builds on the success of earlier phases of the project, which revolutionized the fields of model evaluation, uncertainty quantification, and societal impacts studies by allowing universal access to results of the world's major climate models. In that effort, USGCRP agencies were primarily responsible for developing Earth System Grid software that allows users to download model output from multiple locations without needing to know where the datasets physically reside—giving them faster, easier access to climate data.

The new CMIP models achieve finer spatial resolution and better representation of certain climate processes than older-generation models. These improvements are based upon careful comparison of model output to real-world observations—an area in which USGCRP agencies have particular expertise. For example, scientists funded by DOE and NASA worked with partners to create a diagnostic tool known as the Cloud Feedback Model Intercomparison Project Observation Simulator Package (COSP), which enables comparison of model outputs with observations from satellite instruments. COSP is used by most major climate and weather prediction models worldwide and will play an important role in the evaluation of models slated for review in the next Intergovernmental Panel on Climate Change (IPCC) report.

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[10] Lack, D.A., C.D. Cappa, J. Langridge, R. Bahreini, G. Buffaloe, C. Brock, K. Cerully, D. Coffman, K. Hayden, J. Holloway, B. Lerner, P. Massoli, S.-M. Li, R. McLaren, A.M. Middlebrook, R. Moore, A. Nenes, I. Nuaaman, T.B. Onasch, J. Peischl, A. Perring, P.K. Quinn, T. Ryerson, J.P. Schwarz, R. Spackman, S.C. Wofsy, D. Worsnop, B. Xiang, and E. Williams. 2011. Impact of fuel quality regulation and speed reductions on shipping emissions: Implications for climate and air quality. *Environmental Science and Technology* 45, 9052–9060.

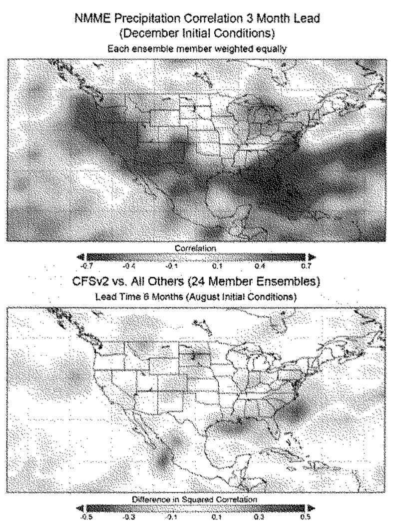
[11] Fan, J., L.R. Leung, Z. Li, H. Morrison, H. Chen, Y. Zhou, Y. Qian, and Y. Wang. 2012. "Aerosol Impacts on Clouds and Precipitation in Southeast China – Results From Bin and Bulk Microphysics." *J. Geophys. Res.*, 117, D00K36, DOI:10.1029/2011JD016537.

Finally, individual models often display strong predictive "skill" (ability to forecast future conditions) in particular regions or for particular variables. Overall skill can often be enhanced by combining models with unique strengths. DOE, NSF, NASA, and academic partners are investigating how such model combinations could potentially improve climate forecasts through the National Multi-Model Ensemble system (NMME) (Figure 8). NOAA's Climate Prediction Center has already begun using the NMME system to inform its monthly climate briefings. A second phase of the project commenced in Fall 2012.

High-Tech Satellite Systems Observe Earth with Record Accuracy

USGCRP scientists and engineers continually seek new and innovative ways to observe the Earth. In October 2011, NASA, NOAA, and DoD launched the Suomi National Polar-orbiting Partnership (NPP) satellite with a mission to acquire a wide range of land, ocean, and atmospheric measurements. The project, formerly known as the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project, carries five scientific instruments that collect data for climate monitoring, operational weather forecasting, and global change science.

Figure 8. (Top) Areas where the NMME system provides high degrees of skill in predicting precipitation patterns two months in advance are indicated by warm colors. (Bottom) Warm colors indicate regions where value was added by using a multi-model approach. Image courtesy of Ben Kirtman.



The NPP mission is a bridge between NASA's Earth Observing System (EOS) satellites and the forthcoming series of Joint Polar Satellite System (JPSS) satellites, and will provide a wide range of data, including atmospheric and sea surface temperatures, land and ocean biological productivity measurements, cloud and aerosol property information, ozone measurements, and information about fluxes in Earth's radiation budget.

In addition, six microsatellites that were launched jointly by the United States and Taiwan in 2006 have significantly improved weather forecasts. The system, called the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC), continues to provide meteorological, climate, and space-weather data with unprecedented accuracy.

COSMIC uses instrumentation designed by NASA, is managed domestically by NSF, and receives co-funding from NOAA, NASA, the Air Force, and the Navy. The system's capacity for collecting high-resolution global information has already been shown to reduce lower-stratosphere temperature measurement errors by up to 11 percent and improve forecasts of tropical cyclone tracks, among other important advances.

Polar Change Sets All-Time Records

The National Snow and Ice Data Center—an interagency center funded jointly by NASA, NOAA, and NSF—recently reported that Arctic sea ice reached its lowest-ever measured extent in September 2012.

The rapid reduction in Arctic sea ice extent (defined as horizontal area with at least 85 percent ice cover) and changes in sea ice thickness are being studied closely by USGCRP agency scientists. A recent NASA analysis showed, for example, that the average thickness of sea ice in the Arctic is on the decline.[12] In fact, the oldest and thickest Arctic sea ice is disappearing faster than younger, thinner ice that surrounds it—creating an overall thinning effect and more areas of open, ice-free water during the summer months.

Other USGCRP research, on the crysophere (solid-state water, including ice, snow, and permafrost), is assessing trends in ice sheet and glacial melt—major potential contributors to sea level rise.

[12] Comiso, J.C. (2012). Large Decadal Decline of the Arctic Multiyear Ice Cover, *Journal of Climate*, 25, 1176–1193 10.1175/JCLI-D-11-00113.1

NASA satellites recently detected that 97% of Greenland's surface was covered by meltwater—more than has been observed in 30 years of satellite monitoring. And, a recent study supported by DOE and others estimated that because of climate change, Greenland's Mittivakkat Gletscher glacier would eventually lose at least 70 percent of its current area and 80 percent of its volume—even in the absence of further climate change.[13] In 2011, on the other icy end of the globe, NASA flew 24 science flights during a six-week campaign called Operation IceBridge to collect data on the thickness and depth of Antarctic ice sheets as well as glacial movement (Figure 9). During one of the flights, researchers discovered a large crack across the Pine Island Glacier ice shelf—a precursor to the anticipated separation of an estimated 310-square-mile iceberg into the ocean (Figure 10).

Tropical Forest Carbon Mapped with Unprecedented Precision

Tropical forests store massive quantities of carbon in the wood and roots of their trees. When trees are cut down, burned, or naturally decompose, these stores of carbon are released into the atmosphere. The IPCC estimated that in the 1990's, net carbon emissions from land-use change constituted about 20 percent of human greenhouse gas emissions. That estimate was based largely upon self-reporting by countries to the United Nations Food and Agriculture Organization.

A new study using satellite measurements found that gross carbon emissions (emissions from forest loss, not including carbon absorption from forest regrowth) from tropical regions between 2000 and 2005 were only 25 to 50 percent of previous estimates—a large discrepancy with potential implications for policy and decision making.[14]

The new estimate was made possible by the first-ever global inventory of tropical forest carbon, created in 2011 using a variety of NASA satellite data. The inventory effort resulted in the most precise map ever produced depicting the amount and location of carbon stored in Earth's tropical forests.

These and similar studies are important for countries planning to participate in the Reducing Emissions from Deforestation and Degradation (REDD+) program—an international effort to set a financial value for the carbon stored in forests. The Program offers incentives to preserve forestland in the interest of reducing carbon emissions and investing in low-carbon paths toward development.

Figure 9. Map of flight lines from NASA's Antarctic IceBridge mission in 2011. Image Credit: NASA.

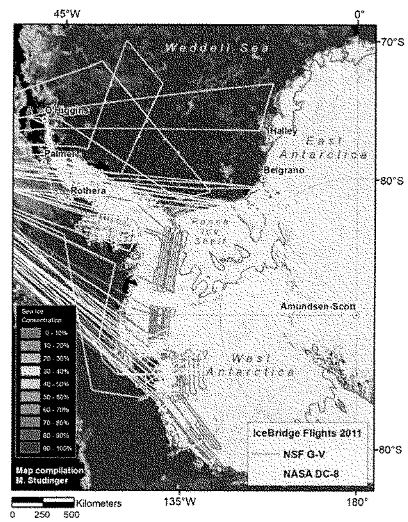
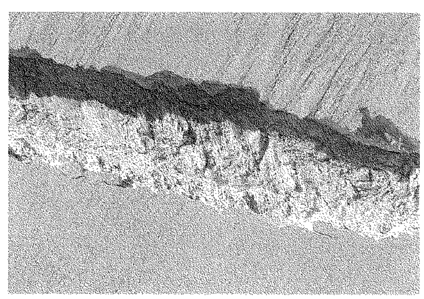


Figure 10. A close-up image of the crack spreading across the ice shelf of Pine Island Glacier that NASA's DC-8 flew over in October 2011.



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[13] Mernild, S. H., N. T. Knudsen, W. H. Lipscomb, J. C. Yde, J. K. Malmros, B. Hasholt, and B. H. Jakobsen, Increasing mass loss from Greenland's Mittivakket Gletscher, *The Cryosphere*, 5, 341-348, 2011.

[14] Harris, Nancy L., Sandra Brown, Stephen C. Hagen, Sassan S. Saatchi, Silvia Petrova, William Salas, Matthew C. Hansen, Peter V. Potapov, and Alexander Lotsch. 2012. *Science* (336): 6088: 1573-1576

2.3 INFORM DECISIONS

Goal 2—Inform Decisions: *Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.*

People, businesses, communities, and entire nations are making decisions to minimize (mitigate) and prepare for (adapt to) global change. USGCRP's *Inform Decisions* goal is designed to support those decisions by translating research results into information that is relevant, usable, and accessible as well as by facilitating meaningful engagements between scientists and decision makers. Specifically, USGCRP is focused on advancing *adaptation science* and providing *global change information* in ways that are useful to those who need it.

ADAPTATION SCIENCE: More extreme precipitation events, longer wildfire seasons, reduced snowpack, increased extreme heat events, warming ocean temperatures, and rising sea levels are already beginning to affect our Nation's critical infrastructure, ecosystems, food production, energy supply, national security, human health, and cultural heritage.[15] As changes in our climate continue, these impacts are expected to intensify and new impacts may emerge. Preparing for and adapting to these changes is a common sense approach to ensuring a safer, more prosperous future.

USGCRP agencies are already working to increase dialogue between climate researchers and decision makers to ensure there is mutual understanding of the most pressing adaptation science needs. They are also leveraging internal expertise to prepare for the impacts of climate change. For example, NASA is sponsoring research on potential adaptation approaches to climate change in the regions where its facilities reside. Other agencies are collaborating with State and local officials to co-produce specific information products relevant to managing climate variability and future change.

Despite the tremendous value of these steps, major challenges remain. Many methodologies used to inform adaptation decisions are nascent and not rigorously tested, and many existing climate models cannot provide reliable local-scale information. There is also a need to identify critical knowledge gaps, optimize allocation of limited resources, and ensure that there is sustained engagement between scientists and decision makers on the ground.

[15] USGCRP. (2009). Global Climate Change Impacts in the United States. www.globalchange.gov/publications/reports and National Research Council. (2011). America's Climate Choices. The National Academies Press. Washington, DC. www.nap.edu/catalog.php?record_id=12781

GLOBAL CHANGE INFORMATION: Informed decisions require credible information and data. Decision makers need global change information that is centrally accessible, clearly described, authoritative, and relevant. Meeting this need efficiently—when both the demand for reliable data and the diversity of available data are ballooning rapidly—is a sizable challenge.

In direct response to this challenge and to feedback from the National Academy of Sciences (NAS), USGCRP is developing a new, systematic approach to global change information provision. The approach confronts the reality that while many credible, topic-specific data delivery services exist across the Federal government, there is no single point of access for authoritative information on interrelated, multidisciplinary global change issues such as the coastal impacts of sea level rise, the health costs associated with temperature extremes, and others. Absent a central and intuitively structured access point, it can be difficult for users to find the data they need.

The main component of USGCRP's information provision plan is development of a Global Change Information System (GCIS)—a comprehensive web-based data integration platform that will efficiently deploy the broad range of global change information to diverse user communities. When fully developed, the GCIS will be a central access point for authoritative global change data from across the Federal agencies and beyond (including fundamental observational and modeling data, and derivative communication products and services). As a first but significant step, the GCIS will provide data related to the forthcoming National Climate Assessment (NCA), scheduled for release in 2013.

This effort will require multiple Federal agency partnerships; comprehensive access to *in situ* and space-based observing assets across the government; access to and translation of modeled data; significant data management capabilities; and consideration of diverse audience needs to create appropriate user-experiences.

RECENT HIGHLIGHTS: INFORM DECISIONS

New Plant Zone Map Informs Gardeners and Growers

In early 2012, USDA released a new Plant Hardiness Zone Map—a tool widely used by growers and gardeners across the United States to understand which plants are most likely to thrive in a given location. The last such map was released in 1990.

Notably, two new zones (that fall only in Hawaii and Puerto Rico) have been added that represent particularly warm regions—where average coldest temperatures are above 50 and 60 degrees F. In addition, the new map is generally one half-zone warmer than previous maps.

Because the 2012 map was created with more precise techniques and additional data from new weather-reporting stations, these zone differences—as stand-alone observations—are not sufficient evidence to confirm whether there has been global warming in a particular location. However, the zone differences overall *do* reflect broader climate change trends observed by scientists through systematic evaluation of data from much longer time periods.

The map is an example of the many important uses of temperature data that reach beyond the walls of science labs, into the daily lives of Americans. Growers and gardeners across the country rely on this type of information to make day-to-day decisions about which species to plant and how to care for them that can affect the success of their home gardens, community gardens, and businesses.

New Climate Adaptation Strategies Strengthen National Resilience

In FY2012, USGCRP collaborated closely with the Interagency Climate Change Adaptation Task Force (ICCATF) to inform three major National adaptation strategies: (1) *National Action Plan for Managing Freshwater Resources in a Changing Climate*[16]; (2) *National Ocean Policy: Implementation Plan*[17]; and (3) *National Fish, Wildlife and Plants Climate Adaptation Strategy* (Figure 11).[18]

These strategies will help Federal agencies incorporate climate change adaptation considerations into their decisions and actions related to our Nation's freshwater, ocean, fish, wildlife, and plant resources.

USGCRP is also supporting efforts by individual Federal agencies to plan for climate change impacts on their own operations. In response to Executive Order (E.O.) 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, Agencies developed individual Adaptation Plans to evaluate and manage the risks, vulnerabilities, and impacts of climate change.

[16] National Action Plan for Managing Freshwater Resources in a Changing Climate: http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf

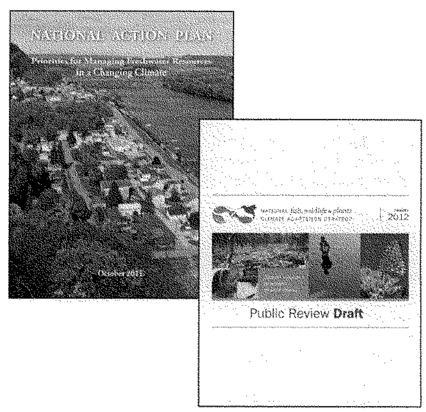
[17] National Ocean Policy: Implementation Plan: http://www.whitehouse.gov/sites/default/files/microsites/ceq/national_ocean_policy_draft_implementation_plan_01-12-12.pdf

[18] National Fish, Wildlife and Plants Climate Adaptation Strategy: http://www.wildlifeadaptationstrategy.gov/

With scientific support from USGCRP, Federal agencies submitted full draft Adaptation Plans to the Council on Environmental Quality (CEQ) and the Office of Management and Budget (OMB) in June 2012 and continue to make progress. For example:

- USDA issued a new Departmental Regulation (D.R. 1070-001) to develop and implement adaptation actions to help the Nation's agricultural enterprise prosper in the face of a changing climate.
- The United States Army Corps of Engineers (USACE) is leading multi-agency and international teams to produce guidance on how to incorporate considerations of sea level change into Army Corps coastal projects.
- NASA's Climate Adaptation Science Investigators (CASI) Workgroup is currently developing climate projections for each NASA Center, an inventory of climate-relevant data and projects within NASA, and a set of recommendations for future research initiatives, among other activities.
- New regional maps developed by NOAA allowed the General Services Administration (GSA) to complete an initial high-level assessment of its vulnerabilities to climate change across the country.

Figure 11. National Adaptation Strategies. Images of the 2011 National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate and the Public Review Draft of the National Fish, Wildlife, and Plants Climate Adaptation Strategy.



Best Practices and Lessons Learned Parse Menu of Adaptation Options

Increasingly, decision makers are adopting an array of climate adaptation policies, plans, and actions. Moving forward, it will be critical to evaluate what works, what fails, and where more scientific support is needed. USGCRP is working to meet this need by monitoring and evaluating adaptation actions taking place on the ground. This will help decision makers determine whether their adaptation actions are successful and how they can be enhanced.

In March 2012, USGCRP's Adaptation Science Workgroup developed a bibliography of best practices (expected to be published and referenced in the next NCA in 2013) for monitoring and evaluating adaptation actions. The bibliography is the first step of an ongoing project that will:

- Mine literature for examples of strategic planning, indicators, performance measures, and evaluation of climate adaptation actions;
- Capture the knowledge of practitioners who are engaged in implementing and evaluating climate adaptation activities through interviews; and
- Provide a suite of products such as performance measures, best management practices, and lessons learned to help practitioners better evaluate their adaptation efforts.

Agencies Collaborate to Help U.S. National Parks Adapt

USGCRP agencies including DOI's USGS and National Park Service (NPS), USDA's Forest Service, in collaboration with other partners have jointly analyzed the vulnerability of six United States National Parks to climate change impacts. Analysis of 13 additional Parks is currently underway.

The analyses examine the three components of vulnerability (exposure, sensitivity, and adaptive capacity), across species, ecosystems, cultural resources, and infrastructure in each Park. Analysis results are now being used to identify particularly vulnerable areas and potential areas of refuge, develop adaptation measures, and prioritize areas for adaptation action. As a result of this effort, peer-reviewed scientific articles or government technical reports have been published on the following topics:

- Coastal ecosystems in 22 national parks, desert southwest species in Bryce Canyon National Park, Cedar Breaks National Monument, and Zion National Park;
- Forest ecosystems in Olympic National Forest and Olympic National Park;
- Joshua trees in Joshua Tree National Park;
- Pacific coast ecosystems in Point Reyes National Seashore; and
- Tropical ecosystems in Hawaii national parks.

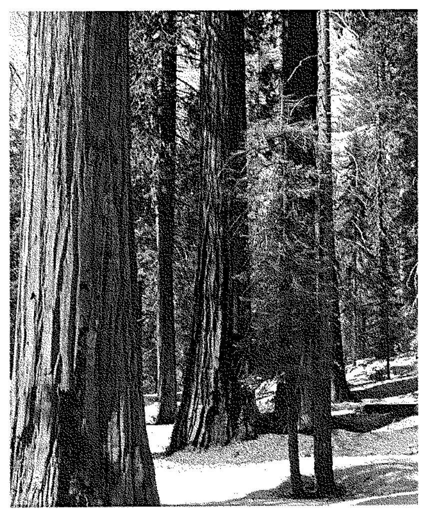
Analyses in progress examine a range of ecosystems in Sequoia, Kings Canyon, Yosemite, and Badlands National Parks as well as Sequoia National Forest and other locations (Figure 12).

New Adaptation Tools for Water Resource Managers

USGCRP is supporting natural resource managers and region-based decision makers with tools, applications, and case studies to inform adaptation strategies.

Through its Carolinas Integrated Sciences and Assessments (CISA) program based at the University of South Carolina, NOAA and partners are working with regional stakeholders to incorporate climate information into water and coastal

Figure 12. Analyses by NPS, USGS, USDA Forest Service, and the University of California provide data to Sequoia, Kings Canyon, and Yosemite National Parks and Sequoia National Forest to adapt fire management under climate change (Photo by Patrick Gonzalez).

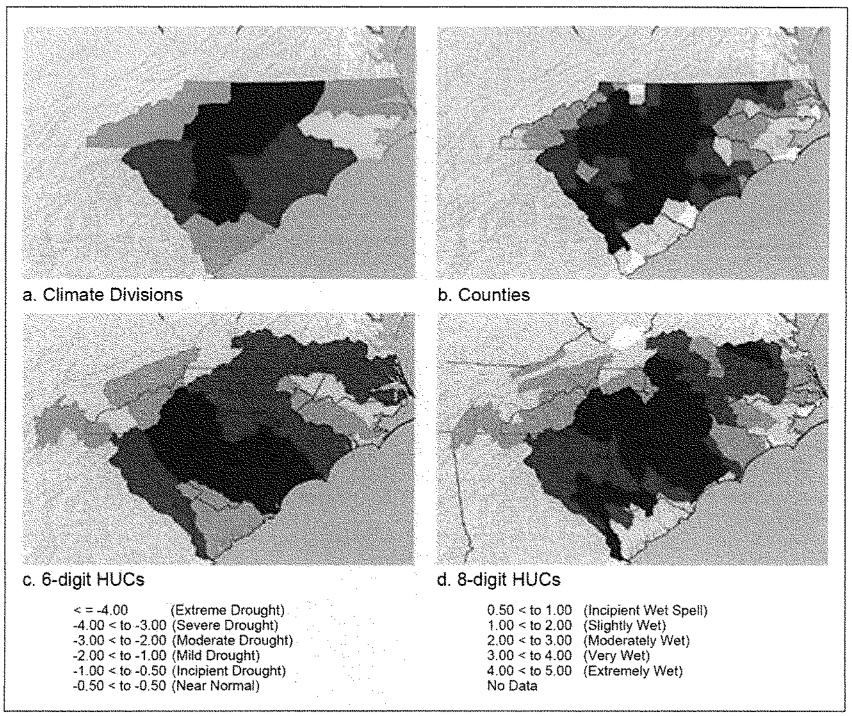


management decisions. CISA has already developed the Carolinas Dynamic Drought Index Tool to display multiple drought indices over different time scales and across user-specified regions (Figure 13). The tool is currently being refined and transferred for use by NOAA's regional climate centers.

The Environmental Protection Agency (EPA) has developed two additional assessment tools, the BASINS Climate Assessment Tool (BASINS CAT) and the Water Erosion Prediction Project Climate Assessment Tool (WEPPCAT), to foster the use of existing water simulation models to understand the effects of climate change on water resources. A series of six case studies has been conducted to illustrate the capabilities of these tools for real world problem solving (see Figure 14).

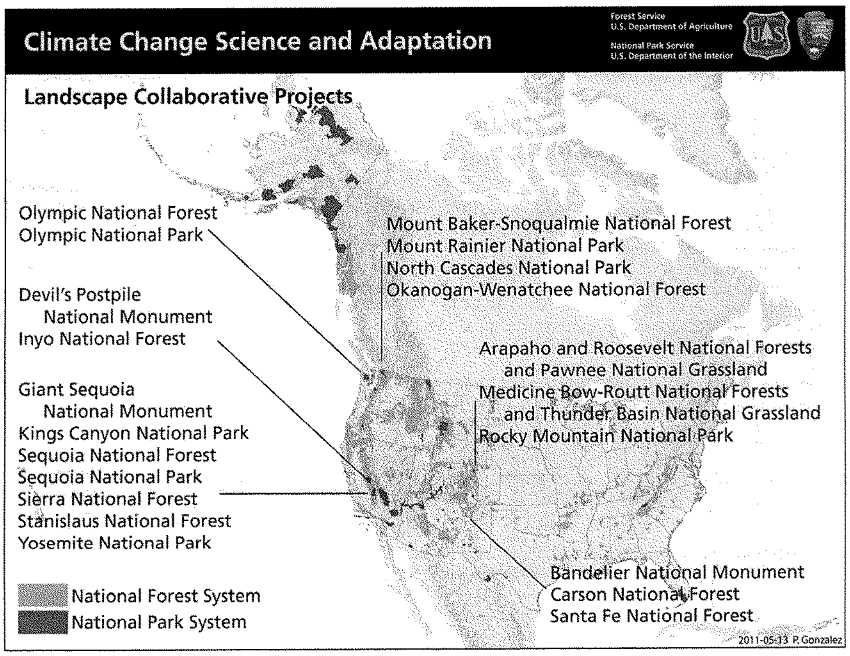
EPA also reported on the activities of four domestic water utilities to evaluate their potential vulnerability to climate change. These additional case studies illustrate a range of issues being faced by U.S. water utilities and approaches being taken to assess vulnerabilities to climate risks. The case studies will be shared with water sector stakeholders, who will help identify additional scientific and technical needs to support such vulnerability assessments.

Figure 13. July 2002 Monthly Palmer Drought Severity Index (PDSI) maps. Source: **http://www.cisa.sc.edu/**



Other valuable adaptation tools have been developed by USDA's U.S. Forest Service (USFS) and DOI's NPS for vulnerability, including: Scanning the Conservation Horizon, a guide to climate change vulnerability assessment; A System for Assessing Vulnerability of Species (SAVS) to Climate Change, a system that quantifies the relative impacts of expected climate change effects for terrestrial vertebrate species; and Responding to Climate Change in National Forests, a guidebook for developing adaptation options.

Figure 14. Joint vulnerability assessments by the USDA's Forest Service and DOI's National Park Service. Image: Patrick Gonzalez, NPS.



2.4 CONDUCT SUSTAINED ASSESSMENTS

Goal 3—Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

The Global Change Research Act of 1990 requires USGCRP to conduct a National Climate Assessment (NCA) every four years. USGCRP also coordinates Federal participation in international assessment efforts such as those led by the IPCC.

Here, "assessment" refers to the syntheses of peer-reviewed and other credible literature that summarize current scientific understanding of global change. Some, such as USGCRP's NCA, are focused on specific geographical regions, while others are focused on specific aspects or impacts of global change. The best-known international assessments—IPCC Assessment Reports—cover the field very broadly. The effort required to produce such assessments is immense, but yields highly valuable sources of credible information for use by scientists and decision makers worldwide. Assessments are also important sources of information for members of the media and public who are seeking up-to-date information about the state of global change and projections for the future.

A major new goal for USGCRP is to strengthen and advance the Program's capacity to conduct assessments on an iterative and sustained basis, rather than at widely spaced multi-year intervals. The Program is building upon its demonstrated ability to produce periodic assessments by developing a process that will ultimately enable continuous and transparent participation of scientists and stakeholders across regions and sectors.

THE NATIONAL CONTEXT: USGCRP's National Climate Assessment (NCA) is widely recognized as one of the most robust, authoritative sources of information about the current status of the United States climate, climate changes, climate change impacts, and anticipated trends. Local and state governments, tribes, businesses, and the public regularly use Assessment findings to plan and strategize for the future.

The NCA integrates scientific information from a wide range of credible sources to highlight key findings of significance and important knowledge gaps. It also establishes consistent methods for evaluating climate vulnerabilities, impacts, and response strategies.

USGCRP has begun to approach its NCAs as an ongoing, or "sustained," effort, rather than periodic report-writing activity. For example, the Program is focusing considerable attention on building long-term partnerships with public and private sector organizations, and on establishing a strong stakeholder engagement process to support the development and release of future NCA products.

THE INTERNATIONAL CONTEXT: The long-term strength of global change research depends on intimate engagement with international efforts, including international climate assessments.

USGCRP-supported researchers continue to play important roles in the development of several major international assessments, including the forthcoming IPCC 5th Assessment Report. They are lead authors, reviewers, and working group co-chairs. They also provide technical support and scientific expertise as reviewers to IPCC assessments and other international projects.

USGCRP also ensures that U.S. interests are represented internationally, where appropriate. For example, the Program coordinates and supports U.S. participation in and review of the IPCC's global assessment of the climate, the Arctic Climate Impact Assessment, and the Scientific Assessment of Ozone Depletion.

Finally, USGCRP collaborates with neighboring nations to achieve common goals related to water resources, shifting habitats, transportation, and other sectors impacted by global change. The United States benefits from such scientific diplomacy because it creates new opportunities for leveraging of resources, knowledge sharing, and efficiency.

RECENT HIGHLIGHTS: CONDUCT SUSTAINED ASSESSMENTS

Development of the 2013 National Climate Assessment Continues

In early 2012, The National Climate Assessment's Federal Advisory Committee selected more than 240 authors from academic institutions, non-governmental organizations (NGO), and the public and private sectors to write the 2013 Assessment report. These authors completed first draft chapters in June 2012 and have continued to conduct revisions prior to the release of the final report in early 2014. In addition, 30 review editors will be selected to ensure that comments and edits identified through the National Research Council, USGCRP agencies, and general public review are adequately addressed in the spring of 2013.

In an important new step, authors of the 2013 National Climate Assessment will be delivering the report in a Web-based format (an e-book). Though this has placed significant new demands on Assessment authors, tremendous benefits are expected as a result, including significantly greater traceability and accessibility of assessment data.

Dozens of Technical Reports to Inform 2013 National Climate Assessment

USGCRP agencies have coordinated development of more than 25 technical reports that provided important foundational input to the 2013 National Climate Assessment, including:

- *Ecosystems, Biodiversity, and Ecosystems Services:* This report, developed by USGS, other USGCRP agencies, and external partners, explains current and projected future impacts of global change on biodiversity, ecosystem processes, and ecosystem services.
- *Urban Infrastructure and Vulnerability:* Two reports, by DOE and NOAA respectively, tackled the challenge of assessing and predicting climate change impacts on the Nation's cities and urban areas–which are home to more than 80 percent of the U.S. population.
- *Energy-Water-Land:* An interdisciplinary team led by DOE developed a report describing potential impacts of climate change on the Nation's competing needs for water, energy, and land-use sectors.
- *Coastal Zone, Development, and Ecosystems:* NOAA and USGS supported development of a report that summarizes recent information on the effects of climate change on coastal resources.
- *Northeast Region:* NOAA and NASA convened a workshop of Federal, state, and other stakeholders to develop a technical report on climate variability and change, impacts, and adaptation efforts in the region spanning from Maine to West Virginia.

New Global Change Scenarios to Inform Projections for the Next Century

The Global Change Research Act of 1990 requires that National Climate Assessments include projections of global change for the next 25 to 100 years. To meet this requirement for the 2013 Assessment, USGCRP developed a scenarios strategy that was implemented in FY 2012. Scenarios provide a consistent framework for projecting future conditions. The strategy designates two well-established IPCC scenarios for greenhouse gas emissions (SRES B1 and A2) as the minimum set for author teams to consider when preparing the 2013 Assessment. USGCRP's strategy also led to the development of new scenarios tailored for use by the NCA in key areas, including:

- **Climate** – NOAA led the development of a set of plausible representations of future climate conditions, based on the greenhouse gas emissions scenarios mentioned above, for each of the eight NCA regions as well as the Nation as a whole.
- **Sea Level** – Multiple agencies and external partners developed new sea level change scenarios, including estimates of future global average sea level from processes such as melting of ice sheets, and descriptions of anomalies along United States coastlines resulting from land subsidence.
- **Land Cover, Land Use, and Socioeconomic Factors** – EPA's Integrated Climate and Land Use Scenarios project and USGS' National Land Cover Database informed projections of socioeconomic change (e.g., urbanization) and the extent and distribution of land use categories resulting from climate change and other factors.

2013 NCA Receives Unprecedented Input from Stakeholders and Public

A broad engagement process was launched in FY 2010 to solicit stakeholder input to the 2013 National Climate Assessment report and has succeeded in attracting input from many diverse groups. For example, in response to an FY 2011 public *"Request for Information,"* more than 130 teams submitted more than 500 discrete technical input products for consideration in development of the 2013 report.

During FY 2011 and FY 2012, USGCRP coordination staff, agency representatives, and partners convened more than 70 workshops, listening sessions, and discussions to invite input from a broad range of groups. Also in FY 2012 USGCRP launched, "NCAnet," a network of partners that connects the National Climate Assessment process to interested professional societies, and members of the public, private, academic, and non-profit sectors.

2009 NCA, Global Climate Change Impacts in the United States Report, Redeployed Online

In 2011, the 2009 NCA – *Global Climate Change Impacts in the United States* – was redeployed on the *web* (Figure 15).[19] This activity allowed USGCRP to test new methods of searchability, transparency, and data access for the NCA, and

[19] USGCRP, 2009: Global Climate Change Impacts in the United States, online website: http://nca2009.globalchange.gov.

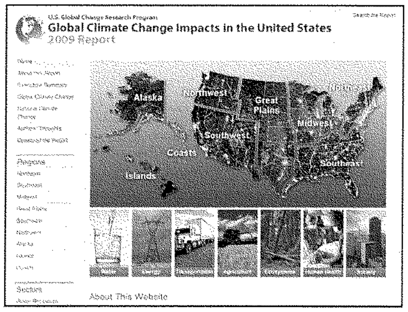


Figure 15. Redeployment of the 2009 Global Climate Change Impacts in the United States Report. This online access allows for stakeholders to navigate the report in a more interactive manner.

to receive feedback from key groups. While this redeployment was a trial effort, initial feedback has been positive and will help inform the development of forthcoming 2013 NCA products and the larger Global Change Information System (GCIS) effort.

United States Provides Key Support to IPCC Fifth Assessment Report (AR5)

Intergovernmental Panel on Climate Change (IPCC) assessments are the most comprehensive, scientifically credible products that review current knowledge of climate change, its impacts, and associated adaptation and mitigation options. Unlike USGCRP's National Climate Assessment, which focuses on the United States, IPCC Assessment Reports are global in scope, and include discussions of mitigation options.

USGRCP contributes to the IPCC through agency scientists who act as authors, reviewers, and editors for Assessment Reports and Special Reports.

In addition, the USGCRP hosts a support unit for the IPCC that is responsible for managing the funds that enable participation of U.S. authors and contributors to IPCC's Fifth Assessment Report. USGCRP, the Department of State (DOS), and others are also responsible for hosting U.S. author nominations and government and expert reviews of IPCC special reports, including *Renewable Energy Sources and Climate Change (SRREN)* and *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*.

2.5 COMMUNICATE & EDUCATE

Goal 4—Communicate and Educate: *Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.*

USGCRP's new decadal research plan identifies *Communicate and Educate* as one of four key strategic goals. This is an explicit recognition of the importance of keeping the public informed about societally-relevant global change science, of showing taxpayers and members of Congress the results and value of their research investments, and of cultivating a national workforce with the skills and knowledge to address the challenges and opportunities posed by global change.

A rapidly growing body of social science, education research, and public surveys show that communicating research results in plain English and tailoring communications to the interests and needs of specific audiences are important components of broadening public understanding of science. Global change education is also essential for producing the next generation of scientists, researchers, and technical professionals who will ultimately be responsible for confronting the challenges of global change. Because of their direct societal relevance and focus on multidisciplinary science issues, global change education programs may also help draw students into science, technology, engineering, and mathematics (STEM) fields generally—a major benefit to the Nation's global competitiveness.

USGCRP has a long history of producing highly relevant and authoritative science products. Now the Program is working to improve communication of those products to the broadest possible set of users, including the public. Better coordination across Federal agencies will ensure that global change communication activities use the highest quality science information, are consistent and efficiently deployed, and reach diverse audiences.

RECENT HIGHLIGHTS: COMMUNICATE AND EDUCATE

Agencies Communicate Record-Breaking Extreme Weather to Americans

Recent surveys show that American views on climate change are shaped, in large part, by personal observations of temperature and weather phenomena.[20] Other studies show that a large majority of Americans report personally experiencing at least one extreme weather or natural disaster in the year preceding March 2012 and that more than one-third of Americans report having been personally affected by one or more such events.[21]

USGCRP is responsible for communicating scientific information about global change to American citizens in meaningful ways, in the context of topics that matter to them. That's why USGCRP agencies are engaged in several activities to communicate information on the recent surge in extreme weather events clearly, accurately, and to the broadest possible set of audiences. For example:

- NOAA hosts monthly public climate webinars featuring expert scientists who summarize climate and weather observations from the preceding month, and provide a three-month climate outlook in plain English.
- NASA releases near-real-time satellite images of severe and extreme weather, such as "Tropical Storm Isaac by Night"—a captivating image of Hurricane Isaac over the Gulf Coast of the United States captured by the Suomi NPP satellite that quickly went viral on the Internet (Figure 16).
- USDA releases regular Agricultural Weather and Drought updates on its widely viewed blog, which feature the latest maps of drought-affected areas of the United States and clear accompanying explanations of observed trends for lay audiences.

[20] Borick, C. and Rabe, B. 2011. "Fall 2011 National Survey of American Public Opinion on Climate Change." Brookings Institution. Issues in Governance Studies (44).

[21] Leiserowitz, A., Maibach, E., Roser-Renouf, C., & Hmielowski, J. D. (2012) Extreme Weather, Climate & Preparedness in the American Mind. Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change Communication.

Federal Web-Based Climate Communications More Effective than Ever

In 2012, USGS' online Climate Connections video series won a Blue Pencil and Gold Screen Award in the category of "Public Affairs Program" from the National Association of Government Communicators (NAGC). The series features scientists answering questions gathered from people across the Nation and highlights what people want to know, from locations they recognize. Thus far, USGS has published episodes of the Climate Connections series from North Carolina, South Carolina, Puerto Rico, Glacier National Park, and Washington, D.C.

Also in 2012, USGCRP launched a revamped online Resource Library for easier, more intuitive access to Federal global change resources, including publications, reports, educational materials, and fact sheets. The revamped Resource Library provides free and easy access to more than 100 products containing data and information on climate change, many of which are used by schools, colleges, nonprofit organizations and other institutions seeking reliable global change information sources at little to no cost.

Finally, the NASA climate website (climate.nasa.gov) won the "Best Science Site" Webby Award in 2011. The main NASA portal (www.nasa.gov), which won two Webby Awards in 2012, also highlights climate and Earth system science on a routine basis. These sites are a powerful tool that USGCRP harnesses to communicate climate science to the public.

New Science Centers to Offer Week-long Climate "Boot Camp" for Students

DOI is currently establishing eight Climate Science Centers across the Nation to provide scientific support for those who manage natural and cultural resources and need to plan for a changing climate. When fully established, the Climate Science Centers will support more than 50 graduate students and post-doctoral candidates per year to work on issues directly related to climate change management challenges. To complement coursework and research activities, the Centers are also developing innovative education approaches such as a week-long "Climate Boot Camp" for students and managers at the Northwest Climate Science Center, and a two-week intensive short course on climate downscaling at the Alaska Climate Science Center. Both will combine classroom learning with real-world experience and interactions with managers on the ground.

Growing Network of Citizen Scientists Provides Data on Nature's Changing Calendar

Scientists are increasingly turning to members of the public for help conducting phenology research—the study of plant and animal life cycles, or "nature's calendar." These "citizen scientists" are mobilizing to record and report climate-relevant observations that scientists can't track as comprehensively on their own, including the shifting timing of flower blooms, leaf fall, animal reproduction, species migration, crop maturation, and insect emergence.

An effort to incorporate the work of citizen scientists into the phenology research community is being coordinated through the USA National Phenology Network (USA-NPN) in close collaboration with USGS, other USGCRP agencies, and external partners. This effort greatly expands the Nation's capacity to collect phenological observations across the full range of geographic and time scales.

Approximately 4,000 people have registered to track the activity of nearly 16,000 plants and animal species across the Nation—and the number is growing. The NPN provides scientists, resource managers and decision makers with a more comprehensive view of the pace and patterns of phenological change. This information is particularly valuable to farmers and gardeners who must decide when to harvest crops, managers who must anticipate drought and wildfire risks, and public health officials who must track the onset of allergy seasons.

Agency Funds Support Climate Literacy among Midwestern Farmers

In 2011 USDA made a 5-year, $20 million grant to Iowa State University to integrate research, extension, and education on climate change adaptation and mitigation for farmers across eight Midwestern states. As part of this project, extension and education programs will work with

Figure 16. Tropical Storm Isaac by Night. Exceptionally crisp nighttime images of Hurricane Isaac as it made landfall in August 2012 were made possible by the Suomi National Polar-orbiting Partnership satellite (NPP). Photo Credit: NASA Observatory.

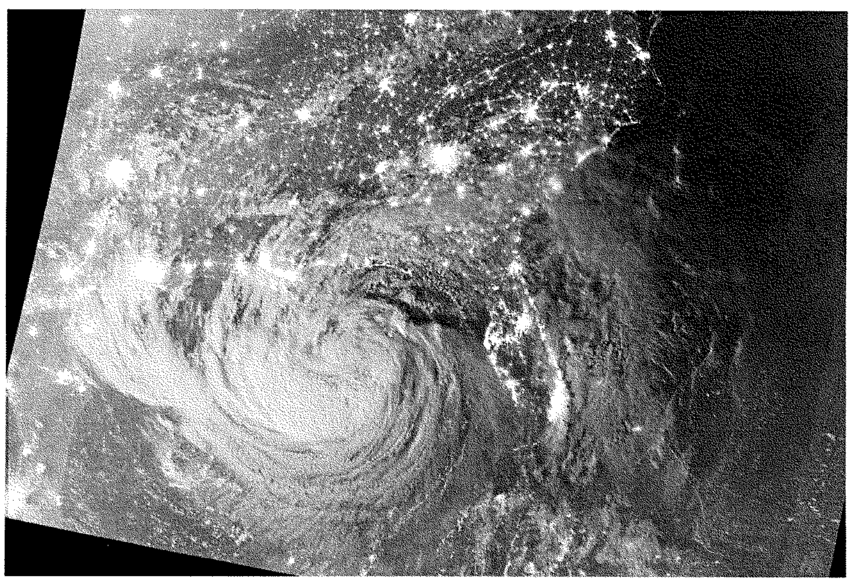


Figure 17. A small dam, terraces, buffer strips, and grass plantings are part of a conservation project to improve the quality of water entering Union Grove Lake in Tama County, Iowa. Photo credit: USDA-NRCS.

farmers, teachers, and students to promote climate literacy and collaborative learning.

An Iowa Agricultural Educators survey[22] of middle- and high-school teachers showed that nearly 70 percent of respondents think climate change is caused primarily or in large part by human activities. Nearly 92 percent said they are interested in educational curricula and other materials that focus specifically on climate change and agriculture in Iowa.

[22] Arbuckle, J. Gordon Jr., Daren S. Mueller, and Adam Sisson. 2011. Climate Change in the Classroom: A Survey of Iowa Agricultural Educators. CSCAP2011-1. Ames, IA: Iowa State University Extension Sociology. (2 pp.)

2.6 INTERNATIONAL RESEARCH & COOPERATION

USGCRP coordinates international activities related to global change occurring across Federal agencies, with the following goals:

- Increase cooperation between U.S. scientists, institutions, and agencies and their international counterparts on topics related to global change;
- Empower scientists and institutions in less developed countries to improve understanding of and responses to global change;
- Promote international efforts to develop standards for data quality and accessibility at low cost;
- Sustain and improve observations of the Earth system globally; and
- Support international negotiations and overseas development assistance.

The landscape of international research and cooperation is evolving rapidly. Organizations and governments at home and abroad are recognizing the growing need for scientific knowledge to better inform policy and decision making. USGCRP is playing an integral role in providing such scientific knowledge and stands to significantly benefit from the knowledge and experience of partners around the world.

RECENT HIGHLIGHTS: INTERNATIONAL RESEARCH AND COOPERATION

Agencies Support Research and Tools to Reduce Agricultural Greenhouse Gas Emissions

In 2009, USDA led Federal efforts to formally establish the Global Research Alliance (GRA) on Agricultural Greenhouse Gases, an international research collaboration to manage climate change. As of June 2011, 30 countries have signed onto the Alliance. In cooperation with United States Agency for International Development (USAID), USDA supports researchers in developing countries that participate in the Alliance by providing fellowship opportunities to work side-by-side with USDA scientists on climate change mitigation research.

USDA also developed and released a Web-based book, *Greenhouse Gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) Soil Carbon Sampling Protocols*, to establish soil carbon sampling protocols across many locations and within different agro-ecosystems. The 30 countries currently participating in the Alliance are now considering adopting these protocols to enable comparison of soil carbon across space and time.

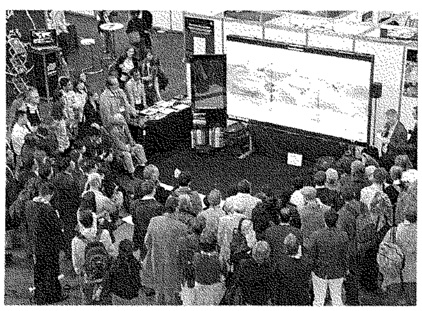
USGCRP Showcases National Activities on International Stage

USGCRP continues to participate in *Planet Under Pressure*, an international conference organized by leaders in the worldwide global change research community. The 2012 conference focused on improving connections between natural sciences, social sciences, economics, decision making, and development to support responses to global change.

USGCRP agencies contributed to sessions, provided speakers, and exhibited at the conference. For example, NASA displayed its "Hyperwall" to demonstrate the global change communications power of compelling visualizations (Figure 18).

USGCRP agencies also showcased their work at the United Nations Framework Convention on Climate Change's 17th Convention of the Parties (COP-17) in South Africa. USAID, USGS, USDA, NASA, and NOAA, for example, jointly showcased their Famine Early Warning System (FEWS), which provides climate information needed to prevent food insecurity. USDA also helped showcase the Presidential Feed the Future (FTF) Initiative, a $3.5 billion program designed to help countries fight hunger by investing in agricultural developments such as climate-resilient cereals and increased grain and legume productivity.

Figure 18. NASA Hyperwall. At the Planet Under Pressure 2012 Conference, NASA's hyperwall was showcased to demonstrate global change results visually. Photo Credit: NASA.



2.7 CLIMATE CHANGE & HUMAN HEALTH

Climate change poses potentially serious challenges to human health, including increased heat stress mortality, increases in diarrheal disease, degraded air and water quality, changes in vector-borne disease patterns, more severe pollen seasons, and danger from more frequent extreme weather events. In addition to threatening human well-being, these challenges can also contribute to increased healthcare costs.

In 2009, the National Research Council recommended that USGCRP strengthen its focus on integrating areas of high interest to decision makers, including climate change and human health. In direct response to this recommendation and in alignment with the Program's own strategic vision, USGCRP launched a cross-cutting initiative to better understand the impacts of climate change on human health both today and in the future.

RECENT HIGHLIGHTS: CLIMATE CHANGE AND HUMAN HEALTH

With Climate Change, Longer Stronger Pollen Seasons

Carbon dioxide (CO_2) in the atmosphere directly affects plants by supplying the carbon they need for photosynthesis. In some cases, elevated CO_2 levels can help plants grow faster—a potential boon when that plant is an agriculturally important species, but CO_2 does not discriminate between desirable and undesirable plants. That means that while there may be benefits to more rapid growth in species like forest trees, for example, there can be serious negative consequences when these growth spurts occur in other plants, like ragweed—a plant to which at least ten percent of the United States population is sensitive.

A previous field study by USDA scientists and partners found that both higher atmospheric CO_2 levels and warmer temperatures—two key aspects of climate change—"significantly influence" pollen production in common ragweed and can increase pollen concentrations in the atmosphere.[23]

[23] Ziska, L. et al. 2003. "Cities as harbingers of climate change: Common ragweed, urbanization, and public health." *Journal of Allergy and Clinical Immunology*. 11, 2.

[24] Ziska, L. et al. 2011. "Recent warming by latitude associated with increased length of ragweed pollen season in central North America." *Proceedings of the National Academy of Sciences*. DOI: 10.1073/pnas.1014107108.

In a more recent study, USDA researchers and collaborators found that in parts of North America, the ragweed pollen season is up to three weeks longer than it was in the mid-1990's because of climate change.[24]

Today, allergic disorders, including asthma, comprise the 6th leading cause of chronic illness in the Nation. They affect more than 50 million Americans per year and cost the United States nearly $20 billion annually.

Workshops Bridge Health, Climate, and Adaptation Communities

Several recent outreach events convened diverse stakeholders to share knowledge, promote dialogue, and bridge gaps between health professionals, climate scientists, and decision makers on critical issues related to climate and health.

In October 2011, USGCRP collaborated with the White House Office of Science & Technology Policy to convene climate adaptation planners from across the Federal government to identify linkages between climate change adaptation strategies, public health issues, and relevant resources.

Also in October 2011, USGCRP participated in the Annual Meeting of the American Public Health Association, the oldest and largest annual gathering of public health professionals, which attracted more than 13,000 national and international public health specialists. USGCRP's Climate Change and Human Health working group hosted a listening session and a skills-development workshop as part of the conference's Learning Institute for professional development. Participants in the skills development workshop, *Effectively Communicating the Human Health Impacts of Climate Change*, indicated anecdotally that the course increased their understanding of climate change communications and provided relevant resources for future use.

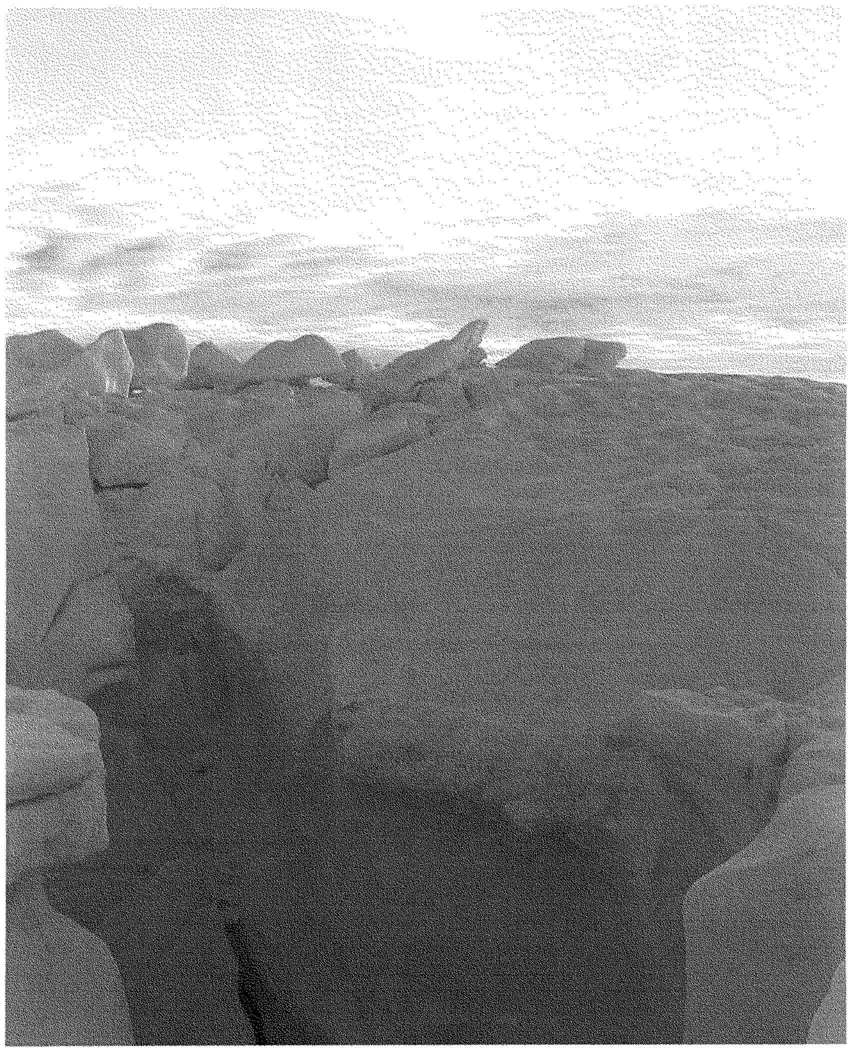
Finally, in 2012, USGCRP convened regional climate change and human health workshops in collaboration with NOAA, the Centers for Disease Control and Prevention (CDC), and the National Institutes of Health (NIH) in Charleston and Seattle. Each workshop convened 50 – 60 people to develop nuanced representations of regional climate change impacts on human health. The workshops were important venues for dialogue and yielded synthesis reports that will inform the 2013 National Climate Assessment.

USGCRP Develops New Climate-and-Health Data Tool

In 2012, USGCRP began development of the Metadata Access Tool for Climate and Health (MATCH), an interactive clearinghouse of datasets and tools related to the human health impacts of global climate change. The MATCH project is a pilot data-integration effort that will inform development of a broader Global Change Information System (GCIS). It presents a publically accessible user search interface for Federal datasets and allows for automated deposition of metadata into Data.gov and other existing Federal portals.

A fully operational MATCH portal—expected over the next few years and in collaboration with GCIS—will allow Federal agencies, universities, researchers, and stakeholders to:

- Analyze and integrate local, state, and national climate and human health data assets
- Facilitate the integration of other datasets related to climate and human health; and
- Integrate and link United States efforts to address climate change and human health concerns with international efforts such as GEO.



3. FY 2013 PRIORITIES

3.1 OVERVIEW

USGCRP's FY 2013 priorities are based on recommendations from stakeholders and the scientific community, including multiple National Academy reports on global change science and related human dimensions, the 2009 Global Climate Change Impacts in the United States report, a Pew Center report on the drivers of a coordinated Federal global change research program,[25] the National Adaptation Summit[26] report, and the National Academy of Sciences (NAS) *America's Climate Choices* reports,[27] among others.

This suite of reports shared a common recommendation: that the Federal climate and global change research enterprise should focus sharply on acquiring information for more effective and more iterative risk management in the face of global and climate change and place stronger emphasis on building resilience within the human component of the Earth system.

In response to this input and in support of the Program's new strategic goals, USGCRP has identified five priority areas of focus for FY 2013:

- Integrated Observations, Research and Modeling for Earth and Social Systems;
- Adaptation Research;
- Sustained Assessments;
- Interagency Global Change Information System; and
- Communications, Education, and Engagement.

USGCRP has also recognized that climate and global change impacts may be most evident when thresholds and tipping points are reached (e.g., outbreak of disease, collapse of ecological systems, proliferation of invasive species, ice-sheet collapse) and extreme events occur (e.g., tornadoes, droughts, floods, hurricanes). Therefore, thresholds, tipping points, and extremes have been selected as a unifying theme that cuts across all priority areas for FY 2013.

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[25] Center for Climate and Energy Solutions (formerly Pew Center for Global Climate Change), 2010. Adapting to Climate Change: A Call for Federal Leadership. http://www.c2es.org/publications/report/adapting-to-climate-change-call-for-federal-leadership

[26] National Climate Adaptation Summit, 2010. http://www.joss.ucar.edu/events/2010/ncas/

[27] America's Climate Choices. http://nas-sites.org/americasclimatechoices/

3.2 FY 2013 PRIORITY AREAS

Integrated Research, Observations, and Modeling for Earth and Social Systems

USGCRP's FY 2013 priority targets in the area of Observations, Research, and Modeling include:

- Support the continued availability and new development of key satellite and *in situ* observation data that are required to improve scientific understanding and climate modeling;
- Conduct research to enhance understanding of predictability and better characterize highly uncertain processes, feedbacks, and environmental parameters (e.g., carbon cycling, biosphere interactions, atmospheric aerosols, clouds, ice sheet mass balance, and ocean circulation);
- Develop more comprehensive, highly-integrated models at spatially-relevant scales to increase understanding Earth systems and climate-related phenomena, and to inform adaptation and mitigation of climate impacts; and
- Develop mechanisms to incorporate human-system processes into models in order to improve scientific understanding, and enhance adaptation and mitigation capacities.

Adaptation Research

USGCRP's adaptation research in FY 2013 will emphasize anticipation and planning for thresholds, tipping points, and climate extremes, including research to:

- Advance understanding of social and ecological tipping points and thresholds to help define options and limits to adaptation;
- Integrate social, behavioural, and economic sciences (e.g. decision making under uncertainty, assessing adaptation trade-offs, costs of action vs. inaction) to improve understanding of human responses to rapid changes and extreme events; and
- Determine the effects of multiple cross-sectoral interacting stressors on human and natural systems that affect resilience to tipping points, extremes and thresholds.

USGCRP will also conduct fundamental work to support adaptation decision making by: (a) identifying flexible criteria for evaluating the effectiveness of near- and long-term adaptation options; (b) developing effective science translation strategies (e.g., methods to explain scientific jargon into laymen's terms) to expand translation capacity; and (c) mapping Federal science and decision support assets.

Establish and Sustain Assessments

The highest priority efforts related to the National Climate Assessment (NCA) in FY 2013 include:

- Writing, reviewing, and revising the draft 2013 NCA report in response to comments by USGCRP agencies, National Research Council, and the public in the spring of 2013. The final release of the NCA report will occur in early FY 2014. Concurrently, as part of the ongoing assessment process, the NCA staff will begin developing targeted special reports and other products for release between major quadrennial Assessment efforts and for web-based deployment. Partners in the NCA Network ("NCAnet") will help distribute key assessment findings to their stakeholders;
- Advancing development of the first national system of physical, ecological, and societal indicators that communicate key aspects of the physical climate, climate impacts, vulnerabilities, and preparedness to inform decision makers. Specific goals of this effort are to 1) provide meaningful, authoritative climate-relevant measures about the status, rates, and trends of key physical, ecological, and societal variables to inform decisions at multiple scales; 2) identify climate-related conditions and impacts to help develop effective mitigation and adaptation measures; and 3) provide analytical tools for users to derive indicators for particular purposes. This effort will build on or leverage existing data, observations, model output, as well as extant indicator networks and systems. Stakeholder engagement in the development of the indicators will be a strong focus in FY 2013; and
- Strengthening integration of land use and land cover scenarios, socioeconomic scenarios, and participatory scenario planning into future NCA processes and products; continually updating climate and sea level change scenarios as new scientific information becomes available; and incorporating global scenarios and related data from the IPCC's upcoming fifth assessment report into regional and sectoral assessments.

Interagency Global Change Information System (GCIS)

To meet growing public demand for timely, accessible, authoritative scientific information about global change and its impacts, USGCRP will work toward establishing a GCIS in FY2013.

In its initial phase, the GCIS will provide enhanced accessibility, transparency, and utility of data related to the 2013 National Climate Assessment report, including documentation and traceability of all relevant data sources. These steps will also directly respond to a recommendation by the Interagency Climate Change Adaptation Task Force to *ensure scientific information about the impacts of climate change is easily accessible.*

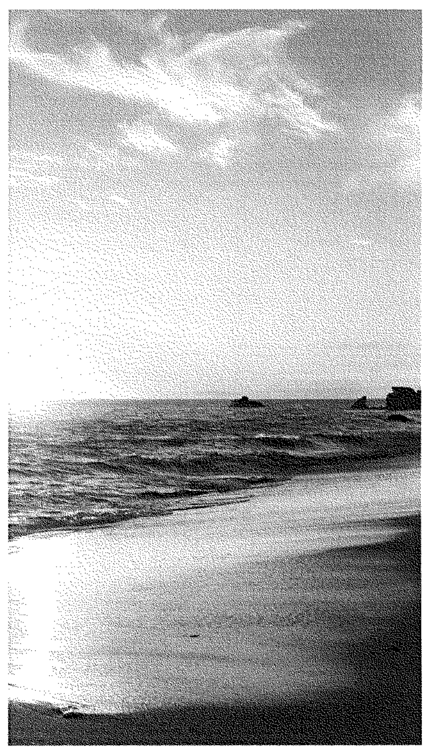
Moving forward, the GCIS will evolve to incorporate broader sets of data, information, applications, tools, and services and disseminate that information more rapidly and to broader set of audiences.

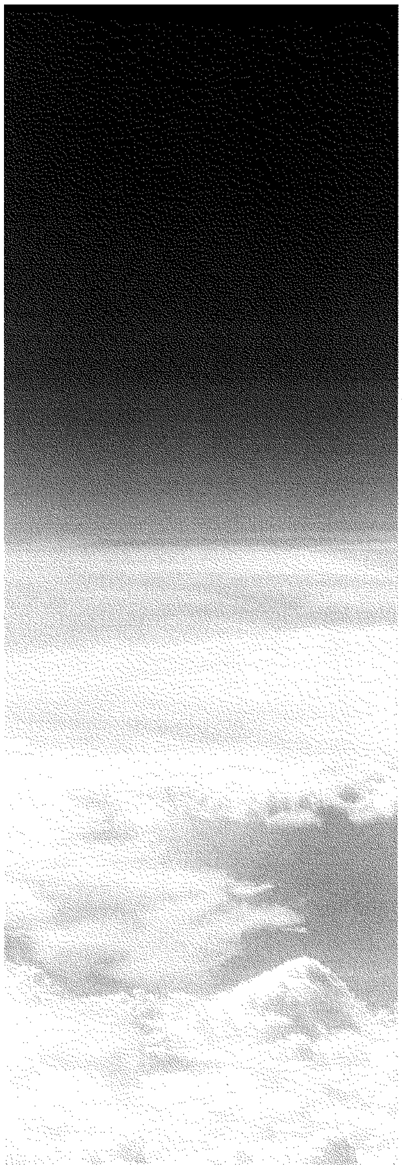
Communication, Education, and Engagement

In April 2012, USGCRP launched a new Interagency Communications & Education Team (ICE-t) to advance the Program's goal to *Communicate & Educate*. The Team's working vision is to: *build and cultivate an attentive, conversant public who understand the reality, causes, and costs of climate and global change as well as the options for effective response.*

Priority communication, education, and engagement activities for USGCRP in FY2013 include:

- Strengthen the application of social science research to Federal global change science communications and education. Through the ICE-t, USGCRP has launched a new expert engagement series called *"Outside-In,"* to increase exposure of Federal communicators to emerging social science research related to climate change communications and education. USGCRP has already hosted three *Outside-In* events featuring social science experts from George Mason University, Yale University, and Stanford University;
- Strengthen communications about the relationship between climate change and extreme weather events. Through the ICE-t, USGCRP is developing plans to create communications materials about connections between various extreme weather events and the larger climate system with the goal of being ready to deploy those materials during or soon after an extreme weather event occurs;
- Support communication, education, and outreach related to the 2013 National Climate Assessment. USGCRP will prioritize the development of communications materials, outreach events, and engagement opportunities to deploy scientific information contained in the new NCA to broad and diverse audiences. Specifically, the ICE-t will provide strategic communications guidance and input to support dissemination of the 2013 Assessment;
- Apply communication and education expertise to development of a Global Change Information System (GCIS). USGCRP will make it a priority in FY2013 to develop the GCIS as not only an information system but also a communications tool. This will include engaging communications and education specialists in the design and implementation of the GCIS, including its visible user interfaces and the narrative and visual content it will disseminate; and
- Strengthen USGCRP's web presence. *Globalchange.gov* and the web generally are key communications interfaces for USGCRP. In FY2013, the Program will prioritize activities to make *globalchange.gov* a more intuitive, engaging, and informative website by increasing the frequency with which new content is posted, improving the design of the homepage, and testing new web-based communication platforms (i.e., social media) for dissemination of scientific information to diverse audiences.





4. BUDGET HIGHLIGHTS

The FY 2013 budget request for USGCRP programs is $2.7 billion—an increase of approximately 7 percent over the 2012 enacted level. This increase reflects the needs discussed formerly and represents a commitment by the Administration to ensure that the USGCRP can fulfill its responsibilities under the law.

It is important to remember that the budget crosscut table represents those funds self-identified by the USGCRP agencies as their contributions to the USGCRP. The budget crosscut does not include the costs of many agency investments that are directly relevant, and indeed necessary, to the ability of the USGCRP to address national objectives related to climate and global change (e.g., many of the observing networks and satellite systems so critical to documenting trends were originally carried out by their sponsoring agencies for current operational purposes, and those are not typically included in the budget crosscut).

4.1 BUDGET BY AGENCY

Table 1: FY 2011-2013 U.S. Global Change Research Program Budget by Agency

Agency	FY 2011 Budget Enacted ($M)	FY 2012 Budget Enacted ($M)	FY 2013 Budget Requested ($M)
Department of Agriculture (USDA)	85.9	115.0	122.6
Department of Commerce (DOC)	341.9	326.5	363.9
Department of Energy (DOE)	186.5	211.5	230.5
Department of Health and Human Services (HHS)	6.0	6.0	6.0
Department of the Interior (DOI)	64.3	58.9	67.7
Department of Transportation (DOT)	0.7	1.4	1.5
Environmental Protection Agency (EPA)	20.5	18.3	20.3
National Aeronautics and Space Administration (NASA)	1431.0	1422.0	1522.0
National Science Foundation (NSF)	321.3	333.4	332.9
Smithsonian Institution (SI)	7.0	8.0	8.0
[U.S. Agency for International Development (USAID)]	25.0	10.0	10.0
TOTALS	2490.2	2511.0	2685.5

4.2 BUDGET BY GOAL & PROGRAM ELEMENT

Table 2: FY 2011-2013 U.S. Global Change Research Program Budget by Goal and Program Element

Program Element	Description	Budgets ($M) FY 2011 Budget Enacted	FY 2012 Budget Enacted	FY 2013 Budget Requested	Agency(ies)
GOAL 1: ADVANCE SCIENCE – Advance scientific knowledge of the integrated natural and human components of the Earth system.		2073.7	2094.6	2243.3	USDA, DOC, DOE, HHS, DOI, DOT, EPA, NASA, NSF, SI
Integrated Earth Observations	Funds capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales to gain fundamental scientific understanding and monitor important variations and trends	1252.3	1221.5	1348.4	USDA, DOC, DOE, HHS, EPA, NASA, NSF, SI
Multidisciplinary Scientific Understanding of Earth Systems	Funds research that contributes to advancing the fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among them, to improve knowledge of the causes and consequences of global change	667.3	719.7	729.8	USDA, DOC, DOE, HHS, DOI, DOT, EPA, NASA, NSF, SI
Integrated Earth System Modeling	Funds activities that contribute to improving and developing advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among them, to represent more comprehensively and predict more realistically global change processes	154.1	153.4	165.1	USDA, DOC, DOE, NSF
GOAL 2: INFORM DECISIONS – Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.		371.4	375.1	397.7	USDA, DOC, HHS, DOI, DOT, EPA, NASA, NSF
Adaptation Science	Funds activities that contribute to improving the research, application, and deployment of science that is specifically designed to inform adaptation decisions	126.3	113.5	134.6	USDA, DOC, HHS, DOI, DOT, EPA, NSF, USAID
Global Change Information	Funds activities that contribute to the advancement of capability to store, access, visualize, and share data and information about the integrated Earth-Human systems as well as fund the development of tools and scientific basis to support an integrated system of global change information to support decision making. This leverages much greater investments in collecting observational data.	245.1	261.6	263.1	USDA, DOC, HHS, DOT, NASA
GOAL 3: CONDUCT SUSTAINED ASSESSMENTS – Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.		34.0	29.7	34.7	USDA, DOC, HHS, DOI, EPA
Conduct Sustained Assessments	Funds activities that contribute to building a sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities	34.0	29.7	34.7	USDA, DOC, HHS, DOI, EPA
GOAL 4: COMMUNICATE AND EDUCATE – Advance communication and education to broaden public understanding of global change and develop the scientific workforce of the future.		11.0	11.6	9.8	USDA, DOC, DOE, HHS, NSF, SI
Communicate and Educate	Funds activities that contribute to advancing communications and education to broaden public understanding of global change, and develop the scientific workforce of the future	11.0	11.6	9.8	USDA, DOC, DOE, HHS, NSF, SI
USGCRP BUDGET CROSSCUT TOTAL		**2490.2**	**2511.0**	**2685.5**	**USDA, DOC, DOE, HHS, DOI, DOT, EPA, NASA, NSF, SI, USAID**

4.3 BUDGET BY AGENCY & PROGRAM ELEMENT

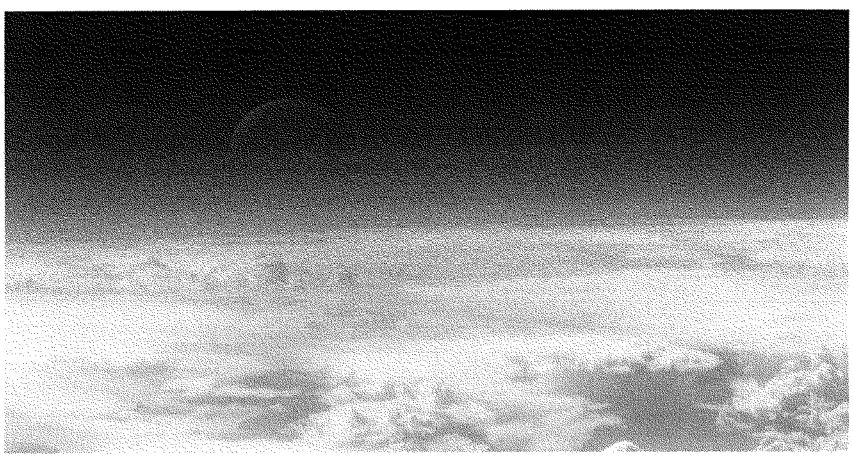
Table 3: FY 2011-2013 U.S. Global Change Research Program Budget by Agency and Program Element

FY 2011 Budget Enacted	Goal & Program Element							
	GOAL 1			GOAL 2		GOAL 3	GOAL 4	
Agency Name	Integrated Earth Observations	Multidisciplinary Scientific Understanding of Earth Systems	Integrated Earth System Modeling	Adaptation Science	Global Change Information	Conduct Sustained Assessments	Communicate and Educate	TOTALS
USDA	2.2	35.4	3.26	27.7	1.8	12.4	3.2	**85.9**
DOC	121.6	85.6	31.2	31.4	62.4	7.0	2.7	**341.9**
DOE	50.0	57	79.3	0.0	0.0	0.0	0.2	**186.5**
HHS	0.7	3.2	0.0	0.5	0.9	0.4	0.3	**6.0**
DOI	0.0	28.5	0.0	25.9	0.0	10.0	0.0	**64.3**
DOT	0.0	0.7	0.0	0.0	0.0	0.0	0.0	**0.6**
EPA	1.5	8.9	0.0	5.8	0.0	4.2	0.0	**20.5**
NASA	995.0	256.0	0.0	0.0	180.0	0.0	0.0	**1431.0**
NSF	81.0	185.5	40.3	10.0	0.0	0.0	4.5	**321.3**
SI	0.3	6.5	0.0	0.0	0.0	0.0	0.2	**7.0**
USAID	0.0	0.0	0.0	25.0	0.0	0.0	0.0	**25.0**
PROGRAM ELEMENT TOTALS	**1252.3**	**667.3**	**154.1**	**126.3**	**245.1**	**34.0**	**11.1**	**2490.2**
GOAL TOTALS	**2073.7**			**371.4**		**34.0**	**11.1**	

FY 2012 Budget Enacted	Goal & Program Element							
	GOAL 1			GOAL 2		GOAL 3	GOAL 4	
Agency Name	Integrated Earth Observations	Multidisciplinary Scientific Understanding of Earth Systems	Integrated Earth System Modeling	Adaptation Science	Global Change Information	Conduct Sustained Assessments	Communicate and Educate	TOTALS
USDA	2.4	46.7	9.3	42.4	1.2	9.0	4.1	**115.0**
DOC	135.9	69.6	30.5	19.6	63.5	5.1	2.3	**326.5**
DOE	71.0	66.0	74.3	0.0	0.0	0.0	0.2	**211.5**
HHS	0.7	3.2	0.0	0.5	0.9	0.4	0.3	**6.0**
DOI	0.0	22.0	0.0	27.9	0.0	9.0	0.0	**58.9**
DOT	0.0	1.4	0.0	0.0	0.0	0.0	0.0	**1.4**
EPA	1.5	7.5	0.0	3.1	0.0	6.2	0.0	**18.3**
NASA	928.0	298.0	0.0	0.0	196.0	0.0	0.0	**1422.0**
NSF	81.4	198.2	39.3	10.0	0.0	0.0	4.5	**333.4**
SI	0.7	7.1	0.0	0.0	0.0	0.0	0.2	**8.0**
USAID	0.0	0.0	0.0	10.0	0.0	0.0	0.0	**10.0**
PROGRAM ELEMENT TOTALS	**1221.6**	**719.7**	**153.4**	**113.5**	**261.6**	**29.7**	**11.6**	**2511.0**
GOAL TOTALS	**2094.7**			**375.1**		**29.7**	**11.6**	

Table 3 (continued)

FY 2013 Budget Requested	Goal & Program Element							
	GOAL 1			GOAL 2		GOAL 3	GOAL 4	
Agency Name	Integrated Earth Observations	Multidisciplinary Scientific Understanding of Earth Systems	Integrated Earth System Modeling	Adaptation Science	Global Change Information	Conduct Sustained Assessments	Communicate and Educate	TOTALS
USDA	2.2	48.0	9.0	46.1	0.9	11.6	4.8	**122.56**
DOC	146.0	76.8	39.0	24.3	67.3	7.7	2.8	**363.9**
DOE	74.0	78.0	78.3	0.0	0.0	0.0	0.2	**230.53**
HHS	0.7	3.2	0.0	0.5	0.9	0.4	0.3	**6.05**
DOI	0.0	23.2	0.0	35.1	0.0	9.4	0.0	**67.741**
DOT	0.0	1.5	0.0	0.0	0.0	0.0	0.0	**1.52**
EPA	1.8	9.1	0.0	3.9	0.0	5.6	0.0	**20.27**
NASA	1040.0	288.0	0.0	0.0	194.0	0.0	0.0	**1522**
NSF	83.0	194.9	38.8	14.8	0.0	0.0	1.5	**332.91**
SI	0.7	7.1	0.0	0.0	0.0	0.0	0.2	**8.0**
USAID	0.0	0.0	0.0	10.0	0.0	0.0	0.0	**10.0**
PROGRAM ELEMENT TOTALS	**1348.4**	**729.8**	**165.1**	**134.7**	**263.1**	**34.7**	**9.8**	**2685.5**
GOAL TOTALS	**2243.3**			**397.8**		**34.7**	**9.8**	



APPENDIX A: OVERVIEW OF USGCRP

USGCRP was established by Presidential initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990 in order to *"assist the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."*[28]

USGCRP operates as a unified Federal program that integrates the global change research capacities of thirteen Federal agencies and departments (Figure 1). The Program promotes close interagency coordination and streamlined development, translation, and deployment of scientific information related to global change.

Over several decades, USGCRP research has substantially improved our understanding of global environmental changes and their effects on society. The Program continues to expand this fundamental understanding and supply scientific information to inform the Nation's response to global change.

A.1 VISION & MISSION

Vision – *A nation, globally engaged and guided by science, meeting the challenges of climate and global change*

Mission – *To build a knowledge base that informs human responses to climate and global change through coordinated and integrated Federal programs of research, education, communication, and decision support*

[28] See http://library.globalchange.gov/.

A.2 PROGRAM GOVERNANCE & MANAGEMENT

USGCRP is steered by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, Natural Resources and Sustainability and overseen by the White House Office of Science and Technology Policy (Figure 19).

In consultation with White House officials and the SGCR, USGCRP's Executive Director ensures that USGCRP meets all mandated requirements (Table A.1).

USGCRP works closely with the SGCR and White House offices to establish research priorities in alignment with national priorities, budgetary planning, and GCRA requirements. The Program also coordinates with other Federal interagency bodies such as the National Ocean Council (NOC), the Interagency Climate Change Adaptation Task Force (ICCATF), and other Subcommittees of the CENRS to ensure that USGCRP's work can be leveraged by other Federal groups working to prepare for or minimize the impacts of global change.

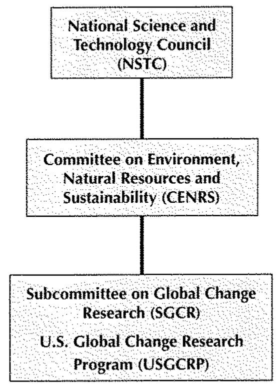


Figure 19: USGCRP Governance Structure

Table A.1: Global Change Research Act (GCRA) of 1990 Requirements

Requirement	Global Change Research Act of 1990 Requirement Description
Program Governance	Serve as the forum for developing the National Global Change Research Plan and for overseeing its implementation.
Global Change Research Coordination	Improve cooperation among Federal agencies and departments with respect to global change research activities.
Budget Coordination	Provide budgetary guidance and advice as specified in section 105 of the GCRA.
Programmatic Review	Work with academic, State, industry, and other groups conducting global change research, to provide for periodic public and peer review of the Program.
International Research and Cooperation	Cooperate with the Secretary of State in: (i) providing representation at international meetings and conferences on global change research in which the U.S. participates; and (ii) coordinating the Federal activities of the U.S. with programs of other nations and with international global change research activities.
Inform Response to Global Change	Consult with actual and potential users of the results of the Program to ensure that such results are useful in developing national and international policy responses to global change.
Annual Report	Report at least annually to the President and the Congress, through the OSTP Director, on Federal global change research priorities, policies, and programs.
National Global Change Research Plan	The Plan shall contain recommendations for national global change research...and establish, the goals and priorities for Federal global change research. A revised Plan shall be submitted at least once every three years.
Quadrennial Assessment	Prepare and submit to the President and the Congress an assessment which (1) integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings; (2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and (3) analyzes current trends in global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.

A.3 PLANNING & PRIORITIZATION

USGCRP is currently developing a three-year implementation roadmap that describes near- and medium-term priorities as well as steps needed to accomplish longer-term goals. The roadmap will be updated periodically and will be used to inform development of a Revised Research Plan (RRP) for public comment and publication every three years. These triennial updates, which are mandated by the Global Change Research Act, will be based upon self-evaluation and external evaluation and will reflect changing conditions and new information. The Program will continue to consult the National Research Council (NRC) for independent scientific perspectives and report progress to Congress and the public annually in *Our Changing Planet*.

The Global Change Research Act (section 105) sets requirements for USGCRP to develop interagency priorities that are linked to annual budget development. Each year, the SGCR develops a set of global change research funding priorities by identifying Program activities that fill critical scientific gaps or address evolving societal needs. These priorities are communicated in a memo that is used by USGCRP agencies as guidance in their individual budgetary and prioritization processes. The memo also provides a framework for effective communication between the SGCR and the White House Office of Management and Budget (OMB) on the topic of global change research. Detailed information about annual prioritization criteria is provided in the new 10-year Research Plan.[29]

A.4 ORGANIZATION

The Global Change Research Act mandates the development of a 10-year *National Global Change Research Plan* for USGCRP. The previous such Plan was published in 2003. The Plan for 2012–2021 identifies seven new programmatic and budgetary categories, or "Program Elements," that are described in Table A.2.

[29] USGCRP, 2012. National Global Change Research Plan 2012–2012: A Strategic Plan for the U.S. Global Change Research Program http://library.globalchange.gov/u-s-global-change-research-program-strategic-plan-2012-2021

Table A.2: Description of Program Elements

2012 Strategic Plan Program Elements	Budgetary Definition
Program Element 1: Integrated Observations	Funds capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales to gain fundamental scientific understanding and monitor important variations and trends.
Program Element 2: Multidisciplinary Earth and Human System Understanding	Funds research that contributes to advancing the fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among them, to improve knowledge of the causes and consequences of global change.
Program Element 3: Integrated Modeling	Funds activities that contribute to improving and developing advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among them, to represent more comprehensively and predict more realistically global change processes.
Program Element 4: Science of Adaptation and Science to Inform Adaptation Decisions	Funds activities that contribute to improving the research, application, and deployment of science that is specifically designed to inform adaptation decisions.
Program Element 5: Global Change Information	Funds activities that contribute to the advancement of capability to store, access, visualize, and share data and information about the integrated Earth-Human systems, as well as fund the development of tools and scientific basis to support an integrated system of global change information, informed by sustained, relevant, and timely data and information to support decision making.
Program Element 6: Assessments	Funds activities that contribute to building a sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.
Program Element 7: Communication and Education	Funds activities that contribute to advancing communications and education to broaden public understanding of global change, and develop the scientific workforce of the future.

Table A.3 illustrates USGCRP's budget crosscut areas for FY 2010–2013 and their alignment with the strategic goals described in USGCRP's new *National Global Change Research Plan* for 2012–2021. This alignment is critical to ensuring continuity of progress, ongoing support for priority efforts, and overall endurance of the Program.

A.5 OPERATIONS

USGCRP's primary mechanism for interagency coordination is a set of interagency working groups made up of individuals from USGCRP's 13 member agencies and staff from the Program's National Coordination Office. USGCRP has recently developed a revised portfolio of interagency working groups to align with the new Research Plan for 2012–2021, and is increasing the involvement of interagency working groups in priority setting activities. The revised portfolio will be evaluated periodically and modified as interim goals and objectives are accomplished. Table A.4 lists the current portfolio of interagency working groups and their corresponding activity areas.

A.6 PURPOSE OF THIS REPORT

Since 1989, USGCRP has submitted annual reports to Congress called *Our Changing Planet*. The reports describe

Table A.3: Budget Crosscut Areas for FY 2010, FY2011, & FY2013

FY 2010 Budget Crosscut Areas (based on 2003 Strategic Plan Goals)	**FY 2011 Budget Crosscut Areas (based on Transitional Focus Areas)**	**FY 2013 Budget Crosscut Areas (based on 2012 Strategic Plan Program Elements)**	**2012–2021 New Strategic Goals**
Goal 1: Improve knowledge of the Earth's past and present climate and environment, including it natural variability, and improve understanding of the causes of observed variability and changes	**Focus Area 1:** Improving our knowledge of Earth's past and present climate variability and change	**Program Element 1:** Integrated Observations	**Goal 1 - Advance Science:** Advance scientific knowledge of the integrated natural and human components of the Earth system
Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems	**Focus Area 2:** Improving our understanding of natural and human forces of climate change	**Program Element 2:** Multidisciplinary Earth and Human System Understanding	
Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future	**Focus Area 3:** Improving our capability to model and predict future conditions and impacts	**Program Element 3:** Integrated Modeling	
Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change	**Focus Area 5:** Providing climate information and decision support tools	**Program Element 4:** Science of Adaptation and Science to Inform Adaptation Decisions	**Goal 2 - Inform Decisions:** Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation
		Program Element 5: Global Change Information	
Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes	**Focus Area 4:** Assessing the nation's vulnerability to current and anticipated impacts of climate change	**Program Element 6:** Assessments	**Goal 3 - Conduct Sustained Assessments:** Build sustained assessment capacity that improves the nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities
N/A	**Focus Area 6:** Climate Change Communication and Education	**Program Element 7:** Communication and Education	**Goal 4 - Communicate and Educate:** Advance communications and education to broaden public understanding of global change, and develop the scientific workforce of the future

the status of USGCRP research activities, provide progress updates, and document recent accomplishments. This FY 2013 edition of *Our Changing Planet* provides a summary of programmatic achievements, recent progress, future priorities, and budgetary information. It thereby meets the requirements set forth in the U.S. Global Change Research Act of 1990 (GCRA; Section 102, P. L. 101-606) to provide an annual report on *"Federal global change research priorities, policies, and programs."*

Table A.4: USGCRP Interagency Working Groups (IWGs)

2012 Strategic Plan Program Elements, International, and Crosscutting Initiatives	**USGCRP Interagency Working Group**
Program Element 1: Integrated Observations	Integrated Observations IWG
Program Element 2: Multidisciplinary Earth and Human System Understanding	Process Research IWG Carbon Cycle Interagency Working Group (CCIWG)
Program Element 3: Integrated Modeling	Interagency Group on Integrated Modeling (IGIM)
Program Element 4: Science of Adaptation and Science to Inform Adaptation Decisions	Adaptation Science Workgroup
Program Element 5: Global Change Information	Global Change Information System (GCIS)
Program Element 6: Assessments	Interagency National Climate Assessment (INCA) IWG
Program Element 7: Communication and Education	Interagency Communications and Education Team (ICE-t)
International Research and Cooperation	International Research and Cooperation IWG
USGCRP Crosscutting Initiative	Climate Change and Human Health Group (CCHHG)

Full descriptions of each working group are provided in Appendix B: USGCRP Interagency Working Groups.

APPENDIX B: USGCRP INTERAGENCY WORKING GROUPS (IWGS)

B.1 ADVANCE SCIENCE

Integrated Observations Interagency Working Group

A new Integrated Observations IWG Scoping Team is coordinating agency activities to sustain essential Earth observations capabilities and achieve more comprehensive, integrated Earth observations in the future.

The first activity for this Team is to coordinate, along with the U.S. Group on Earth Observations, is to support National Earth Observations (NEO) Task Force activities by assessing critical observations of "Climate and Related Global Change." This will require coordinate evaluation of the importance and performance of current observational capabilities and assets in the context of strategic Earth observations objectives.

Process Research Interagency Working Group

USGCRP's Process Research IWG helps identify and prioritize scientific issues that require an integrated, coordinated response and fosters linkages with other IWG's to ensure that the Program's Advance Science portfolio is as integrated as possible. Specifically, the Process Research IWG is coordinating the following activities:

- Develop a research framework for Objectives 1.1 and 1.2 of USGCRP's new decadal Research Plan and explore pathways for implementing such a framework;
- Plan a workshop to refine this research framework and organize an initial set of work teams to begin implementation;
- Define a set of high-priority activities and key near-term deliverables; and
- Ensure sustained flexibility to evolve as needed and deliver on new priorities as they emerge.

Interagency Group on Integrated Modeling

USGCRP's Interagency Group on Integrated Modeling (IGIM) is charged with coordinating global-change related modeling activities across the Federal government and providing guidance to USGCRP on modeling priorities. The 10 Federal Agencies that participate in the IGIM engage on range of relevant topics, including physical models of the Earth system, socioeconomic models of human systems and their interactions with the Earth system, as well as impacts models.

Carbon Cycle Interagency Working Group

USGCRP's Carbon Cycle Interagency Working Group (CCIWG) coordinates carbon cycle research funded by USGCRP member agencies. Because the carbon cycle and changes to the carbon cycle are associated with a wide range of global change research needs, the CCIWG works closely with other interagency working groups and engages with international partners. CCIWG works to establish priorities for carbon cycle science and evaluate needs emerging from new findings and observations. Currently, CCIWG coordinates work to advance the following priorities:

- Explain past and current variations in observed atmospheric concentrations of the major carbon-containing greenhouse gases (CO_2 and methane);
- Understand and quantify socioeconomic drivers of carbon emissions;
- Develop transparent methods to monitor and verify both natural and anthropogenic carbon emissions;
- Assess and evaluate the vulnerability of carbon fluxes and stocks under future conditions of global change and human activities;
- Predict the effects of different CO_2 and climate change scenarios on biodiversity, ecosystems, and natural resources, including potential positive feedbacks to the climate system;
- Assess the effectiveness and potential for unintended consequences of carbon management options that may be undertaken to mitigate GHG emissions and climate change; and
- Address needs of decision makers of all levels for useable data, information, models, projections, and decision support tools.

B.2 INFORM DECISIONS

Adaptation Science Workgroup

In 2009, the Obama Administration convened an Interagency Climate Change Adaptation Task Force (ICCATF), including participation from more than 20 Federal agencies. Shortly thereafter, President Obama signed Executive order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance," directing the ICCATF to recommend ways the Federal government can strengthen the Nation's ability to adapt to the impacts of climate change.

USGCRP's Adaptation Science Workgroup works to ensure that Federal science effectively informs adaptation decisions at a range of scales, in diverse sectors. It also provides scientific support to agencies in the adaptation planning process. Specifically, USGCRP's Adaptation Science Workgroup is leading the following efforts:

- Identification of existing capabilities and critical gaps in science for informing adaptation decisions and policies;
- Improvement of the application and translation of science to meet the needs of decision makers;
- Advancement of the social, behavioral, and economic sciences needed to visualize, analyze, and understand adaptation options; and
- Guidance for evaluating the effectiveness of adaptive actions.

Global Change Information System Interagency Working Group

The Global Change Information System IWG provides support, advice, and strategic guidance for developing and implementing an interagency Global Change Information System (GCIS). The GCIS itself is being developed as a federated data structure that bridges multiple data sources and formats from across USGCRP agencies and departments. It is intended to become a single web-based Global Change Web Portal that delivers authoritative, accessible, usable, and timely information for climate and global change for use by diverse audiences.

The GCIS IWG is a forum for agencies to discuss and agree upon metadata and interoperability standards for the GCIS as well as to share information and ensure that any related efforts are complementary. The key first task for the GCIS IWG is to inform implementation of a data system specifically focused on the 2013 National Climate Assessment—which will serve as a pilot for the larger GCIS.

B.3 CONDUCT SUSTAINED ASSESSMENTS

Interagency National Climate Assessment Working Group

The USGCRP's Interagency National Climate Assessment (INCA) Working Group plays a vital role in coordinating, supporting, and implementing the Federal components of the assessment, including deploying essential research and infrastructure for a sustained assessment process and products. The INCA Working Group is responsible for coordinating, developing, and implementing an interagency operational plan for the NCA, providing critical input to identify and support future NCA products, and developing interagency assessment capacity at the national and regional scales. The INCA Working Group plans, coordinates, and implements the development of numerous technical products necessary for the assessment process, many of which have generated cutting-edge, interagency research on climate change science, impacts, and vulnerabilities. Under INCA leadership, the USGCRP agencies have hosted a wide range of expert and stakeholder workshops over the years in numerous regions and sectors to support the development of these technical products, advance assessment methodologies, and identify research needs.

B.4 COMMUNICATE & EDUCATE

Interagency Communication and Education Team

In April 2012, USGCRP launched a new Interagency Communications and Education Team (ICE-t). The ICE-t is made up of more than 100 self-selected volunteers from 12 Federal agencies who actually *do* climate communications—including press officers, writers, educators, park rangers, website designers, legislative affairs specialists, graphic designers, and other experts.

The ICE-t is organized as "community of practice" that is inherently ***inclusive*** (anyone in any agency can participate), ***adaptive*** (tasks, members, and leaders are able to evolve as needed), and ***action-oriented*** (there is a focus on near term, concrete, achievable tasks). An initial set of tentatively planned activities includes:

- Develop tools and strategies to link climate information on USGCRP agency websites;
- Increase use of social media to disseminate global change information to broad audiences;
- Develop communications material on relationships between extreme weather, climate events, and human-caused climate change for rapid deployment when an extreme weather event occurs;

- Support engagement activities related to the 2013 National Climate Assessment;
- Increase the application of social science research to Federal climate communications by inviting leading experts to engage with Federal communicators; and
- Apply communications expertise to the design of a Global Change Information System (GCIS).

B.5 INTERNATIONAL RESEARCH & COOPERATION

International Research and Cooperation Interagency Working Group

The International Research and Cooperation IWG advises and assists the Subcommittee on Global Change Research on advancing USGCRP's strategic goals through strategic international relationships, partnerships, and funding. The group is developing a portfolio of activities, priorities, and goals for USGCRP's international activities. Once the portfolio is established, the group will gradually transition into a working-level implementation and coordination.

B.6 CLIMATE CHANGE & HUMAN HEALTH

Climate Change and Human Health Group

The Interagency Crosscutting Group on Climate Change and Human Health (CCHHG) is charged with planning, coordinating, implementing, evaluating, and reporting on Federal research related to the human health impacts of global change. The ultimate goal is to ensure that communities are healthy and resilient to the impacts of climate change.

The CCHHG supports all four of USGCRP's new strategic goals and works to address key gaps in understanding of the human health–related impacts of global change. Specific activity areas include:

- **Adaptation**—including ongoing support for the Interagency Climate Change Adaptation Task Force;
- **Assessment**—including technical input and stakeholder engagement support for the development of the NCA reports;
- **Communication, Education, and Engagement**—including coordination with USGCRP's Interagency Communication & Education Team (ICE-t);
- **Data Integration**—including development of an interactive metadata clearinghouse (MATCH) of data sets, early warning systems, and monitoring tools related to the human health impacts of global climate change;
- **Joint Research and Funding Planning**—including development of a human health and climate change research framework, gap analysis, prioritization of research needs, and coordination of joint funding opportunities; and
- **International**—including review of International human health adaptation plans and assessments to capture lessons learned and engagement with the global health community on climate change and human health.

APPENDIX C: USGCRP MEMBER AGENCIES

This section summarizes the principal areas of focus related to global change research for each USGCRP member agency.

Department of Agriculture (USDA)

USDA's global change research program empowers land managers, policy makers, and Federal agencies with science-based knowledge to manage the risks and opportunities posed by climate change; reduce GHG emissions; and enhance carbon sequestration. USDA's global change research program includes contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service, Natural Resources Conservation Service (NRCS), National Agricultural Statistics Service (NASS), and Economic Research Service. This work is important to ensuring sustained food security for the nation and the world; maintaining and enhancing forest and natural resource health; and identifying risks to agricultural production from temperature and precipitation changes, pests, invasive species, and disease.

Specifically, USDA conducts assessments and projections of climate change impacts on agricultural and natural systems, and develops GHG inventories. USDA also develops cultivars, cropping systems, and management practices to improve drought tolerance and build resilience to climate variability. USDA promotes integration of USGCRP research findings into farm and natural resource management, and helps build resiliency to climate change by developing and deploying decision support. USDA maintains critical long-term data collection and observation networks, including the Snowpack Telemetry (SNOTEL) network, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Assessment (FIA). Finally, USDA also engages in communication, outreach, and education through multiple forums, including its vast network of agricultural extension services.

Department of Commerce (DOC)

NOAA and NIST comprise the DOC contribution to USGCRP.

NOAA's strategic climate goal is "an informed society anticipating and responding to climate and its impacts." NOAA's overall objective is to provide decision makers with a predictive understanding of the climate and to communicate climate information so that people can make more informed decisions in their lives, businesses, and communities. These outcomes are pursued by implementing a global observing system, conducting research to understand climate processes, developing improved modeling capabilities, and developing and deploying climate educational programs and information services. NOAA aims to achieve its climate goal through the following strategic objectives:

- Improved scientific understanding of the changing climate system and its impacts;
- Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions;
- Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services; and
- A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions.

NIST works with other Federal agencies to develop or extend internationally accepted traceable measurement standards, methodologies, and technologies that enhance measurement capabilities for science-based GHG emission inventories and measurements critical to advancing climate science research. NIST provides measurements and standards that support accurate, comparable, and reliable climate observations and provides calibrations and special tests to improve the accuracy of a wide range of instruments and techniques used in climate research and monitoring. In FY 2009, NIST was included as a discrete element of USGCRP's budget crosscut to provide specific measurements and standards of direct relevance to the program.

Department of Defense (DoD)

DoD—while not supporting a formal mission dedicated to global change research—is developing policies and plans to manage and respond to the effects of climate change on DoD missions, assets, and the operational environment. Various research agencies within the DoD sponsor and undertake basic research activities that concurrently satisfy both national security requirements as well as the strategic goals of USGCRP. These include the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), and the Defense Advanced Research Projects Agency (DARPA). When applicable, the research activities of these agencies are coordinated with other Federally-sponsored research via USGCRP and other entities.

Because the performance of DoD systems and platforms are influenced by environmental conditions, understanding the variability of the Earth's environment and the potential for change is of great interest to the Department. The DoD is responsible for the environmental stewardship of hundreds of installations throughout the U.S., and must continue incorporating geostrategic and operational energy considerations into force planning, requirements development, and acquisition processes. The DoD relies on the Strategic Environmental Research and Development Program (SERDP), a joint effort among DoD, DOE, and EPA, to develop climate change assessment tools and to identify the environmental variables that must be forecast with sufficient lead time to facilitate appropriate adaptive responses. Each service agency within the DoD incorporates the potential impact of global change into their long-range strategic plans. For example, the Navy's Task Force Climate Change (TFCC) assists in the development of science-based recommendations, plans, and actions to adapt to climate change. The USACE Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) also actively investigates the impacts of climate trends for USACE, Army, DoD and other agencies. The CRREL research program responds to the needs of the military, but much of the research also benefits the civilian sector and is funded by non-military customers such as NSF, NOAA, NASA, DOE, and state governments.

Department of Energy (DOE)

DOE's Office of Science supports fundamental research to understand the energy-environment-climate connection and its implications for energy production, use, sustainability, and security—with particular emphasis on the potential impact of increased anthropogenic emissions. The ultimate goal is to advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges.

Two DOE research areas focus on areas of uncertainty in Earth systems models: Atmospheric System Research (science of aerosols, clouds, and radiative transfer); and Terrestrial Ecosystem Science (role of terrestrial ecosystems and carbon cycle observations). DOE also collaborates with NSF to develop the widely used Community Earth System Model, supports methods to obtain regional climate information, integrates analysis of climate change impacts, and analyzes and distributes large climate datasets through the Program for Climate Model Diagnosis and Intercomparison and the Earth System Grid. The Department also supports the ARM Climate Research Facility, a scientific user facility that provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol and precipitation characteristics in climate sensitive sites around the world.

Finally, DOE also conducts applied climate-related research through the CCTP, which is centered in DOE's Office of Policy and International Affairs. CCTP develops and utilizes energy-economic models, including integrated assessment models, to evaluate policies and programs that enable cost-effective GHG reductions and accelerate the development and deployment of clean energy technologies. As part of this mission CCTP supports work to characterize climate change impacts for use in policy analysis, vulnerability and adaptation assessment and agency rulemakings. DOE also conducts assessments of climate change on electric grid stability, water availability for energy production, and site selection of the next generation of renewable energy infrastructure.

Department of Health and Human Services (HHS)

The U.S. Department of Health and Human Services (HHS) supports a broad portfolio of research and decision support initiatives related to environmental health and the health effects of global climate change, primarily through the National Institutes of Health (NIH) and the Centers for Disease Control (CDC). Research focuses on the need to better understand the vulnerabilities of individuals and communities to climate-related changes in health risks such as heat-related morbidity and mortality, respiratory effects of altered air contaminants, changes in transmission of infectious diseases, and impacts in the aftermath of severe weather events, among many others. Research efforts also seek to assess the effectiveness of various public health adaptation strategies to reduce climate vulnerability, as well as the potential health effects of interventions to reduce GHG emissions.

Specifically, HHS supports USGCRP by conducting fundamental and applied research on linkages between climate change and health, translating scientific advances into decision support tools for public health professionals, conducting ongoing monitoring and surveillance of climate-related health outcomes, and engaging the public health community in two-way communication about climate change.

Department of the Interior (DOI)

USGS conducts global change research for DOI and comprises DOI's contribution to USGCRP.

USGS scientists work with other agencies to provide policy makers and resource managers with scientifically valid information and predictive understanding of global change and its effects with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

Specifically, the USGS Climate and Land Use Change Research and Development Program supports research to understand processes controlling Earth system responses to global change and model impacts of climate and land-cover change on natural resources. USGS geographic analyses and land remote-sensing programs (such as the Landsat satellite mission and the National Land Cover Database) provide data that is used assess changes in land use, land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems. The science products and data sets from these programs are essential for conducting quantitative studies of carbon storage and GHG flux in the Nation's ecosystems.

USGS is also leading the establishment of regional Climate Science Centers that will provide science and technical support to region-based partners dealing with the impacts of climate change on fish, wildlife, and ecological processes.

Department of State (DOS)

Through DOS annual funding, the U.S. is the world's leading financial contributor to the United Nations Framework Convention on Climate Change (UNFCCC) and to the IPCC—the principal international organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate change initiatives and partnerships.

Department of Transportation (DOT)

The Department of Transportation (DOT) conducts research to examine potential climate change impacts on transportation, methods for increasing transportation efficiency, and methods for reducing emissions that contribute to climate change. The U.S. DOT's Center for Climate Change and Environmental Forecasting coordinates transportation and climate change research, policies, and actions within DOT and promotes comprehensive approaches to reduce emissions, address climate change impacts, and develop adaptation strategies. DOT also contributes directly to USGCRP's National Climate Assessment through focused research such as the Center's Gulf Coast Studies.

The Federal Highway Administration, the Federal Transit Administration (FTA) and other DOT agencies are also undertaking climate impact and adaptation studies (including vulnerability and risk assessments), working with science agencies to develop regional climate data and projections, methodological research, supporting pilot programs, and providing assistance to transportation stakeholders including State and local agencies. The Federal Aviation Administration (FAA), for example, conducts research to support USGCRP by working with NASA, NOAA, and EPA in the Aviation Climate Change Research Initiative (ACCRI) to identify and address key scientific gaps regarding aviation climate impacts and inform mitigation.

Other DOT initiatives address climate change and improve the sustainability of the U.S. transportation sector including: The FAA and NASA manage the Continuous Lower Energy, Emissions, and Noise (CLEEN) program as a government industry consortium to develop technologies for energy efficiency, noise and emissions reduction, and alternative fuels; and FAA participates in the Commercial Aviation Alternative Fuels Initiative (CAAFI), a public-private coalition to encourage the development of alternative jet fuels.

Environmental Protection Agency (EPA)

The core purpose of EPA's Global Change Research Program is to develop scientific information that supports stakeholders, policy makers, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic systems. EPA's research is driven by the Agency's mission and statutory requirements, and includes: (1) improving scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and developing adaptation options to effectively respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and (3) developing an understanding of the potential environmental impacts and benefits of GHG emission reduction strategies to support sustainable mitigation solutions. This research is leveraged by EPA Program Offices and Regions to support mitigation and adaptation, decisions and to promote communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific data and understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global change. EPA's Global Change Research Program connects these results to specific human and ecosystem health endpoints in ways that enable local, regional, and national decision makers to develop and implement strategies to protect human health and the environment. In turn, EPA's research provides USGCRP agencies with information about the connections between global change and local impacts and how local actions influence global changes.

Research activities include efforts to connect continental-scale temperature and precipitation changes to regional and local air quality and hydrology models to better understand the impacts of climate change on air quality and water quality, and to examine how watersheds will respond to large-scale climate and other global changes to inform decisions about management of aquatic ecosystems and expand understanding of the impacts of global change. Satellite and other observational efforts conducted by USGCRP are crucial to supporting EPA's efforts to understand how land use change, climate change, and other global changes are affecting watersheds and ecosystems, and the services they provide.

National Aeronautics and Space Administration (NASA)

As stated in the 2010 National Space Policy, NASA plays a crucial role in conducting global change research, ensuring sustained monitoring capabilities, and advancing scientific knowledge of the global integrated Earth system through satellite observations and satellite system development. As such, NASA fully supports USGCRP's new *National Global Change Research Plan* to advance science, inform decisions, conduct sustain assessments, and communicate and educate. NASA actively contributes to USGCRP's National Climate Assessment and provides roughly half of the funding for USGCRP as a whole.

NASA's global change activities have four integrated foci: satellite observations; technology development; research and analysis; and applications. Satellites provide critical global atmosphere, ocean, land, sea ice, and ecosystem measurements. NASA's sixteen on-orbit satellites measure numerous variables required to enhance understanding of Earth interactions. In February 2013, NASA launched the Landsat Data Continuity Mission (LDCM) satellite to measure land cover and evapotranspiration and is developing other satellites for launch in 2014 and beyond.

NASA's technology development efforts lead to new and enhanced space-based instruments and information technologies. Science research and analysis of satellite observations and model results improve predictability and knowledge of the global integrated Earth system. Airborne systems provide high resolution observations of variables relevant global change research—including polar seas and ice sheets; atmospheric composition; carbon storage and flux in the Arctic; hurricanes in the Atlantic Ocean; and root-zone soil moisture at different locales in North America.

National Science Foundation (NSF)

NSF addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained, workforce and developing resources for public education. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage inter-disciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the development and enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment. Long-term, continuous and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

NSF regularly collaborates with other USGCRP agencies to provide support for a range of multi-disciplinary research projects and is actively engaged in a number of international partnerships.

Smithsonian Institution (SI)

Within the Smithsonian Institution (SI), global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on multiple time scales, and defining longer term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record. Most of these units participate in the Smithsonian Institution Group on Earth Observations (SIGEO) examining the dynamics of forests over decadal time frames.

The Smithsonian Grand Challenge Consortium for Understanding and Sustaining a Biodiverse Planet brings together researchers from around the Institution to focus on joint programs ranging from estimating volcanic emissions to ocean acidification measurement. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food and music. Finally, Smithsonian outreach and education expands our scientific and social understanding of processes of change and represents them in exhibits and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research and education programs on these topics.

U.S. Agency for International Development (USAID)

The USAID supports programs that enable decision makers to apply high-quality climate information to decision making. USAID's climate change and development strategy calls for enabling countries to accelerate their transition to climate resilient, low emission sustainable economic development through direct programming and integrating climate change adaptation and mitigation objectives across the Agency's development portfolio. USAID is the lead contributor to bilateral assistance, with a focus on capacity building, civil society building, and governance programming, and creating the legal and regulatory environments needed to address climate change. USAID leverages scientific and technical resources from across the government (e.g., NASA, NOAA, USDA, USGS) as it applies its significant technical expertise to provide leadership in development and implementation of low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agriculture lands and forests, and mainstreaming adaptation into development activities in countries most at risk. USAID has long-standing relationships with host country governments that enable it to work together to develop shared priorities and implementation plans. USAID's engagement and expertise in agriculture, biodiversity, infrastructure, and other critical climate sensitive sectors provide an opportunity to implement innovative cross-sectoral climate change programs. Finally, USAID bilateral programs work in key political and governance areas where multilateral agencies cannot.

APPENDIX D: GLOSSARY & ACRONYMS

D.1 DEFINITION OF KEY TERMS

Adaptation: Adjustment in natural or *human systems* to a new or changing environment that exploits beneficial opportunities and moderates negative impacts.

Adaptation Science: Integrated scientific research that directly contributes to enabling adjustments in natural or human systems to a new or changing environment and that exploits beneficial opportunities or helps moderate negative effects.

Adaptive management: Operational decisions, principally for managing entities that are influenced by *climate variability* and change. These decisions can apply to the management of infrastructure (e.g., a wastewater treatment plant), the integrated management of a natural resource (e.g., a watershed), or the operation of societal response mechanisms (e.g., human health alerts, water restrictions). *Adaptive management* operates within existing policy frameworks or uses existing infrastructure, and the decisions usually occur on time scales of a year or less.

Aerosols: Fine solid or liquid particles suspended in a gas. *Aerosols* may be of either natural or *anthropogenic* origin.

Anthropogenic: Resulting from or produced by human beings.

Assessments: Processes that involve analyzing and evaluating the state of scientific knowledge (and the associated degree of scientific certainty) and, in interaction with users, developing information applicable to a particular set of issues or decisions.

Atmosphere: The gaseous envelope surrounding Earth.

Belmont Forum: A collaborative mechanism among international organizations, such as the International Council for Science (ICSU), and national funding agencies to identify GCR priorities that might benefit from better cooperation and how best to address these.

Biodiversity: The total diversity of all organisms and ecosystems at various spatial scales.

Biomass: The total mass of living organisms in a given area or volume.

Biosphere: The part of the Earth system comprising all ecosystems and living organisms, in the *atmosphere*, on land or in the ocean, including derived dead organic matter, such as litter, soil organic matter, and oceanic detritus.

Carbon cycle: The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide, calcium carbonate) through the *atmosphere*, ocean, terrestrial *biosphere*, and *lithosphere*.

Carbon sequestration: The process of increasing the carbon content of a carbon reservoir other than the atmosphere.

Climate: The mean and variability of relevant measures of the *atmosphere*-ocean system over periods ranging from weeks to thousands or millions of years.

Climate change: A statistically significant variation in either the mean state of the climate or in its *variability*, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing, including changes in solar radiation and volcanic eruptions, or to persistent human-induced changes in atmospheric composition or in land use. See also *climate variability*.

Climate model: A numerical representation of the *climate system* based on the mathematical equations governing the physical, chemical and biological properties of its components and including treatment of key physical processes and interactions, cast in a form suitable for numerical approximation making use of computers.

Climate prediction: A *climate* prediction or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate – including weather variations – in the future, for example, at seasonal, interannual, or long-term timescales.

Climate projection: A projection of the response of the climate system to emission or concentration scenarios of *greenhouse gases* or *aerosols*, or *radiative forcing scenarios*, often based upon simulations by *climate models*. Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the *emission*/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate scenario: A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of *anthropogenic climate change*, often serving as input to impact models.

Climate system: The highly complex system consisting of five major components: the *atmosphere*, the hydrosphere, the cryosphere, the land surface, and the *biosphere*, and the interactions among them.

Climate variability: Variations in the mean state and other statistics (such as the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual *weather* events. These variations are often due to internal processes within the *climate system* (internal variability), or to variations in natural or *anthropogenic* external forcing (external variability).

Committee on Environment, Natural Resources, and Sustainability (CENRS): A subcommittee of the *National Science and Technology Council* (NSTC) established to assist the NSTC in increasing the overall productivity and application of Federal research and development efforts in the areas of environment, natural resources, and sustainability, and to provide a formal mechanism for interagency coordination in these areas. CENRS encompasses the *Subcommittee on Global Change Research*, the steering committee of the *U.S. Global Change Research Program*.

Decision support: The provision of timely and useful information that addresses specific questions.

Downscaling: A method that derives local- to regional-scale (10 to 100 km) information from larger-scale (100 to 1000 km) models or data analyses.

Earth system: The unified set of physical, chemical, biological, and social components, processes and interactions that together determine the state and dynamics of planet Earth.

Earth System Modeling Framework: Open-source software for building and coupling weather, climate, and related models.

Ecosystem: A system of living organisms interacting with each other and their physical environment as an ecological unit.

Ecosystem services: The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. Examples include provision of clean water, maintenance of liveable climates, pollination of crops and native vegetation, and fulfillment of people's cultural, spiritual, intellectual needs.

Emissions: In the *climate change* context, emissions refer to the release of radiatively or chemically active substances (e.g., *greenhouse gases* and/or their precursors, *aerosols*) into the atmosphere over a specified area and period of time.

End-to-end: The nature of research needed to address the *climate* and *global change* issue, from understanding causes and processes to supporting actions needed to cope with the impending societal problems of climate and global change.

Extreme weather event: An event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme *weather* event would normally be as rare as or rarer than the 10^{th} or 90^{th} percentile of the observed probability density of weather events.

Feedback: An interaction mechanism between processes such that the result of an initial process triggers changes in a second process and that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

Fiscal Year (FY): A period used for calculating annual ("yearly") financial statements in the Federal government.

General Circulation (GCM) or Atmosphere/Ocean Global Climate Model: A numerical representation of the *climate system* based on the physical and chemical properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

Geo-engineering: Deliberate large-scale manipulation of the planetary environment as a strategy to counteract *anthropogenic* climate change.

Global change: Changes in the global environment (including alterations in *climate*, land productivity, oceans or other water resources, atmospheric composition and/or chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life.

Global change information system: An information system that establishes data interfaces and interoperable repositories of *climate* and *global change* data which can be easily and efficiently accessed, integrated with other data sets, maintained over time and expanded as needed into the future.

Global change research: Study, monitoring, assessment, prediction, and information management activities to describe and understand the interactive physical, chemical, and biological processes that regulate the total *Earth system;* the unique environment that the Earth provides for life; changes that are occurring in the *Earth system;* and the manner in which such system, environment, and changes are influenced by human actions.

Global Change Research Act (GCRA; Section 102, P. L. 101-606): A 1990 act establishing the *U.S. Global Change Research Program,* an interagency program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes.

Global Earth Observing System of Systems (GEOSS): A "system of systems" linking together existing and planned *observing systems* around the world and promoting common technical standards so that data from thousands of different instruments can be combined into coherent data sets.

Global Framework for Climate Services: An outcome of the World Climate Conference (WCC-3) of the United Nations World Meteorological Organization, with the goal of the development and provision of relevant science-based climate information and prediction for climate risk management and adaptation to climate variability and change, throughout the world.

Greenhouse effect: Trapping and build-up of infrared radiation (heat) in the *atmosphere* (troposphere) near the Earth's surface. Some of the heat flowing back toward space from Earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward Earth's surface. If the atmospheric concentrations of these *greenhouse gases* rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse gas (GHG): Any gas that absorbs infrared radiation (heat) in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, ozone, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

Human system: Any system in which human organizations play a major role. Often, but not always, the term is synonymous with 'society' or 'social system' e.g., agricultural system, political system, technological system, or economic system.

Human-natural system: Integrated systems in which human and natural components interact, such as the interaction between socioeconomic and biophysical processes in urban ecosystems.

In situ: Measurements obtained through instruments that are in direct contact with the subject (e.g., a soil thermometer), as opposed to those collected by remote instruments (e.g., a radar altimeter).

Integrated Assessment Models: A method of analysis that combines results and models from the physical, biological, economic, and social sciences, and the interactions between these components, in a consistent framework, to evaluate the status and consequences of environmental change and the policy responses to it.

Intergovernmental Panel on Climate Change (IPCC): An international scientific body for the assessment of *climate change,* established by the United Nations Environmental Programme and the United Nations World Meteorological Organization.

IPCC AR4: The fourth in a series of assessment reports by the *Intergovernmental Panel on Climate Change,* intended to assess the most recent scientific, technical, and socioeconomic information produced worldwide concerning *climate change,* its potential effects, and options for *adaptation* and *mitigation.*

IPCC AR5: The fifth in a series of assessment reports by the *Intergovernmental Panel on Climate Change,* intended to assess the socioeconomic aspects of climate change and implications for sustainable development, risk management, and the framing of a response through both *adaptation* and *mitigation.*

Land cover: The land surface covering, including areas of vegetation (forests, shrub lands, crops, deserts, lawns), bare soil, developed surfaces (paved land, buildings), and wet areas and bodies of water (watercourses, wetlands).

Landsat Program: The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey.

Land use: The total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

Land use and land cover change: A change in the use or management of land by humans that may lead to a change in land cover.

Metadata: Information about meteorological and climatological data concerning how and when they were measured, their quality, known problems, and other characteristics.

Mitigation (climate change): An intervention to reduce the sources or enhance the sinks of *greenhouse gases* and other climate forcing agents. This intervention could include approaches devised to reduce *emissions* of *greenhouse gases* to the *atmosphere;* to enhance their removal from the atmosphere through storage in geological formations, soils, biomass, or the ocean.

Monitoring: A scientifically designed system of continuing standardized measurements and observations and the evaluation thereof. Monitoring is specifically intended to continue over long time periods.

National Academy of Sciences (NAS): An honorific society of distinguished scholars engaged in scientific and engineering research established by an Act of Congress in 1863, which calls upon the NAS to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government.

National Climate Assessment (NCA): An assessment conducted under the auspices of the Global Change Research Act of 1990, which requires a report to the President and the Congress every four years that evaluates, integrates and interprets the findings of the *U.S. Global Change Research Program.*

National Research Council (NRC): An arm of the *National Academy of Sciences* that forms committees to enlist the nation's top scientists, engineers, and other experts to provide independent advice to the government on matters of science, technology, and medicine.

National Science and Technology Council (NSTC): A Cabinet-level Council established by Executive Order 12881 that is the principal means within the executive branch to coordinate science and technology policy across the diverse entities that make up the Federal research and development enterprise.

Observations: Measurements (either continuing or episodic) of variables in *climate* and related systems.

Observing system: A coordinated series of instruments for long-term observations of the land surface, *biosphere,* solid Earth, *atmosphere,* and/or oceans to improve understanding of Earth as an integrated system.

Ocean acidification: The phenomenon in which the pH of the ocean becomes more acidic due to increased levels of carbon dioxide in the atmosphere from human activities, which, in turn, increase the amount of dissolved carbon dioxide in seawater. Ocean acidification may lead to reduced calcification rates of calcifying organisms such as corals, mollusks, algae and crustacea.

Office of Science and Technology Policy (OSTP): A division of the Executive Office of the President (EOP) established by Congress in 1976 with a broad mandate to advise the President and others within the EOP on the effects of science and technology on domestic and international affairs. The 1976 Act also authorizes OSTP to lead interagency efforts to develop and implement sound science and technology policies and budgets, and to work with the private sector, state and local governments, the science and higher education communities, and other nations toward this end.

Ozone: A very active colorless gas consisting of three atoms of oxygen, readily reacting with many other substances.

Permafrost: Ground (soil or rock and including water, ice, and organic material) that remains at or below freezing for at least two consecutive years.

Prediction: A probabilistic description or forecast of a future *climate* outcome based on *observations* of past and current climatological conditions and quantitative models of climate processes (e.g., a prediction of an El Niño event).

Projection: A description of the response of the *climate system* to an assumed level of future *radiative forcing.* Climate "projections" are distinguished from climate "predictions" in order to emphasize that climate projections depend on *scenarios* of future socioeconomic, technological, and policy developments that may or may not be realized.

Practical Salinity Units (PSU): Used to describe the concentration of dissolved salts in water, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Practical Salinity Scale of 1978 (PSS78) defines salinity in terms of a conductivity ratio, so it is dimensionless. Salinity was formerly expressed in terms of parts per thousand (ppt) or by weight (parts per thousand or 0/00). That is, a salinity of 35 ppt meant 35 pounds of salt per 1,000 pounds of seawater. Open ocean salinity is generally in the range from 32 to 37.

Radiative forcing: A process that directly changes the average energy balance of the Earth-atmosphere system by affecting the balance between incoming solar radiation and outgoing radiation. A positive forcing warms the surface of the Earth and a negative forcing cools the surface.

Remote sensing: The technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the object of investigation. In the climate context, remote sensing is commonly performed from satellites or aircraft.

Scenario: A coherent description of a potential future situation that serves as input to more detailed analyses or modeling. Scenarios are tools that explore, "if..., then...." statements, and are not predictions of or prescriptions for the future.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by *climate*-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Sink: Any process, activity, or mechanism that removes a *greenhouse gas*, an *aerosol*, or a precursor of a *greenhouse gas* or aerosol from the atmosphere. Sinks may be of natural or human origin.

Stakeholders: Individuals or groups whose interests (financial, cultural, value-based, or other) are affected by *climate variability, climate change*, or options for *adapting* to or *mitigating* these phenomena. Stakeholders are important partners with the research community for development of decision support resources.

Storm surge: The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds).

Subcommittee on Global Change Research (SGCR): The steering committee of the *U.S. Global Change Research Program* (USGCRP) under the *Committee on Environment, Natural Resources, and Sustainability*, overseen by the Executive Office of the President. SGCR is composed of representatives from each of the member agencies of the USGCRP.

Sustainability: Balancing the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

System: Integration of interrelated, interacting, or interdependent components into a complex whole.

Technology: An approach, including both the experimental technique and the instrumental and scientific infrastructure needed to implement it.

Tipping point: A critical *threshold* at which a tiny perturbation can qualitatively alter the state or development of a system.

Threshold: A point in a system after which any change that is described as *abrupt* is one where the change in the response is much larger than the change in the *forcing*. The changes at the threshold are therefore abrupt relative to the changes that occur before or after the threshold and can lead to a transition to a new state.

Uncertainty: An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty in future climate arises from imperfect scientific understanding of the behavior of physical systems, and from inability to predict human behavior.

United Nations Framework Convention on Climate Change (UNFCCC): The United Nations Framework Convention on Climate Change is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED) intended to stabilize *greenhouse gas* concentrations in the atmosphere at a level that would prevent dangerous *anthropogenic* interference with the *climate system*.

U.S Global Change Research Program (USGCRP): An interagency program that coordinates and integrates Federal research on changes in the global environment and their implications for society. USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606). Thirteen departments and agencies participate in the USGCRP. The program is steered by the *Subcommittee on Global Change Research* under the *Committee on Environment and Natural Resources*, overseen by the Executive Office of the President, and facilitated by a National Coordination Office (NCO).

U.S. Group on Earth Observations (USGEO): An interagency group established in 2005 under the White House *Office of Science and Technology Policy's Committee on Environment, Natural Resources, and Sustainability* to lead Federal efforts to achieve a national Integrated Earth Observation System. Through USGEO, the U.S. further supports cooperative, international efforts to build the *Global Earth Observation System of Systems* (GEOSS).

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of *climate* and *global change*, including *climate variability and extremes*, as well as climate change in conjunction with other stressors.

Weather: The specific condition of the atmosphere at a particular place and time. It is measured in terms of parameters such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

D.2 ABBREVIATIONS & ACRONYMS

ABoVE – Arctic-Boreal Vulnerability Experiment

ACCRI – Aviation Climate Change Research Initiative

ACIS – Applied Climate Information System

ACRIMSAT – Activity Cavity Radiometer Irradiance Monitor SATellite

AFOSR – Air Force Office of Scientific Research

AFRI – Agriculture and Food Research Initiative

AgMIP – Agricultural Model Intercomparison and Improvement Project

AMF – Atmospheric Radiation Measurement Mobile Facility

AMOC – Atlantic Meridional Overturning Circulation

AR4 – IPCC Fourth Assessment Report

AR5 – IPCC Fifth Assessment Report

ARL – Air Resources Laboratory

AMR – Atmospheric Radiation Measurement

ARO – Army Research Office

ARS – Agricultural Research Service

BASINS CAT – BASINS Climate Assessment Tool

BIO – NSF Directorate for Biological Science

BDR – Budget Data Request

CAAFI – Commercial Aviation Alternative Fuels Initiative

CALIPSO – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation

CARB – California Air Resources Board

CARVE – Carbon in Artic Reservoirs Vulnerability Experiment

CASI – Climate Adaptation Science Investigators

CATs – Climate Assessment Tools

CCHHG – Climate Change and Human Health Group

CCIWG – Carbon Cycle Interagency Working Group

CDC – Centers for Disease Control and Prevention

CCSP – Climate Change Science Program

CENRS – Committee on Environment, Natural Resources, and Sustainability

CEQ – Council on Environmental Quality

CFMIP – Cloud Feedback Model Intercomparison Project

CH_4 – Methane

CISA – Carolinas Integrated Sciences and Assessments

CLEEN – Continuous Lower Energy, Emissions, and Noise

CLIC – Climate and the Cryosphere

CLIVAR – Climate Variability and Prediction

CLM – Community Land Model

CloudSat – Cloud Satellite

CMIP5 – Fifth-phase Coupled Model Intercomparison Project

CNH – Coupled National and Human systems

CO_2 – Carbon Dioxide

COP – Conference of Parties

COSMIC – Constellation Observing System for Meteorology, Ionosphere, and Climate

COSP – Cloud Feedback Model Intercomparison Project Observation Simulator Package

CRREL – Cold Regions Research and Engineering Laboratory

CSC – Climate Science Centers

DARPA – Defense Advanced Research Projects Agency

DDIT – Dynamic Drought Index Tool

DHS – Department of Homeland Security

DMS – Digital Mapping System

DMUU – Decision Making Under Uncertainty

DoD – Department of Defense

DOE – Department of Energy

DOI – Department of the Interior

DOS – Department of State

DOT – Department of Transportation

DR – Departmental Regulation

DRMS – Decision, Risk, and Management Sciences

EaSM – Earth System Models

EID – Ecology of Infectious Diseases

ENSO – El Niño-Southern Oscillation

EO – Earth Observer

EPA – Environmental Protection Agency

EPPA – Emissions Prediction and Policy Analysis

ERDC – Engineer Research and Development Center

ERS – Economic Research Center

ESM – Earth System Modeling

ESMF – Earth System Modeling Framework

ESSI – Earth System Sustainability Initiative

ESSP – Earth System Science Partnership

EV – Earth Venture

FAA – Federal Aviation Administration

FACA – Federal Advisory Committee Act

FEWS – Famine Early Warning Systems

FIA – Forest Inventory Analysis

FTF – Feed the Future Initiative

FY – Fiscal Year

GCIS – Global Change Information System

GCOS – Global Climate Observing System

GCRA – Global Change Research Act

GCRIO – Global Change Research Information Office

GDP – Gross Domestic Product

GEO – Group on Earth Observations

GEOSS – Global Earth Observation System of Systems

GEWEX – Global Energy and Water Cycle Experiment

GHG – Greenhouse Gas

GLOBE – Global Learning and Observations to Benefit the Environment

GOOS – Global Ocean Observation System

GPS – Global Positioning System

GRA – Global Research Alliance

GRACE – Gravity Recovery and Climate Experiment

GRACEnet – Greenhouse Gas Reduction through Agricultural Carbon Enhancement network

GSA – General Services Administration

GVP – Global Volcanism Program

HHS – U.S. Department of Health and Human Services

HPC – High Performance Computing

HUC – Hydrological Unit Code

IAM – Integrated Assessment Models

ICCATF – Interagency Climate Change Adaptation Task Force

ICESat – Ice, Cloud, and land Elevation Satellite

ICE-t – Interagency Communications and Education Team

ICLUS – Integrated Climate and Land Use Scenarios

ICSU – International Council of Science

IEHS – Chinese National Institute of Environmental Health and Related Product Safety

IGBP – International Geosphere-Biosphere Program

IGFA – International Group of Funding Agencies for Global Change Research

IGIM – Interagency Group on Integrated Modeling

IHDP – International Human Dimensions Program

INCA – Interagency National Climate Assessment Working Group

INFLUX – Indianapolis Flux Experiment

IOSS – Integrated Ocean Observing System

IPCC – Intergovernmental Panel on Climate Change

ISSC – International Social Science Council

IT – Information Technology

IWG – Interagency Working Group

JPSS – Joint Polar Satellite System

LBA – Large Scale Biosphere-Atmosphere

LDCM – Landsat Data Continuity Mission

LTER – Long-Term Ecological Research

LTREB – Long-Term Research in Environmental Biology

LULC – Land Use/Land Cover

MARKAL – MARKet ALlocation

MATCH - Metadata Access Tool for Climate and Health

MC3E – Midlatitude Continental Convective Cloud Experiment

MERRA – Modern Era Retrospective Analysis for Research and Applications

MIT – Massachusetts Institute of Technology

MODIS – Moderate Resolution Imaging Spectroradiometer

MPS – Division of Mathematical and Physical Sciences

NAS – National Academy of Sciences

NSAS – National Aeronautics and Space Administration

NASS – National Agricultural Statistics Service

NCA – National Climate Assessment

NCADAC – National Climate Assessment and Development Advisory Committee

NCAR – National Center for Atmospheric Research

NCCWCS - National Climate Change and Wildlife Science Center

NCDC – National Climatic Data Center

NCEP – National Center for Environmental Prediction

NCO – National Coordination Office

NDVI – Normalized Difference Vegetation Index

NEO – National Earth Observations

NEON – National Ecological Observatory Network

NESDIS – National Environmental Satellite, Data, and Information Service

NGDC – National Geophysical Data Center

NGEE – Next Generation Ecosystem Experiment

NGO – Non-governmental Organizations

NHTSA – National Highway Traffic Safety Administration

NIEHS – National Institute of Environmental Health Sciences

NIFA – National Institute of Food and Agriculture

NIH – National Institutes of Heath

NMME – National Multi-Model Ensemble

NMNH – National Museum of Natural History

NOAA – National Oceanic and Atmospheric Administration

NOC – National Ocean Council

NODC – National Oceanographic Data Center

NO_x – Nitrogen Oxide

NPOESS – National Polar-orbiting Operational Environmental Satellite System

NPP – NPOESS Preparatory Project

NPS – National Park Service

NRC – National Research Council

NRCS – Natural Resources Conservation Service

NRI – National Resources Inventory

NSF – National Science Foundation

NSTC – National Science and Technology Council

NWS – National Weather Service

NZP – National Zoological Park

OAR – Oceanic and Atmospheric Research

Obs4MIPs – Observation for Model Intercomparison Projects

OCO – Orbiting Carbon Observatory

OMB – Office of Management and Budget

ONR – Office of Naval Research

OPP – Office of Polar Programs

ORD – Office of Research and Development

OSTM – Ocean Surface Topography Mission

OSTP – Office of Science and Technology Policy

PAR – Photosynthetically Active Radiation

PARTNER – Partnership for Air Transportation Noise and Emissions Reduction

PDSI – Palmer Drought Severity Index

ppm – parts per million

PSU – practical salinity units

QDR – Quadrennial Defense Review

QuikSCAT – Quick Scatterometer

RAMA – Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction

RCC – Regional Climate Centers

RCP – Representative Concentration Pathways

RDD – Research and Development Division

REDD+ – Reducing Emissions from Deforestation and Degradation

RISA – Regional Integrated Sciences and Assessments

RO – Radio Occultation

RRED – Resource and Rural Economics Division

RRP – Revised Research Plan

SAGE – Stratospheric Aerosol and Gas Experiment

SBA – Societal Benefit Area

SBE – Directorate for Social, Behavioral and Economic Sciences

SCAN – Soil Climate Analysis Network

SEES – Science, Engineering, and Education for Sustainability

SERDP – Strategic Environmental Research and Development Program

SGCR – Subcommittee for Global Change Research

SIGEO – Smithsonian Institution Group on Earth Observations

SNOTEL – Snowpack Telemetry

SO_2 – Sulfur Oxides

SORCE – Solar Radiation and Climate Experiment

SPARC – Stratospheric Processes and their Role in Climate

SPURS – Salinity Processes in the Upper Ocean Regional Study

SREX – Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

SSREN – Special Report on Renewable Energy Sources and Climate Change Mitigation

SSS – Sea Surface Salinity

SST – Sea Surface Temperature

STEM – Science, Technology, Engineering, and Mathematics

STRI – Smithsonian Tropical Research Institute

Suomi-NPP – Suomi National Polar-orbiting Partnership

TFCC – Task Force Climate Change

TRMM – Tropical Rainfall Measuring Mission

TSU – Technical Support Unit

UCAE – University Corporation for Atmospheric Research

ULTRA – Urban Long-Term Research Area

UN – United Nations

UNEP – United Nations Environment Programme

UNESCO – United Nations Educational, Scientific, and Cultural Organization

UNFCCC – United Nations Framework Convention on Climate Change

USACE – U.S. Army Corps of Engineers

USAID – U.S. Agency for International Development

USA-NPN – USA National Phenology Network

USDA – U.S. Department of Agriculture

USGCRP – U.S. Global Change Research Program

USGEO – U.S. Group on Earth Observation

USGS – U.S. Geological Society

WCRP – World Climate Research Programme

WEPPCAT – Water Erosion Prediction Project Climate Assessment Tool

WGII – Working Group II

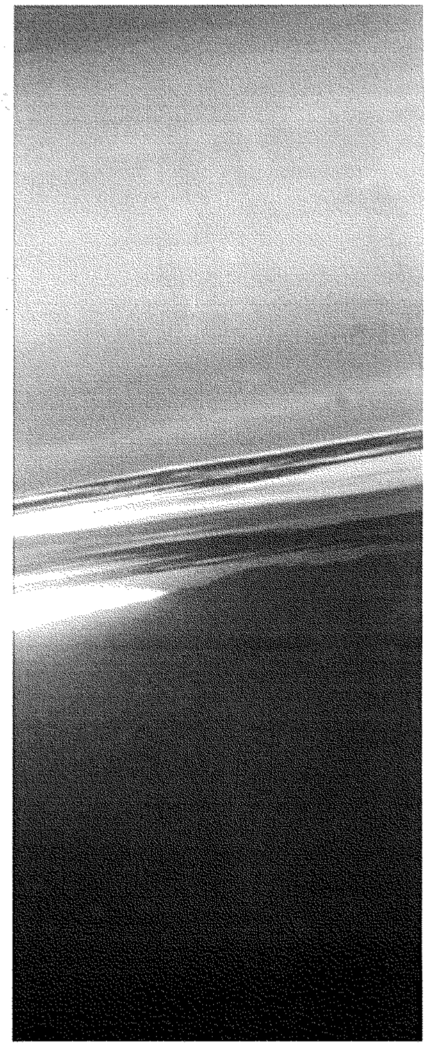
WGISS – CEOS Working Group on Information Systems and Science

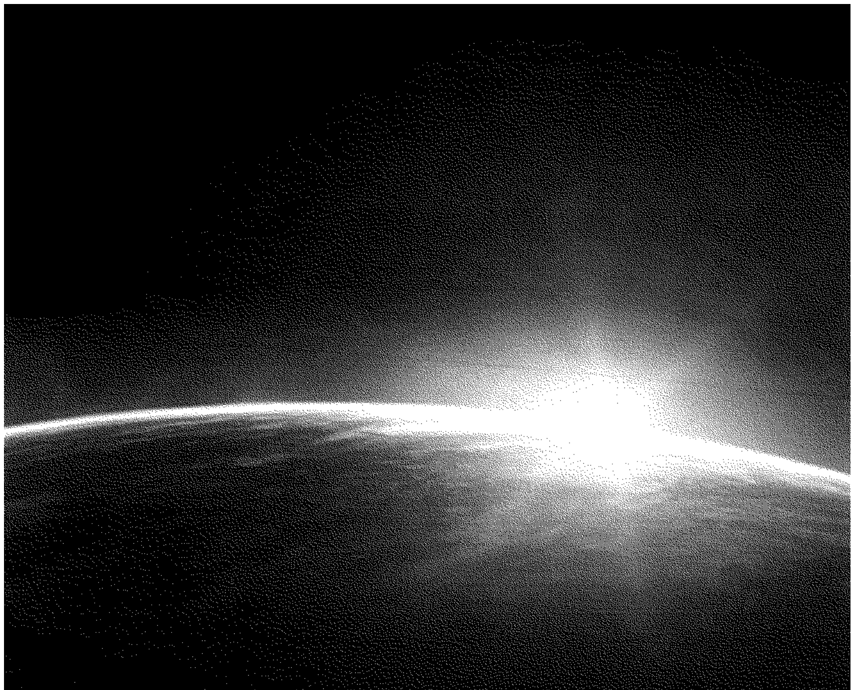
WMO – World Meteorological Organization

WOA – World Ocean Assessment

WRAP – Water Resource Adaptation Program

WWRP – World Weather Research Program





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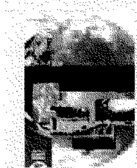

Adapting to the Impacts of Climate Change

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2. Our Changing Climate

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Key Messages

1. **Global climate is changing now and this change is apparent across a wide range of observations. Much of the climate change of the past 50 years is primarily due to human activities.**
2. **Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the climate is to those emissions.**
3. **U.S. average temperature has increased by about 1.5°F since record keeping began in 1895; more than 80% of this increase has occurred since 1980. The most recent decade was the nation's warmest on record. U.S. temperatures are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, smooth across the country or over time.**
4. **The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases**

occurring in the western U.S., affecting ecosystems and agriculture. Continued lengthening of the growing season across the U.S. is projected.

5. **Precipitation averaged over the entire U.S. has increased during the period since 1900, but regionally some areas have had increases greater than the national average, and some areas have had decreases. The largest increases have been in the Midwest, southern Great Plains, and Northeast. Portions of the Southeast, the Southwest, and the Rocky Mountain states have experienced decreases. More winter and spring precipitation is projected for the northern U.S., and less for the Southwest, over this century.**

6. **Heavy downpours are increasing in most regions of the U.S., especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas.**

7. **Certain types of extreme weather events have become more frequent and intense, including heat waves, floods, and droughts in some regions. The increased intensity of heat waves has been most prevalent in the western parts of the country, while the intensity of flooding events has been more prevalent over the eastern parts. Droughts in the Southwest and heat waves everywhere are projected to become more intense in the future.**

8. **There has been an increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s. The intensity of the strongest hurricanes is projected to continue to increase as the oceans continue to warm; ocean cycles will also affect the amount of warming at any given time. With regard to other types of storms that affect the U.S., winter storms have increased slightly in frequency and intensity, and their tracks have shifted northward over the U.S. Other trends in severe storms, including the numbers of hurricanes and the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds are uncertain and are being studied intensively.**

9. **Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.**

10. **Rising temperatures are reducing ice volume and extent on land, lakes, and sea. This loss of ice is expected to continue.**

11. **The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about potential impacts on marine ecosystems.**

Our Changing Climate

This chapter summarizes how climate is changing, why it is changing, and what is projected for the future. While the focus is on changes in the United States, the need to provide context requires a broader geographical perspective in some parts of the discussion. Additional geographic detail is presented in the regional chapters of this report. Further details on the topics of this chapter are provided in the Appendix.

Since the previous national climate assessment was published in 2009, the climate has continued to change, with resulting effects on the U.S. The trends described in the 2009 report have continued, and our understanding of the data and ability to model the many facets of the climate system have increased substantially. Several noteworthy advances are mentioned below.

What's New?

- Continued warming and an increased understanding of the U.S. temperature record, as well as multiple other sources of evidence, have strengthened our confidence in the conclusions that the warming trend is clear and primarily the result of human activities.
- Heavy precipitation and extreme heat events are increasing in a manner consistent with model projections; the risks of such extreme events will rise in the future.
- The sharp decline in summer Arctic sea ice has continued, is unprecedented, and is consistent with human-induced climate change. 2012 has set a new record for minimum area of Arctic ice.
- A longer and better-quality history of sea level rise has increased confidence that recent trends are unusual and human-induced. Limited knowledge of ice sheet dynamics leads to a broad range of potential increases over this century.
- New approaches to building scenarios of the future have allowed for investigations of the implications of deliberate reductions in heat-trapping gas emissions.

Eleven key messages are presented below, together with supporting evidence. The discussion of each key message begins with a summary of recent variations or trends, followed by information on the corresponding changes projected for the future.

Observed Climate Change

Global climate is changing now and this change is apparent across a wide range of observations. Much of the climate change of the past 50 years is due primarily to human activities.

Many aspects of the global climate are changing rapidly, and the primary drivers of that change are human in origin. Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans (Kennedy et al. 2010). This evidence has been painstakingly compiled by scientists and engineers from around the world using satellites, weather balloons, thermometers at surface stations, and many other types of observing systems that monitor the Earth's climate system. The sum total of this evidence tells an unambiguous story: the planet is warming. Temperatures at the surface, in the troposphere (the active weather layer extending up to about 8 to 12 miles above the ground), and in the oceans have all increased over recent decades. Snow and ice cover have decreased in most areas. Atmospheric water vapor due to increased evaporation from the warmer surface has been increasing in the lower atmosphere, as have sea levels. Changes in other climate-relevant indicators such as growing season length have been observed in many areas. Worldwide, the observed changes in average conditions have been accompanied by trends in extremes of heat, cold, drought, and heavy precipitation events (Alexander et al. 2006).

Climate model simulations reinforce scientific understanding that observed variations in global average surface temperature over the past century can only be explained through a combination of human and natural factors. However, natural drivers of climate cannot explain the recent observed warming; over the last five decades, natural factors (solar forcing and volcanoes) alone would actually have led to a slight cooling (Gillett et al. 2012). Natural variability, including the effects of El Niño and La Niña events and various ocean cycles, also affects climate, but the changes observed over the past 50 years are far larger than natural variability can account for. The majority of the warming can only be explained by the effects of human influences (Gillett et al. 2012; Stott et al. 2010), especially the emissions from burning of fossil fuels such as coal, oil, and natural gas. This robust scientific attribution of observed changes to human influence extends to many other climate quantities, such as precipitation (Min et al. 2011; Pall et al. 2011), humidity (Santer et al. 2007; Willett et al. 2007), pressure (Gillett and Stott 2009), ocean heat content (AchutaRao et al. 2006), and tropospheric and stratospheric temperature (Santer et al. 2012) in addition to surface temperature. Further discussion of attribution is provided in the Appendix.

Natural variations in climate include the effects of the natural cycles mentioned above, plus the 11-year sunspot cycle and other changes in the radiation from the Sun, as well as the effects of volcanic eruptions. Natural variations can be as large as human-induced climate change over timescales of up to a decade or two at the global scale. As a result, global temperature does not always increase steadily, as evidenced, for example, by the period between 1998 and 2007, which showed little change. This time period is too short to signify a change in the warming trend, as climate trends are measured over periods of decades, not years (Easterling and Wehner 2009; Foster and Rahmstorf 2011; Knight et al. 2009; Rahmstorf et al. 2012; Santer et al. 2011). Over the time scale of multiple decades, the human influence has been dominant, and the most recent 10-year period is clearly the hottest on record. Note that changes in temperature at local scales, such as urban areas, can be quite different than those at larger spatial scales, in part because of local land-use patterns.

Box: Models Used in the Assessment

Throughout the 2013 National Climate Assessment report, there are references to projections from models of the physical processes affecting the Earth's climate system. Three distinct sets of model simulations are discussed:

- Climate Model Intercomparison Project, 3rd phase (CMIP3): global model analyses done for the 2007 IPCC assessment. Spatial resolutions typically vary from 125 to 187 miles (at mid-latitudes); approximately 25 representations of different models (not all are used in all studies). CMIP3 findings are the foundation for most of the impact assessments included in this report.
- Climate Model Intercomparison Project, 5th phase (CMIP5): Newer global model analyses done for the 2013 IPCC assessment. Spatial resolutions typically vary from 62 to 125 miles; about 30 representations of different models (not all are used in all studies); this new information was not available in time for it to serve as the foundation for the impacts assessments in this report, and information from CMIP5 is primarily provided for comparison purposes.
- North American Regional Climate Change Assessment Program (NARCCAP): 6 regional climate model analyses (and one global model) for the continental U.S. run at about 30-mile horizontal resolution.

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Ten Indicators of a Warming World

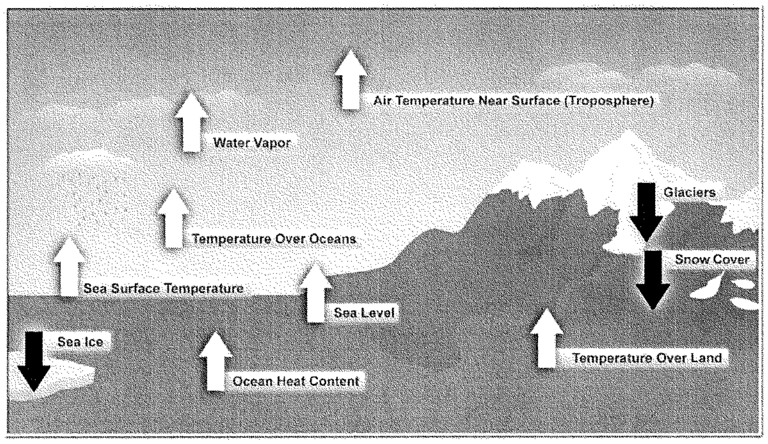

Figure 2.1: Ten Indicators of a Warming World

Caption: These are just some of the many indicators that have been measured globally over many decades and that show that Earth's climate is warming. White arrows indicate increasing trends, black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are increasing, and all those expected to decrease in a warming world are decreasing. (Figure source: NOAA NCDC)

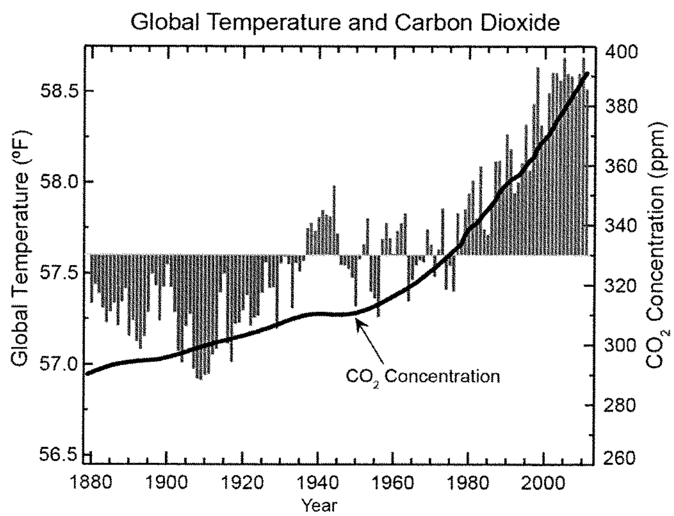

Figure 2.2: Global Temperature and Carbon Dioxide

Caption: Global annual average temperature (as measured over both land and oceans; scale on left) has increased by more than 1.4°F (0.8°C) since 1880. Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm); scale on right. While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and the eruption of large volcanoes. (Figure source: NOAA NCDC. Temperature data from NOAA NCDC 2012; CO2 data from NOAA ESRL 2012.)

Future Climate Change

Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the climate is to those emissions.

A certain amount of continued warming of the planet is projected to occur as a result of human-induced emissions to date; another 0.5°F increase would occur even if all emissions from human activities were suddenly stopped (Matthews and Zickfeld 2012). However, choices made now and in the next few decades will determine the amount of additional future warming. Beyond mid-century, lower levels of heat-trapping gases in scenarios with reduced emissions will lead to noticeably less future warming. Higher emissions levels will result in more warming, and thus more severe impacts on many aspects of human society and the natural world.

Our confidence in projections of future climate change has increased. The wider range of potential changes in global average temperature in the latest generation of climate model simulations (Taylor et al. 2012) used in the IPCC's current assessment versus those in the previous assessment (IPCC 2007) is simply a result of considering more options for future human behavior. For example, one of the scenarios included in the IPCC's latest assessment assumes aggressive emissions reduction designed to limit the global temperature increase to 3.6°F (2°C) above pre-industrial levels (Schnellnhuber et al. 2006). This path would require emission reductions (more than 70% reduction in human-related emissions by 2050 – see Appendix, Key Message 5) sufficient to achieve heat-trapping gas concentrations well below those of any of the scenarios considered by the IPCC in its 2007 assessment. Such scenarios enable the investigation of climate impacts that would be avoided by deliberate, substantial, and aggressive reductions in heat-trapping gas emissions.

Projections of changes in precipitation largely follow recently observed patterns of change, with overall increases in the global average but substantial shifts in where and how precipitation falls. Generally, areas closest to the poles are projected to receive more precipitation, while the dry belt that lies just outside the tropics (greater than 23°N/S) expands further poleward and receives less rain. Increases in tropical precipitation are projected during rainy seasons (such as monsoons), especially over the tropical Pacific. Certain regions, including the western U.S. (especially the Southwest (Karl et al. 2009)) and the Mediterranean, are already dry and are expected to become drier. The widespread trend toward more heavy downpours is expected to continue, with precipitation becoming less frequent but more intense. The patterns of the projected changes of precipitation do not contain the spatial details that characterize observed precipitation, especially in mountainous terrain, because the projections are averages from multiple models and because the resolution of global climate models is typically about 60 miles.

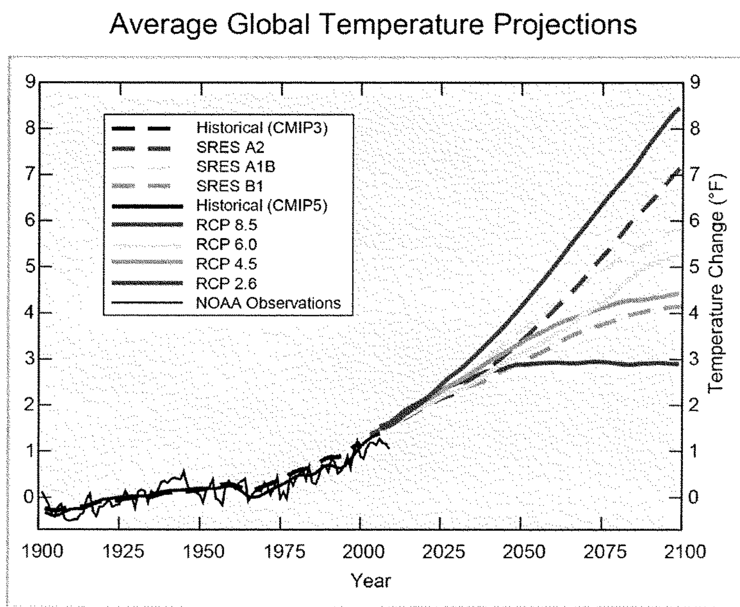

Figure 2.3: Average Global Temperature Projections

Caption: Projected global average annual temperature changes (°F) for multiple future emissions scenarios relative to the 1901-1960 average temperature. The dashed lines are results from the previous generation of climate models using the previous generation of emissions scenarios (the SRES set). The solid lines are results from the most recent generation of climate models using the most recent emissions scenarios (the RCP set), some of which consider explicit climate policies, which the older ones did not. Differences among these projections are principally a result of differences in the emissions scenarios rather than differences among the climate models. (Figure source: Michael Wehner, LBNL. Data from CMIP3, CMIP5, and NOAA, 2012.)

Largest Temperature Increases Over Continents

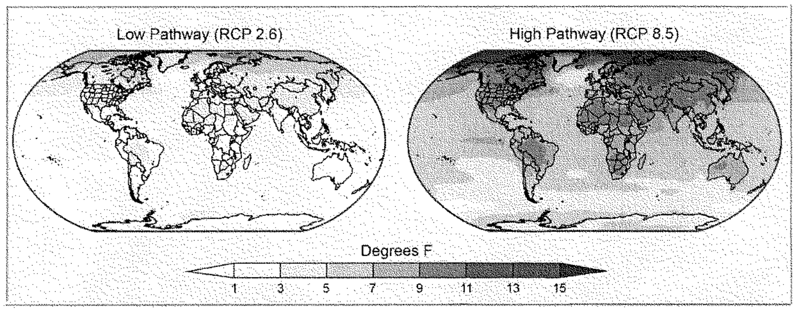

Figure 2.4: Largest Temperature Increases Over Continents

Caption: Projected change (°F) in annual average temperature over the period 2071-2099 (compared to the period 1971-2000) under a low emissions pathway (RCP 2.6, left graph) that assumes rapid reductions in emissions and a high pathway (RCP 8.5, right graph) that assumes continued increases in emissions. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5.)

Generally, Wet Get Wetter and Dry Get Drier

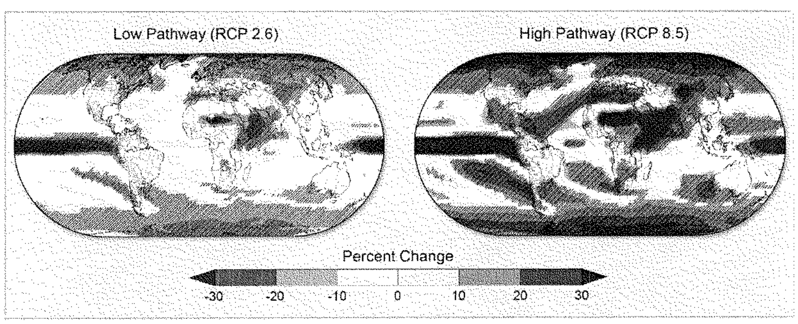

Figure 2.5: Generally, Wet Get Wetter and Dry Get Drier

Caption: Projected percent change in annual average precipitation over the period 2071-2099 (compared to the period 1901-1960) under a low emissions pathway (RCP 2.6) that assumes rapid reductions in emissions and a high pathway (RCP 8.5) that assumes continued increases in emissions. Teal indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. Wet regions generally tend to become wetter while dry regions become drier. In general, the northern parts of the U.S. (especially the Northeast and Alaska) are projected to see more precipitation, while the southern part (especially the Southwest) is projected to see less. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5, analyzed by Michael Wehner, LBNL.) *(note: to be redone with base period 1971-2000)*

Recent U.S. Temperature Trends

U.S. average temperature has increased by about 1.5°F since record keeping began in 1895; more than 80% of this increase has occurred since 1980. The most recent decade was the nation's warmest on record. U.S. temperatures are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, smooth across the country or over time.

There have been substantial advances in our understanding of the U.S. temperature record since the 2009 assessment (Fall et al. 2010; Fall et al. 2011; Karl et al. 2009; Menne and Williams Jr 2009; Menne et al. 2009; Menne et al. 2010; Vose et al. 2012; Williams et al. 2012) (Appendix, Key Message 6 for more information). These advances, together with the continued warming, have strengthened our confidence in, and understanding of the reasons for, the warming. They also confirm that the average annual temperatures have increased over most of the U.S. by about 1.5°F since 1895 (Menne et al. 2009). However, this increase was not constant over time. In particular, temperatures generally rose until about 1940, declined until about 1980, then increased rapidly thereafter, with 80% of the total increase occurring after 1980. Over even shorter time scales up to a decade or more, natural variability (see the Appendix) can reduce the rate of warming or even create a temporary cooling. The cooling in mid-century that was especially prevalent over the eastern half of the U.S. may also have stemmed partly from the cooling effects of sulfate particles from coal burning power plants (Leibensperger et al. 2012), before these sulfur emissions were regulated to address health and acid rain concerns.

Since 1991, temperatures have averaged 1°F to 1.5°F higher than 1901-1960 over most of the U.S., except for the Southeast, where the warming has been less than 1°F. On a seasonal basis, long-term warming has been greatest in winter and spring.

The cooling in mid-century extended over most of the southern and eastern U.S., and temperatures decreased slightly in parts of the Southeast if measured as a trend over the full century 1900-2000 (in contrast to almost all other global land areas, which warmed over that period). Such regional cooling can occur occasionally because natural variations can be larger than human influences over small areas for periods of decades. However, the Southeast has warmed over the past few decades and warming is ultimately projected for all parts of the nation during this century. In the next few decades, this warming will be roughly 2°F to 4°F in most areas. By the end of the century, U.S. warming is projected to correspond closely to the level of global emissions: roughly 3°F to 5°F under lower emissions scenarios (B1 or RCP 4.5) involving substantial reductions in emissions, and 5°F to 10°F for higher emissions scenarios (A2 or RCP 8.5) that assume continued increases in emissions; the largest temperature increases are projected for the upper Midwest and Alaska.

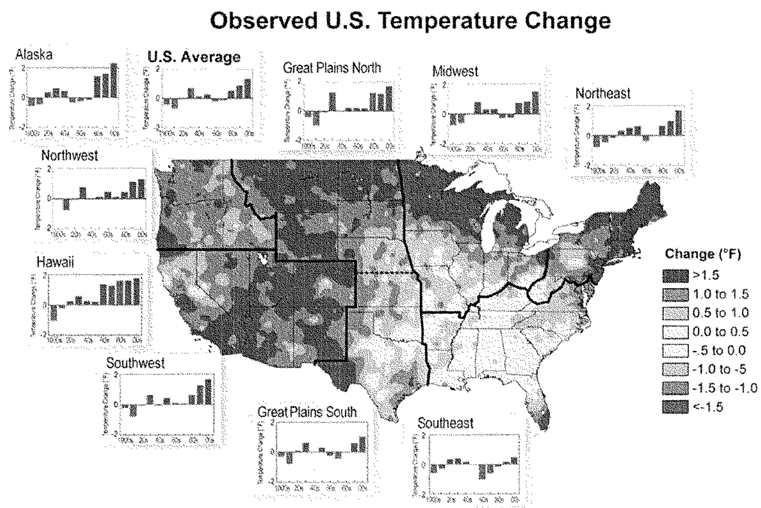

Figure 2.6: Observed U.S. Temperature Change

Caption: The colors on the map show temperature changes over the past 20 years in °F (1991-2011) compared to the 1901-1960 average. The bars on the graphs show the average temperature changes by decade for 1901-2011 (relative to the 1901-1960 average) for each region. The far right bar in each graph (2000s decade) includes 2011. The period from 2001 to 2011 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC. Data from NOAA NCDC.)

Future human-induced warming depends on both past and future emissions of heat-trapping gases and changes in the amount of particle pollution. The amount of climate change (aside from natural variability) expected for the next two to three decades is a combination of the warming already built into the climate system by the past history of human emissions of heat-trapping gases, and the expected ongoing increases of emissions of those gases. The amount of warming over the next few decades is projected to be similar regardless of emissions scenario. However, the magnitude of temperature increases over the second half of this century, both in the U.S. and globally, will be primarily determined by future emissions, and there are substantial differences between higher, fossil-fuel intensive scenarios compared to scenarios in which emissions are reduced. The most recent model projections of climate change due to human activities expand the range of future scenarios considered (particularly at the lower end), but are entirely consistent with the older model results. This consistency increases our confidence in the projections.

Projected Temperature Change

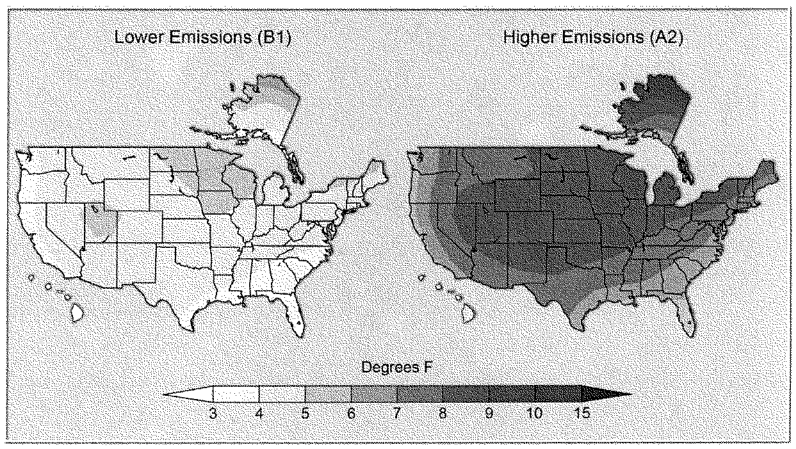

Figure 2.7: Projected Temperature Change

Caption: Maps show projected change in average surface air temperature in the later part of this century (2070-2099) relative to the later part of the last century (1971-1999) under a scenario that assumes substantial reductions in heat trapping gases (B1, left) and a higher emissions scenario that assumes continued increases in global emissions (A2, right). These scenarios are used throughout this report for assessing impacts under lower and higher emissions. Projected changes are averages from 15 CMIP3 models for the A2 scenario and 14 models for the B1 scenario. (See Appendix, Key Message 5 for a discussion of temperature changes under a wider range of future scenarios for various periods of this century). (Figure source: adapted from (Kunkel et al. 2012).)

BOX: Newer Simulations for Projected Temperature (CMIP5 models)

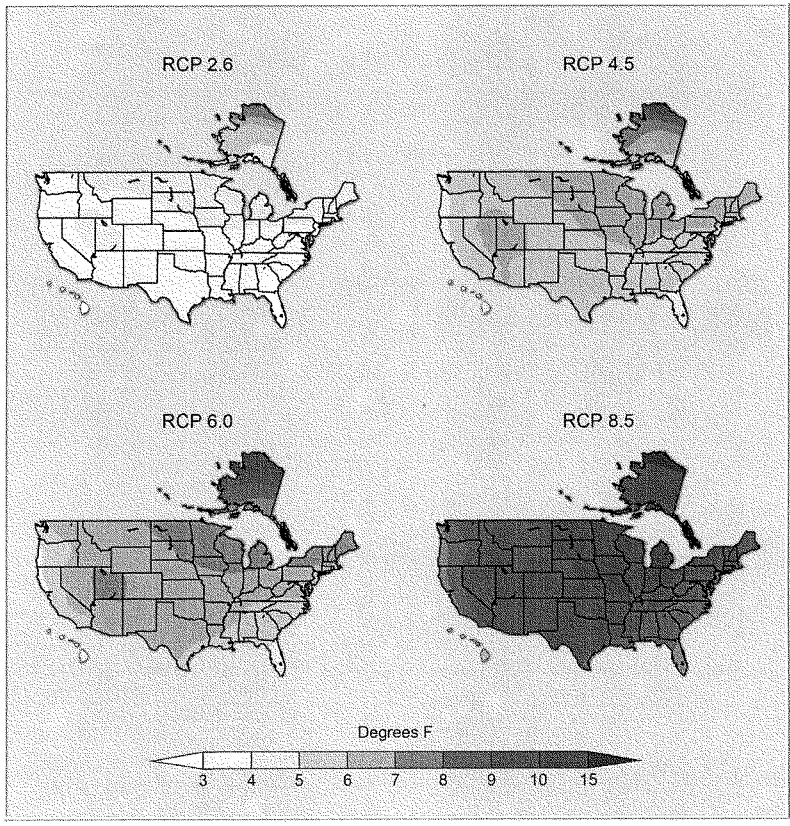

Figure 2.8:

Caption: The largest uncertainty in projecting future climate change is the level of emissions. The most recent model projections (shown above) take into account a wider range of options with regard to human behavior; these include a lower emissions scenario (RCP 2.6, top left) than has been considered before. This scenario assumes rapid reductions in emissions – more than 70% cuts from current levels by 2050 – and the corresponding smaller amount of warming. On the high end, they include a scenario that assumes continued increases in emissions (RCP 8.5, bottom right) and the corresponding greater amount of warming. Also shown are temperature changes (°F) for the intermediate scenarios RCP 4.5 (top right, which is most similar to B1) and RCP 6.0 (bottom left, which is most similar to A1B; see the Appendix). Projections show change in average surface air temperature in the later part of this century (2071-2099) relative to the late part of the last century (1971-2000). (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5.)

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Lengthening Frost-free Season

The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western U.S., affecting ecosystems and agriculture. Continued lengthening of the growing season across the U.S. is projected.

The length of the frost-free season (or growing season, in common usage) is a major determinant of the types of plants and crops that are well-adapted to a particular region. The frost-free season length has been gradually increasing since the 1980s (U.S. Environmental Protection Agency 2010). The last occurrence of 32°F in the spring has been occurring earlier in the year, and the first occurrence of 32°F in the fall has been happening later. During 1991-2011, the average frost-free season was about 10 days longer than during 1901-1960. These observed climate changes have been mirrored by changes in the biosphere, including increases in forest productivity (Dragoni et al. 2011), satellite estimates of the length of the growing season (Jeong et al. 2011), and length of the ragweed pollen season (Ziska et al. 2011). A longer growing season can mean greater evaporation and loss of moisture through plant transpiration associated with higher temperatures so that even with a longer frost-free season, crops could be negatively affected by drying. Likewise, increases in forest productivity can be offset by drying, leading to an earlier and longer fire season and more intense fires.

The lengthening of the frost-free season has been somewhat greater in the western U.S. than the eastern U.S. (Karl et al. 2009), increasing by 2 to 3 weeks in the Northwest and Southwest, 1 to 2 weeks in the Midwest, Great Plains, and Northeast, and slightly less than 1 week in the Southeast. These differences mirror the overall trend of more warming in the north and west and less warming in the Southeast.

In a future in which heat-trapping gas emissions continue to grow, increases of a month or more in the lengths of the frost-free and growing seasons are projected across most of the U.S. by the end of the century, with slightly smaller increases in the northern Great Plains. The largest increases in the frost-free season (more than 8 weeks) are projected for the western U.S., particularly in high elevation and coastal areas, consistent with rising sea surface temperatures. The increases would be considerably smaller if heat-trapping gas emissions are reduced, although still substantial. These increases are projected to be much greater than the normal year-to-year variability experienced today. The projected changes also imply that the southern boundary of the seasonal freeze zone will move north, with increasing frequencies of years without subfreezing temperatures in the most southern parts of the U.S.

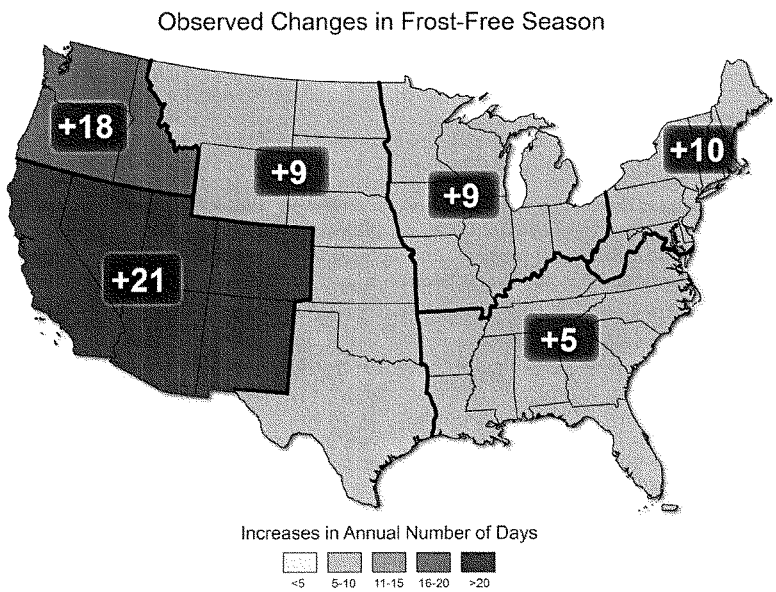

Figure 2.9: Observed Changes in Frost-Free Season

Caption: The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each U.S. region during 1991-2011 relative to 1901-1960. Increases in frost-free days correspond to similar increases in growing season length. (Figure source: NOAA/NCDC / CICS-NC. Data from Kunkel et al. 2012a, 2012b, 2012c, 2012d, 2012e, 2012f).

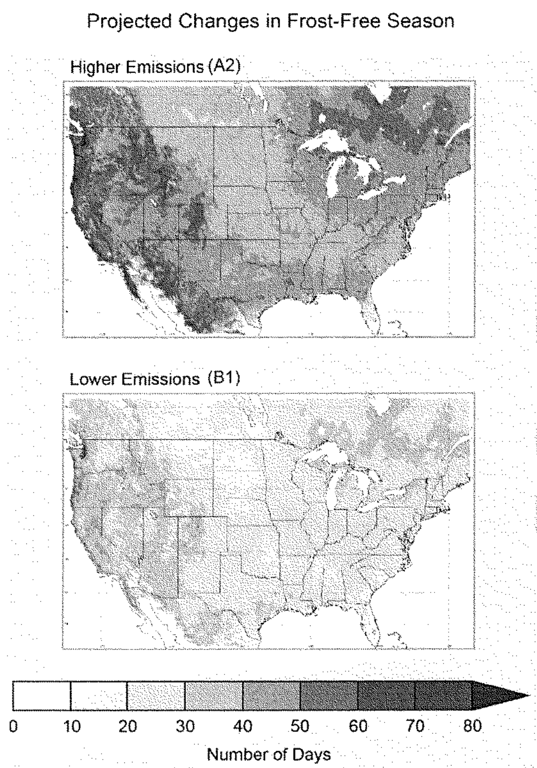

Figure 2.10: Projected Changes in Frost-Free Season

Caption: The maps show projected increases in frost-free days for the last three decades of this century (2070-2099 as compared to 1971-2000) under two emissions scenarios, one in which heat-trapping gas emissions continue to grow (A2, top map) and one in which emissions are rapidly reduced (B1, bottom map). Increases in the frost-free season correspond to similar increases in the growing season. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3 Daily Statistically Downscaled; Hayhoe et al. 2008; Hayhoe et al. 2004; Kunkel et al. 2012)

U.S. Precipitation Change

Precipitation averaged over the entire U.S. has increased during the period since 1900, but regionally some areas have had increases greater than the national average, and some areas have had decreases. The largest increases have been in the Midwest, southern Great Plains, and Northeast. Portions of the Southeast, the Southwest, and the Rocky Mountain states have experienced decreases. More winter and spring precipitation is projected for the northern U.S., and less for the Southwest, over this century.

Since 1900, average annual precipitation over the U.S. has increased by roughly 5%. This increase reflects, in part, the major droughts of the 1930s and 1950s, which made the early half of the record drier. There are important regional differences. For instance, precipitation since 1991 (relative to 1901-1960) increased the most in the Northeast (8%), Midwest (9%), and southern Great Plains (8%), while much of the Southeast and Southwest had a mix of areas of increases and decreases (McRoberts and Nielsen-Gammon 2011; Peterson et al. 2012).

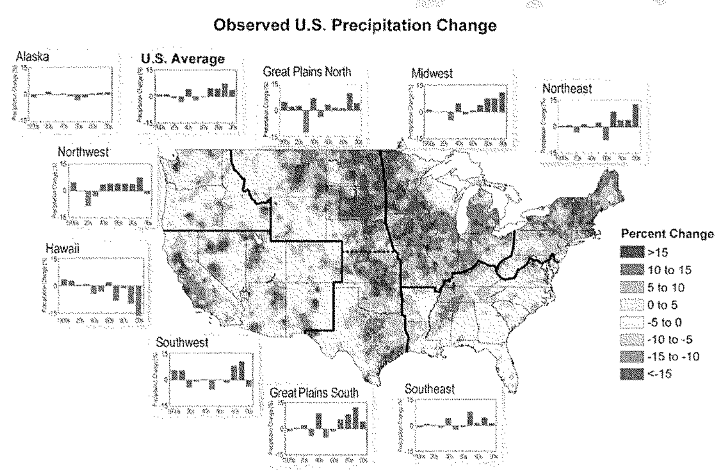

Figure 2.11: Observed U.S. Precipitation Change

Caption: The colors on the map show annual total precipitation changes (percent) for 1991-2011 compared to the 1901-1960 average, and show wetter conditions in most areas (McRoberts and Nielsen-Gammon 2011). The bars on the graphs show average precipitation differences by decade for 1901-2011 (relative to the 1901-1960 average) for each region. The far right bar is for 2001-2011. (Figure source: NOAA NCDC / CICS-NC. Data from NOAA NCDC.)

While significant trends in average precipitation have been detected, the fraction of these trends attributable to human activity is difficult to quantify because the range of natural variability in precipitation is large. However, if emissions of heat-trapping gases continue their upward trend, clear patterns of precipitation change are projected to emerge. The northern U.S. is projected to experience more precipitation in the winter and spring (except for the Northwest in the spring), while the Southwest is projected to experience less, particularly in the spring.

The projected changes in the northern U.S. are a consequence of both a warmer atmosphere and associated large-scale circulation changes. Warmer air can hold more moisture than colder air, leading to more intense rainfall. The projected reduction in Southwest precipitation is a result of large-scale circulation changes caused by increased heating of the global atmosphere. Recent improvements in the understanding of these mechanisms of change increase confidence in these projections (Held and Soden, 2008). The patterns of the projected changes of precipitation resulting from human alterations of the climate are geographically smoother in these maps than what will actually be observed because: 1) natural variations can not be projected far into the future; and 2) current climate models are too coarse to capture fine topographic details, especially in mountainous terrain. Hence, there is considerably more confidence in the large-scale patterns of change than in the small details.

Projected Precipitation Change by Season

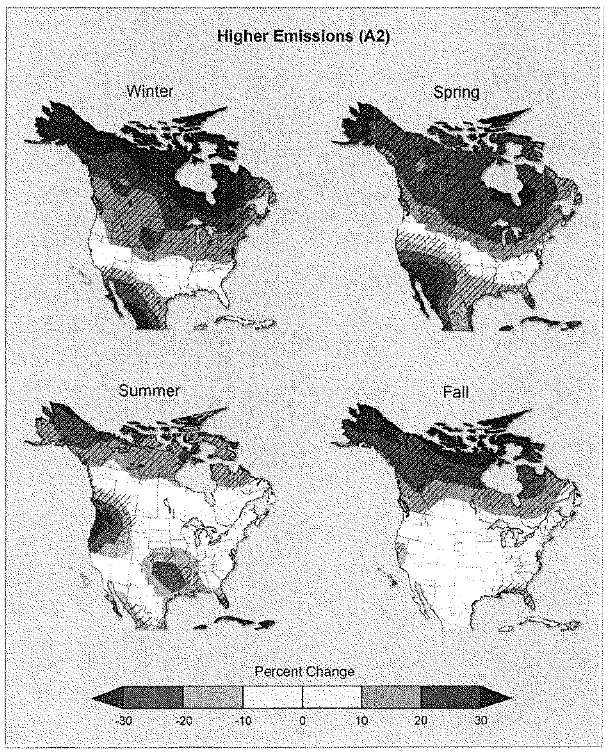

Figure 2.12: Projected Precipitation Change by Season

Caption: Projected percent change in seasonal precipitation for 2070-2099 (compared to the period 1901-1960) under an emissions scenario that assumes continued increases in emissions (A2). Teal indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. Wet regions tend to become wetter while dry regions become drier. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the Southwest is projected to experience less precipitation in the spring. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3; analyzed by Michael Wehner, LBNL.) *(note: to be redone with base period 1971-2000)*

In general, a comparison of the various sources of climate model data used in this assessment provides a consistent picture of the large-scale projected precipitation changes across the U.S. These include the global models used in the Coupled Model Intercomparison Project, versions 3 and 5 (CMIP3, CMIP5) as well as the suite of regional models (from the North American Regional Climate Change Assessment Program, NARCCAP). Multi-model average changes in all three of these sources show a general pattern of wetter future conditions in the north and drier conditions in the south, but the regional suite generally shows conditions that are overall somewhat wetter in the wet areas and not as dry in the dry areas. The general pattern agreement among these three sources, with the wide variations in their spatial resolution, provides confidence that this pattern is robust and not sensitive to the limited spatial resolution of the models. The slightly different conditions in the North American NARCCAP regional suite for the U.S. appear to arise partially or wholly from the choice of the four global climate models used to drive the regional simulations. These four models, averaged together, project average changes that are slightly (2%) wetter than the average of the suite of global models used in CMIP3.

The patterns of precipitation change in the newer CMIP5 simulations are essentially the same as in the earlier CMIP3 and NARCCAP simulations used in impact analyses throughout this report, increasing confidence in our scientific understanding. The subtle differences between these two sets of projections are mostly due to the wider range of future emissions scenarios considered in the more recent simulations. Thus, the overall picture remains the same: wetter conditions in the north and drier conditions in the Southwest in the winter and spring. Drier conditions in the summer are projected in most areas of the contiguous U.S. but, outside of the Northwest and south-central region, there is generally not high confidence that the changes will be large compared to natural variability. In all models and scenarios, a transition zone between drier (to the south) and wetter (to the north) shifts northward from the southern U.S. in winter to southern Canada in summer. Wetter conditions are projected for Alaska and northern Canada in all seasons.

BOX: Newer Simulations for Projected Precipitation Change (CMIP5 models)

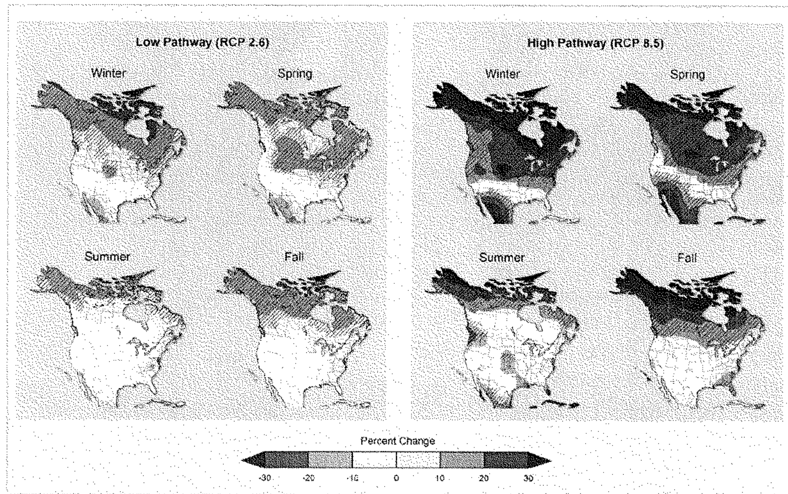

Figure 2.13

Projected seasonal precipitation change (percent) for 2071-2099 (compared to 1901-1960) as projected by recent simulations that include a wider range of emissions scenarios. The maps on the left (RCP 2.6) assume rapid reductions in emissions – more than 70% cuts from current levels by 2050 – and a corresponding much smaller amount of warming and far less precipitation change. On the right, RCP 8.5 assumes continued increases in emissions, with associated large increases in warming and major precipitation changes. These would include, for example, large reductions in spring precipitation in the Southwest and large increases in the Northeast and Midwest. Rapid emissions reductions could be expected to yield the more modest changes in the maps on the left. In these seasonal projections, teal indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analyzed by Michael Wehner, LBNL.) *(note: to be redone with base period 1971-2000)*

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Heavy Downpours Increasing

Heavy downpours are increasing in most regions of the U.S., especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas.

Across most of the U.S., the heaviest rainfall events have become heavier and more frequent. The amount of rain falling on the heaviest rain days has also increased over the past few decades. Since 1991, the amount of rain falling in very heavy precipitation events has been above average in every region of the country, except Hawaii. This increase has been greatest in the Northeast, Midwest, and Great Plains – more than 30% above the 1901-1960 average (Karl et al. 2009). There has also been an increase in flooding events in the Midwest and Northeast where the largest increases in heavy rain amounts have occurred.

Warmer air can contain more water vapor than cooler air. Global analyses show that the amount of water vapor in the atmosphere has in fact increased over both land and oceans (Dai 2006; Simmons et al. 2010; Willett et al. 2008). Climate change also alters dynamical characteristics of the atmosphere that in turn affect weather patterns and storms. In the mid-latitudes, where most of the continental U.S. is located, there is an upward trend in extreme precipitation in the vicinity of fronts associated with mid-latitude storms (Kunkel et al. 2012h).

Projections of future climate over the U.S. suggest that the recent trend towards a greater percentage of precipitation falling in heavy rain events will continue. In regions of increasing precipitation, such as the northern U.S., increasingly large percentages of the total precipitation will come from heavy downpours. In these areas, heavy-precipitation events that are presently rare will become more common in the future. Moreover, heavy downpours will account for increasingly large portions of the total precipitation in regions such as the Southwest, where total precipitation is projected to decrease (Kunkel et al. 2012h; Wehner 2012; Wuebbles et al. 2012).

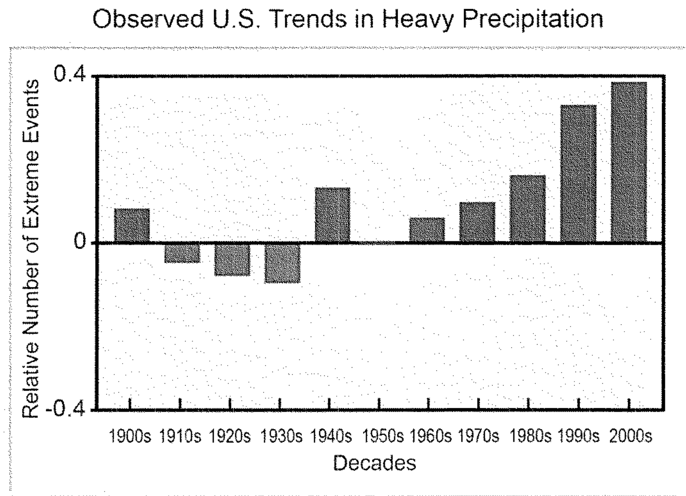

Figure 2.14: Observed U.S. Trends in Heavy Precipitation

Caption: One measure of a heavy-precipitation event is a 2-day precipitation total that is exceeded on average only once in a five year period, also known as the once-in-five-year event. As this extreme precipitation index for 1901-2011 shows, the occurrence of such events has become much more common in recent decades. Changes are compared to the period 1901-1960 and do not include Alaska or Hawaii. The 2000s decade (far right bar) includes 2001-2011. (Figure source: adapted from (Kunkel et al. 2012)

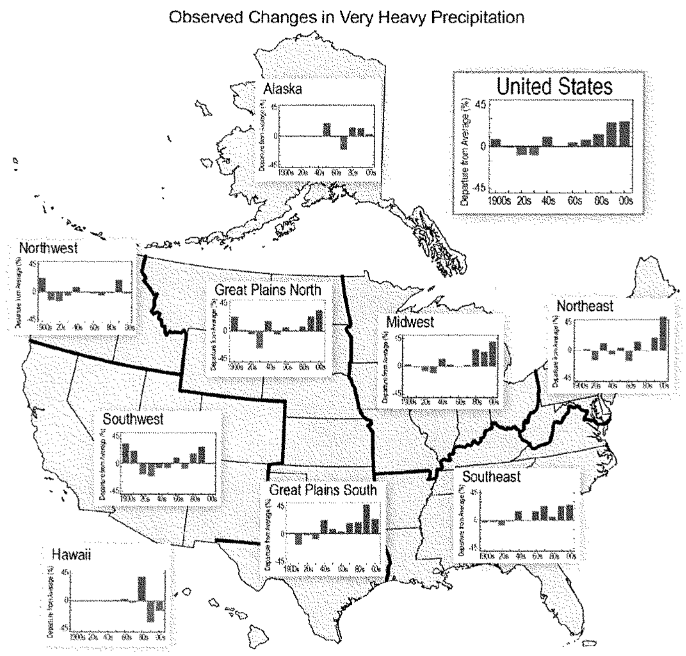

Figure 2.15: Observed Changes in Very Heavy Precipitation

Caption: Percent changes in the annual amount of precipitation falling in *very heavy* events, defined as the heaviest 1% of all daily events from 1901 to 2011 for each region. The far right bar is for 2001-2011. In recent decades there have been increases everywhere, except for the Southwest, Northwest, and Hawaii, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawaii, which are relative to the 1951-1980 average. (Figure source: NOAA NCDC / CICS-NC)

Percentage Change in Very Heavy Precipitation

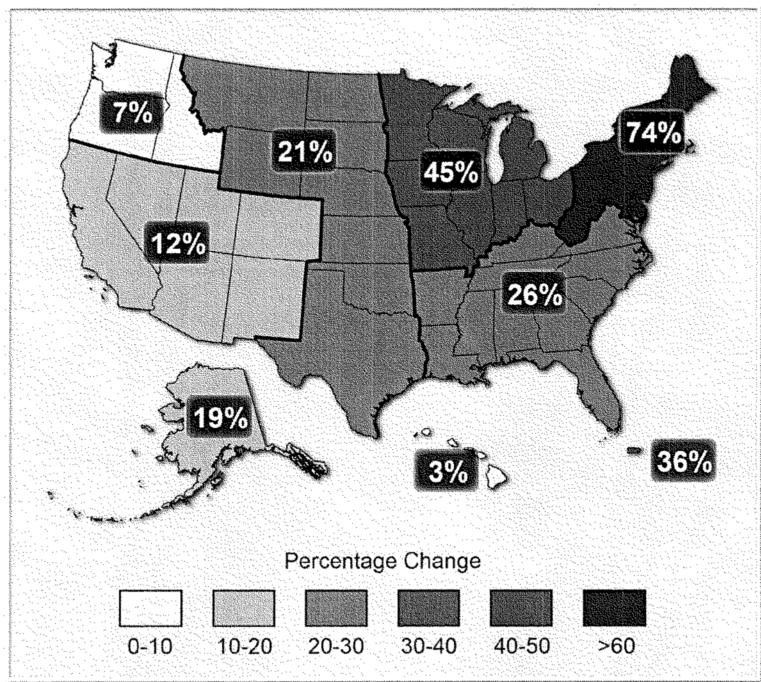

Figure 2.16: Percentage Change in Very Heavy Precipitation

Caption: The map shows percent increases in the amount of precipitation falling in *very heavy* events (defined as the heaviest 1% of all daily events) from 1958 to 2011 for each region. There are clear trends toward a greater amount of *very heavy* precipitation for the nation as a whole, and particularly in the Northeast and Midwest. (Figure source: updated from (Karl et al. 2009) with data from NCDC)

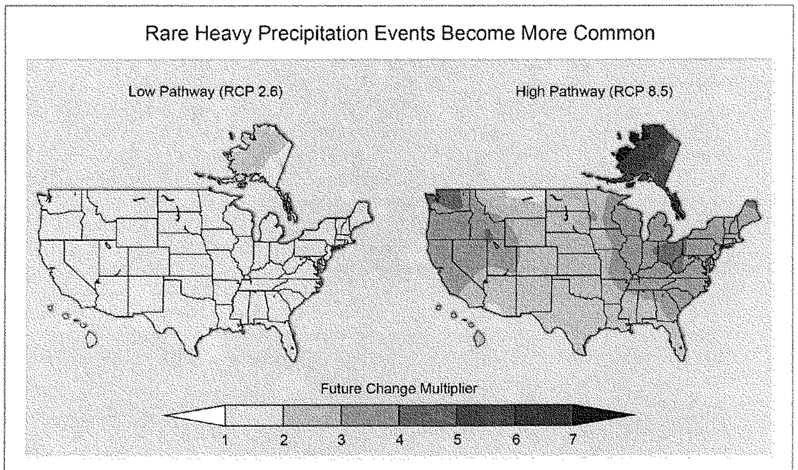

Figure 2.17: Rare Heavy Precipitation Events Become More Common

Caption: Maps show the increase in frequency of extreme daily precipitation events (now occurring about once every twenty years) by the later part of this century (2081-2100) compared to later part of last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the U.S. Under the rapid emissions reduction scenario (RCP 2.6, left), these events would occur up to about twice as often. For the scenario assuming continued increases in emissions (RCP 8.5, right), these events would occur up to five times as often. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analysis by Michael Wehner, LBNL; based on methods from (Kharin et al. submitted)

Extreme Weather

Certain types of extreme weather events have become more frequent and intense, including heat waves, floods, and droughts in some regions. The increased intensity of heat waves has been most prevalent in the western parts of the country, while the intensity of flooding events has been more prevalent over the eastern parts. Droughts in the Southwest and heat waves everywhere are projected to become more intense in the future.

Heat waves are periods of abnormally and uncomfortably hot weather lasting days to weeks (Kunkel et al. 1999). Heat waves have generally become more frequent across the U.S. in recent decades, with western regions (including Alaska) setting records for numbers of these events in the 2000s. Tree ring data suggests that the drought over the last decade in the western U.S. represents the driest conditions in 800 years (Karl et al.

2009; Schwalm et al. 2012). Most other regions in the country had their highest number of short-duration heat waves in the 1930s, when the multi-year severe drought of the Dust Bowl period, combined with deleterious land-use practices (Cook et al. 2009), contributed to the intense summer heat through depletion of soil moisture and reduction of the moderating effects of evaporation (Kunkel et al. 2008). However, recent prolonged (multi-month) extreme heat has been unprecedented. The 2011 and 2012 events set records for highest monthly average temperatures, exceeding in some cases records set in the 1930s, including the highest monthly temperature on record (July 2012, breaking the July 1936 record); for the spring and summer months, 2012 had the largest area of record-setting monthly average temperatures, including both hot daytime maximum temperatures and warm nighttime minimum temperatures (Karl et al. 2012). Corresponding with this increase in extreme heat, the number of cold waves has reached the lowest levels on record.

In the past 3 to 4 decades in the U.S. the ratio of record daily high temperatures to record daily low temperatures has steadily increased (also see Meehl et al. 2009). This ratio is now higher than in the 1930s, mostly due to the rapidly declining number of low temperature records. During this same period there has been an increasing trend in persistently high nighttime temperatures (Karl et al. 2009). In some areas, prolonged periods of record high temperatures associated with droughts contribute to dry conditions that are driving wildfires (Trenberth 2011). Numerous studies have documented that human-induced climate change has increased the frequency and severity of heat waves across the globe (Christidis et al. 2011; Stott et al. 2010).

There is emerging evidence that most of the increases of heat wave severity over the U.S. are likely due to human activity (Hansen et al. 2012; Meehl et al. 2007);, with a detectable human influence in recent heat waves in the southern Great Plains (Karl et al. 2009; Rupp et al. 2012) as well as in Europe (Stott et al. 2010; Trenberth 2011) and Russia (Christidis et al. 2011; Duffy and Tebaldi 2012; Meehl et al. 2009). Research has found that the human contribution to climate change approximately doubled the probability of the record heat in Texas in the summer of 2011 (Hoerling et al. 2012a). So while this Texas heat wave and drought could have occurred naturally, the likelihood of record-breaking temperature extremes has increased and will continue to increase as the global climate warms. Generally, the changes in climate are increasing the likelihood for these types of severe events.

Ratio of Record Daily High to Record Daily Low Temperatures

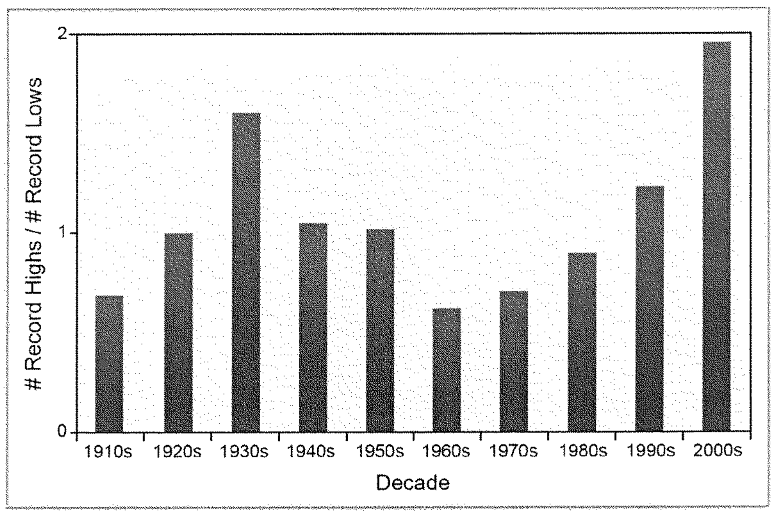

Figure 2.18: Ratio of Record Daily High to Record Daily Low Temperatures

Caption: The ratio of record daily high temperatures to record daily lows for 1911-2010 (relative to the entire history of observations) at about 1,800 weather stations in the 48 contiguous United States has increased from about 1:1 in the 1950s to about 2:1 in the most recent decade, and is higher than the ratio of 1.6:1 in the 1930s, primarily due to very small numbers of low temperature records. The ratios were even higher in 2011 and 2012, which are not shown here. (Figure source: NOAA NCDC / CICS-NC. Data from NOAA NCDC.)

Expectations for future heat wave occurrences in the U.S. are shaped by two important considerations. First, the average as well as extreme summer temperatures occurring during individual years of the past decade have approached or exceeded those of the decade of the 1930s over much of the U.S; hence summer temperatures are already moving out of their historical bounds. Second, summer drying is projected for much of the western and central U.S. As discussed below, drying exacerbates heat waves. Accordingly, the number of extremely hot days is projected to continue to increase dramatically over much of the U.S., especially by late century. Climate models project that the same summertime temperatures that ranked among the hottest 5% in 1950-1979 will occur at least 70% of the time by 2035-2064 in the U.S. if global emissions of heat-trapping gases continue to grow (as in the A2 scenario) (Duffy and Tebaldi 2012). By the end of this century, what have previously been once-in-20-year heat waves (4-day events) are projected to occur every two or three years over most of the U.S. (Karl et al. 2008). In other words, what now seems like an extreme heat wave will become commonplace. Confidence has risen in computer model projections because recent observations are consistent with past model projections.

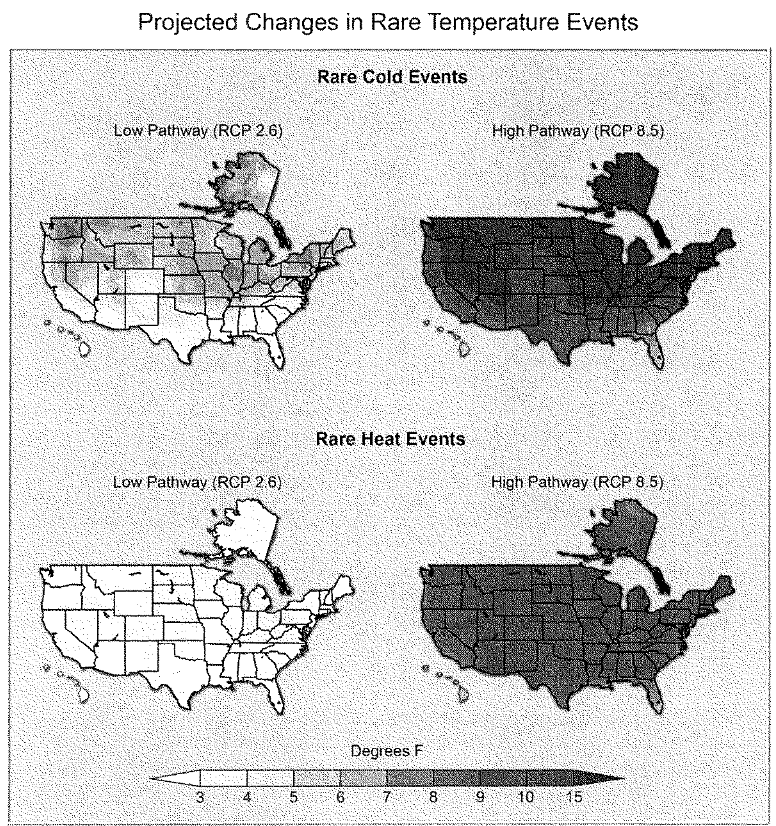

Figure 2.19: Projected Change in Rare Temperature Events

Caption: These maps show that both the hottest and coldest days are projected to be warmer. They show the projected changes in surface air temperature at the end of this century (2081-2100) relative to the end of the last century (1981-2000) on very rare cold and hot days, under a scenario that assumes rapid reductions in emissions (RCP 2.6, left) and a scenario that assumes continued increases in emissions (RCP 8.5, right). In this analysis, very rare cold and hot days are defined as those having a 5% chance of occurring during any given year. The projected temperature increases on such very cold days as well as for very hot days are larger than for the average temperature. In particular, the largest temperature increases will be on rare cold days meaning that bitter cold winter days will be much less frequent across most of the contiguous U.S. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analysis by Michael Wehner, LBNL; based on method from (Kharin et al. submitted).)

In the U.S., flooding in the northern half of the eastern Great Plains and much of the Midwest has been increasing, especially over the last several decades. Flooding has decreased in the Southwest, although there have been small increases in other western states. In the areas of increased flooding, increases in both total precipitation and extreme precipitation are contributing to the flooding increases. Attribution of flood events is a relatively new area of research. There is evidence of a detectable human influence in the timing and magnitude of snowmelt and resulting streamflow in some western U.S. states (Barnett et al. 2008; Hidalgo et al. 2009; Pierce et al. 2008), in recent flooding events in England and Wales (Pall et al. 2011), and in other specific events around the globe during 2011 (Peterson et al. 2012). In general, heavier rains lead to a larger fraction of rainfall running off and, depending on the situation, more potential for flooding. While a 2-inch rain may not cause major impacts in the Southeast where such an event can occur several times a year, it can be disastrous if it occurs in the northern Great Plains.

Trends in Flood Magnitude

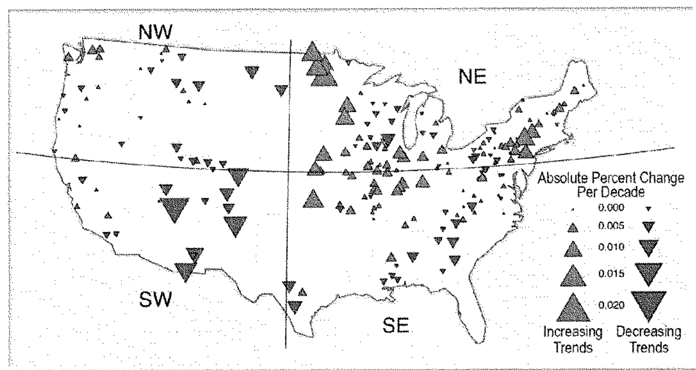

Figure 2.20: Trends in Flood Magnitude

Caption: Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. (Source: Hirsch and Ryberg 2012).

Projected higher temperatures cause increases in evaporation and loss of moisture through plant leaves, leading to drier soils. Precipitation has already declined in some areas within the Southwest and the Rocky Mountain states, and decreases in precipitation are projected to intensify in those areas and spread northward and eastward in summer (see Key Message 5). However, even in areas where precipitation does not decrease, projected higher air temperatures will cause increases in surface evaporation and loss of water from plants, leading to drier soils. As soil dries out, a larger proportion of the incoming heat from the sun goes into heating the soil and adjacent air rather than evaporating its moisture, resulting in hotter summers under drier climatic conditions (Mueller and Seneviratne 2012). Under higher emissions scenarios, widespread drought is projected to become more common over most of the central and southern U.S. (Cayan et al. 2010; Dai 2012; Hoerling et al. 2012b ; Liang et al. 1996; Liang et al. 1994; Maurer et al. 2002; Nijssen et al. 1997; Schwalm et al. 2012; Wehner et al. 2011; Wood and Lettenmaier 2006; Wood et al. 2005)

Extreme Drought in the U.S. and Mexico, Past and Future

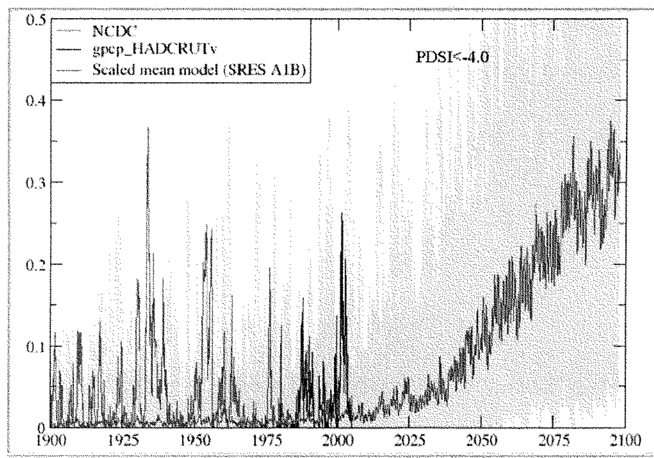

Figure 2.21: Extreme Drought in the U.S. and Mexico, Past and Future

Caption: The percentage area of the U.S. and Mexico in extreme drought according to projections of the Palmer Drought Severity Index under a mid-range emissions scenario (SRES A1B). The Palmer Drought Severity Index is the most widely used measure of drought, although it is more sensitive to temperature than other drought indices and may over-estimate the magnitude of drought increases. The red line is based on observed temperature and precipitation. The blue line is from the average of 19 different climate models. The gray lines in the background are individual results from over 70 different simulations from these models. These results suggest an increasing probability of drought over this century throughout most of the U.S. Source: (Wehner et al. 2011)

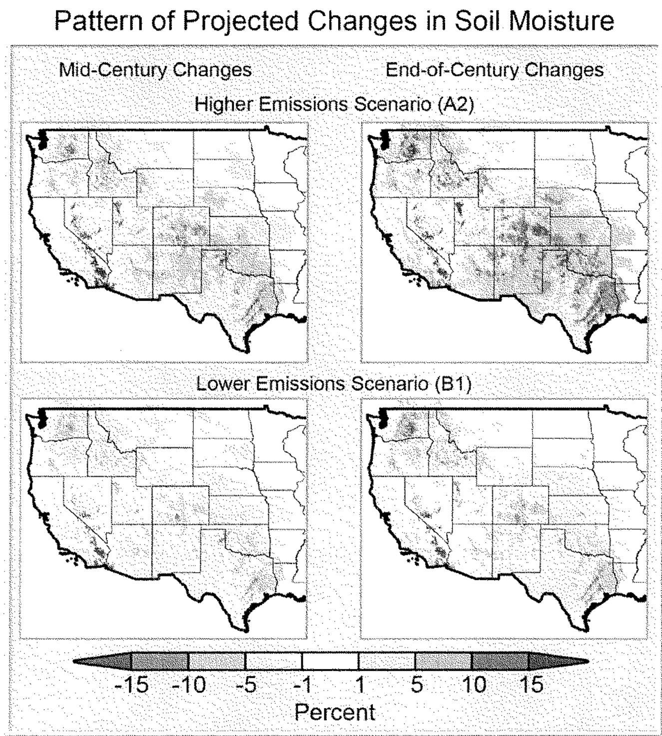

Figure 2.22: Pattern of Projected Changes in Soil Moisture

Caption: Average percent change in soil moisture compared to 1971-2000, as projected in the middle of this century (2041-2070) and late this century (2071-2100) under two emissions scenarios, a lower scenario assuming significant reductions in emissions (B1) and a higher scenario (A2) assuming that emissions continue to grow (Dai 2012; Liang et al. 1996; Liang et al. 1994; Maurer et al. 2002; Nijssen et al. 1997; Wood and Lettenmaier 2006; Wood et al. 2005). The future drying of soils in most areas simulated by this sophisticated hydrologic model (VIC model) is consistent with the future drought increases using the simpler Palmer Drought Severity Index (PDSI) metric. (Figure source: NOAA NCDC / CICS-NC. Data from VIC model.)

Changes in Storms

There has been an increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s. The intensity of the strongest hurricanes is projected to continue to increase as the oceans continue to warm. With regard to other types of storms that affect the U.S., winter storms have increased slightly in frequency and intensity, and their tracks have shifted northward over the U.S. Other trends in severe storms, including the numbers of hurricanes and the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds are uncertain and are being studied intensively.

Trends in the occurrences of storms, ranging from severe thunderstorms to winter storms to hurricanes, are subject to much greater uncertainties than trends in temperature and variables that are directly related to temperature (snow and ice cover, ocean heat content, sea level). Recognizing that the impacts of changes in the frequency and intensity of these storms can easily exceed the impacts of changes in average temperature or precipitation, climate scientists are actively researching the connections between climate change and severe storms.

Hurricanes

There has been a substantial increase in virtually every measure of hurricane activity in the Atlantic since the 1970s. These increases are linked, in part, to higher sea surface temperatures in the region that Atlantic hurricanes form in and move through. Numerous factors influence these local sea surface temperatures, including human-induced emissions of heat-trapping gases and particulate pollution and natural variability (Booth et al. 2012; Camargo et al. 2012; Evan et al. 2012; Evan et al. 2011; Evan et al. 2009; Mann and Emanuel 2006; Ting et al. 2009; Zhang and Delworth 2009). However, hurricanes respond to more than just sea surface temperature. How hurricanes respond also depends on how the local atmosphere responds to changes in local sea surface temperatures, and this atmospheric response depends critically on the *cause* of the change (Emmanuel 2012; Zhang and Delworth 2009);. For example, the atmosphere responds differently when local sea surface temperatures increase due to a local decrease of particulate pollution that allows more sunlight through to warm the ocean, versus when sea surface temperatures increase more uniformly around the world due to increased amounts of heat-trapping gases. So the link between hurricanes and ocean temperatures is complex and this is an active area of research. Climate models that incorporate the best understanding of all these factors project further increases in the frequency and intensity of the strongest Atlantic hurricanes, as well as increased rainfall rates in response to continued warming of the tropical oceans by heat-trapping gases. Hurricane activity in other ocean basins has not shown such clear increases as those found in the Atlantic. Consequently, there is much greater uncertainty that hurricane activity in those basins has increased substantially in the past 40 years or so. Reducing these uncertainties is another active area of research.

Severe Convective Storms

Tornadoes and other severe thunderstorm phenomena frequently cause as much annual property damage in the U.S. as do hurricanes, and often cause more deaths. Although recent research has yielded insights into the connections between global warming and the factors that cause tornados and severe thunderstorms (such as atmospheric instability and increases in wind speed with altitude (Del Genio et al. 2007; Trapp et al. 2007)), these relationships remain mostly unexplored, largely because of the challenges in observing thunderstorms and tornadoes and simulating them with computer models.

Winter Storms

Over the U.S., changes in winter storm frequency and intensity are small and not significant, with the exception that there is limited evidence of an overall increase in storm activity near the northeast and northwest U.S. coastlines during the second half of the 1950-2010 period (Vose, 2012). However, for the Northern Hemisphere as a whole, there is evidence of an increase in both storm frequency and intensity during the cold season since 1950 (Vose, 2012), with storm tracks having shifted slightly towards the poles (Wang et al. 2006; Wang et al. 2012). Extremely heavy snowstorms increased in number during the last century in northern and eastern parts of the U.S., but have been less frequent since 2000 (Kunkel et al. 2012h; Squires et al. 2009). Total seasonal snowfall has generally decreased in southern and some western areas (Kunkel et al. 2009b), increased in the northern Plains and Great Lakes (Kunkel et al. 2009a, 2009b), and not changed in other areas, such as the Sierra Nevada (Christy 2012). Very snowy winters have generally been decreasing in frequency in most regions over the last 10 to 20 years, although the Northeast has been seeing a normal number of such winters (Kunkel et al. 2009). Heavier-than-normal snowfalls recently observed in the Midwest and Northeast U.S. in some years, with little snow in other years, are consistent with indications of increased blocking of the wintertime circulation of the Northern Hemisphere (Francis and Vavrus 2012). Overall snow cover has decreased in the Northern Hemisphere, due in part to higher temperatures that shorten the time snow spends on the ground (BAMS 2012).

Observed Trends in Hurricane Intensity

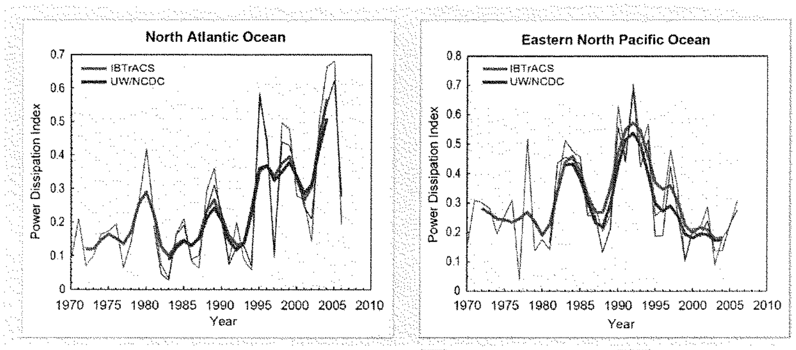

Figure 2.23: Observed Trends in Hurricane Intensity

Caption: Recent variations of the Power Dissipation Index (PDI), a measure of overall hurricane intensity in a hurricane season. Historical and satellite observations show a significant upward trend in the strength of hurricanes and in the number of strong hurricanes (Category 4 and 5) in the North Atlantic from 1983 to 2009. A significant decreasing trend in hurricane intensity is detected for the eastern North Pacific from 1984 to 2009, but no trend in the number of storms is apparent. Updated from (Kossin et al. 2007)

Projected Changes in Atlantic Hurricane Frequency by Category

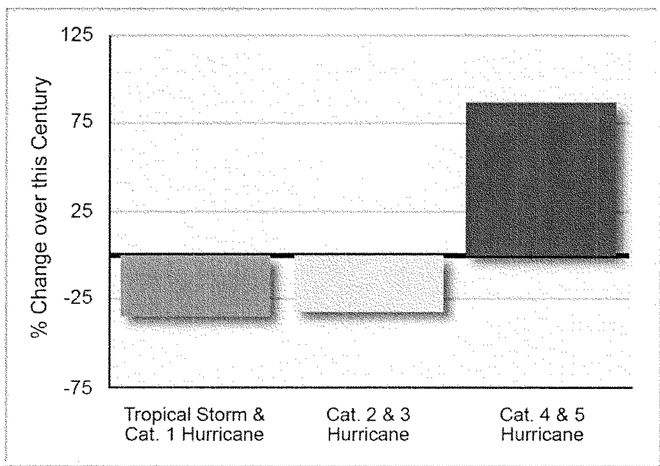

Figure 2.24: Projected Changes in Atlantic Hurricane Frequency by Category

Caption: Model projections of percentage changes in Atlantic hurricane and tropical storm frequencies for different storm categories, by the late this century. Projected changes are for the period 2081-2100 compared with the period 2001-2020. (Figure source: NOAA GFDL)

Sea Level Rise

Global sea level has risen by about 8 inches since 1880. It is projected to rise another 1 to 4 feet by 2100.

The oceans are absorbing over 90% of the increased atmospheric heat associated with emissions from human activity (Church et al. 2011). Like mercury in a thermometer, water expands as it warms up (this is referred to as "thermal expansion") causing sea levels to rise. Melting of glaciers and ice sheets is also contributing to sea level rise at increasing rates (Arctic Monitoring and Assessment Programme 2011).

Since the late 1800s, tide gauges throughout the world have shown that global sea level has risen by about 8 inches. Proxy data have shown that this rate of sea level rise is faster than at any time in at least the past 2000 years (Kemp et al. 2012). Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence that the current rate is faster still (Church and White 2011a).

Projecting future rates of sea level rise is challenging. Even the most sophisticated climate models, which explicitly represent Earth's physical processes, cannot simulate recent rapid changes in ice sheet dynamics, and thus tend to underestimate sea level rise. In recent years, "semi-empirical" models, based on statistical relationships between historical rates of global warming and sea level rise, have been developed. Early efforts at semi-empirical models suggested much higher rates of sea level rise (as much as 6 feet by 2100) (Jevrejeva et al. 2010; Vermeer and Rahmstorf 2009). More recent semi-empirical models have suggested upper ends closer to 3 or 4 feet by 2100 (Jevrejeva et al. 2012; Rahmstorf et al. 2012). It is not clear, however, whether these statistical relationships will hold in the future.

Scientists are working to narrow the range of sea level rise projections for this century. Recent projections show that for even the lowest emissions scenarios, thermal expansion of ocean waters (Yin 2012) and the melting of small mountain glaciers (Marzeion et al. 2012) will result in 11 inches of sea level rise by 2100, even without any contribution from the ice sheets in Greenland and Antarctica. This suggests that about 1 foot of global sea level rise by 2100 is probably a realistic low end. On the high end, recent work suggests that 4 feet is plausible. (Gladstone et al. 2012; Jevrejeva et al. 2012; Joughin et al. 2010; Katsman et al. 2011; Rahmstorf et al. 2012). In the context of risk-based analysis, some decision makers may wish to use a wider range of scenarios, from 8 inches to 6.6 feet by 2100 (Burkett and Davidson 2012; Parris et al. 2012). In particular, the high end of these scenarios may be useful for decision makers with a low tolerance for risk (Burkett and Davidson 2012; Parris et al. 2012) (see figure on global sea level rise). Although scientists cannot yet assign likelihood to any particular scenario, in general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of sea level rise.

Nearly 5 million people in the U.S. live within 4 feet of the local high-tide level. In the next several decades, storm surges and high tides could combine with sea level rise and land subsidence to further increase flooding in many of these regions (Strauss et al.

2012). Sea level rise is not expected to stop in 2100. The oceans take a very long time to respond to warmer conditions at the Earth's surface. Ocean waters will therefore continue to warm and sea level will continue to rise for many centuries.

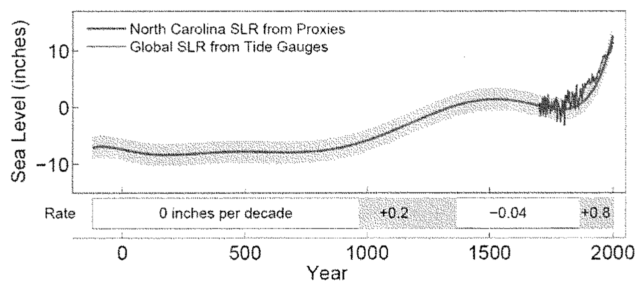

Figure 2.25

Caption: Rates of sea level change in the North Atlantic Ocean based on data collected from the U.S. East Coast (Kemp et al. 2012) (red line, pink band shows the uncertainty range) compared with a reconstruction of global sea level rise based on tide gauge data (Jevrejeva et al. 2008) (blue line). (Figure source: Josh Willis, NASA Jet Propulsion Laboratory)

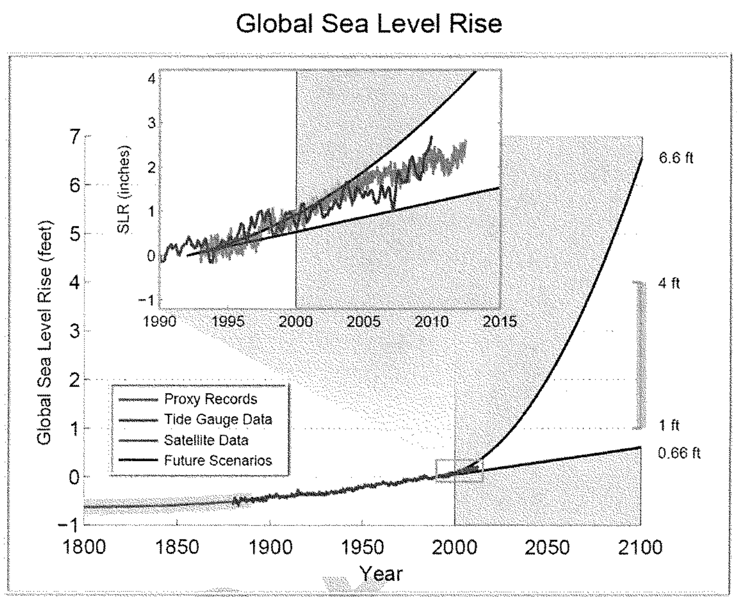

Figure 2.26: Global Sea Level Rise

Caption: Estimated, observed and possible amounts of global sea level rise from 1800 to 2100. Proxy estimates (Kemp et al. 2012) (for example, based on sediment records) are shown in red (pink band shows uncertainty), tide gauge data in blue (Church and White 2011a), and satellite observations are shown in green (Nerem et al. 2010). The future scenarios range from 0.66 feet to 6.6 feet in 2100 (Parris et al. 2012). Higher or lower amounts of sea level rise are considered implausible, as represented by the gray shading. The orange line at right shows the currently projected range of sea level rise of 1 to 4 feet by 2100, which falls within the larger risk-based scenario range. The large projected range reflects uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere, and changing winds and currents. As seen in the observations, there are year-to-year variations in the trend. (Figure source: Josh Willis, NASA Jet Propulsion Laboratory)

Melting Ice

Rising temperatures are reducing ice on land, lakes, and sea. This loss of ice is expected to continue.

Rising temperatures across the U.S. have reduced lake ice, sea ice, glaciers, and seasonal snow cover over the last few decades (Arctic Monitoring and Assessment Programme 2011). In the Great Lakes, for example, total winter ice coverage has decreased by 63% since the early 1970s (Wang et al. 2011).

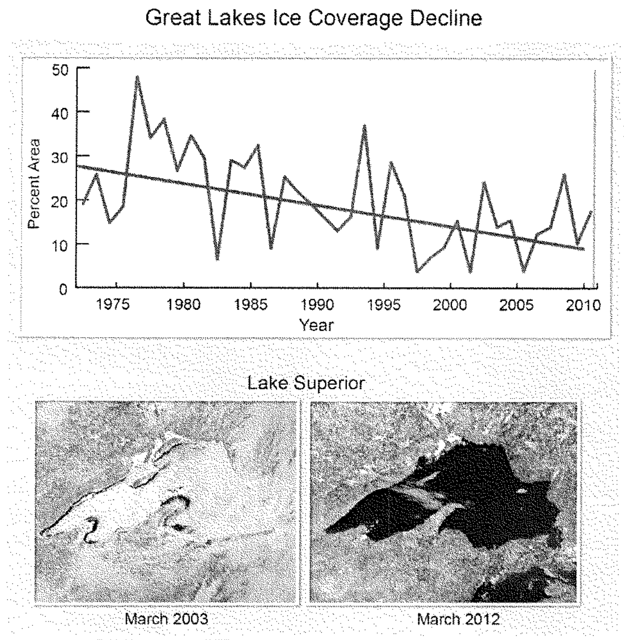

Figure 2.27: Great Lakes Ice Coverage Decline

Caption: Blue line shows annual average Great Lakes ice coverage from 1973 to 2011 and red line shows the trend. (Figure source updated from Wang et al. 2011) Satellite images show Lake Superior in a high ice year and a more recent low ice year. (Satellite images courtesy of NASA)

Sea ice in the Arctic has also decreased dramatically since the late 1970s, particularly in summer and autumn. Since the satellite record began in 1978, minimum Arctic sea ice extent (which occurs in early to mid September) has decreased by more than 40% (NSIDC 2012). This decline is unprecedented in the historical record and is consistent with human-induced climate change. The 2012 sea ice minimum broke the preceding record (set in 2007) by more than 200,000 square miles. Ice loss increases Arctic warming by replacing white, reflective ice with dark water that absorbs more energy from the sun. More open water can also increase snowfall over northern land areas and increase the north-south meanders of the jet stream, consistent with the occurrence of unusually cold and snowy winters at mid-latitudes in several recent years (Francis and Vavrus 2012; Liu et al. 2012).

Arctic Sea Ice Decline

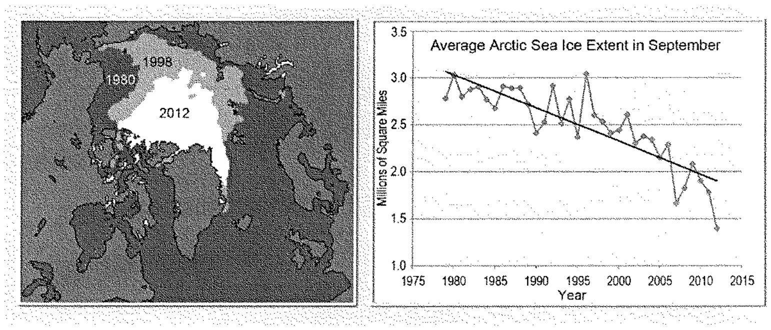

Figure 2.28: Arctic Sea Ice Decline

Caption: Summer Arctic sea ice has declined dramatically since satellites began measuring it in 1979. The extent of sea ice in September 2012, shown in white in the figure on the left, was more than 40% below the median for 1979-2000. It is also notable that the ice has become much thinner in recent years, so its total volume has declined even more rapidly than the extent shown here (Arctic Monitoring and Assessment Programme 2011). The graph on the right shows annual variations in September Arctic sea ice extent for 1979-2012. (Figure and data from National Snow and Ice Data Center)

The loss of sea ice has been greater in summer than in winter. The Bering Sea, for example, experiences sea ice only in the winter-spring portion of the year, and shows no trend in ice coverage over the past 30 years. However, seasonal ice in the Bering Sea and elsewhere in the Arctic is thin and susceptible to rapid melt during the following summer. Sea ice in the Antarctic is largely seasonal and has shown a slight increase in extent since 1979.

This seasonal pattern of observed ice loss is generally consistent with simulations by global climate models, in which the extent of sea ice decreases more rapidly in summer than in winter. However, the models tend to underestimate the amount of decrease since 2007. Projections by these models indicate that summer sea ice in the Arctic Ocean could disappear before mid-century under scenarios that assume continued growth in global emissions, although sea ice would still form in winter (Stroeve et al. 2012; Wang and Overland 2009). Even during a long-term decrease, occasional temporary increases in Arctic summer ice can be expected over timescales of a decade or so because of internal variability (Kay et al. 2011).

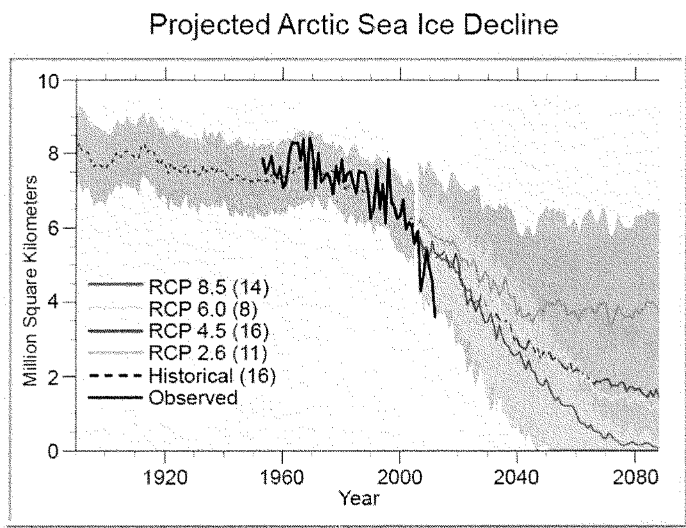

Figure 2.29: Projected Arctic Sea Ice Decline

Caption: Model simulations of Arctic sea ice extent for September, 1900-2100, based on observed concentrations of heat-trapping gases and particles (through 2005) and four emissions scenarios: RCP 2.6 (green line), RCP 4.5 (blue line), RCP 6.0 (yellow line), and RCP 8.5 (red line); numbers in parentheses denote number of models represented. Colored lines for RCP scenarios are model averages (CMIP5). Shading shows ranges among models (pink for RCP 8.5 simulations, blue for RCP 4.5 simulations). The thick black line shows observed data for 1953-2012. These newer model simulations project acceleration in sea ice loss relative to older simulations. (Figure source: adapted from Stroeve et al. 2012).

The surface of the Greenland Ice Sheet has been experiencing summer melting over increasingly large areas during the past several decades. In the decade of the 2000s, the daily melt area summed over the warm season was double the corresponding amounts of the 1970s (Fettweis et al. 2011), culminating in summer melt that was far greater (97% of the Greenland Ice Sheet area) in 2012 than in any year since the satellite record began in

1979. More importantly, the rate of mass loss from the Greenland Ice Sheet has accelerated in recent decades, increasing Greenland's contribution to sea level rise (Dahl-Jensen et al. 2011). The proportion of global sea level rise coming from Greenland is expected to continue to increase (Dahl-Jensen et al. 2011). However, the dynamics of the Greenland Ice Sheet are generally not included in present global climate models.

Glaciers are retreating and/or thinning in Alaska and in the lower 48 states. In addition, permafrost temperatures are increasing over Alaska and much of the Arctic. Regions of discontinuous permafrost in interior Alaska (where annual average soil temperatures are already close to 32°F) are highly vulnerable to thaw. Thawing permafrost releases carbon dioxide and methane, heat-trapping gases that contribute to even more warming. Methane emissions have been detected from Alaskan lakes underlain by permafrost (Walter et al. 2007), and measurements suggest potentially even greater releases from the Arctic continental shelf in the East Siberian Sea (Shakhova et al. 2010).

Ocean Acidification

The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about potential impacts on marine ecosystems.

As human-induced emissions of carbon dioxide (CO_2) build up in the atmosphere, excess CO_2 is dissolving into the oceans where it reacts with seawater to form carbonic acid, lowering ocean pH levels ("acidification") and threatening a number of marine ecosystems (Doney et al. 2009). Currently, the oceans absorbs about a quarter of the CO_2 humans produce every year (Le Quere et al. 2009). Over the last 250 years, the oceans have absorbed 530 billion tons of CO_2, increasing the acidity of surface waters by 30% (Caldeira and Wickett 2003; Hall-Spencer et al. 2008; Hönisch et al. 2012). Although the average oceanic pH can vary on interglacial timescales (Caldeira and Wickett 2003), the current observed rate of change is roughly 50 times faster than known historical change (Byrne et al. 2010). Regional factors such as coastal upwelling (Feely et al. 2008), changes in riverine and glacial discharge rates (Mathis et al. 2011), sea ice loss (Yamamoto-Kawai et al. 2009), and urbanization (Feely et al. 2010) have created "ocean acidification hotspots" where changes are occurring at even faster rates.

The acidification of the oceans has already caused a suppression of carbonate mineral concentrations that are critical for marine calcifying animals such as corals, zooplankton, and shellfish. Many of these animals form the foundation of the marine food web. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Ocean acidification puts this important resource at risk.

Observations have shown that the northeastern Pacific Ocean, including the arctic and sub-arctic seas, is particularly susceptible to significant shifts in pH and calcium carbonate concentrations. Recent analyses show that large areas of the oceans along the U.S. west coast (Gruber et al. 2012), the Bering Sea, and the western Arctic Ocean (Orr et al. 2005) will become difficult for calcifying animals within the next 50 years. In particular, animals that form calcium carbonate shells, including corals, crabs, clams, oysters, and tiny free-swimming snails called pteropods, could be particularly vulnerable, especially during the larval stage (Doney et al. 2012; Fabry et al. 2009).

Projections indicate that in a high emissions scenario such as SRES A2 or RCP 8.5, current pH could be reduced from the current level of 8.07 to as low as 7.67 by the end of the century, roughly five times the amount of acidification that has already occurred (NOAA 2012). Such large changes in ocean pH have probably not been experienced on the planet for the past 21 million years, and scientists are unsure whether and how quickly ocean life could adapt to such rapid acidification.

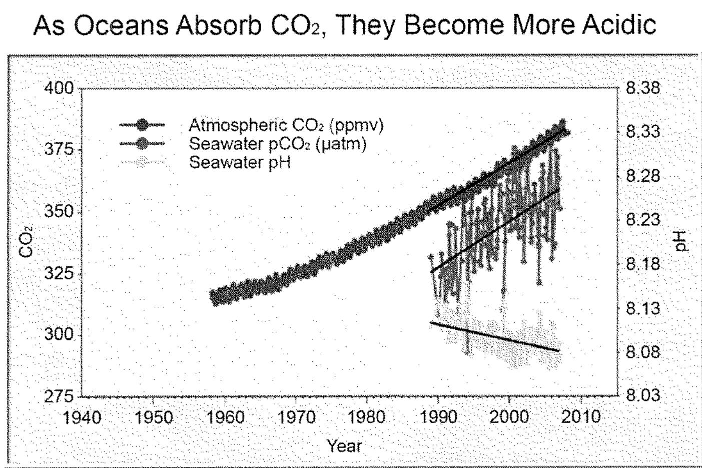

Figure 2.30: As Oceans Absorb CO_2, They Become More Acidic

Caption: The correlation between rising levels of carbon dioxide in the atmosphere at Mauna Loa with rising carbon dioxide levels and falling pH in the nearby ocean at Station Aloha. As carbon dioxide accumulates in the ocean, the water becomes more acidic. Figure source: modified from (Feel.y et al. 2008).

Shells Dissolve in Acidified Ocean Water

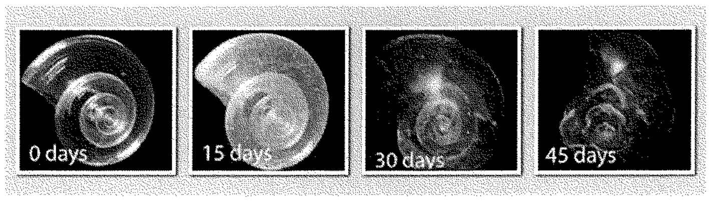

Figure 2.31: Shells Dissolve in Acidified Ocean Water

Caption: The Pteropod, or "sea butterfly", is a tiny sea creature about the size of a small pea. Pteropods are eaten by marine species ranging in size from krill to whales and are a major source of food for North Pacific young salmon. The photos above show what happens to a pteropod's shell when placed in seawater with pH and carbonate levels projected for the year 2100. The shell slowly dissolves after 45 days. (Photo credit: National Geographic Images)

Traceable Accounts

Chapter 2: Our Changing Climate

Key Message Process: Development of the key messages involved: 1) discussions of the lead authors and accompanying analyses conducted via one in-person meeting plus a number of teleconferences over the last 8 months (from February thru September 2012) including reviews of the scientific literature; and 2) the findings from four special workshops that related to the latest science understanding of climate extremes. Each workshop had a different theme related to climate extremes, had approximately 30 attendees (the CMIP5 meeting had more than 100), and resulted in a paper submitted to BAMS (2012). The first was held in July 2011, titled Monitoring Changes in Extreme Storm Statistics: State of Knowledge (https://sites.google.com/a/noaa.gov/severe-storms-workshop/). The second was held in November 2011, titled November 2011 – Forum on Trends and Causes of Observed Changes in Heatwaves, Coldwaves, Floods, and Drought (https://sites.google.com/a/noaa.gov/heatwaves-coldwaves-floods-droughts/). The third was held in January 2012, titled Forum on Trends in Extreme Winds, Waves, and Extratropical Storms along the Coasts (https://sites.google.com/a/noaa.gov/extreme-winds-waves-extratropical-storms/). The fourth, the CMIP5 results workshop, was held in March 2012 in Hawaii.

In developing key messages, the Chapter Author Team engaged in multiple technical discussions over the last 8 months via teleconferences and emails as they reviewed over 80 technical inputs provided by the public, as well as other published literature, and professional judgment. These discussions were supported by targeted consultation with additional experts, and they were based on criteria that help define "key vulnerabilities." A consensus-based approach was used for final key message selection.

Key message #1/11	**Global climate is changing now and this change is apparent across a wide range of observations. The climate change of the past 50 years is primarily due to human activities.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Generally, those reports did not add much to the author team's process in the way of observation and model data analyses and their use of the peer-reviewed literature. Evidence for changes in global climate arises from multiple analyses of data from in-situ, satellite, and other records undertaken by many groups over several decades (Kennedy et al. 2010). Changes in the mean state have been accompanied by changes in the frequency and nature of extreme events (Alexander et al. 2006) . A substantial body of analysis comparing the observed changes to a broad range of climate simulations consistently points to the necessity of invoking human-caused changes to adequately explain the observed climate system behavior(Gillett et al. 2012; Stott et al. 2010). The influence of human impacts on the climate system was also observed in a number of individual climate variables (AchutaRao et al. 2006; Gillett and Stott 2009; Min et al. 2011; Pall et al. 2011; Santer et al. 2007; Santer 2012; Willett et al. 2007) .
New information and remaining uncertainties	Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to simulate and attribute such changes using climate models. Innovative new approaches to climate data analysis, continued improvements in climate modeling, and instigation and maintenance of reference quality observation networks such as the US Climate Reference Network can all reduce uncertainties.
Assessment of confidence based	There is **very high** confidence that global climate is changing and this change is apparent across a wide range of observations given the evidence base and remaining

on evidence	uncertainties. All observational evidence is consistent with a warming climate since the late 1800's. There is **very high** confidence that the climate change of the past 50 years is primarily due to human activities given the evidence base and remaining uncertainties. Recent changes have been consistently attributed in large part to human factors across a very broad range of climate system characteristics.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 2: Climate Science

Key Message Process: See KM#1.

Key message #2/11	**Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the climate is to those emissions.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Evidence of continued global warming is based on past observations of climate change and our knowledge of the climate system's response to heat-trapping gases. Models have projected increased temperature under a number of different scenarios (IPCC 2007; Schnellnhuber et al. 2006; Taylor et al. 2012). Evidence that the planet has warmed is "unequivocal" (IPCC 2007), and is corroborated though multiple lines of evidence, as is the conclusion that the causes are very likely human in origin. The evidence for future warming is based on fundamental understanding of the behavior of heat-trapping gases in the atmosphere. Model simulations provide bounds on the estimates of this warming.
New information and remaining uncertainties	There are several major sources of uncertainty in making projections of climate change. The relative importance of these changes over time. In next few decades, the effects of natural variability will be an important source of uncertainty for climate change projections. Uncertainty in future human emissions becomes the largest source of uncertainty by the end of this century. Uncertainty in how sensitive the climate is to increased concentrations of heat-trapping gases is especially important beyond the next few decades. Uncertainty in natural climate drivers, e.g. how much will the solar output change over this century, also affects the accuracy of projections.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that global climate is projected to continue to change over this century and beyond.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 2: Climate Science

Key Message Process: See KM#1.

Key message #3/11	**U.S. average temperature has increased by about 1.5 degrees F since record keeping began in 1895; more than 80% of this increase has occurred since 1980. The most recent decade was the nation's warmest on record. U.S. temperatures are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, smooth across the country or over time.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Evidence for the long-term increase in temperature is based on analysis of daily maximum and minimum temperature observations from the U.S. Cooperative Observer Network. With the increasing understanding of U.S. temperature measurements, (Fall et al. 2010; Fall et al. 2011; Karl et al. 1986; Menne and Williams Jr 2009; Menne et al. 2009; Menne et al. 2010; Vose et al. 2012; Williams et al. 2012) a temperature increase has been observed and is projected to continue rising (Menne et al. 2009). Observations show that the last decade was the warmest in over a century. A number of climate model simulations were performed to assess past, and to forecast future changes in climate; temperatures are generally projected to increase across the U.S. All peer-reviewed studies to date satisfying the assessment process agree that the U.S. has warmed over the past century and in the past several decades. Climate model simulations consistently project future warming and bracket the range of plausible increases.
New information and remaining uncertainties	There have been substantial advances in our understanding of the U.S. temperature record since the previous National Climate Assessment (Fall et al. 2010; Fall et al. 2011; Karl et al. 2009; Menne and Williams Jr 2009; Menne et al. 2009; Menne et al. 2010; Vose et al. 2012; Williams et al. 2012). A potential uncertainty is the sensitivity of temperature trends to bias adjustments that account for historical changes in station location, temperature instrumentation, observing practice, and siting conditions. However, quality analyses of these uncertainties have not found any major issues of concern affecting the conclusions made in the key message While numerous studies verify the efficacy of the bias adjustments, the information base can be improved in the future through continued refinements to the adjustment approach. Model biases are subject to changes in physical effects on climate; for example, model biases can be affected by snow cover and hence are subject to change in a warming climate.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, smooth across the country or over time.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 2: Climate Science

Key Message Process: See KM#1.

Key message #4/11	**The length of the frost-free season (and the corresponding growing season) is increasing nationally, with the largest increases occurring in the western U.S., affecting ecosystems and agriculture. Continued lengthening of the growing seasons across the U.S. is projected.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Evidence that the length of the frost-free season is lengthening is based on extensive analysis of daily minimum temperature observations from the U.S. Cooperative Observer Network. The geographic variations of increasing number of frost-free days are similar to changes in mean temperature. Separate analysis of surface data also indicates a trend towards an earlier onset of spring. Key references: U.S. Environmental Protection Agency (2010), Dragoni et al. (2011), Jeong et al.(2011), Ziska et al.(2011). Nearly all studies to date published in the peer-reviewed literature (e.g., Dragoni et al. (2011), U.S. Environmental Protection Agency (2010), Jeong et al.(2011)) agree that the freeze-free and growing seasons have lengthened. This is most apparent in the western U.S. Peer-reviewed studies also indicate that continued lengthening will occur if concentrations of heat-trapping gases continue to rise. The magnitude of future changes based on model simulations is large in the context of historical variations.
New information and remaining uncertainties	A key issue (uncertainty) is the potential effect of station inhomogeneities on observed trends, particularly those arising from instrumentation changes. A second key issue is the extent to which observed regional variations (more lengthening in the west/less in the east) will persist into the future. Local temperature biases in climate models contribute to the uncertainty in projections. Viable avenues to improving the information base are to investigate the sensitivity of observed trends to potential biases introduced by station inhomogeneities and to investigate the causes of observed regional variations.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **very high** that the length of the frost-free season (also referred to as the growing season) is increasing nationally, with the largest increases occurring in the western U.S, affecting ecosystems, gardening, and agriculture. Confidence is **very high** that there will be continued lengthening of these seasons across the U.S. given the evidence base.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See KM#1.

Key message #5/11	**Precipitation over the U.S. has increased on average during the period since 1900, with the largest increases the Midwest, southern Great Plains, and Northeast. Portions of the Southeast, the Southwest, and the Rocky Mountain states have experienced decreases. More winter and spring precipitation is projected for the northern U.S., and less for the Southwest, over this century.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Evidence of long-term change in precipitation is based on analysis of daily observations from the U.S. Cooperative Observer Network. Published work shows the regional differences in precipitation (McRoberts and Nielsen-Gammon 2011; Peterson et al. 2012) . Evidence of future change is based on our knowledge of the climate system's response to heat-trapping gases and an understanding of the regional mechanisms behind the projected changes (e.g., IPCC 2007).
New information and remaining uncertainties	A key issue (uncertainty) is the sensitivity of observed precipitation trends to historical changes in station location, rain gauges, and observing practice. A second key issue is the extent to which observed regional variations will persist into the future. An uncertainty in projected precipitation concerns the extent of the drying of the Southwest. Shifts in precipitation patterns due to changes in pollution are uncertain and is an active research topic. Viable avenues to improving the information base are to investigate the sensitivity of observed trends to potential biases introduced by station changes and to investigate the causes of observed regional variations. A number of peer-reviewed studies (e.g., (McRoberts and Nielsen-Gammon 2011; Peterson et al. 2012)) document precipitation increases at the national scale as well as regional-scale increases and decreases. The variation in magnitude and pattern of future changes from climate model simulations is large relative to observed (and modeled) historical variations.
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, confidence is **high** that precipitation over the U.S. has increased on average during the period since 1900, with the largest increases the Midwest, southern Great Plains, and Northeast. Confidence is **high** given the evidence base and uncertainties that portions of the Southeast, the Southwest, and the Rocky Mountain states have experienced precipitation decreases. There **is less certainty** for Southwest mountain states because they sit in the transition region. Confidence is **high** given the evidence base and uncertainties that more winter and spring precipitation is projected for the northern U.S., and less for the Southwest, over this century.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See KM#1.

Key message #6/11	**Heavy downpours are increasing nationally, especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Evidence that extreme precipitation is increasing is based primarily on analysis of hourly and daily precipitation observations from the U.S. Cooperative Observer Network and is supported by observed increases in atmospheric water vapor (Dai 2012). Recent publications have projected an increase in extreme precipitation events (Kunkel et al. 2012h; Wang and Overland 2009), with some areas getting larger increases (Karl et al. 2009) and some getting decreases (Wehner 2012; Wuebbles et al. 2012). Nearly all studies to date published in the peer-reviewed literature agree that extreme precipitation event number and intensity have risen, when averaged over the United States. The pattern of change for the wettest day of the year is projected to roughly follow that of the average precipitation with both increases and decreases across the U.S. Extreme hydrologic events are likely to increase over most of the U.S.
New information and remaining uncertainties	A key issue (uncertainty) is the ability of climate models to simulate precipitation. This is one of the more challenging aspects of modeling of the climate system because precipitation involves not only large-scale processes that are well-resolved by models but small-scale process, such as convection, that must be parameterized in the current generation of global and regional climate models. Viable avenues to improving the information base are to perform some long very high resolution simulations of this century's climate under different emissions scenarios
Assessment of confidence based on evidence	Given the evidence base and uncertainties, confidence is **high** that heavy downpours are increasing nationally, with especially large increases in the Midwest and Northeast. Confidence is **high** that further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas given the evidence base and uncertainties.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See KM#1.

Key message #7/11	**Certain types of extreme weather events have become more frequent and intense, including heat waves, floods, and droughts in some regions. The increased intensity of heat waves has been most prevalent in the western parts of the country, while the intensity of flooding events has been more prevalent over the eastern parts. Droughts in the Southwest and heat waves everywhere are projected to become more intense in the future.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Analysis of U.S. temperature records indicates that record cold events are becoming progressively less frequent relative to record high events. Evidence for these trends in the United States is provided by Meehl et al.(2009). Cited papers by Stott et al. (2010) and Christidis et al.(2011) contain evidence for the corresponding trends in a global framework. A number of publications have explored the increasing trend of heat waves (Karl et al. 2008; Stott et al. 2010; Trenberth 2011). Additionally, heat waves observed in the southern Great Plains (Karl et al. 2009), Europe (Stott et al. 2010; Trenberth 2011) and Russia (Christidis et al. 2011; Duffy and Tebaldi 2012; Meehl et al. 2009) have now been shown to have a higher probability of having occurred because of human-induced climate change. Some parts of the U.S. have been seeing changing trends for floods and droughts over the last 50 years, with some evidence for human influence (Barnett et al. 2008; Hidalgo et al. 2009; Pall et al. 2011; Peterson et al. 2012; Pierce et al. 2008). Further evidence for these trends is provided by Trenberth (2011). Projections of increased drought are supported by the results of Wehner et al.(2011), with a number of publications projecting drought as becoming a more normal condition over much of the southern and central U.S. (most recent references: Dai 2012; Hoerling et al. 2012b). Analyses of U.S. daily temperature records indicate that low records are being broken at a much smaller rate than high records, and at the smallest rate in the historical record. However, in certain localized regions, natural variations can be as large or larger than the human induced change.
New information and remaining uncertainties	The key uncertainty regarding projections of future drought is how soil moisture responds to precipitation changes and potential evaporation increases. Most studies indicate that many parts of the U.S. will experience drier soil conditions but the amount of that drying is uncertain. Natural variability is also an uncertainty affecting extreme event occurrences in shorter timescales (several years to decades), but the changes become larger relative to natural variability as the timescale lengthens. Stakeholders should view the occurrence of extreme events in the context of increasing probabilities. Continuation of long term temperature and precipitation observations is critical to monitoring trends in extreme weather events.
Assessment of confidence based on evidence	Give the evidence base and uncertainties: Heat waves have become more frequent and intense, and confidence is **high** that these trends are projected to continue. Droughts have become more frequent and intense in some regions, and confidence is **high** that these trends are projected to continue.

	Floods have become more frequent and intense in some regions, and confidence is **medium** to **high** that these trends are projected to continue.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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Key Message Process: See KM#1.

Key message #8/11	**There has been an increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s. The intensity of the strongest hurricanes is projected to continue to increase as the oceans continue to warm. With regard to other types of storms that affect the U.S., winter storms have increased slightly in frequency and intensity, and their tracks have shifted northward over the U.S. Other trends in severe storms, including the numbers of hurricanes and the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds are uncertain and are being studied intensively.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Recent studies suggest that the most intense Atlantic hurricanes have become stronger since the early 1980s, as documented by (Kossin et al. 2007) . While this is still the subject of active research, this trend is projected to continue (Bender et al. 2010). Current work by Vose et al. (2012) has provided evidence in the increase in frequency and intensity of winter storms, with the storm tracks shifting poleward (Wang et al. 2006; Wang et al. 2012), but some areas have experienced a decrease in winter storm frequency (Karl et al. 2009). Some recent research has provided insight into the connection of global warming to tornados and severe thunderstorms (Del Genio et al. 2007; Trapp et al. 2007).
New information and remaining uncertainties	Detecting trends in Atlantic and eastern North Pacific hurricane activity is challenged by a lack of consistent historical data and limited understanding of all of the complex interactions between the atmosphere and ocean that influence hurricanes. Significant uncertainties remain in making projections of hurricane number and intensity. While the best analyses to date suggest an increase in intensity and in the number of most intense storms over the century, there remain significant uncertainties. The figure in the chapter for KM#8 that shows projected changes in occurrences of hurricanes of different intensities includes data points from different models, illustrating the spread. Other types of storms have even greater uncertainties in their recent trends and projections. The text for this key message explicitly acknowledges the state of knowledge, pointing out "what we don't know".
Assessment of confidence based on evidence	Given the evidence and uncertainties, confidence is **medium** that the strongest hurricanes are projected to increase in intensity as the oceans warm due to more available energy. Confidence is **low** regarding other trends in severe storms due to the many uncertainties that remain about frequency and intensity of other types of storms.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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Key Message Process: See KM#1.

Key message #9/11	Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Nearly all studies to date published in the peer-reviewed literature agree that global sea level has risen during the past century, and that it will continue to rise over the next century. Tide gauges throughout the world have documented rising sea levels during the last 130 years. This rise has been further confirmed over the past 20 years by satellite observations, which are highly accurate and have nearly global coverage. Recent studies have shown current sea level rise rates are increasing (Kemp et al. 2012; Parris et al. 2012) and project that future sea level rise over the rest of this century will be faster than those of the last 100 years (Parris et al. 2012; Willis et al. 2010).
New information and remaining uncertainties	The key issue in predicting future rates of global sea level rise is to understand and predict how ice sheets in Greenland and Antarctica will react to a warming climate. Current projections of global sea level rise do not account for the complicated behavior of these giant ice slabs as they interact with the atmosphere, the ocean and the land. Lack of knowledge about the ice sheets and their behavior is the primary reason that projections of global sea level rise includes such a wide range of plausible future conditions. Early efforts at semi-empirical models suggested much higher rates of sea level rise (as much as 6 feet by 2100) (Jevrejeva et al. 2010; Vermeer and Rahmstorf 2009). More recent semi-empirical models have suggested upper bounds closer to 3 or 4 feet (Jevrejeva et al. 2012; Rahmstorf et al. 2012). It is not clear, however, whether these statistical relationships will hold in the future. More recent work suggests that a high-end of 3 to 4 feet is more plausible. (Gladstone et al. 2012; Jevrejeva et al. 2012; Joughin et al. 2010; Katsman et al. 2011; Rahmstorf et al. 2012). Some decision makers may wish to consider a broader range of scenarios such as 8 inches or 6.6 feet by 2100 in the context of risk-based analysis (Burkett and Davidson 2012; Parris et al. 2012) .
Assessment of confidence based on evidence	Given the evidence and uncertainties, confidence is **very high** that global sea level has risen during the past century, and that it will continue to rise over this century. Given the evidence and uncertainties about ice sheet dynamics, confidence is **high** that the rate of global sea level rise has been faster since the early 1990s, but there is **medium** confidence in global sea level rise will be in the range of 1 to 4 feet by 2100.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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Key Message Process: See KM#1.

Key message #10/11	**Rising temperatures are reducing ice on land, lakes, and sea. This loss of ice is expected to continue.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. There have been a number of publications reporting decreases in ice on land (Fettweis et al. 2011) and glacier recession . Evidence that winter lake ice and summer sea ice are rapidly declining is based on satellite data and is incontrovertible (for lake ice Arctic Monitoring and Assessment Programme 2011; Wang et al. 2012). Nearly all studies to date published in the peer-reviewed literature agree that summer Arctic sea ice extent is rapidly declining and that if heat-trapping gas concentrations continue to rise, an essentially ice-free Arctic ocean will be realized sometime during this century (e.g., Stroeve et al. 2012; KM 10). September 2012 has the lowest levels of Arctic ice in recorded history. Great Lakes ice should follow a similar trajectory. Glaciers will generally retreat, except for a small percentage of glaciers that experience dynamical surging (Arctic Monitoring and Assessment Programme 2011). The rate of permafrost degradation is complicated by changes in snow cover and vegetation.
New information and remaining uncertainties	A key issue (uncertainty) is the rate of sea-ice loss through this century, which stems from a combination of large differences in projections between different climate models, natural climate variability and future rates of fossil fuel emissions. This uncertainty is illustrated in the figure showing the CMIP5-based projections (from Stroeve et al. 2012). Viable avenues to improving the information base are determining the primary causes of the range of different climate model projections and determining which climate models exhibit the best ability to reproduce the observed rate of sea ice loss.
Assessment of confidence based on evidence	Given the evidence base and uncertainties, confidence is **very high** that rising temperatures are melting sea ice, lake ice, and glaciers and that this melting is expected to continue. Given the evidence base and uncertainties, confidence is **high** that rising temperatures are thawing permafrost and that this thawing is expected to continue.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 2: Climate Science

Key Message Process: See KM#1.

Key message #11/11	**The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about potential impacts on marine ecosystems.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input. Work done by LeQuere et al. 2009 reported that the oceans currently absorb a quarter of anthropogenic CO_2. Publications have shown that this absorption causes the ocean to become more acidic (Doney et al. 2009). Recent publications demonstrate the adverse effects further acidification will have on marine life (Doney et al. 2012; Fabry et al. 2009; Gruber et al. 2012; Orr et al. 2005).
New information and remaining uncertainties	The key issue is to understand how future levels of ocean acidity will affect marine ecosystems. Absorption of anthropogenic CO_2, reduced pH, and lower calcium carbonate (CaCO3) saturation in surface waters, where the bulk of oceanic production occurs, are well verified from models, hydrographic surveys, and time series data(Orr et al. 2005).
Assessment of confidence based on evidence	**Very high** for trend of ocean acidification; **low-to-medium** for ecological consequences. Our present understanding of potential ocean acidification impacts on marine organisms stems largely from short-term laboratory and mesocosm experiments; consequently, the response of individual organisms, populations, and communities to more realistic gradual changes is largely unknown. Given the evidence base and uncertainties, confidence is **very high** that oceans are absorbing a quarter of emitted CO2.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

References

AchutaRao, K.M., B.D. Santer, P.J. Gleckler, K.E. Taylor, D.W. Pierce, T.P. Barnett, and T.M.L. Wigley, 2006: Variability of ocean heat uptake: Reconciling observations and models. *Journal of Geophysical Research*, **111,** 20 doi: 10.1029/2005jc003136

Alexander, L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. Rupa Kumar, J. Revadekar, G. Griffiths, L. Vincent, D.B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J.L. Vazquez-Aguirre, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, **111,** 22 doi: 10.1029/2005jd006290

Arctic Monitoring and Assessment Programme, 2011: *Snow, Water, Ice and Permafrost in the Arctic (SWIPA).* Cambridge University Press.

BAMS, cited 2012: State of the Climate Reports. NCDC. [Available online at http://www.ncdc.noaa.gov/bams-state-of-the-climate/]

Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger, 2008: Human-induced changes in the hydrology of the western United States. *Science*, **319,** 1080-1083 doi: 10.1126/science.1152538, [Available online at http://www.sciencemag.org/cgi/content/abstract/1152538]

Bender, M.A., T.R. Knutson, R.E. Tuleya, J.J. Sirutis, G.A. Vecchi, S.T. Garner, and I.M. Held, 2010: Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science*, **327,** 454-458 doi: 10.1126/science.1180568

Booth, B.B.B., N.J. Dunstone, P.R. Halloran, T. Andrews, and N. Bellouin, 2012: Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability. *Nature*, **484,** 228-232

Burkett, V. and M. Davidson, 2012: Coastal Impacts, Adaptation & Vulnerabilities: A Technical Input to the 2013 National Climate Assessment. U.S. Global Change Research Program

Byrne, R.H., S. Mecking, R.A. Feely, and X. Liu, 2010: Direct observations of basin-wide acidification of the North Pacific Ocean. *Geophysical Research Letters*, **37,** L02601 doi: 10.1029/2009GL040999

Caldeira, K. and M.E. Wickett, 2003: Oceanography: Anthropogenic carbon and ocean pH. *Nature*, **425,** 365-365, [Available online at http://dx.doi.org/10.1038/425365a]

Camargo, S., M. Ting, and Y. Kushnir, 2012: Influence of local and remote SST on North Atlantic tropical cyclone potential intensity. *Climate Dynamics* doi: 10.1007/s00382-012-1536-4

Cayan, D.R., T. Das, D.W. Pierce, T.P. Barnett, M. Tyree, and A. Gershunov, 2010: Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proceedings of the National Academy of Sciences of the United States of America*, **107,** 21271-21276 doi: 10.1073/pnas.0912391107

Christidis, N., P.A. Stott, and S.J. Brown, 2011: The role of human activity in the recent warming of extremely warm daytime temperatures. *Journal of Climate*, **24**, 1922-1930 doi: 10.1175/2011JCLI4150.1

Christy, J.R., 2012: Searching for information in 133 years of California snowfall observations. *Journal of Hydrometeorology*, **13,** 895-912 doi: 10.1175/JHM-D-11-040.1

Church, J.A. and N.J. White, 2011a: Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, **32,** 585-602 doi: 10.1007/s10712-011-9119-1

Church, J.A., N.J. White, L.F. Konikow, C.M. Domingues, J.G. Cogley, E. Rignot, J.M. Gregory, M.R. van den Broeke, A.J. Monaghan, and I. Velicogna, 2011: Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. *Geophys. Res. Lett.*, **38,** L18601 doi: 10.1029/2011GL048794, [Available online at http://dx.doi.org/10.1029/2011GL048794]

Cook, B.I., R.L. Miller, and R. Seager, 2009: Amplification of the North American "Dust Bowl" drought through human-induced land degradation. *Proceedings of the National Academy of Sciences*, **106,** 4997-5001, [Available online at http://www.pnas.org/content/106/13/4997.abstract]

Dahl-Jensen, D., J.J. Bamber, C.E. Bøggild, E. Buch, J.H.H. Christensen, K. Dethloff, and M. Fahnestock, 2011: Chapter 8: The Greenland Ice Sheet in a changing climate. *Snow, Water, Ice and Permafrost in the Arctic (SWIPA)* Arctic Monitoring and Assessment Programme (AMAP)

Dai, A., 2006: Recent climatology, variability, and trends in global surface humidity. *Journal of Climate*, **19,** 3589-3606 doi: 10.1175/JCLI3816.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/JCLI3816.1]

——, 2012: Increasing drought under global warming in observations and models. *Nature Climate Change* doi: 10.1038/nclimate1633 [Available online at http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate1633.html?utm_source=feedblitz&utm_medium=FeedBlitzEmail&utm_content=559845&utm_campaign=0]

Del Genio, A.D., M.S. Yao, and J. Jonas, 2007: Will moist convection be stronger in a warmer climate? *Geophysical Research Letters*, **34,** 5 doi: 10.1029/2007GL030525 [Available online at http://www.agu.org/pubs/crossref/2007/2007GL030525.shtml]

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009: Ocean Acidification: The Other CO_2 Problem. *Annual Review of Marine Science*, **1,** 169-192 doi: 10.1146/annurev.marine.010908.163834, [Available online at http://www.annualreviews.org/doi/abs/10.1146/annurev.marine.010908.163834]

Doney, S.C., M. Ruckelshaus, J.E. Duffy, J.P. Barry, F. Chan, C.A. English, H.M. Galindo, J.M. Grebmeier, A.B. Hollowed, and N. Knowlton, 2012: Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, **4,** 11-37 doi: 10.1146/annurev-marine-041911-111611, [Available online at http://www.annualreviews.org/eprint/fzUZd7Z748TeHmB7p8cn/full/10.1146/annurev-marine-041911-111611]

Dragoni, D., H.P. Schmid, C.A. Wayson, H. Potter, C.S.B. Grimmond, and J.C. Randolph, 2011: Evidence of increased net ecosystem productivity associated with a longer vegetated season in a deciduous forest in south-central Indiana, USA. *Global Change Biology*, **17,** 886-897 doi: 10.1111/j.1365-2486.2010.02281.x, [Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02281.x/full]

Duffy, P.B. and C. Tebaldi, 2012: Increasing prevalence of extreme summer temperatures in the U.S. *Climatic Change*, **111,** 487-495 doi: 10.1007/s10584-012-0396-6

Easterling, D.R. and M.F. Wehner, 2009: Is the climate warming or cooling? *Geophysical Research Letters*, **36** doi: 10.1029/2009GL037810, [Available online at http://dx.doi.org/10.1029/2009GL037810]

Emmanuel, W., 2012: Projected Changes in Seasonal Precipitation

Evan, A., G. Foltz, and D. Zhang, 2012: Physical response of the tropical-subtropical North Atlantic Ocean to decadal-multidecadal forcing by African dust. . *Journal of Climate*, **in press**

Evan, A.T., G.R. Foltz, D. Zhang, and D.J. Vimont, 2011: Influence of African dust on ocean-atmosphere variability in the tropical Atlantic. *Nature Geoscience*, **4,** 762-765 doi: 10.1038/ngeo1276 [Available online at http://www.nature.com/ngeo/journal/v4/n11/full/ngeo1276.html]

Evan, A.T., D.J. Vimont, A.K. Heidinger, J.P. Kossin, and R. Bennartz, 2009: The role of aerosols in the evolution of tropical North Atlantic Ocean temperature anomalies. *Science*, **324,** 778-781 doi: 10.1126/science.1167404 [Available online at http://www.sciencemag.org/content/324/5928/778.short]

Fabry, V.J., J.B. McClintock, J.T. Mathis, and J.M. Grebmeier, 2009: Ocean Acidification at high latitudes: The Bellwether. *Oceanography*, **22,** 160-171, [Available online at http://www.tos.org/oceanography/archive/22-4_fabry.html]

Fall, S., D. Niyogi, A. Gluhovsky, R.A.P. Sr, E. Kalnay, and G. Rochon, 2010: Impacts of land use land cover on temperature trends over the continental United States: assessment using the North American Regional Reanalysis. *International Journal of Climatology*, **30,** 1980-1993 doi: 10.1002/joc.1996

Fall, S., A. Watts, J. Nielsen-Gammon, E. Jones, D. Niyogi, J.R. Christy, and R.A.P. Sr, 2011: Analysis of the impacts of station exposure on the US Historical Climatology Network temperatures and temperature trends. *Journal of Geophysical Research*, **116,** 15 doi: 10.1029/2010JD015146

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson, and B. Hales, 2008: Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf. *Science*, **320,** 1490-1492 doi: 10.1126/science.1155676, [Available online at http://www.sciencemag.org/content/320/5882/1490.short]

Feely, R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy, 2010: The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. *Estuarine, Coastal and Shelf Science*,

88, 442-449 doi: 10.1016/j.ecss.2010.05.004,, [Available online at http://www.sciencedirect.com/science/article/pii/S027277141000185X]

Fettweis, X., M. Tedesco, M.R.v.d. Broeke, and J. Ettema, 2011: Melting trends over the Greenland ice sheet (1958–2009) from spaceborne microwave data and regional climate models. *The Cryosphere*, **5,** 359-375, [Available online at http://www.the-cryosphere.net/5/359/2011/tc-5-359-2011.html]

Foster, G. and S. Rahmstorf, 2011: Global temperature evolution 1989-2010. *ERL*, **6**

Francis, J.A. and S.J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*, **39,** 6 doi: 10.1029/2012GL051000 [Available online at http://www.agu.org/pubs/crossref/2012/2012GL051000.shtml]

Gillett, N. and P. Stott, 2009: Attribution of anthropogenic influence on seasonal sea level pressure. *Geophys. Res. Lett*, **36,** 5 doi: 10.1029/2009GL041269

Gillett, N.P., V.K. Arora, G.M. Flato, J.F. Scinocca, and K.v. Salzen, 2012: Improved constraints on 21st-century warming derived using 160 years of temperature observations. *Geophysical Research Letters*, **39,** 5 doi: 10.1029/2011GL050226 [Available online at http://www.agu.org/pubs/crossref/2012/2011GL050226.shtml]

Gladstone, R.M., V. Lee, J. Rougier, A.J. Payne, H. Hellmer, A. Le Brocq, A. Shepherd, T.L. Edwards, J. Gregory, and S.L. Cornford, 2012: Calibrated prediction of Pine Island Glacier retreat during the 21st and 22nd centuries with a coupled flowline model. *Earth and Planetary Science Letters*, **333,** 191-199

Gruber, N., C. Hauri, Z. Lachkar, D. Loher, T.L. Frölicher, and G.K. Plattner, 2012: Rapid progression of ocean acidification in the California Current System. *Science*, **337,** 220-223 doi: 10.1126/science.1216773 [Available online at http://www.sciencemag.org/content/337/6091/220.short]

Hall-Spencer, J.M.; R. Rodolfo-Metalpa; S. Martin; E. Ransome; M. Fine; S.M. Turner; S.J. Rowley; D. Tedesco; and M.-C. Buia (2008). Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature, 3 July 2008: Vol. 454 no. 7200pp96-99. DOI: http://dx.doi.org/10.1038/nature07051

Hansen, J., M. Sato, and R. Ruedy, 2012: Perception of climate change. *Proceedings of the National Academy of Sciences*, **109,** E2415-E2423, [Available online at http://www.pnas.org/content/109/37/E2415.abstract]

Hayhoe, K., C.P. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles, 2008: Regional Climate Change Projections for the Northeast U.S. *Mitigation and Adaptation Strategies for Global Change*, **13,** 425-436

Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emissions Pathways, Climate Change, and Impacts on California. *Proceedings of the National Academy of Sciences*, **101,** 12422-12427 doi: DOI 10.1073/pnas.0404500101

Hidalgo, H.G., T. Das, M.D. Dettinger, D.R. Cayan, D.W. Pierce, T.P. Barnett, G. Bala, A. Mirin, A.W. Wood, and C. Bonfils, 2009: Detection and attribution of streamflow timing changes to climate change in the western United States. *Journal of Climate*, **22,** 3838-3855 doi: 10.1175/2009JCLI2470.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2009JCLI2470.1]

Hirsch, R.M. and K.R. Ryberg, 2012: Has the magnitude of floods across the USA changed with global CO_2 levels? *Hydrological Sciences Journal*, **57,** 1-9 doi: 10.1080/02626667.2011.621895, [Available online at http://www.tandfonline.com/doi/abs/10.1080/02626667.2011.621895]

Hoerling, M., H. Diaz, R.D.D. Easterling, J. Eischeid, X.-W. Quan, and R. Webb, 2012b Is a Transition to Semi-Permanent Drought Conditions Imminent in the Great Plains? *Journal of Climate*, **submitted**

Hoerling, M., M. Chen, R. Dole, J. Eischeid, A. Kumar, J.W. Nielsen-Gammon, P. Pegion, J. Perlwitz, X.-W. Quan, and T. Zhang, 2012a: Anatomy of an extreme event. *Journal of Climate*, **in press** doi: 10.1175/JCLI-D-12-00270.1

Hönisch, B.; A. Ridgwell; D.N. Schmidt; E. Thomas; S.J. Gibbs; A. Sluijs, R. Zeebe; L. Kump; R.C. Martindale; S.E. Greene; W. Kiessling; J. Ries; J.C. Zachos; D.L. Royer; S. Barker; T.M. Marchitto Jr.; R. Moyer; C. Pelejero; P. Ziveri; G.L. Foster; and B. Williams (2012). The Geological Record of Ocean Acidification, Science, 2 March 2012: Vol. 335 no. 6072 pp. 1058-1063. DOI: 10.1126/science.1208277

IPCC, 2007: Climate Change 2007: The Physical Science basis: Summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 996 pp

Jeong, S.J., C.H. Ho, H.J. Gim, and M.E. Brown, 2011: Phenology shifts at start vs. end of growing season in temperate vegetation over the Northern Hemisphere for the period 1982-2008. *Global Change Biology*, **17**, 2385-2399 doi: 10.1111/j.1365-2486.2011.02397.x, [Available online at <Go to ISI>://WOS:000291221000010]

Jevrejeva, S., A. Grinsted, and J.C. Moore, 2010: Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics*, **34,** 461-472 doi: 10.1007/s00382-008-0507-2

Jevrejeva, S., J.C. Moore, and A. Grinsted, 2012: Sea level projections to AD2500 with a new generation of climate change scenarios. *Global and Planetary Change*, **80-81,** 14-20 doi: 10.1016/j.gloplacha.2011.09.006

Jevrejeva, S., J. Moore, A. Grinsted, and P. Woodworth, 2008: Recent global sea level acceleration started over 200 years ago. *Geophysical Research Letters*, **35,** 4 doi: doi:10.1029/2008GL033611 [Available online at http://www.agu.org/pubs/crossref/2008/2008GL033611.shtml]

Joughin, I., B.E. Smith, and D.M. Holland, 2010: Sensitivity of 21st century sea level to ocean-induced thinning of Pine Island Glacier, Antarctica. *Geophys. Res. Lett.*, **37,** L20502 doi: 10.1029/2010GL044819, [Available online at http://dx.doi.org/10.1029/2010GL044819]

Karl, T.R., J.T. Melillo, and T.C. Peterson, 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press, 189 pp.

Karl, T.R., C.N.W. Jr, P.J. Young, and W.M. Wendland, 1986: A model to estimate the time of observation bias associated with monthly mean maximum, minimum and mean temperatures for the United States. *Journal of Climate Applied Meteorology*, **25,** 145-160 doi: 10.1175/1520-0450(1986)025<0145:AMTETT>2.0.CO;2

Karl, T.R., G.A. Meehl, T.C. Peterson, K.E. Kunkel, J. W.J. Gutowski, and D.R. Easterling, 2008: Executive Summary. *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and US Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray, Eds.

Karl, T.R., B.E. Gleason, M.J. Menne, J.R. McMahon, J. R.R. Heim, M.J. Brewer, K.E. Kunkel, D.S. Arndt, J.L. Privette, J.J. Bates, P.Y. Groisman, and D.R. Easterling, 2012: U.S. temperature and drought: Anomalies of spring and summer 2011-12 and trends. *EOS Transactions, AGU*, **93,** 473

Katsman, C.A., A. Sterl, J.J. Beersma, H.W. van den Brink, W. Hazeleger, R.E. Kopp, D. Kroon, J. Kwadijk, R. Lammersen, J. Lowe, M. Oppenheimer, H.-P. Plag, J. Ridley, H. von Storch, D.G. Vaughan, P. Vellinga, L.L.A. Vermeersen, R.S.W. van de Wal, and R. Weisse, 2011: Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta - the Netherlands as an example. *Climatic Change* doi: 10.1007/s10584-011-0037-5

Kay, J.E., M.M. Holland, and A. Jahn, 2011: Inter-annual to multi-decadal Arctic sea ice extent trends in a warming world. *Geophysical Research Letters*, **38,** 6 doi: 10.1029/2011GL048008 [Available online at http://www.agu.org/pubs/crossref/2011/2011GL048008.shtml]

Kemp, A.C., B.P. Horton, J.P. Donnelly, M.E. Mann, M. Vermeer, and S. Rahmstorf, 2012: Climate related sea-level variations over the past two millennia. *Proceedings of the National Academy of Sciences of the United States of America*, **108,** 11017-11022 doi: 10.1073/pnas.1015619108

Kennedy, J.J., P.W. Thorne, T.C. Peterson, R.A. Reudy, P.A. Stott, D.E. Parker, S.A. Good, H.A. Titchner, and K.M. Willett, 2010: How do we know the world has warmed? State of the Climate in 2009. *Bulletin of the American Meteorological Society*, **91,** S26-27

Kharin, V.V., F.W. Zwiers, X. Zhang, and M. Wehner, submitted: Changes in temperature and precipitation extremes in the CMIP5 ensemble. *Climatic Change*

Knight, J., J.J. Kennedy, C. Folland, G. Harris, G.S. Jones, M. Palmer, D. Parker, A. Scaife, and P. Stott, 2009: Do global temperature trends over the last decade falsify climate predictions. *Bulletin of the American Meteorological Society*, **90,** S1-196

Kossin, J.P., K.R. Knapp, D.J. Vimont, R.J. Murnane, and B.A. Harper, 2007: A Globally Consistent Reanalysis of Hurricane Variability and Trends. *Geophysical Research*

Letters, **34,** 6 doi: 10.1029/2006GL028836 [Available online at http://www.agu.org/pubs/crossref/2007/2006GL028836.shtml]

Kunkel, K.E., P.D. Bromirski, H.E. Brooks, T. Cavazos, A.V. Douglas, and D.R. Easterling, 2008: Ch. 2: Observed changes in weather and climate extremes. *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North American, Hawaii, Caribbean, and U. S. Pacific Islands. Washington, D. C.: U. S. Climate Change Science Program and the Subcommittee on Global Change Research*, T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray, Eds.

Kunkel, K.E., M.A. Palecki, L. Ensor, D. Easterling, K.G. Hubbard, D. Robinson, and K. Redmond, 2009: Trends in twentieth-century US extreme snowfall seasons. *Journal of Climate*, **22,** 6204-6216

Kunkel, K.E., D. Easterling, L. Ensor, K.G. Hubbard, M. Palecki, K. Redmond, and D. Robinson, 2009a: A new look at lake-effect snowfall trends in the Laurentian Great Lakes using a temporally homogeneous data set. *Journal of Great Lakes Research*, **35,** 23-29 doi: 10.1016/j.jglr.2008.11.003

——, 2009b: Trends in twentieth-century US snowfall using a quality-controlled dataset. *Journal of Atmospheric and Oceanic Technology*, **26,** 33-44 doi: 10.1175/2008JTECHA1138.1

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, and J.G. Dobson, 2012g: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 9. Climate of the Contiguous United States.

——, 2012f: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 6. Climate of the Northwest U.S.

——, 2012e: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 5. Climate of the Southwest U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, J. Rennells, A. DeGaetano, and J.G. Dobson, 2012a: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 1. Climate of the Northeast U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S.D. Hilberg, M.S. Timlin, L. Stoecker, N.E. Westcott, and J.G. Dobson, 2012c: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 3. Climate of the Midwest U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. Konrad, C. Fuhrman, B. Keim, M.C. Kruk, A. Billet, H. Needham, M. Schafer, and J.G. Dobson, 2012b: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M.C. Kruk, D.P. Thomas, M. Shulski, N. Umphlett, K. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T. Pathak, T. Bergantino, and J.G. Dobson, 2012d: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 4. Climate of the U.S. Great Plains.

Kunkel, K.E., T.R. Karl, H. Brooks, J. Kossin, J. Lawrimore, D. Arndt, L. Bosart, D. Changnon, S.L. Cutter, N. Doesken, K. Emanuel, P.Ya. Groisman, R.W. Katz, T. Knutson, J. O'Brien, C. J. Paciorek, T. Peterson, K. Redmond, D. Robinson, J. Trapp, R. Vose, S. Weaver, M. Wehner, K. Wolter, and D. Wuebbles, 2012h: Monitoring and understanding changes in extreme storm statistics: state of knowledge. *Bulletin of the American Meteorological Society*, **in press**

Le Quere, C., M.R. Raupach, J.G. Canadell, and G. Marland, 2009: Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, **2,** 831-836 doi: 10.1038/ngeo689, [Available online at http://www.nature.com/ngeo/journal/v2/n12/full/ngeo689.html]

Leibensperger, E.M., L.J. Mickley, D.J. Jacob, W.T. Chen, J.H. Seinfeld, A. Nenes, P.J. Adams, D.G. Streets, N. Kumar, and D. Rind, 2012: Climatic effects of 1950-2050 changes in US anthropogenic aerosols - Part 1: Aerosol trends and radiative forcing. *Atmospheric Chemistry and Physics Discussions*, **11,** 24085–24125 doi: 10.5194/acp-12-3333-2012, [Available online at <Go to ISI>://WOS:000302806700013]

Liang, X., E.F. Wood, and D.P. Lettenmaier, 1996: Surface soil moisture parameterization of the VIC-2L model: Evaluation and modification. *Global and Planetary Change*, **13,** 195-206 doi: 10.1016/0921-8181(95)00046-1

Liang, X., D.P. Lettenmaier, E.F. Wood, and S.J. Burges, 1994: A simple hydrologically based model of land surface water and energy fluxes for general circu-lation models. *Journal of Geophysical Research*, **99,** 14415-14428

Liu, J., J.A. Curry, H. Wang, M. Song, and R.M. Horton, 2012: Impact of declining Arctic sea ice on winter snowfall. *Proceedings of the National Academy of Sciences of the United States of America*, **109,** 4074-4079 doi: 10.1073/pnas.1114910109, [Available online at http://www.pnas.org/content/early/2012/02/17/1114910109.abstract]

Mann, M.E. and K.A. Emanuel, 2006: Atlantic hurricane trends linked to climate change. *Eos, Transactions American Geophysical Union*, **87,** 233 doi: 10.1029/2006EO240001

Marzeion, B., A.H. Jarosch, and M. Hofer, 2012: Past and future sea-level change from the surface mass balance of glaciers. *The Cryosphere Discuss*, **6,** 3177-3241 doi: 10.5194/tcd-6-3177-2012, [Available online at www.the-cryosphere-discuss.net/6/3177/2012/]

Mathis, J.T., J.N.Cross, and N.R. Bates, 2011: Coupling primary production and terrestrial runoff to ocean acidification and carbonate mineral suppression in the eastern Bering Sea. *Journal of Geophysical Research*, **116,** C02030 doi: 10.1029/2010JC006453

Matthews, H.D. and K. Zickfeld, 2012: Climate response to zeroed emissions of greenhouse gases and aerosols. *Nature Climate Change*, **2,** 338-341 doi: 10.1038/nclimate1424, [Available online at http://www.nature.com/nclimate/journal/v2/n5/full/nclimate1424.html]

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002: A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States*. *Journal of Climate*, **15,** 3237-3251

McRoberts, D.B. and J.W. Nielsen-Gammon, 2011: A New Homogenized Climate Division Precipitation Dataset for Analysis of Climate Variability and Climate Change. *Journal of Applied Meteorology and Climatology*, **50,** 1187-1199

Meehl, G.A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel, 2009: Relative increase of record high maximum temperatures compared to record low minimum temperatures in the US. *Geophysical Research Letters*, **36,** 5 doi: 10.1029/2009GL040736 [Available online at http://www.agu.org/pubs/crossref/2009/2009GL040736.shtml]

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, and Z.-C.Zhao, 2007: Ch. 10: Global Climate Projections. *Climate Change 2007: The Physical Science basis: Summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Cambridge University Press, 747-845. [Available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf]

Menne, M.J. and C.N. Williams Jr, 2009: Homogenization of temperature series via pairwise comparisons. *Journal of Climate*, **22,** 1700-1717 doi: 10.1175/2008JCLI2263.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2008JCLI2263.1]

Menne, M.J., C.N. Williams, and R.S. Vose, 2009: The US Historical Climatology Network monthly temperature data, version 2. *Bulletin American Meteorology Society*, **90,** 993-1007

Menne, M.J., C.N. Williams, and M.A. Palecki, 2010: On the reliability of the U.S. surface temperature record. *Journal of Geophysical Research*, **115,** 9 doi: 10.1029/2009JD013094 [Available online at http://www.agu.org/pubs/crossref/2010/2009JD013094.shtml]

Min, S.K., X. Zhang, F.W. Zwiers, and G.C. Hegerl, 2011: Human contribution to more-intense precipitation extremes. *Nature*, **470,** 378-381 doi: 10.1038/nature09763 [Available online at http://www.nature.com/nature/journal/v470/n7334/abs/nature09763.html]

Mueller, B. and S.I. Seneviratne, 2012: Hot days induced by precipitation deficits at the global scale. *Proceedings of the National Academy of Sciences of the United States of America*, **109,** 12398-12403

Nerem, R.S., D.P. Chambers, C. Choe, and G.T. Mitchum, 2010: Estimating mean sea level change from the TOPEX and Jason altimeter missions. *Marine Geodesy*, **33,** 435-446 doi: 10.1080/01490419.2010.491031

Nijssen, B., D.P. Lettenmaier, X. Liang, S.W. Wetzel, and E.F. Wood, 1997: Streamflow simulation for continental-scale river basins. *Water resources research*, **33,** 711-724 doi: 10.1029/96WR03517 [Available online at http://www.agu.org/pubs/crossref/1997/96WR03517.shtml]

NOAA, cited 2012: Ocean Acidification, Today and in the Future. NOAA's Climate.gov. [Available online at http://www.climatewatch.noaa.gov/image/2010/ocean-acidification-today-and-in-the-future]

NSIDC, cited 2012: Arctic sea ice reaches lowest extent for the year and the satellite record. The National Snow and Ice Data Center. [Available online at http://nsidc.org/news/press/2012_seaiceminimum.html]

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, **437,** 681-686 doi: 10.1038/nature04095, [Available online at http://www.nature.com/nature/journal/v437/n7059/abs/nature04095.html]

Pall, P., T. Aina, D.A. Stone, P.A. Stott, T. Nozawa, A.G.J. Hilberts, D. Lohmann, and M.R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature*, **470,** 382-385 doi: 10.1038/nature09762, [Available online at http://www.nature.com/nature/journal/v470/n7334/abs/nature09762.html]

Parris, A., P. Bromirski, V. Burkett, D. R. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss, 2012: Global sea Level Rise Scenarios for the United States National Climate Assessment

Peterson, T.C., R.R.J. Heim, R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmaier, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B.S. Silva, B.C. Stewart, A.V. Vecchia, G. Villarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C.A. Woodhouse, and D. Wuebbles, 2012: Monitoring and Understanding Changes in Heat Waves, Cold Waves, Floods and Droughts in the United States: State of Knowledge. . *Bulletin American Meteorology Society*, **submitted**

Pierce, D.W., T.P. Barnett, H.G. Hidalgo, T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D. Dettinger, D.R. Cayan, and A. Mirin, 2008: Attribution of declining western US snowpack to human effects. *Journal of Climate*, **21,** 6425-6444 doi: 10.1175/2008JCLI2405.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2008JCLI2405.1]

Rahmstorf, S., G. Foster, and A. Cazenave, 2012: Comparing climate projections to observations up to 2011. *Environmental Research Letters*, **7** doi: 10.1088/1748-9326/7/4/044035

Rahmstorf, S., M. Perrette, and M. Vermeer, 2012: Testing the robustness of semi-empirical sea level projections. *Climate Dynamics*, **39,** 861-875 doi: 10.1007/s00382-011-1226-7, [Available online at http://dx.doi.org/10.1007/s00382-011-1226-7]

Rupp, D.E., P.W. Mote, N. Massey, C.J. Rye, R. Jones, and M.R. Allen, 2012: Did human influence on climate make the 2011 Texas drought more probable? Explaining extreme events of 2011 from a climate perspective. *Bulletin American Meteorological Society*, T. C. Peterson, P. A. Stott, and S. Herring, Eds., 1041-1067

Santer, B., C. Mears, C. Doutriaux, P. Caldwell, P. Gleckler, T. Wigley, S. Solomon, N. Gillett, D. Ivanova, and T. Karl, 2011: Separating signal and noise in atmospheric temperature changes: The importance of timescale. *Journal of Geophysical Research*, **116,** 19 doi: 10.1029/2011JD016263

Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P. Gleckler, T. Wigley, T. Barnett, J. Boyle, W. Brüggemann, and N. Gillett, 2007: Identification of human-induced changes in atmospheric moisture content. *Proceedings of the National Academy of Sciences of the United States of America*, **104,** 15248-15253

Santer, B.D., J.F. Painter, C.A. Mears, C. Doutriaux, P. Caldwell, J.M. Arblaster, P.J. Cameron-Smith, N.P. Gillett, P.J. Gleckler, J. Lanzante, J. Perlwitz, S. Solomon, P.A. Stott, K.E. Taylor, L. Terray, P.W. Thorne, M.F. Wehner, F.J. Wentz, T.M.L. Wigley, L.J. Wilcox, and C.-Z. Zou, 2012: Identifying human influences on atmospheric temperature. *Proceedings of the National Academy of Sciences*, [Available online at http://www.pnas.org/content/early/2012/11/28/1210514109.abstract]

Santer, B.D., J. Painter, C. Mears, et al., , 2012: Identifying human influences on atmospheric temeprature: are results robust to uncertainties? *Proc. Nat. Acad. Sci., submitted.*

Schnellnhuber, H.J., W.P. Cramer, N. Nakicenovic, T. Wigley, and G. Yohe, 2006: *Avoiding dangerous climate change.* Cambridge University Press.

Schwalm, C.R., C.A. Williams, K. Schaefer, D. Baldocchi, T.A. Black, A.H. Goldstein, B.E. Law, W.C. Oechel, and R.L. Scott, 2012: Reduction in carbon uptake during turn of the century drought in western North America. *Nature Geoscience*, **5,** 551-556 doi: 10.1038/ngeo1529 [Available online at http://www.nature.com/ngeo/journal/v5/n8/full/ngeo1529.html]

Shakhova, N., I. Semiletov, A. Salyuk, V. Joussupov, and D.G. Kosmach, O. , 2010: Extensive methane venting to the atmosphere from sediments of the East Siberian Arctic Shelf. *Science*, **327,** 1246-1250 doi: 10.1126/science.1182221

Simmons, A., K. Willett, P. Jones, P. Thorne, and D. Dee, 2010: Low-frequency variations in surface atmospheric humidity, temperature, and precipitation: Inferences from reanalyses and monthly gridded observational data sets. *Journal of Geophysical Research*, **115,** 21 doi: 10.1029/2009JD012442

Squires, M.F., J. Lawrimore, R. Heim, D. Robinson, M. Gerbush, T. Estilow, C. Tabor, and A. Wilson, 2009: Development of New Snowstorm Indices and Databases at the National Climatic Data Center. *American Geophysical Union, Fall Meeting 2009*, San Francisco, CA.

Stott, P.A., N.P. Gillett, G.C. Hegerl, D.J. Karoly, D.A. Stone, X. Zhang, and F. Zwiers, 2010: Detection and attribution of climate change: a regional perspective. *Wiley Interdisciplinary Reviews: Climate Change*, **1,** 192-211 doi: 10.1002/wcc.34

Strauss, B.H., R. Ziemlinski, J.L. Weiss, and J.T. Overpeck, 2012: Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters*, **7** doi: 10.1088/1748-9326/7/1/014033

Stroeve, J.C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W.N. Meier, 2012: Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. *Geophysical Research Letters*, **39,** 7 doi: 10.1029/2012GL052676

Taylor, K.E., R.J. Stouffer, and G.A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, **93,** 485

Ting, M., Y. Kushnir, R. Seager, and C. Li, 2009: Forced and internal twentieth-century SST Trends in the North Atlantic*. *Journal of Climate*, **22,** 1469-1481

Trapp, R.J., N.S. Diffenbaugh, H.E. Brooks, M.E. Baldwin, E.D. Robinson, and J.S. Pal, 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. *Proceedings of the National Academy of Sciences of the United States of America*, **104,** 19719-19723 doi: 10.1073/pnas.0705494104

Trenberth, K.E., 2011: Changes in precipitation with climate change. *Climate Research*, **47,** 123

U.S. Environmental Protection Agency, 2010: Climate Change Indicators in the United States. [Available online at www.epa.gov/climatechange/indicators.html]

Vermeer, M. and S. Rahmstorf, 2009: Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences of the United States of America*, **106,** 21527-21532 doi: 10.1073/pnas.0907765106. [Available online at <Go to ISI>://000272994200014]

Vose, R.S., S. Applequist, M.J. Menne, C.N. Williams Jr, and P. Thorne, 2012: An intercomparison of temperature trends in the US Historical Climatology Network and recent atmospheric reanalyses. *Geophysical Research Letters*, **39,** 6 doi: 10.1029/2012GL051387 [Available online at http://www.agu.org/pubs/crossref/2012/2012GL051387.shtml]

Walter, K.M., L.C. Smith, and F.S. Chapin III, 2007: Methane bubbling from northern lakes: present and future contributions to the global methane budget. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **365,** 1657-1676 doi: 10.1098/rsta.2007.2036

Wang, J., X. Bai, H. Hu, A. Clites, M. Colton, and B. Lofgren, 2011: Temporal and spatial variability of Great Lakes ice cover, 1973-2010. *Journal of Climate*, [Available online at http://adsabs.harvard.edu/abs/2011AGUFM.H51K1357W]

Wang, M. and J.E. Overland, 2009: A sea ice free summer Arctic within 30 years. *Geophysical Research Letters*, **36,** 5, [Available online at http://www.agu.org/pubs/crossref/2009/2009GL037820.shtml]

Wang, X.L., V.R. Swail, and F.W. Zwiers, 2006: Climatology and changes of extratropical cyclone activity: Comparison of ERA-40 with NCEP-NCAR reanalysis for

1958-2001. *Journal of Climate*, **19,** 3145-3166 doi: 10.1175/JCLI3781.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/JCLI3781.1]

Wang, X.L., Y. Feng, G. Compo, V. Swail, F. Zwiers, R. Allan, and P. Sardeshmukh, 2012: Trends and low frequency variability of extra-tropical cyclone activity in the ensemble of twentieth century reanalysis. *Climate Dynamics*, 1-26 doi: 10.1007/s00382-012-1450-9

Wehner, M., D.R. Easterling, J.H. Lawrimore, R.R. Heim Jr, R.S. Vose, and B.D. Santer, 2011: Projections of Future Drought in the Continental United States and Mexico. *Journal of Hydrometeorology*, **12,** 1359-1377 doi: 10.1175/2011JHM1351.1 [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2011JHM1351.1]

Wehner, M.F., 2012: Very extreme seasonal precipitation in the NARCCAP ensemble: Model performance and projections. *Climate Dynamics*, **1,** 03 doi: 10.1007/s00382-012-1393-1

Willett, K.M., N.P. Gillett, P.D. Jones, and P.W. Thorne, 2007: Attribution of observed surface humidity changes to human influence. *Nature*, **449,** 710-712 doi: 10.1038/nature06207, [Available online at http://www.nature.com/nature/journal/v449/n7163/abs/nature06207.html]

Willett, K.M., P.D. Jones, N.P. Gillett, and P.W. Thorne, 2008: Recent changes in surface humidity: Development of the HadCRUH dataset. *Journal of Climate*, **21,** 5364-5383

Williams, C.N., M.J. Menne, and P.W. Thorne, 2012: Benchmarking the performance of pairwise homogenization of surface temperatures in the United States. *Journal of Geophysical Research*, **117,** 16 doi: 10.1029/2011JD016761

Willis, J.S.K., D. Chamber, C.Y. Kuo, and C. Shum, 2010: Global sea level rise: Recent progress and challenges for the decade to come. *Oceanography*, **23**

Wood, A.W. and D.P. Lettenmaier, 2006: A test bed for new seasonal hydrologic forecasting approaches in the western United States. *Bulletin of the American Meteorological Society*, **87,** 1699-1712

Wood, A.W., A. Kumar, and D.P. Lettenmaier, 2005: A retrospective assessment of National Centers for Environmental Prediction climate model–based ensemble hydrologic forecasting in the western United States. *Journal of Geophysical Research*, **110,** 16 doi: 10.1029/2004JD004508 [Available online at http://www.agu.org/pubs/crossref/2005/2004JD004508.shtml]

Wuebbles, D.J., G. Meehl, K. Hayhoe, T.R. Karl, K. Kunkel, B. Santer, M. Wehner, B. Colle, E.M. Fischer, R. Fu, A. Goodman, E. Janssen, H. Lee, W. Li, L.N. Long, S. Olsen, A.J. Sheffield, and L. Sun, 2012: CMIP5 climate model analyses: Climate extremes in the United States. *Bulletin of the American Meteorology Society*, **submitted**

Yamamoto-Kawai, M., F.A. McLaughlin, E.C. Carmack, S. Nishino, and K. Shimada, 2009: Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt. *Science*, **326,** 1098-1100 doi: 10.1126/science.1174190 [Available online at http://www.sciencemag.org/content/326/5956/1098.abstract]

Yin, J., 2012: Century to multi-century sea level rise projections from CMIP5 models. *Geophysical Research Letters*, **39,** 7 doi: 10.1029/2012GL052947

Zhang, R. and T.L. Delworth, 2009: A new method for attributing climate variations over the Atlantic Hurricane Basin's main development region. *Geophysical Research Letters*, **36,** 5 doi: 10.1029/2009GL037260

Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M.A. Elder, W. Filley, J. Shropshire, L.B. Ford, C. Hedberg, P. Fleetwood, K.T. Hovanky, T. Kavanaugh, G. Fulford, R.F. Vrtis, J.A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz, 2011: Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences of the United States of America*, **108,** 4248-4251 doi: 10.1073/pnas.1014107108, [Available online at <Go to ISI>://000288120400079]