S. HRG. 114–373

DATA OR DOGMA? PROMOTING OPEN INQUIRY IN THE DEBATE OVER THE MAGNITUDE OF HUMAN IMPACT ON EARTH'S CLIMATE

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

DECEMBER 8, 2015

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

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DATA OR DOGMA? PROMOTING OPEN INQUIRY IN THE DEBATE OVER THE MAGNITUDE OF HUMAN IMPACT ON EARTH'S CLIMATE

TUESDAY, DECEMBER 8, 2015

U.S. SENATE,
SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 3:10 p.m., in room SR–253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

Present: Senators Cruz [presiding], Gardner, Daines, Nelson, Schatz, Markey, Booker, Udall, and Peters.

OPENING STATEMENT OF HON. TED CRUZ, U.S. SENATOR FROM TEXAS

Senator CRUZ. This hearing will come to order.

Good afternoon, everyone. Welcome to what I hope will be an important and informative hearing.

This is a hearing on the science behind claims of global warming. Now this is the Science Subcommittee of the Senate Commerce Committee, and we are hearing from distinguished scientists, sharing their views, their interpretation, their analysis of the data and the evidence.

Now I am the son of two mathematicians, two computer programmers and scientists. And I believe that public policy should follow the actual science and the actual data and evidence and not political and partisan claims that run contrary to the science and data and evidence.

On November 28, 2013, an intrepid band of explorers set off from New Zealand on a research expedition to the Antarctic. Among their goals was investigating the impact of global warming on the Antarctic continent and islands.

On Christmas Eve, they became stuck in ice, ice that the climate industrial complex had assured us were vanishing. This expedition was there to document how the ice was vanishing in the Antarctic, but the ship became stuck. It had run into an inconvenient truth, as Al Gore might put it.

Three icebreakers tried and failed to reach the trapped ship because the ice was too thick. After a week of rescue attempts, the passengers were airlifted from the vessel.

Here are the inconvenient facts about the polar ice caps. The Arctic is not ice-free. This year's minimum sea ice extent was well above the record low observed in 2011. In the Antarctic, a recent study from the *Journal of Glaciology* indicates that the ice is not only not decreasing but is, in fact, increasing in mass, directly contrary to what the global warming alarmists had told us would be happening. This is not what their climate models projected.

Yet these inconvenient facts never seem to get the attention of people like John Kerry. And indeed, I would note behind me, on August 31, 2009, then-Senator John Kerry said, "Scientists project that the Arctic will be ice free in the summer of 2013. Not in 2050, but 4 years from now."

Well, the summer of 2013 has come and gone, and John Kerry was not just a little bit, he was wildly, extraordinarily, entirely wrong. Had the Antarctic expedition in the picture next to it not believed the global warming alarmists, had they actually looked to the science and the evidence, they wouldn't have gone down and been surprised when they got stuck in ice.

Facts matter. Science matters. Data matters. That is what this hearing is about—data.

According to the satellite data, there has been no significant global warming for the past 18 years. Those are the data. The global warming alarmists don't like these data. They are inconvenient to their narrative. But facts and evidence matters.

And I would note that many in the media reflexively take the side of the global warming alarmists. Reflexively oppose anyone who actually points out, well, was John Kerry's prediction accurate? No, it was stunningly and entirely false.

Was the prediction of computer model after computer model that showed dramatic warming, were those predictions correct? No. The satellite data demonstrate no significant warming over 18 years.

Public policy should follow science and evidence and data, and I would note that I found it amusing that our friends on the Democratic side of the aisle, I have discovered, held a press conference today as a "prebuttal" to this hearing. I suppose I should view that, in a sense, as a back-handed compliment. I am reminded of the Bard, "Methinks she doth protest too much."

What does it say when members of the United States Senate are protesting how dare the Science Subcommittee in the U.S. Senate hear testimony from scientists about actual science? How dare we focus on such topics? I think that is, indeed, exactly what we were elected to do.

Senator Peters?

STATEMENT OF HON. GARY PETERS, U.S. SENATOR FROM MICHIGAN

Senator PETERS. Thank you, Mr. Chairman.

And I would first like to thank the witnesses for being here today and for your testimony on what is surely a very important topic.

When we think about global warming, there are risks and there are certainties. Let us talk first about the certainties. By burning fossil fuels, humans are releasing carbon into the atmosphere that would have otherwise remained locked away. This process creates

carbon dioxide, a greenhouse gas that traps heat that otherwise would have been radiated off into space.

We know that by the law of conservation of energy that additional heat can't just magically disappear. Instead, it causes our planet to get warmer.

What else is certain? We are already seeing the symptoms of a warming planet not just in the temperature records, but in the rising sea and shrinking ice levels, in toxic algae blooms that are flourishing in the Great Lakes that were made worse by increased precipitation, runoff, and warmer water temperatures, tainting drinking water for 2.8 million people in recent years. All of that is certain.

Now let us talk about the risk. Managing risk is all about looking at a range of possible outcomes and consequences, looking at the likelihood of each of those consequences, and then looking to see if there is anything you can do to reduce the likelihood of those consequences or both.

From our models and from our understanding of the science, we see a range of potential outcomes, a range of possible warming trends, a range of consequences based on those trends. There are implications for our national security, for the economic health of our country, for our food supply and agriculture, and for the health and safety of Michiganders, Americans, as well as people all around the planet.

The possible consequences of all these areas range from the bad to the catastrophic. Given our best scientific judgment of our risk posture of the consequences we face as a civilization and the likelihood of those consequences occurring, we must do what we can to mitigate these risks.

We are going to hear today that there is some disagreement, some disagreement in the scientific community over the magnitude of that risk. As a matter of fact, I know we are going to hear from three scientists and a political commentator and blogger who disagree with varying aspects of the scientific consensus, as well as to argue that the science is not settled.

We will hear we need to support our scientific community so that they can continue to answer the open questions and help policymakers make better—or better understand the risks that we face. And we will hear that scientists need to be protected from political interference from either side of the aisle. And I certainly agree that we need to support our scientific community and protect them from political influence, but I also know that while we continue to refine the science, we have to act on the risks and findings that our scientists have discovered.

I would like to introduce into the record statements and letters from various science professional organizations representing tens of thousands, tens of thousands of scientists, including the American Association for the Advancement of Science, the American Chemical Society, the American Geophysical Union, the American Meteorological Society, the American Society for Agronomy, Crop Science Society of America, Soil Science Society of America, the American Statistical Association, the Ecological Society of America, the American Institute of Biological Sciences, and the Geological Society of America.

It is the position of these organizations that the evidence is overwhelming that the Earth is warming, global warming is real, and that human activity is the primary contributor.

I would like unanimous consent, Mr. Chairman, to enter these statements into the record.

Senator CRUZ. Without objection.

[The information referred to follows:]

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

December 7, 2015

The Honorable Ted Cruz
Committee on Commerce, Science, and Transportation
404 Russell Senate Office Building
Washington, DC 20510

The Honorable Gary Peters
Committee on Commerce, Science, and Transportation
724 Hart Senate Office Building
Washington, DC 20510

Dear Senators Cruz and Peters:

As you convene for a hearing to consider our understanding of the magnitude of human impact on Earth's climate, I write on behalf of the American Association for the Advancement of Science (AAAS) to state the scientific consensus view, as echoed in our Board of Directors' 2006 Statement on Climate Change (attached): "climate change is occurring, and rigorous scientific research demonstrates that the greenhouse gases emitted by human activities are the primary driver. These conclusions are based on multiple independent lines of evidence." There is virtually no scientific controversy on the core facts of climate change based on scientific principles we've known from over a hundred years to more recent research.

Scientists from a broad-range of disciplines continue to work each day to strengthen and deepen our understanding of the Earth's climate and humanity's impact thereon. Asking questions and collecting and reexamining evidence is how the scientific process works. We are committed to the principle that scientific inquiry and open scientific communication—regardless of field of study—should proceed unhampered by intrusions on academic freedom.

We share the Congress's goal of enabling objective and meritorious climate science research, and stand ready to provide assistance as you seek to better understand humanity's impact on the Earth's climate.

Sincerely,

Gerald R. Fink

Gerald R. Fink
Chair, AAAS Board of Directors
Herman and Margaret Sokol Professor
Whitehead Institute/Massachusetts Institute of Technology

American Association for the Advancement of Science
1200 New York Avenue, NW, Washington, DC 20005 USA
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Embargoed: Not for release until 12:30 p.m. Pacific Standard Time
Sunday, 18 February 2007

AAAS Board Statement on Climate Change

Approved by the Board of Directors
American Association for the Advancement of Science
9 December 2006

The scientific evidence is clear: global climate change caused by human activities is occurring now, and it is a growing threat to society. Accumulating data from across the globe reveal a wide array of effects: rapidly melting glaciers, destabilization of major ice sheets, increases in extreme weather, rising sea level, shifts in species ranges, and more. The pace of change and the evidence of harm have increased markedly over the last five years. The time to control greenhouse gas emissions is now.

The atmospheric concentration of carbon dioxide, a critical greenhouse gas, is higher than it has been for at least 650,000 years. The average temperature of the Earth is heading for levels not experienced for millions of years. Scientific predictions of the impacts of increasing atmospheric concentrations of greenhouse gases from fossil fuels and deforestation match observed changes. As expected, intensification of droughts, heat waves, floods, wildfires, and severe storms is occurring, with a mounting toll on vulnerable ecosystems and societies. These events are early warning signs of even more devastating damage to come, some of which will be irreversible.

Delaying action to address climate change will increase the environmental and societal consequences as well as the costs. The longer we wait to tackle climate change, the harder and more expensive the task will be.

History provides many examples of society confronting grave threats by mobilizing knowledge and promoting innovation. We need an aggressive research, development and deployment effort to transform the existing and future energy systems of the world away from technologies that emit greenhouse gases. Developing clean energy technologies will provide economic opportunities and ensure future energy supplies.

In addition to rapidly reducing greenhouse gas emissions, it is essential that we develop strategies to adapt to ongoing changes and make communities more resilient to future changes.

The growing torrent of information presents a clear message: we are already experiencing global climate change. It is time to muster the political will for concerted action. Stronger leadership at all levels is needed. The time is now. We must rise to the challenge. We owe this to future generations.

The conclusions in this statement reflect the scientific consensus represented by, for example, the Intergovernmental Panel on Climate Change (www.ipcc.ch/), and the Joint National Academies' statement (http://nationalacademies.org/onpi/06072005.pdf).

For more information:
www.aaas.org/climate

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

AAAS Board Statement on Climate Change

Approved by the AAAS Board of Directors
9 December 2006

Gilbert S. Omenn, Chair, AAAS Board
University of Michigan Health System

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Harvard University and The Woods Hole Research Center

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7 December 2015

The Honorable Ted Cruz, chairman
Subcommittee on Space, Science, and Competitiveness
Committee on Commerce, Science & Transportation
Russell Senate Office Building, Room 254
Washington DC, 20510

Dear Senator Cruz:

The topics identified for discussion in the hearing titled "Data or Dogma? Promoting Open Inquiry in the Debate over the Magnitude of Human Impact on Earth's Climate" are important ones. The American Meteorological Society (AMS) is strongly committed to open scientific debate, the free expression of scientific ideas, and the freedom for scientists to pursue research topics without political interference.[1] In response to two recent efforts to question the integrity of scientists that appear politically motivated, AMS wrote letters expressing concern, with one of those letters supporting two of the witnesses selected by you and the Majority staff to appear in this hearing.[2]

AMS has also been a strong champion of the scientific process. That process includes peer-review of scientific articles followed by further vetting, testing, and validating of concepts and ideas by independent experts — discarding findings that cannot successfully withstand such testing. Scientists face strong professional incentives to prove each other wrong and relish doing so. This constitutes an extremely robust and self-correcting nature for scientific research. This process is not without instances of failure, but indeed, we know of those failures precisely because of this self-correcting nature. The scientific process has an overall record of success that is outstanding and it has served this nation and the world well for many decades.

While Congressional hearings can be useful in highlighting areas of concern, exploring specific issues in more depth, or providing explanations of the peer-reviewed literature, science-based policy decisions should build on knowledge and understanding developed from the full corpus of peer-reviewed scientific literature. In terms of climate change, AMS has noted[3]:

> The primary findings of climate change science have been well established in the peer-reviewed science literature and replicated by numerous independent investigators and methodologies. Blue-ribbon panels of scientists convened by organizations such as the National Academy of Sciences have carried out formal evaluations of scientific studies and provide a consensus opinion regarding climate change. Leading scientific organizations beyond the AMS (e.g., American Association for the Advancement of Science, American Geophysical Union, and European Geophysical Union) have considered the state of the science and are in consensus on the topic as well. There are small scientific differences as research continues to refine the details, but there is strong agreement on the primary findings and essentially no controversy with respect to them.

Those findings can be summarized as[4]:

> There is unequivocal evidence that Earth's lower atmosphere, ocean, and land surface are warming; sea level is rising; and snow cover, mountain glaciers, and Arctic sea ice are shrinking. The dominant cause of the warming since the 1950s is human activities. This scientific finding is

> based on a large and persuasive body of research. The observed warming will be irreversible for many years into the future, and even larger temperature increases will occur as greenhouse gases continue to accumulate in the atmosphere.

To be sure, there are uncertainties in many aspects of the science on climate variability and climate change, but AMS has been clear in stating that those uncertainties do not alter the nature of the policy challenge facing the United States and the world: people are responsible for most of the recent climate change, climate change poses serious risks to our society, and we have numerous options for responding that can help reduce those risks. Quoting again from the same statement[4]:

> Technological, economic, and policy choices in the near future will determine the extent of future impacts of climate change. Science-based decisions are seldom made in a context of absolute certainty. National and international policy discussions should include consideration of the best ways to both adapt to and mitigate climate change. Mitigation will reduce the amount of future climate change and the risk of impacts that are potentially large and dangerous. At the same time, some continued climate change is inevitable, and policy responses should include adaptation to climate change.

Science is the pursuit of knowledge and understanding. Therefore, science alone cannot determine the best policy option because policy choices include subjective value judgments (i.e., opinions and personal preferences). Nevertheless, we encourage the Subcommittee to rely on the full body of peer-reviewed literature on climate science as the most reliable source for knowledge and understanding that can be applied to the policy options. AMS stands ready to provide you and the Subcommittee clarification on its positions with respect to freedom of scientific inquiry, academic freedom, the peer-review process, or climate science.

Sincerely,

Dr. Keith L. Seitter
Executive Director

CC: The Honorable Gary Peters, Ranking Member

---

[1] See AMS Statement: "Freedom of Scientific Expression" (2012):
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-statements/statements-of-the-ams-in-force/freedom-of-scientific-expression/

[2] See AMS letters:
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-formal-letters-of-support/letter-to-house-committee-on-natural-resources-on-challenges-to-academic-freedom/
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-formal-letters-of-support/letter-to-house-committee-on-science-space-and-technology-on-noaa-science/
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-formal-letters-of-support/joint-letter-to-house-committee-on-science-space-and-technology-on-noaa-science/

[3] See AMS Statement: "Climate Science Is Core to Science Education" (2013):
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-statements/statements-of-the-ams-in-force/climate-science-is-core-to-science-education/

[4] See AMS Statement: "Climate Change" (2012):
https://www2.ametsoc.org/ams/index.cfm/about-ams/ams-statements/statements-of-the-ams-in-force/climate-change/

American Institute of Biological Sciences

December 7, 2015

The Honorable Ted Cruz
Chairman
Senate Commerce Subcommittee on Space, Science, and Competitiveness
512 Dirksen Senate Office Building
Washington, DC 20510

The Honorable Gary Peters
Ranking Member
Senate Commerce Subcommittee on Space, Science, and Competitiveness
427 Hart Senate Office Building
Washington, DC 20515

Dear Chairman Cruz and Ranking Member Peters,

At a time when the world's political, civic, and business leaders are gathered to negotiate a global compact to address climate change, it is disappointing that the Subcommittee on Space, Science, and Competitiveness is holding a hearing intended to sew seeds of uncertainty about climate science. A more timely hearing would be one that focuses the nation's attention on actions that will help us to mitigate and adapt to rapid climate change.

The vast majority of scientists agree that the composition of Earth's atmosphere is changing rapidly and that humans are causing these changes. The resulting increase in global temperatures is having profound impacts on the planet's natural and human systems. These impacts are expected to intensify if climate change is not addressed. Many living systems are not able to respond to our rapidly changing environment. Species are being driven to extinction and the ecosystem processes we depend upon for such things as clean air and water are being disrupted.

The scientific evidence for the climate change we are experiencing is vast and can be found in the pages of the leading scientific and technical journals from around the world.

The scientific community encourages the Subcommittee to focus attention on the science that can help inform climate mitigation and adaptation.

Sincerely,

Robert Gropp

Robert Gropp, Ph.D.
Interim Co-Executive Director

Senator PETERS. Thank you.

We know that there will always be more to learn. We will undoubtedly find more down the road that there is more to discover about what we don't know. And that is really the beautiful thing about science, we always have more to learn.

But knowing that there is more to learn should not, it should not stop us from acting on what we know now. We must discuss and determine what actions we need to take to limit the serious risks that we face, and there are many things that we can do that are not just good for the environment, but are good for the economy. Investments in clean energy create good-paying jobs and help us produce the energy we need right here in the United States.

For example, Michigan is home to more than 220 wind and solar companies, representing tens of thousands of jobs. The growth in Michigan's clean energy sector can be attributed in part to the state's renewable electricity standard, which requires 10 percent of the state's energy to come from renewables.

But there is a lot of room to grow. If industry sourced its parts from local manufacturers, renewable energy could support over 20,000 Michigan jobs in manufacturing alone by 2020. What is more, expanding Michigan's renewable electricity standard from 10 percent to over 30 percent by 2030 would generate more than $9 million—$9 billion, $9 billion in new capital investments, investments in research and science, including the understanding of our Sun-Earth system, pay dividends for our country's future economic growth, our economic competitiveness, and our very way of life.

China certainly understands that. So if we miss this opportunity to make these investments now, we may soon find ourselves falling behind in the global economy. So let us focus on innovating our way out of this problem, and let us take a big step forward as a country.

Senator CRUZ. Thank you, Senator Peters.

Senator Nelson, the Ranking Member on the Full Committee, has requested to give an opening statement as well.

STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA

Senator NELSON. Thank you, Mr. Chairman.

Before I make a couple of comments, I want to address a parliamentary inquiry. There is a sign out there on the witness table—Mr. Mair, Aaron Mair, president of the Sierra Club. Did—was Mr. Mair extended a formal invitation by the Chairman of this committee, Senator Thune?

Senator CRUZ. He was invited by me, the Chairman of this subcommittee, and he declined. And momentarily, I am going to describe the circumstances behind that invitation and his decision not to attend.

Senator NELSON. OK. I would just note that the protocol and the rules of the Committee are such that invitations for all witnesses are extended by the Chairman of the Committee, and I would like the record to reflect that such an invitation by Senator Thune, our Chairman, was not extended. And therefore, there should be no place up there at the witness table, but that should be noted for the record.

Now, Mr. Chairman, rather than get this started off in an adversarial way, you and I have had a very good relationship. We have worked together on the space program, and you and I have some significant differences about this issue. And so, rather than it be contentious, I want it to be factual.

First of all, I would like to show a couple of pictures of what is happening in Miami Beach right now. Now I had the privilege a couple of years ago, when I was Chairman of the Science and Space Subcommittee, of taking our Commerce Committee to Miami Beach. And Miami Beach is basically ground zero in the United States for what we are seeing as a consequence of global warming, and that is sea level rise.

We had a NASA scientist that testified at the hearing that over the last 40 years, measurements—these are measurements, not forecasts, not projections, they are measurements—that the seas have risen in south Florida from 5 to 8 inches. This photograph is a consequence at seasonal high tide of what is happening on the streets of Miami Beach.

Now, interestingly, a couple of years earlier, the present Mayor of Miami Beach, in running for Mayor, did an actual campaign commercial in a kayak on Alton Road, which is on the opposite side of the barrier island, the west side of the barrier island from this. This is not far from the actual ocean.

This one as well, you can look down the street there and see the sky in the background. That is about a couple of blocks down toward the beach.

The campaign commercial in a kayak was at the October seasonal high tide on Alton Road, which is on the opposite side of the barrier island. And the fact is that we are having to deal with this.

Now there is another consequence of this, and that is what you heard of saltwater intrusion. Saltwater is heavier than freshwater. Florida sits on a honeycomb of limestone that is filled with freshwater. That is where we get our freshwater, from the aquifer underneath.

As the saltwater rises and sea level rise, the greater pressure because of the heavier water is intruding into the interior, and we have had a number of municipal wells that are now too salty. And it is another consequence.

So some of us, representing our constituents, have to deal with the realities of what we see. I might point out that when you talk about measurements, 1992 we launched a satellite called Topex. It had an altimeter. It takes precise measurements of the surface of the ocean, and its successor satellites, Jason–1 and Jason–2, have been collecting that data. And observation, not projections, the data tells us that the average global sea level is rising at about 3.2 millimeters a year since 1993. That is about a tenth of an inch, or over a decade an inch.

So I am glad that you were kind enough to let Senator Peters invite a minority witness, and we brought in Admiral David Titley, a lifelong public servant, a scientist, a decorated military officer from his naval career. And he is going to discuss this much more in detail. In addition to climate science, the admiral is an expert in oceanography, tropical meteorology, weather risk, and how all of this will impact our national security.

We need to understand how climate change is affecting all of the calculations that go into our national security by our national security teams. And after 32 years in the U.S. Navy, he now works at Pennsylvania State University.

So I will conclude my remarks and insert the rest of them in the record, with the Chairman's permission.

Senator CRUZ. Without objection.

[The prepared statement of Senator Nelson follows:]

PREPARED STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Mr. Chairman, I welcome today's debate about science surrounding the impact of climate change.

In my state of Florida, we have over 1,260 miles of coastline—more than any other state in the continental U.S.

Over three quarters of the state's residents live in coastal counties. And Florida is quite flat. Britton Hill is the highest point at 345 feet above sea level.

In Florida, you can see and touch sea level rise. I'm going to show you some photographs taken on Miami Beach in September.

The first was taken along Indian Creek Road, and you can see the water flooding higher than the curb as this gentleman attempts to cross the street.

In the second, you can see leaves and debris floating down a city sidewalk.

So as you can see, Floridians do care a great deal about what the sea level is doing on any given day.

In 1992, NASA launched a satellite called TOPEX/Poseidon with an instrument called an altimeter, which takes precise measurements of the surface of the ocean. Since then, its successor satellites, JASON–1 and JASON–2, have been collecting that data.

Observation—not models, not projections, not dogma, but the *data*—tells us that the average global sea level is rising at about the rate of 3.2 millimeters a year since 1993.

Today it is my distinct pleasure to welcome one of our panelists, Admiral David Titley—a lifelong public servant, a scientist, *and* a decorated military officer, who will discuss this data in more detail.

In addition to climate science, Admiral Titley is an expert in oceanography, tropical meteorology, weather risk, and how those phenomena impact our national security. After 32 years in service to the U.S. Navy, Admiral Titley now works at Pennsylvania State University.

I look forward to hearing from him and the other members of our panel.

Mr. Chairman, while I welcome today's debate, I'm sorry to say that it won't represent the kind of objective and representative dialogue that's needed.

It's ironic that we've got three scientists giving one side of the story, and only one opportunity to present a different perspective.

As one who fiercely opposes any attempts to intimidate, censor or muzzle scientists, for this panel to hold a hearing without having a broad cross-section of experts only invites questions about the true openness of the hearing and the motives behind it.

Whatever that motive is, I think it's worth mentioning that when the Senate voted in March on my amendment to prohibit the use of tax dollars to censor publically-funded climate-related science a majority of Senators—51 to be exact—agreed with me.

In fact, some of my Republican colleagues on this committee voted for my amendment—so I thank Senator Ayotte and Senator Rubio for their support.

But even with a majority of the Senate's support, the amendment failed because of politics.

To most people, a vote against scientific censorship is common sense. But in the Senate, that was actually a courageous vote.

In the future, I hope more members of this committee will join my fight for open inquiry.

Senator CRUZ. Thank you, Senator Nelson.

I would now like to welcome each of our expert witnesses. Thank you for coming to testify to this panel.

The first witness is Dr. John Christy. Dr. John Christy is the Distinguished Professor of Atmospheric Science at the University of Alabama in Huntsville and is Alabama's State climatologist.

He has been awarded NASA's Medal for Exceptional Scientific Achievement, was elected a fellow of the American Meteorological Society, which also selected him for the special award for building climate datasets from satellites, and served as lead author of the U.N.'s Intergovernmental Panel on Climate Change. Beginning as a teenager, Dr. Christy has studied climate for the past 50 years.

Dr. Judith Curry currently serves as a professor and is former Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology, in addition to serving as President of Climate Forecast Applications Network. Dr. Curry received a Ph.D. in atmospheric science from the University of Chicago.

Dr. Curry has recently served on the NASA Advisory Council Earth Science Subcommittee, the DOE Biological and Environmental Research Advisory Committee, the National Academy's 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.

Dr. William Happer currently serves as a Cyrus Fogg Bracket Professor of Physics at my alma mater, Princeton University, and has spent most of his professional life studying the interactions of visible and infrared radiation with gases, one of the main physical phenomena behind the greenhouse effect.

Throughout his career, he has published over 200 papers in peer-reviewed scientific journals and is a member of a number of professional organizations, including the American Physical Society, and the National Academy of Sciences. Dr. Happer also served as the Director of Energy Research at the Department of Energy from 1990 to 1993, where he supervised all of DOE's work on climate change.

Mr. Mark Steyn is an international bestselling author, a top five jazz recording artist, and a leading Canadian human rights activist. Mr. Steyn recently contributed to the number one climatology bestseller, *Climate Change: The Facts,* and edited another number one climatology bestseller, *A Disgrace to the Profession: The World's Scientists in Their Own Words on Michael Mann, His Hockey Stick, and Their Damage to Science, Volume 1.*

In his capacity as a human rights activist, Mr. Steyn's human rights campaign to restore free speech to Canada led to the repeal by parliament of the notorious Section 12 hate speech law, a battle he recounts in his book, *Lights Out: Islam, Free Speech, and the Twilight of the West.*

And then Dr. David Titley, who Senator Nelson mentioned already. Dr. Titley currently serves as Professor of Practice in the Department of Meteorology at the Pennsylvania State University and is the Founding Director of Penn State's Center for Solutions to Weather and Climate Risk.

Dr. Titley holds a Bachelor of Science in meteorology from the Pennsylvania State University. From the Naval Postgraduate School, he earned a Master's of Science in meteorology and physical oceanography and a Ph.D. in meteorology. Prior to joining Penn

State, Dr. Titley served as a naval officer for 32 years and rose to the rank of Rear Admiral.

His career included duties as Commander, Naval Meteorology and Oceanography Command; oceanographer and navigator of the Navy; and Deputy Assistant Chief of Naval Operations for Information Dominance. He has also served as Senior Military Assistant for the Director, Net Assessment in the Office of the Secretary of Defense. While serving in the Pentagon, Dr. Titley initiated and led the U.S. Navy's task force on climate change.

After retiring from the Navy, Dr. Titley served as the Deputy Under Secretary of Commerce for Operations, the Chief Operating position at the National Oceanic and Atmospheric Administration, NOAA.

The final witness that we had hoped to have today is Mr. Aaron Mair, the President of the Sierra Club. I would note a number of weeks ago, Mr. Mair was witness at another hearing that I chaired in the Oversight Subcommittee of the Judiciary Committee. This was a hearing concerning the effect of overregulation on minority communities and, in particular, the devastating impacts of overregulation in the Obama administration on the Hispanic community and the African-American community.

There were a host of witnesses that testified to the job losses, to the stagnating wages as a consequence of overregulation from the Federal Government. Mr. Mair was one of the witnesses, a minority witness invited by the Democrats. Mr. Mair's testimony concerned global warming.

In the course of that hearing, I asked Mr. Mair about the scientific basis for his testimony. In particular, I asked him how he responded to the fact that the satellite data demonstrate no significant warming whatsoever for the past 18 years.

Mr. Mair, by all appearances, did not have the foggiest idea what the satellite data demonstrated. Indeed, he repeatedly turned to his staff members behind him and was unable to answer even basic questions.

At the conclusion of the questioning, my friend, the Ranking Democrat on the Committee, Senator Chris Coons, stepped to Mr. Mair's defense, and he said—in fact, I will read his quote directly.

Senator Coons said, "Thank you, Mr. Chairman. I just simply wanted to observe that we have a broadly representative and qualified group of folks who were brought here to talk about overregulation and its impact on minority communities. And I do not speak for the Sierra Club, obviously, but it is my hope and expectation that if you want to pursue that line of inquiry with them further, they would be happy to."

At that suggestion from Democratic Senator Coons that we hold a subsequent hearing on global warming, we have announced this hearing. Now I did note at the time that the entire substance of Mr. Mair's both written and oral testimony to the Subcommittee concerned global warming, and yet he was unprepared to discuss even the basic science behind what he was testifying to.

My office reached out to Mr. Mair and invited him to come testify on this panel, and we did so in consultation with the Chairman of the full Committee, Senator Thune. Mr. Mair turned down that invitation. And so, without objection, I would like to enter into the

record the written correspondence, the e-mail between my office and Mr. Mair extending the invitation and the Sierra Club's response to that, declining to attend.

[The information referred to follows:]

From: John Coequyt [mailto:john.coequyt@sierraclub.org]
Sent: Monday, November 23, 2015 5:30 PM
To: Mclean, Sean (Cruz)
Subject: Re: Senate Commerce Committee Hearing

Sean

Nice to meet you electronically. Thanks for reaching out. I am sorry that will not be possible.

John

On Nov 20,2015, at 4:57 PM, Mclean, Sean (Cruz) wrote:

John,

I wanted to introduce myself. I work for US. Senator Ted Cruz and help run his Subcommittee on Space, Science and Competitiveness on the U.S. Senate Commerce Committee. We are planning on holding a hearing on Deeember 8th at 3pm examining global warming. Senator Cruz would like to extend an invitation to Aaron Mair to testify. I wanted to check with you to see how we should proceed in extending an invitation to Mr. Mair? If you prefer, I am more than happy to give you a call to discuss the hearing in additional detail.

Best,

Sean

Sean McLean
Legislative Assistant
U.S. Senator Ted Cruz (R-TX)
www.cruz.senate.gov
Get Cruz updates here

Senator CRUZ. In Mr. Mair's honor, we have a spot at the table for him.

I would note that it is striking the Sierra Club, a national advocacy organization that devotes the lion's share of its energy to advocating for global warming, was unwilling to come and defend the merits of its position based on the science or the data. To any fair or impartial observer, the Sierra Club's refusal even to engage in a discussion of the science should speak volumes.

And with that, Dr. Christy, we are ready to receive your testimony.

Senator NELSON. Mr. Chairman, if I may, I would like to likewise enter into the record all the letters of invitation extended to the witnesses, and the record will note that there is no such letter of invitation to the gentleman that you are speaking about.

Senator CRUZ. Without objection.

[The information referred to follows:]

United States Senate
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
WASHINGTON, DC 20510-6125
WEBSITE: http://commerce.senate.gov

December 2, 2015

Dr. John R. Christy
Professor and Director
Earth System Science Center, NSSTC
University of Alabama in Huntsville
320 Sparkman Drive, NSSTC 4040
Huntsville, AL 35805

Dear Dr. Christy:

The Senate Committee on Commerce, Science, and Transportation will hold a hearing in the Subcommittee on Space, Science, and Competitiveness entitled, "Data or Dogma? Promoting Open Inquiry in the Debate Over the Magnitude of Human Impact on Earth's Climate," on Tuesday, December 8, 2015, at 3:00 p.m. in room 253 of the Russell Senate Office Building. At the request of the Subcommittee Chairman, I invite you to testify.

The hearing will focus on the ongoing debate over climate science and the magnitude of human impact on Earth's climate. We ask that your testimony draw on your experience as the distinguished Professor of Atmospheric Science and Director of the Earth System Science Center at the University of Alabama in Huntsville and discuss satellite temperature trends, surface temperature, and any other relevant issues you wish to bring to the Committee's attention.

Please submit your written testimony to the Committee two business days prior to the hearing. While your full statement will be made part of the hearing record, we ask that you limit your oral remarks to no more than five minutes, highlighting or summarizing the most important points. Attached to this letter are more detailed instructions for Committee witnesses, including directions for submitting an electronic copy of your testimony to the Committee.

If you have any questions, please contact Bailey Edwards of the Republican staff at (202) 224-1251 or Nick Cummings with the Democratic staff at (202) 224-0411. Thank you for your consideration of this request.

Sincerely,

JOHN THUNE
Chairman

United States Senate
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
WASHINGTON, DC 20510–6125
WEBSITE: http://commerce.senate.gov

December 2, 2015

Dr. Judith Curry
School of Earth & Atmospheric Sciences
Georgia Institute of Technology
311 Ferst Drive
Atlanta, GA 30332-0340

Dear Dr. Curry:

The Senate Committee on Commerce, Science, and Transportation will hold a hearing in the Subcommittee on Space, Science, and Competitiveness entitled, "Data or Dogma? Promoting Open Inquiry in the Debate Over the Magnitude of Human Impact on Earth's Climate," on Tuesday, December 8, 2015, at 3:00 p.m. in room 253 of the Russell Senate Office Building. At the request of the Subcommittee Chairman, I invite you to testify.

The hearing will focus on the ongoing debate over climate science and the magnitude of human impact on Earth's climate. We ask that your testimony draw on your experience as the Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology and discuss the question of whether there is consensus in climate science, possible scenarios for the 21st century climate, and any other relevant issues you wish to bring to the Committee's attention.

Please submit your written testimony to the Committee two business days prior to the hearing. While your full statement will be made part of the hearing record, we ask that you limit your oral remarks to no more than five minutes, highlighting or summarizing the most important points. Attached to this letter are more detailed instructions for Committee witnesses, including directions for submitting an electronic copy of your testimony to the Committee.

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December 2, 2015

Dr. William Happer
Department of Physics
Princeton University
258 Jadwin Hall
Princeton, NJ 08544

Dear Dr. Happer:

The Senate Committee on Commerce, Science, and Transportation will hold a hearing in the Subcommittee on Space, Science, and Competitiveness entitled, "Data or Dogma? Promoting Open Inquiry in the Debate Over the Magnitude of Human Impact on Earth's Climate," on Tuesday, December 8, 2015, at 3:00 p.m. in room 253 of the Russell Senate Office Building. At the request of the Subcommittee Chairman, I invite you to testify.

The hearing will focus on the ongoing debate over climate science and the magnitude of human impact on Earth's climate. We ask that your testimony draw on your experience as the Cyrus Fogg Bracket Professor of Physics at Princeton University and discuss the scope of government funding of climate science, its impact on research, as well as any other relevant issues you wish to bring to the Committee's attention.

Please submit your written testimony to the Committee two business days prior to the hearing. While your full statement will be made part of the hearing record, we ask that you limit your oral remarks to no more than five minutes, highlighting or summarizing the most important points. Attached to this letter are more detailed instructions for Committee witnesses, including directions for submitting an electronic copy of your testimony to the Committee.

If you have any questions, please contact Bailey Edwards of the Republican staff at (202) 224-1251 or Nick Cummings with the Democratic staff at (202) 224-0411. Thank you for your consideration of this request.

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AND TRANSPORTATION
WASHINGTON, DC 20510–6125
WEBSITE: http://commerce.senate.gov

December 2, 2015

Mr. Mark Steyn
P.O. Box 30
Woodsville, NH 03785

Dear Mr. Steyn:

The Senate Committee on Commerce, Science, and Transportation will hold a hearing in the Subcommittee on Space, Science, and Competitiveness entitled, "Data or Dogma? Promoting Open Inquiry in the Debate Over the Magnitude of Human Impact on Earth's Climate," on Tuesday, December 8, 2015, at 3:00 p.m. in room 253 of the Russell Senate Office Building. At the request of the Subcommittee Chairman, I invite you to testify.

The hearing will focus on the ongoing debate over climate science and the magnitude of human impact on Earth's climate. We ask that your testimony draw on your experience as an author and commentator on matters related to climate science to discuss the uncertainty and politicization of climate science, and any other relevant issues you wish to bring to the Committee's attention.

Please submit your written testimony to the Committee two business days prior to the hearing. While your full statement will be made part of the hearing record, we ask that you limit your oral remarks to no more than five minutes, highlighting or summarizing the most important points. Attached to this letter are more detailed instructions for Committee witnesses, including directions for submitting an electronic copy of your testimony to the Committee.

If you have any questions, please contact Bailey Edwards of the Republican staff at (202) 224-1251 or Nick Cummings with the Democratic staff at (202) 224-0411. Thank you for your consideration of this request.

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United States Senate
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WEBSITE: http://commerce.senate.gov

December 2, 2015

Dr. David W Titley, RADM USN (ret.)
Professor of Practice in Meteorology
Penn State Department of Meteorology
523 Walker Building
University Park, PA 16802

Dear Dr. Titley:

The Senate Committee on Commerce, Science, and Transportation will hold a hearing in the Subcommittee on Space, Science, and Competitiveness entitled, "Data or Dogma? Promoting Open Inquiry in the Debate Over the Magnitude of Human Impact on Earth's Climate," on Tuesday, December 8, 2015, at 3:00 p.m. in room 253 of the Russell Senate Office Building. At the request of the Subcommittee, I invite you to testify.

The hearing will focus on the ongoing debate over climate science and the magnitude of human impact on Earth's climate. We ask that your testimony draw on your experience in the national security community and as a researcher on climate and climate related issues, and any other relevant issues you wish to bring to the Committee's attention.

Please submit your written testimony to the Committee two business days prior to the hearing. While your full statement will be made part of the hearing record, we ask that you limit your oral remarks to no more than five minutes, highlighting or summarizing the most important points. Attached to this letter are more detailed instructions for Committee witnesses, including directions for submitting an electronic copy of your testimony to the Committee.

If you have any questions, please contact Bailey Edwards of the Republican staff at (202) 224-1251 or Nick Cummings with the Democratic staff at (202) 224-0411. Thank you for your consideration of this request.

Sincerely,

JOHN THUNE
Chairman

Senator CRUZ. And there was no formal letter issued because he had preemptively turned down the invitation on the front end.

And with that, Dr. Christy?

STATEMENT OF JOHN R. CHRISTY, PH.D., DISTINGUISHED PROFESSOR OF ATMOSPHERIC SCIENCE AND DIRECTOR OF EARTH SYSTEM SCIENCE CENTER, UNIVERSITY OF ALABAMA IN HUNTSVILLE

Dr. CHRISTY. Thank you, Chairman Cruz and Ranking Member Peters and Ranking Member Nelson, for this opportunity to speak about climate change.

I am John Christy, Professor of Atmospheric Science at the University of Alabama in Huntsville and Alabama State climatologist. I have served in many climate science capacities, including lead authorship of the United Nations IPCC.

I, along with Dr. Curry, have the distinction of being two of the seven scientists targeted by Representative Grijalva for investigation because our views about climate change differ from those of the administration.

My research might best be described as building datasets from scratch for 50 years to help us understand what the climate is doing and what it might do and why it does what it does. The two main points of my verbal testimony are simple.

First, the basis on which the popular view that human-caused climate change is dangerous does not pass simple validation tests. Second, the attempt to study climate change with an objective eye is thwarted by the Federal funding process.

Now we at UAH monitor climate change for such variables as temperature. However, no one has a direct means to tell us why the temperature changes. Our thermometers only tell us what has happened. They do not tell us why it happened. There is really no way to prove why climate does what it does.

Now so to try to understand why the changes occur, we make claims or hypotheses using climate models whose equations attempt to approximate all of the important factors that affect the climate. If these equations are accurate, we can then see how each factor, such as greenhouse gases or volcanoes, might affect the climate, and therefore, we could learn what the cause of these changes might be.

Now one variable, according to climate models, that has the largest response to extra greenhouse gases is the temperature of the bulk atmosphere, and this is the layer from the surface to about 50,000 feet in altitude. As shown in my written testimony and as you can see on the chart to my left, the models fail this very simplest of validation tests. They can't even reproduce what has already happened in the past 37 years.

One hundred and two climate model runs warm up the bulk layer of the atmosphere by an average factor of 3 more than what has actually occurred. Now being off by a factor of 3 does not qualify as settled science in my view.

Now why are studies like this so hard to find? It goes back to the way Federal funding occurs. Today, contrarian proposals, such as one I might write, that want to, say, look rigorously and test cli-

mate models against reality or to test various ideas about how natural variability causes these changes are rarely, if ever, funded.

This is due to the fact the panels which decide this type of funding are dominated by those with the establishment point of view about dangerous climate change. Since there are many more proposals than funding allows, a contrarian proposal has essentially no chance of receiving funding because the panel decides these things by votes.

Now in my view, Congress needs to fix this problem by directly funding red teams which are not part of the climate modeling industry to test the basis for the claims that human-induced climate change is dangerous. The Congress needs objective eyes on this issue because it is such a big-ticket item for everyone involved.

Now it is no secret that the State of Alabama is in a desperate fight with the Federal EPA. Our elected officials understand, as do I, their state climatologist, that the regulations being established will do nothing to alter whatever the climate is going to do. In fact, even if the United States of America disappeared today—no people, no cars, no factories—the impact would be negligible on whatever the climate does.

Alabama is fighting for our industries, which are being tempted by lower costs in Mexico and China, where their emissions would actually rise if they move there. We are fighting for our utilities, which sell over 30 percent of their electricity production to nearby states who need it. And we are fighting for the many poor people in our state who do not need another hike in their utility rates to satisfy a regulation whose only impact will be to further drain their meager resources.

This is a time when even so-called green countries like Germany and Japan—that is Germany and Japan—are adding to their carbon emissions by building more coal-fired power plants while the rest of the world moves toward more carbon-based energy.

To me, it is not scientifically justifiable or economically rational, that this Nation should establish regulations whose only discernible consequence is an increase in economic pain visited most directly and harshly on the poorest among us. This happens when the scientific process that allegedly underpins regulations lacks objectivity and transparency.

Thank you.

[The prepared statement of Dr. Christy follows:]

PREPARED STATEMENT OF JOHN R. CHRISTY, DISTINGUISHED PROFESSOR OF ATMOSPHERIC SCIENCE AND DIRECTOR OF THE EARTH SYSTEM SCIENCE CENTER, UNIVERSITY OF ALABAMA, HUNTSVILLE; ALABAMA STATE CLIMATOLOGIST

I am John R. Christy, Distinguished Professor of Atmospheric Science, Alabama's State Climatologist and Director of the Earth System Science Center at The University of Alabama in Huntsville. I have served as a Lead Author, Contributing Author and Reviewer of United Nations IPCC assessments, have been awarded NASA's Medal for Exceptional Scientific Achievement, and in 2002 was elected a Fellow of the American Meteorological Society.

It is a privilege for me to offer my analysis of the current situation regarding our understanding of climate change, the effect of regulations on climate, the popular notion of extreme climate events, and the unfortunate direction research in this area has taken. My research area might be best described as building datasets from scratch to advance our understanding of what the climate is doing and why—an activity I began as a teenager over 50 years ago. I have used traditional surface observations as well as measurements from balloons and satellites to document the cli-

mate story. Many of our UAH datasets are used to test hypotheses of climate variability and change.

How well do we understand climate change?

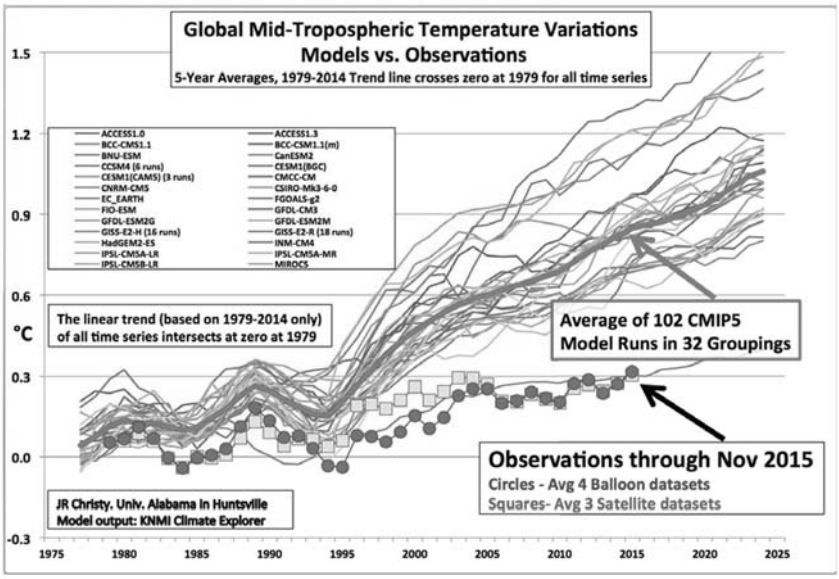
A critical issue in our era is to determine whether emissions from human activities impact the climate and by how much. This is made especially difficult because we know the climate system already is subject to changes without the influence of humans. Because there is no measuring device that explicitly determines the cause of the climate changes we can measure, such as temperature, our science must take a different approach to seek understanding as to what causes the changes, *i.e.,* how much is natural and how much is human induced. The basic approach today utilizes climate models. (The projections of these models are being utilized for carbon policies as well.)

It is important to understand that output from these models, (*i.e.,* projections of the future climate and the specific link that increasing CO_2 might have on the climate) are properly defined as scientific hypotheses or claims—model output cannot be considered as providing proof of the links between climate variations and greenhouse gases. These models are complex computer programs which attempt to describe through mathematical equations as many factors that affect the climate as is possible and thus estimate how the climate might change in the future. The model, it is hoped, will provide accurate responses of the climate variables, like temperature, when extra greenhouse gases are included in the model. However, the equations for nearly all of the important climate processes are not exact, representing the best approximations modelers can devise and that computers can handle at this point.

A fundamental aspect of the scientific method is that if we say we understand a system (such as the climate system) then we should be able to predict its behavior. If we are unable to make accurate predictions, then at least some of the factors in the system are not well defined or perhaps even missing. [Note, however, that merely replicating the behavior of the system (*i.e.,* reproducing "what" the climate does) does not guarantee that the fundamental physics are well-known. In other words, it is possible to obtain the right answer for the wrong reasons, *i.e.,* getting the "what" of climate right but missing the "why".]

Do we understand how greenhouse gases affect the climate, *i.e.,* the link between emissions and climate effects? A very basic metric for climate studies is the temperature of the bulk atmospheric layer known as the troposphere, roughly from the surface to 50,000 ft altitude. This is the layer that, according to models, should warm significantly as CO_2 increases—even faster than the surface. Unlike the surface temperature, this bulk temperature informs us regarding the crux of the global warming question—how much heat is accumulating in the global atmosphere? And, this CO_2-caused warming should be easily detectible by now, according to models. This provides a good test of how well we understand the climate system because since 1979 we have had two independent means of monitoring this layer—satellites from above and balloons with thermometers released from the surface.

I was able to access 102 CMIP–5 rcp4.5 (representative concentration pathways) climate model simulations of the atmospheric temperatures for the tropospheric layer and generate bulk temperatures from the models for an apples-to-apples comparison with the observations from satellites and balloons. These models were developed in institutions throughout the world and used in the IPCC AR5 Scientific Assessment (2013).

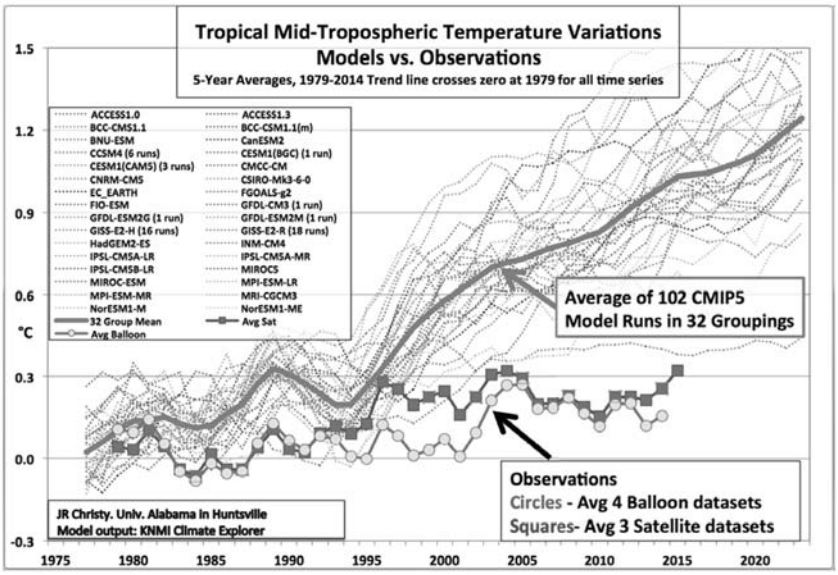


Above: Global average mid-tropospheric temperature variations (5-year averages) for 32 models (lines) representing 102 individual simulations. Circles (balloons) and squares (satellites) depict the observations.

The information in this figure provides clear evidence that the models have a strong tendency to over-warm the atmosphere relative to actual observations. On average the models warm the global atmosphere at a rate three times that of the real world. This is not a short-term, specially-selected episode, but represents the past 37 years, over a third of a century. This is also the period with the highest concentration of greenhouse gases and thus the period in which the response should be of largest magnitude.

Using the scientific method we would conclude that the models do not accurately represent at least some of the important processes that impact the climate because they were unable to "predict" what has already occurred. In other words, these models failed at the simple test of telling us "what" has already happened, and thus would not be in a position to give us a confident answer to "what" may happen in the future and "why." As such, they would be of highly questionable value in determining policy that should depend on a very confident understanding of how the climate system works.

There is a related climate metric that also utilizes atmospheric temperature which in models has an even larger response than that of the global average shown above. This metric, then, provides a stronger test for understanding how well models perform regarding greenhouse gases specifically. In the models, the tropical atmosphere warms significantly in response to the added greenhouse gases—more so than that of the global average atmospheric temperature.



Above: Tropical average mid-tropospheric temperature variations (5-year averages) for 32 models (lines) representing 102 individual simulations. Circles (balloons) and squares (satellites) depict the observations.

In the tropical comparison here, the disparity between models and observations is even greater, with models on average warming this atmospheric region by a factor of four times greater than in reality. Such a result re-enforces the implication above that the models have much improvement to undergo before we may have confidence they will provide information about what the climate may do in the future or even why the climate varies as it does. For the issue at hand, estimates of how the global temperature might be affected by emission reductions from regulations would be exaggerated and not reliable.

Impact of Regulations Will Not Be Attributable or Detectable

The impact on global temperature for current and proposed reductions in greenhouse gases will be tiny. To demonstrate this, let us assume, for example, that the total emissions from the United States were reduced to zero, as of last May 13th, 2015 (the date of the last congressional hearing on which I testified). In other words as of that day and going forward, there would be no industry, no cars, no utilities, no people—*i.e.,* the United States would cease to exist as of that day. Regulations, of course will only hope to reduce emissions a small amount, but to make the point of how minuscule the regulatory impact will be, we shall simply go way beyond reality and cause the United States to vanish. With this we shall attempt to answer the question of climate change impact due to emissions reductions.

Using the U.N. IPCC impact tool known as Model for the Assessment of Greenhouse-gas Induced Climate Change or MAGICC, graduate student Rob Junod and I reduced the projected growth in total global emissions by U.S. emission contribution starting on this date and continuing on. We also used the value of the equilibrium climate sensitivity as determined from empirical techniques of 1.8 °C. After 50 years, the impact as determined by these model calculations would be only 0.05 to 0.08 °C—an amount less than that which the global temperature fluctuates from month to month. [These calculations used emission scenarios A1B–AIM and AIF–MI with U.S. emissions comprising 14 percent to 17 percent of the 2015 global emissions. There is evidence that the climate sensitivity is less than 1.8 °C, which would further lower these projections.]

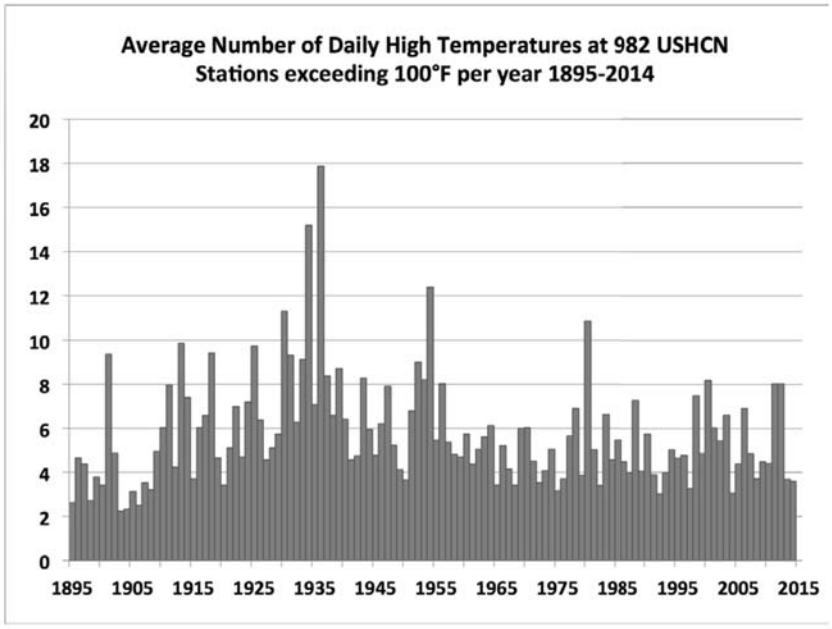
Because changes in the emissions of our entire country would have such a tiny calculated impact on global climate, it is obvious that fractional reductions in emissions through regulation would produce imperceptible results. In other words, there would be no evidence in the future to demonstrate that a particular climate impact was induced by the proposed and enacted regulations. Thus, the regulations will

have no meaningful or useful consequence on the physical climate system—even if one believes climate models are useful tools for prediction.

Alleged impacts of human-induced climate changes regarding extreme events

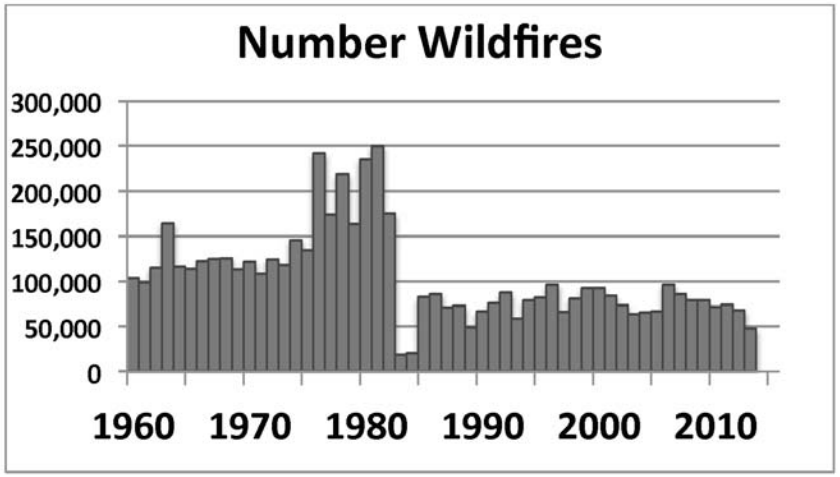
Much of the alarm related to increasing greenhouse gas concentrations shifted in the past decade from global temperature changes to changes in extreme events, *i.e.,* those events which typically have a negative impact on the economy. These events may be heat waves, floods, hurricanes, etc.

In terms of heat waves, below is the number of 100 °F days observed in the U.S. from a controlled set of weather stations. It is not only clear that hot days have not increased, but it is interesting that in the most recent years there has been a relative dearth of them.

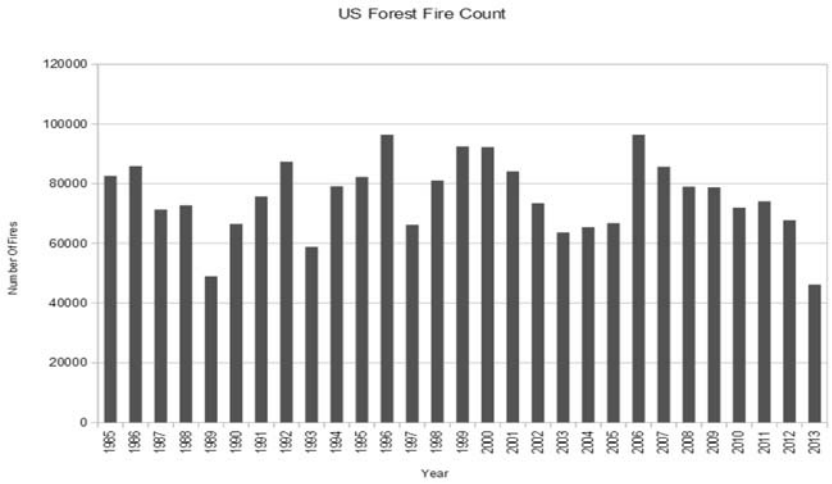


Above: Average number of days per-station in each year reaching or exceeding 100°F in 982 stations of the USHCN database (NOAA/NCEI, prepared by JRChristy).

Forest and wild fires are documented for the US. The evidence below indicates there has not been any change in frequency of wildfires. Acreage (not shown) shows little change as well.



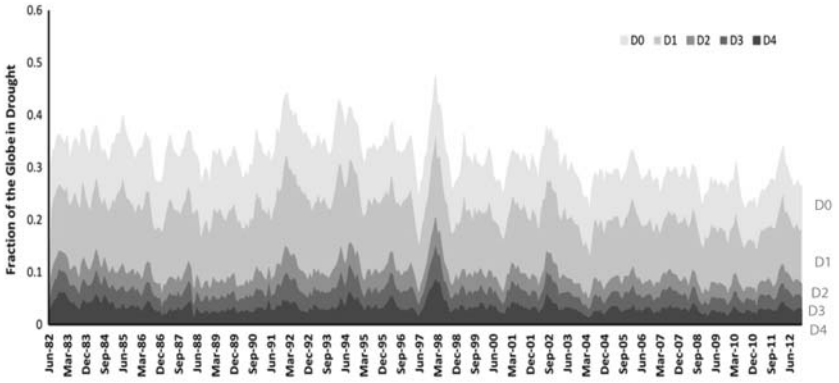
Above: Number of U.S. wildfires. As the management of these events changes, and thus the number also changes, but the number of events since 1985 has remained constant. (National Interagency Fire Center https://www.nifc.gov/fireInfo/nfn.htm)



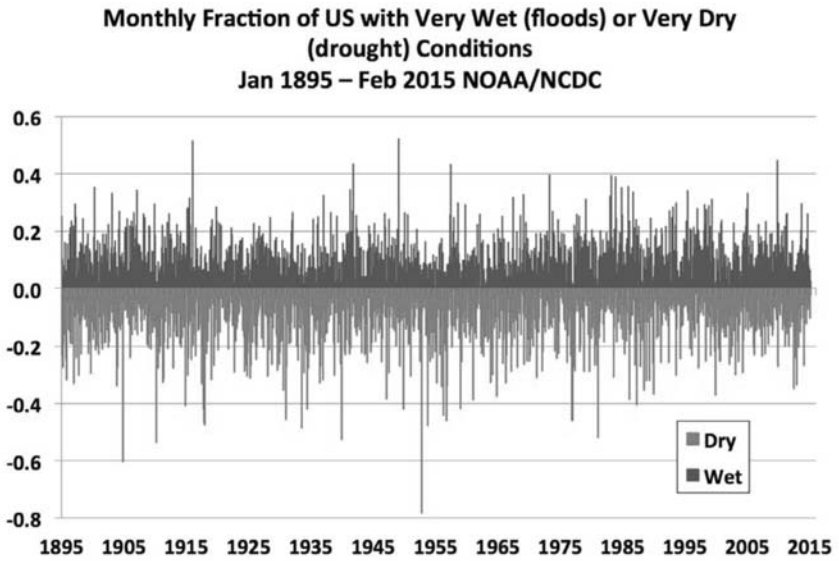
Above: Number of U.S. forest fires per year since 1965.

The two figures above demonstrate that fire events have not increased in frequency in the United States during the past several decades.

The claims that droughts and floods are increasing may be examined by the observational record as well.

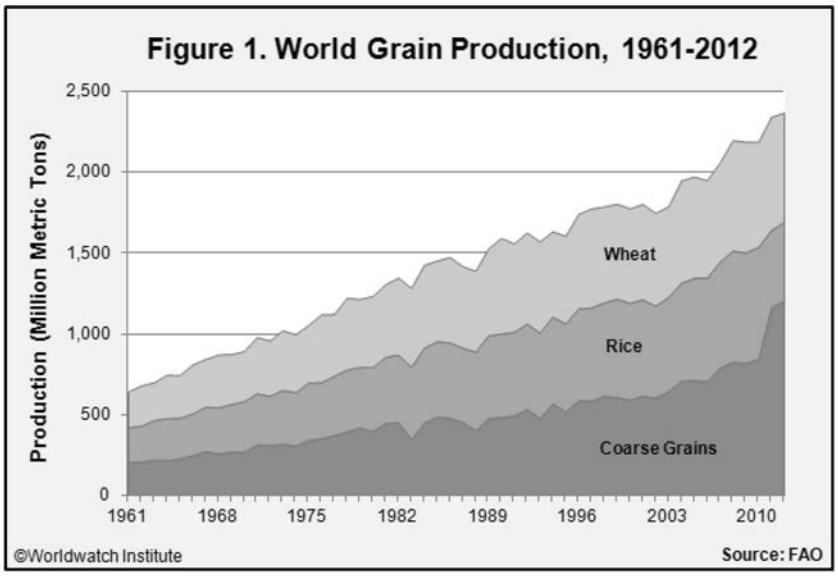


Above: Global areal extent of five levels of drought for 1982–2012 where dryness is indicated in percentile rankings with D0 < 30, D1 < 20, D2 < 10, D3 < 5 and D4 < 2 percentile of average moisture availability. (Hao *et al.,* 2014)



Above: Areal fraction of conterminous U.S. under very wet (blue) or very dry (red) conditions. NOAA/NCEI.

The two figures above demonstrate that moisture conditions have not shown a tendency to have decreased (more drought) or increased (more large-scale wetness). Such information is rarely consulted when it is more convenient simply to make unsubstantiated claims that moisture extremes, *i.e.,* droughts and floods (which have always occurred), are somehow becoming even more extreme. Over shorter periods and in certain locations, there is evidence that the heaviest precipitation events are tending to be greater. This is not a universal phenomenon and it has not been established that such changes may be due to changes in greenhouse gas concentrations as demonstrated earlier because the model projections are unable to reproduce the simplest of metrics.



Above: World grain production 1961–2012. U.N. Food and Agriculture Organization.

It is a simple matter to find documentation of the ever-rising production of grains. One wonders about the Federal Council on Environmental Quality's allegation that there has been "harm to agriculture" from human-induced climate change because when viewing the total growth in production, which appears to be accelerating, one would assume no "harm" has been done during a period of rising greenhouse gases.

With the evidence in these examples above, it is obviously difficult to establish the claims about worsening conditions due to human-caused climate change, or more generally that any change could be directly linked to increasing CO_2. This point also relates to the issue of climate model capability noted earlier. It is clear that climate models fall short on some very basic issues of climate variability, being unable to reproduce "what" has happened regarding global temperature, and therefore not knowing "why" any of it happened. It is therefore premature to claim that one knows the causes for changes in various exotic measures of weather, such as rainfall intensity over short periods, which are not even explicitly generated in climate model output.

The Disappointing Scientific Process

I have written much for previous congressional hearings and other venues about the failure of the scientific community to objectively approach the study of climate and climate change. (See Appendix) Climate science is a murky science with large uncertainties on many critical components such as cloud distributions and surface heat exchanges. As mentioned above, there is no objective instrumentation that can tell us "why" changes occur. That being the case, we are left with hypotheses (claims) to put forward and then to test. The information given above, in my view, is clear evidence that the current theoretical understanding of "why" the climate changes, as embodied in models (and on which current policy is based), fails such tests. Indeed, the theoretical (model) view as expressed in the IPCC AR5 in every case overestimated the bulk tropical atmospheric temperature response of extra greenhouse gases (see above and IPCC Supplementary Material Figure 10.SM.1) indicating the theoretical understanding of the climate response is too sensitive to greenhouse gases.

One problem with our science relates to the funding process for climate studies, the vast majority of which is provided through Federal agencies. Funding decisions are decided by people, and people have biases. Our science has also seen the move toward "consensus" science where "agreement" between people and groups is elevated above determined, objective investigation. The sad progression of events here has even led to congressional investigations designed to silence (with some success) those whose voices, including my own, have challenged the politically-correct views

on climate (*i.e.,* congressional investigation by Rep. Grijalva, 22 Feb 2015, *http://www.scribd.com/doc/256811029/Letter-to-UAH-re-John-Christy.*)

Today, funding decisions are made by review panels. In this process, many proposals for funding are submitted to the agencies, but the agencies only have a fraction of the funds available to support the proposals, so only a few proposals can be funded and these are selected by panels. In the area of climate, it is clear the agencies are convinced of the consensus view of dangerous climate change as indicated by their various statements and press releases on the issue. Therefore, when a contrarian proposal is submitted that seeks to discover other possible explanations besides greenhouse gases for the small changes we now see, or one that seeks to rigorously and objectively investigate climate model output, there is virtually no chance for funding. This occurs because the panel determines by majority vote whom to fund, and with tight competition, any bias by just a couple of panel members against a contrarian proposal is sufficient for rejection. Of course, the agencies will claim all is done in complete objectivity, but that would be precisely the expected response of someone already within the "consensus" and whose agency has stated its position on climate change. This brings me to "consensus science."

The term "consensus science" will often be appealed to regarding arguments about climate change to bolster an assertion. This is a form of "argument from authority." Consensus, however, is a political notion, not a scientific notion. As I testified to the Inter-Academy Council in June 2010, wrote in *Nature* that same year (Christy 2010), and documented in my written testimony for several congressional hearings (*e.g.,* House Space, Science and Technology, 31 Mar 2011) the IPCC and other similar Assessments do not represent for me a consensus of much more than the consensus of those selected to agree with a particular consensus.

The content of these climate reports is actually under the control of a relatively small number of individuals—I often refer to them as the "climate establishment"—who through the years, in my opinion, came to act as *gatekeepers* of scientific opinion and information, rather than *brokers.* The voices of those of us who object to various statements and emphases in these assessments are by-in-large dismissed rather than accommodated. This establishment includes the same individuals who become the "experts" called on to promote IPCC claims in government reports such as the endangerment finding by the Environmental Protection Agency.

As outlined in my previous testimonies, these "experts" become the authors and evaluators of their own research relative to research which challenges their work. This becomes an obvious conflict of interest. But with the luxury of having the "last word" as "expert" authors of the reports, alternative views vanish. This is not a process that provides the best information to the peoples' representatives. The U.S. Congress must have the full range of views on issues such as climate change which are (a) characterized by considerable ambiguity (see model results) (b) used to promote regulatory actions which will be economically detrimental to the American people and, most ironically, (c) will have no impact on whatever the climate will do.

I've often stated that climate science is a "murky" science. We do not have laboratory methods of testing our hypotheses as many other sciences do. As a result what passes for science includes, opinion, arguments-from-authority, dramatic press releases, and fuzzy notions of consensus generated by preselected groups. This is not science.

We know from Climategate e-mails and many other sources that the IPCC has had problems with those who take different positions on climate change than what the IPCC promotes. There is another way to deal with this however. Since the IPCC activity and climate research in general *is* funded by U.S. taxpayers, then I propose that five to ten percent of the funds be allocated to a group of well-credentialed scientists to produce an assessment that expresses legitimate, alternative hypotheses that have been (in their view) marginalized, misrepresented or ignored in previous IPCC reports (and thus the EPA Endangerment Finding and National Climate Assessments).

Such activities are often called "Red Team" reports and are widely used in government and industry. Decisions regarding funding for "Red Teams" should not be placed in the hands of the current "establishment" but in panels populated by credentialed scientists who have experience in examining these issues. Some efforts along this line have arisen from the private sector (*i.e., The Non-governmental International Panel on Climate Change* at *http://nipccreport.org/* and Michaels (2012) *ADDENDUM:Global Climate Change Impacts in the United States*). I believe policymakers, with the public's purse, should actively support the assembling all of the information that is vital to addressing this murky and wicked science, since the public will ultimately pay the cost of any legislation alleged to deal with climate.

Topics to be addressed in this "Red Team" assessment, for example, would include (a) evidence for a low climate sensitivity to increasing greenhouse gases, (b) the role

and importance of natural, unforced variability, (c) a rigorous and independent evaluation of climate model output, (d) a thorough discussion of uncertainty, (e) a focus on metrics that most directly relate to the rate of accumulation of heat in the climate system, (f) analysis of the many consequences, including benefits, that result from CO_2 increases, and (g) the importance that affordable and accessible energy has to human health and welfare.

What this proposal seeks is to provide to the Congress and other policymakers a parallel, scientifically-based assessment regarding the state of climate science which addresses issues which here-to-for have been un-or under-represented by previous tax-payer funded, government-directed climate reports. In other words, our policymakers need to see the entire range of findings regarding climate change.

Summary

The messages of the four points outlined above are: (1) the theoretical understanding of the way greenhouse gases affect climate, as embodied on climate models, fails simple evaluation tests, (2) even if one accepts climate model output, the impact of reducing emissions by any of the regulations now enforce or proposed will be negligible, (3) the claims about increases in frequency and intensity of extreme events are generally not supported by actual observations and, (4) official information about climate science is largely controlled by agencies through (a) funding choices for research and (b) by the carefully-selected (*i.e.,* biased) authorship of reports such as the EPA Endangerment Finding and the National Climate Assessment.

IAC 15 June 2010 Montreal

JOHN R. CHRISTY, DISTINGUISHED PROFESSOR OF ATMOSPHERIC SCIENCE DIRECTOR, EARTH SYSTEM SCIENCE CENTER, ALABAMA STATE CLIMATOLOGIST, UNIVERSITY OF ALABAMA IN HUNTSVILLE

IPCC LEAD AUTHOR: 2001 TAR, CONTRIBUTOR: 1992 SUPPLEMENT

CONTRIBUTOR: 1994 RADIATIVE FORCING OF CLIMATE CHANGE

KEY CONTRIBUTOR: 1995 SAR

CONTRIBUTING AUTHOR: 2007 AR4, WG I AND II

NASA MEDAL FOR EXCEPTIONAL SCIENTIFIC ACHIEVEMENT, AMERICAN METEOROLOGICAL SOCIETY SPECIAL AWARD FOR SATELLITE OBSERVATIONS

FELLOW, AMERICAN METEOROLOGICAL SOCIETY

Mr. Chairman and members of the IAC panel, thank you for inviting me to offer my views on the IPCC process. Five years ago the *New York Times* quoted me saying that an IPCC-like process, ". . . is the worst way to generate scientific information, except for all the others." (23 Aug 2005) I now think I was a bit too generous.

A fundamental problem with the entire issue here is that climate science is not a classic, experimental science. As an emerging science of a complex, chaotic climate system, it is plagued by uncertainty and ambiguity in both observations and theory. Lacking classic, laboratory results, it easily becomes hostage to opinion, groupthink, arguments-from-authority, overstatement of confidence, and even Hollywood movies. When climate scientists are placed in the limelight because this issue can generate compelling disaster scenarios, we simply don't want to say, "We just don't know."

I have been a contributor to the IPCC Assessments since 1992 and a Lead Author in the Third Assessment of 2001. Though I had some good things to say about the IPCC, I did respond in 2001 to the U.S. National Academy of Sciences when they solicited information about certain problems (see Appendix A).

At the time, I was more concerned about the product rather than the process. The first objection I raised regarding the Third Assessment was that the fabled Hockey Stick was oversold as an indicator of past climate change. This was well before the critical work of the Wegman Report, National Academy of Sciences, McIntyre's papers and the East Anglia e-mails. *Indeed, I urge you in the strongest terms to engage Stephen McIntyre in your deliberations at a high level as he has accurately documented specific failures in the IPCC process, some of which I can attest to, as I was there.*

My second objection to the TAR was its overstatement of confidence in model projections.

My role in the Fourth Assessment of 2007 was limited to that of a Contributing Author. This means I submitted recommendations that were dealt with by the Lead Authors who tended to disagree with my published findings. Thus, their views carried the day in the report. In this process, the final result really boils down the opinions of those selected as Lead Authors, a point I will address below.

In March of last year, 8 months before the e-mail fiasco, about 140 former IPCC Lead Authors gathered in Hawaii for a preview of what the Fifth Assessment might tackle. I was the only one there well-known to be essentially outside the IPCC "consensus." I had come to the conclusion that the IPCC establishment demonstrated a disturbing homogeneity-of-thought regarding the hypothesized but unproven role that greenhouse gases might impose on the climate system. My short talk (Appendix B) and poster (Appendix C) at that meeting last year dealt with three science issues and offered a recommendation. The three issues were (1) the surface temperature record is flawed in many ways, but is flawed in particular as a metric to detect greenhouse-imposed warming, (2) direct tests of the so-called fingerprint of climate model temperature changes versus observations indicated significant differences, failing simple hypothesis tests, and (3) the critical value of climate sensitivity to greenhouse gases was overstated because it had not been properly calculated. All of these were supported by peer-reviewed publications which even now continue to appear.

In my view, the IPCC process had drifted away from allowing authors to serve as Brokers of climate science, in which various views are given attention, to becoming Gatekeepers of climate science in which one view is elevated and promoted. The IPCC Assessment had become a "consensus of those who agreed with the consensus." Since "consensus" is a political notion, not a scientific notion, a goal of "consensus" in any forum is at its heart a political goal.

My recommendation last year was to include a chapter written by credentialed climate scientists who would provide evidence concerning these heretofore minimized issues, in particular the low sensitivity of the climate system. My assumption at that time was that the IPCC writing process would be the same, *i.e.,* that the Lead Authors of this chapter, as the others, would be given the sacred right of being their own final reviewers to let a new voice be heard. No one at the meeting thought this was a useful suggestion, I believe, because it would allow the expression of reasonable alternatives to claims too entrenched in the message of looming climate disasters promoted with IPCC indulgence.

Since last March, much has happened to expose some of the scientists who dominated the IPCC, whom I call the establishment, as less than transparent, subject to bias, and who suppress alternative views while using the IPCC's perception as a near-sacred document to promote their own opinions. This establishment dominates not only the IPCC but also the review process of the peer-reviewed literature, making it extremely difficult for alternative evidence to even be published now. This happens when your type of science is rather murky to begin with.

In my view, the three fundamental flaws in the current IPCC process are (1) the two-step political filter by which Lead Authors are selected, (2) the review-authority granted the Lead Authors who write the chapters and synthesis reports, and, (3) the very limited word-count available for each topic, which encourages short and overconfident statements about questions that in truth are plainly nasty to deal with.

In February of this year, *Nature* magazine asked me for a brief discussion about the IPCC and a way forward (Appendix D, last page). My main concern there was to define a process that would let the world know that our ignorance of much of the climate system is simply enormous and we have much to do. Mother Nature has a tremendous number of degrees of freedom up her sleeves, many of which we don't even know about or account for.

So, I suggested a living, carefully-managed, wikipedia-style process. Important questions, most of which are already laid out in the IPCC manifest, would be addressed by teams of Lead Authors who would be far less constrained by the word-count rules, and so would allow fuller expression of uncertainty and disagreement—expressions contributed by the specific people who perform whatever research is being discussed. The Lead Authors main task would be to organize and summarize the information on each question, acting strictly as Brokers, not Gatekeepers. With web-based links to actual text (and data) the Lead Authors would be far less tempted to be biased. Lead Authors need to know they do not have to agree with the findings they report. I believe such transparency would spur the Lead Authors to be fairer and more humble in their summary comments.

Peer-reviewed research of course would dominate the source material, but other documents—whose source is clearly identified—could contribute to the discussion. I know there would be significant issues of managing such a process, but I believe it would be far better than producing big books every six years that are limited, biased and out-of-date when they are printed. We *are* in the 21st Century, and, to the despair of those who find comfort in absolute answers, there are only continuously evolving levels of understanding (and ignorance) to most of the climate questions being asked. This situation begs for a dynamic assessment process.

The selection of Lead Authors through a two-step political process is a problem too. Presently, national governments nominate to the IPCC those who over the years, they can generally count on to be consistent with national policy. From this pool, the IPCC itself selects those it wants to be Lead Authors. To combat the political influence of governments and the U.N., to a small extent, I would recommend that Lead Authors be nominated by appropriate learned societies, such as yours, and selected for overlapping, rotating terms. I'm not completely comfortable with this as I'm aware that councils of science are deeply involved in political maneuvering which is why I state that to a "small extent" the political influence of governments and the U.N. might be mitigated.

Some Lead Authors could and should be scholars from other disciplines but who have a keen awareness of the hard rules of hypothesis testing, admissible evidence, and the power of language. . .physicists, chemists, engineers and yes, even lawyers. As I told a colleague the other day, it is clear to me now that climate science needs some adult supervision.

I realize such a recommendation creates consternation among those who have controlled the process up to now and who believe deeply that the "science is settled" because they find comfort in easy and unimaginative answers to difficult questions. For example, why doesn't the IPCC report on (and funding agencies invest in) major research about the internal dynamical properties of the climate system? At present these properties are incapably represented in climate models to date, and yet have been shown to be a major source of the variability we've seen. Why must we be so unimaginative that we just give up and claim that nothing else but enhanced greenhouse forcing explains most of the temperature rise in the past 50 years?

Others will complain that such an open process I describe will not generate the definitive statements necessary to drive policy. To those I say, "Welcome to climate science." If a specific policy is desired, climate science is a weak leg on which to stand which means a policy should have multiple, defensible reasons for adoption.

You will hear from those within the IPCC establishment that the IPCC does a terrific job of getting down to the truth about climate science and that the consensus reports are the best documents for policymakers. But as one mostly outside the "consensus", I can not agree, and I am far, far from being alone in that disagreement. I say this as a working-stiff climate scientist who builds datasets from scratch to create understanding and test assertions about the climate system. The process followed in the Fourth Assessment, in my view, simply did not provide to the world the true ambiguities, uncertainties and contentions of our fledgling science.

In summary, to me, the impediments to providing a more honest expression of our science to the world in the current IPCC process are (1) Lead Authors essentially having final review authority, (2) the Lead Author selection process which encourages government-approved, homogeneity-of-thought, and (3) the limited size, the dead-line character, and the past-expiration-date of printed documents. Thank you.

nature Vol 463|11 February 2010

OPINION

IPCC: cherish it, tweak it or scrap it?

As calls for reform intensify following recent furores about e-mails, conflicts of interest, glaciers and extreme weather, five climatologists propose ways forward for the Intergovernmental Panel on Climate Change. Their suggestions range from reaffirming the panel's governing principles to increasing the number and speed of its publications to replacing the volunteer organization with a permanently staffed structure.

Split into three panels

Mike Hulme
Coordinating lead author, lead author, review editor (AR3), University of East Anglia, Norwich, UK

STR/AFP/GETTY

An IPCC meeting: the panel will publish its Fifth Assessment Report (AR5), in 2014.

Much has changed since the late 1980s when the Intergovernmental Panel on Climate Change (IPCC) was designed, notably the nature of scientific practice and its relationship with society. How the world's knowledge communities are mobilized to enlighten policy deliberations also needs to be different. The assessments published by the IPCC have firmly elevated anthropogenic climate change to one of the major international political issues of our time. But they have made this impact by drawing in an ever-widening subset of the social, technological, environmental and ethical dimensions of climate change — well beyond the physical sciences.

The IPCC is no longer fit for purpose. It is not feasible for one panel under sole ownership — that of the world's governments, but operating under the delegated management of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) — to deliver an exhaustive 'integrated' assessment of all relevant climate-change knowledge. As I remarked three years ago in these pages, "The IPCC needs a complete overhaul. The structure and process are past their sell-by dates."

> "A new class of short, rapidly prepared, peer-reviewed reports is needed."

My suggestion for radical reform is to dissolve the IPCC after the Fifth Assessment Report (AR5) in 2014. The work would be split into three types of assessment and evaluation, each rather different to the three existing IPCC working groups.

The first would be a Global Science Panel (GSP). An IPCC-like assessment process should continue to operate for the physical sciences that observe and predict the Earth system. Rather than comprehensive reports every six years, this panel would commission, on a rolling basis, a larger number of smaller, sharply focused syntheses of knowledge on fast-moving topics that have great scientific or policy salience. Perhaps two or three would be in production at any one time and each would be no more than 50 pages in length. These would need to be globally coordinated and could be governed either through an intergovernmental process as now, or devolved to a governing council of representative national academies of science.

The second group would be made up of Regional Evaluation Panels (REPs). The cultural, social, economic and development dimensions of climate change are essentially regional in nature. Each region — five to ten continental or subcontinental regions in all — should conduct its own evaluation of relevant knowledge. This should use the work of the GSP, but also draw in a much more diverse set of expertise, knowledge and scholarship. As well as being structured according to the concerns of each region, the ownership and governance patterns of these REPs would vary regionally, but should ideally involve a consortium of national governments, civil-society organizations and businesses.

The third group would be the Policy Analysis Panel (PAP) — a standing panel of expertise, global in reach, with interdisciplinary skills and a diverse analytical capacity. Perhaps 50–100 strong, this panel would undertake focused and rapid (6–12 months) analyses of specific proposed policy options and measures that have global significance. These could be subjects such as environmental effectiveness of controlling black carbon, economic implications of carbon border tariffs or new financing options for reducing emissions from deforestation. The policy options to be analysed can be brought forward by UN bodies, non-governmental organizations (NGOs), businesses and groupings of national governments. The PAP could be governed by a council of women and men of international stature and strong cultural significance to represent the breadth of civil society around the world. Such high quality and transparent policy evaluation would broaden the options available

for national and international deliberations.

This restructuring would allow clearer distinctions to be made in areas that have been troublesome for the IPCC: assessments of published knowledge versus policy analysis and evaluation; the globalized physical sciences versus more geographically and culturally nuanced knowledge; a one-size, top-down model of ownership and governance versus more inclusive, representative and regionally varying forms of governance. It would better serve the world, and its peoples, in understanding and responding to anthropogenic climate change.

Independent agency needed

Eduardo Zorita
Contributing author (AR4), GKSS Research Center in Geesthacht, Germany

Like the financial sector last year, the IPCC is currently experiencing a failure of trust that reveals flaws in its structure. This presents the climate-change community with the opportunity to address these faults. The IPCC currently performs as a diffuse community of government-nominated academic volunteers occupying a blurred space between science and politics, issuing self-reviewed reports under great stresses and unmanageable deadlines. Its undefined structure puts it at the mercy of pressure from advocates.

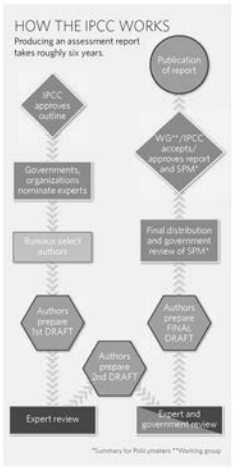
The IPCC should be made stronger and independent. We do not need to reinvent the wheel; there are excellent examples of agencies that society has set up when credibility is of the utmost importance. The European Central Bank, the International Atomic Energy Agency (IAEA), the International Energy Agency and the US Congressional Budget Office all independently navigate their way through strong political pressures, delivering valuable assessments, advice, reports and forecasts, tapping academic research when necessary. These agencies are accountable and respected.

An international climate agency (ICA) along such lines would have a staff of around 200 full-time scientists who would be independent of government, industry and academia. Such an agency should be resourced and empowered to do the following: issue streamlined biennial state-of-the-climate reports; be a repository and quality-controller of observational climate data; advise governments on regional assessments of climate impacts; and coordinate the suite of future-climate simulations by research institutes.

An ICA could be built, for instance, on the IAEA template, encompassing many more countries than the IAEA but with a smaller staff. ICA reports should be independently reviewed in a transparent process, draw only on established, peer-reviewed literature, and highlight research gaps. External reviews would then be incorporated into the reports to form white papers to include possible opposing views in a transparent way.

The process of moving towards such an ICA could start now, alongside the preparation of the next IPCC assessment report, and culminate after its completion. Those climate researchers in the IPCC Bureau who have widely recognized credibility could initiate this transformation, supported by lead authors and review editors more numerous and with a bigger say than presently. These review editors should be elected not by governments but directly by scientific unions, for instance the American Geophysical Union, the European Geosciences Union and similar associations from Asia.

As with finance, climate assessment is too important to be left in the hands of advocates.



SOURCE: IPCC

Apply best practice rules

Thomas F. Stocker
Co-chair IPCC Working Group I (AR5), coordinating lead author (AR3, AR4), University of Bern, Switzerland

The basis of the IPCC is the voluntary contributions of thousands of dedicated scientists from all over the world. The *Principles Governing IPCC Work* (IPCC, 1998) provide a clear framework for an open, transparent and robust process. This bottom-up endeavour is a unique model of providing scientific information, mainly from the peer-reviewed scientific literature, for decision-making on a challenging problem. It has worked extremely successfully for the past 21 years.

Recent controversies have demonstrated both the value and the limitations of these procedures. The team structure of the chapter authors, the multiple reviews by peers and governments, and the full and public documentation of this process largely eliminate personal views or biases in the science assessment. But procedures are only as strong as their enforcement at all levels of the assessment process. When I served as a coordinating lead author of Working Group I in the Third and Fourth Assessment Reports (AR3 and AR4), I was deeply impressed by the strict adherence to these principles by the co-chairs who ensured that these standards were applied at all levels. The combination of the best scientists and clear procedures constitute the authority of the IPCC.

Calls for reform of the IPCC have been made before. Changes were discussed after the completion of the Fourth Assessment Report in 2007. One possibility mooted was the production of more frequent assessments, more limited in scope. Fast-track assessments in support of the United Nations Framework Convention on Climate Change process were also considered. However, the panel concluded that the production of comprehensive reports roughly every six years is preferable because it ensures the robustness required for a thorough and rigorous assessment. Faster turnover would jeopardize the multi-stage review and thus compromise authority and comprehensiveness. In asking scientists to produce reports and assessments every year, say, we could lose their support rather quickly.

The IPCC has served as an honest broker in the past and will do so, hopefully, in the future. Now that the problem of climate change is on the

radar screen of the world, there are many NGOs and other groups, even groups of scientists and institutions, that provide climate-change information in various forms and quality, often lacking comprehensiveness and proper recognition of uncertainties. There is a strong pressure to provide 'just-in-time' scientific updates for policy-makers and stakeholders, as was the case in the preparations for the 2009 climate-change conference in Copenhagen. The IPCC must not yield to this pressure.

In this field of different and divergent forces, confusion may arise. An honest broker therefore is an asset. From my perspective, the IPCC has fulfilled this role with remarkable rigour and integrity. This role is now at risk, as the stakes are higher than ever before. The requirement that assessments are policy relevant but never policy prescriptive, as formulated in the *Principles Governing IPCC Work*, is of paramount importance. Our task is to inform the policy-makers and the public strictly in a 'what if' mode. Any other approach must be left to NGOs, negotiators or individuals. Only with strict adherence to procedures and to scientific rigour at all stages will the IPCC continue to provide the best and most robust information that is needed so much.

Produce more reports faster

Jeff Price
Lead author (AR3, AR4), director, climate-change adaptation, WWF United States

The IPCC is accepting nominations (until 12 March 2010) from governments and participating organizations for authors for its Fifth Assessment Report. One recommendation for the IPCC that could be implemented immediately is in how its coordinating lead authors and review editors are selected.

Currently, authors are selected to represent "a range of views, expertise, gender and geographical representation". However, given the importance placed on these assessments, the most senior positions should be filled by the nominees most expert in their field, regardless of balance. These authors should be the most knowledgeable nominee about the range of topics in their chapter, best able to cooperatively work with a team of international scholars. Preferably, they should have previously been involved in an IPCC assessment and be familiar with IPCC standards and methodologies. Geographic and gender balance should then be used in selection of lead authors. The level of work required in preparing an assessment is large. Increasing the number of lead authors would provide better balance and give more scientists the ability to participate in the process.

A new class of short, rapidly prepared, peer-reviewed reports is also needed. At present, publication options include supplemental material (no peer review required), technical papers (based on existing assessments) or assessments and special reports that undergo two reviews (expert and government/expert, usually taking more than two years to complete). For topics of emerging importance or uncertainty, we need reports based on expert meetings and literature synthesis that undergo only a single round of extensive peer review with review-editor oversight before publication. The IPCC should also expand the number of specialist task forces, task groups and hold more expert meetings to provide additional scientific review and oversight for the broadening array of models (including model comparisons and validation) and methodologies used in emissions reporting, estimating and monitoring impacts, and in developing assessments and adaptation plans.

Finally, the current period between assessments is too long. One option would be for the IPCC, or another body, to produce an annual review, assessment and synthesis of the literature for policy-makers (for example, three annual review volumes with a synthesis chapter in each volume) prepared by experts in the field. Although the editors of the volumes should ideally be drawn from past IPCC authors and editors, the review articles could be submitted by any author, as they would for a journal, with appropriate peer review and assessment for publication.

Open debate: Wikipedia-style

John R. Christy
Lead author (AR3), University of Alabama in Huntsville, USA

Since 1992 I have served as an IPCC contributor and in 2001, as a lead author. My experience has left me of the firm conviction that the IPCC should be removed from UN oversight.

The IPCC selects lead authors from the pool of those nominated by individual governments. Over time, many governments nominated only authors who were aligned with stated policy. Indeed, the selections for the IPCC Fourth Assessment Report represented a disturbing homogeneity of thought regarding humans and climate.

Selected lead authors have the last word in the review cycle and so control the message, often ignoring or marginalizing dissenting comments. 'Consensus' and manufactured-confidence ensued. The recent leaking of e-mails from the Climatic Research Unit at the University of East Anglia in Norwich, UK, put on display the unsavoury cycle of marginalizing different viewpoints. Now several errors of overstatement, such as that of the melting rate of the Himalayan glaciers, have been exposed.

Unfortunately, prestigious media, including *Nature*, became cheerleaders for these official reports, followed then by governments trying to enact policies that drastically reduced emissions to 'stop global warming' while increasing energy costs.

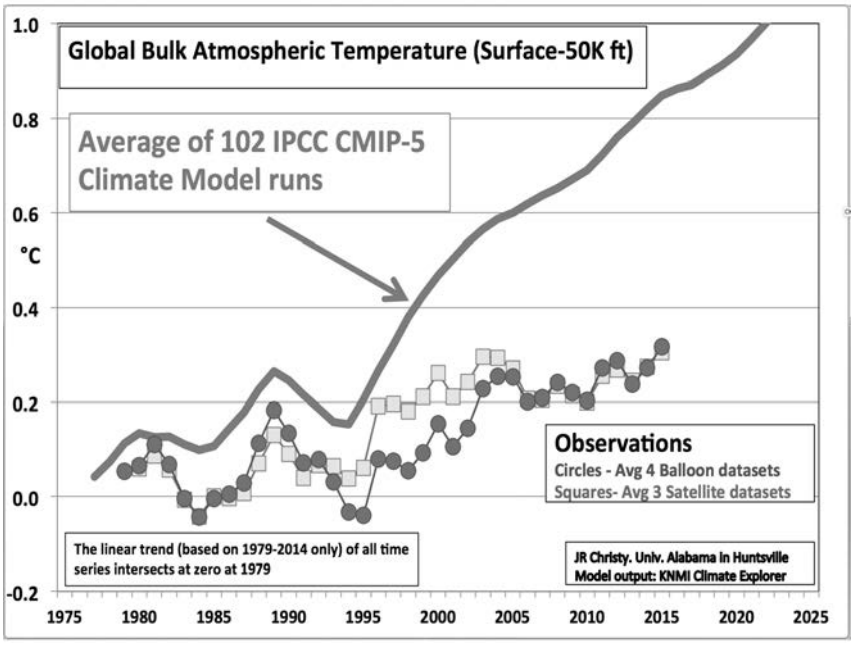
I recommended last year that the next IPCC report invites published authors to write about the evidence for low climate sensitivity and other issues. The IPCC then would be a true reflection of the heterogeneity of scientific views, an 'honest broker', rather than an echo chamber. My recommendation assumed a business-as-usual IPCC process.

However, voluminous printed reports, issued every six years by government-nominated authors, cannot accommodate the rapid and chaotic development of scientific information today. An idea we pitched a few years ago that is now worth reviving was to establish a living, 'Wikipedia-IPCC'. Groups of four to eight lead authors, chosen by learned societies, would serve in rotating, overlapping three-year terms to manage sections organized by science and policy questions (similar to the Fourth Assessment Report). The authors would strike a balance between the free-for-all of true science and the need for summary statements.

Controversies would be refereed by the lead authors, but with input from all sides in the text, with links to original documents and data. The result would be more useful than occasional big books and would be a more honest representation of what our fledgling science can offer. Defining and following rules for this idea would be agonizing, but would provide greater openness.

The truth, and this is frustrating for policy-makers, is that scientists' ignorance of the climate system is enormous. There is still much messy, contentious, snail-paced and now, hopefully, transparent work to do. ■

See also Perspectives, page 747.
Have your say on the future of the IPCC at go.nature.com/orzWau.



Senator CRUZ. Thank you, Dr. Christy.

At this point in the hearing is when Mr. Aaron Mair, the President of the Sierra Club, would be afforded his opportunity to present the Sierra Club's views on global warming. Unfortunately, as we discussed a minute ago, even though he was invited to present the Sierra Club's views, he chose not to attend, and presumably, one reason for that is the last time he presented testimony on this topic, he was unable to answer even the most basic questions on the scientific basis for the political theory he was advancing, that we should massively increase the Federal Government regulation of the economy and dramatically drive up the cost of living, the electricity bills of millions of hard-working Americans.

And so we will not be hearing from Mr. Mair now. Instead, we will hear from Dr. Curry.

STATEMENT OF JUDITH A. CURRY, PH.D., CHAIR OF THE SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES, GEORGIA INSTITUTE OF TECHNOLOGY

Dr. CURRY. I thank the Chairman and the Ranking Members for the opportunity to offer testimony today.

Prior to 2009, I felt that supporting the IPCC consensus on climate change was a responsible thing to do. I bought into the argument don't trust what one scientist says, trust what an international team of 1,000 scientists have said after years of careful deliberation.

That all changed for me in November 2009, following the leaked "Climategate" e-mails that illustrated the sausage making and even bullying that went into building the consensus. I started

speaking out, saying that scientists needed to do better at making the data and supporting information publicly available, being more transparent about how they reach conclusions, doing a better job of assessing uncertainties, and actively engaging with scientists having minority perspectives.

The response of my colleagues to this is summed up by the title of a 2010 article in the *Scientific American,* "Climate Heretic: Judith Curry Turns on Her Colleagues." I came to the growing realization that I had fallen into the trap of group think. I had accepted the consensus based on second-order evidence, the assertion that a consensus existed.

I began making an independent assessment of topics in climate science that had the most relevance to policy. And what have I concluded from this assessment? Human-caused climate change is a theory in which the basic mechanism is well understood, but whose magnitude is highly uncertain.

No one questions that surface temperatures have increased overall since 1880 or that humans are adding carbon dioxide to the atmosphere, or that carbon dioxide and other greenhouse gases have a warming effect on the planet. However, there is considerable uncertainty and disagreement about the most consequential issues—whether the warming has been dominated by human causes versus natural variability, how much the planet will warm in the 21st century, and whether warming is dangerous.

The central issue in the scientific debate on climate change is the extent to which the recent and future warming is caused by humans versus natural climate variability. Research effort and funding has focused on understanding human causes of climate change. However, we have been misled in our quest to understand climate change by not paying sufficient attention to natural causes of climate variability, in particular from the Sun and from the long-term oscillations in ocean circulations.

Why do scientists disagree about climate change? The historical data is sparse and inadequate. There is disagreement about the value of different classes of evidence, notably the value of global climate models. There is disagreement about the appropriate logical framework for linking and assessing the evidence, and scientists disagree over assessments of areas of ambiguity and ignorance.

How then and why have climate scientists come to a consensus about a very complex scientific problem that the scientists themselves acknowledge has substantial and fundamental uncertainties? Climate scientists have become entangled in an acrimonious political debate that has polarized the scientific community.

As a result of my analyses that challenge IPCC conclusions, I have been called a denier by other climate scientists and most recently by Senator Sheldon Whitehouse. My motives have been questioned by Representative Grijalva in a recent letter sent to the president of Georgia Tech.

There is enormous pressure for climate scientists to conform to the so-called consensus. This pressure comes not only from politicians, but from Federal funding agencies, universities, and professional societies, and scientists themselves who are green activists. Reinforcing this consensus are strong monetary, reputational, and authority interests.

In this politicized environment, advocating for carbon dioxide emissions reductions is becoming the default expected position for climate scientists. This advocacy extends to the professional society that publish journals and organize conferences.

Policy advocacy, when combined with understating the uncertainties, risks destroying science's reputation for honesty and objectivity without which scientists become regarded as merely another lobbyist group.

I would like to thank the Committee for raising the issue of data versus dogma in support of improving the integrity of climate science. This concludes my testimony.

[The prepared statement of Dr. Curry follows:]

PREPARED STATEMENT OF JUDITH A. CURRY, PROFESSOR AND FORMER CHAIR, SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES, GEORGIA INSTITUTE OF TECHNOLOGY

I thank the Chairman and the Committee for the opportunity to offer testimony today on 'Data or Dogma? Promoting Open Inquiry in the Debate on Climate Change.' I am Professor and former Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. As a climate scientist, I have devoted 30 years to conducting research on a variety of topics including climate dynamics of the Arctic, climate dynamics of extreme weather events, and reasoning about climate uncertainty. As president of Climate Forecast Applications Network LLC, I have been working with decision makers on climate impact assessments, assessing and developing climate adaptation strategies, and developing subseasonal climate forecasting strategies to support adaptive management and tactical adaptation.

Over the past decade, I have become increasingly concerned about the integrity of climate research, which is being compromised by the politicization of the science. My research on understanding the dynamics of uncertainty at the climate science-policy interface has led me to conclude these dynamics are not operating in a manner that is healthy for either the science or the policy process.

My testimony focuses on the following issues of central relevance to the state of climate science:

- Consensus, uncertainty and disagreement
- Unsettled climate science: the importance of natural climate variability
- Scenarios for the 21st century climate
- The broken contract between climate science and society

Consensus, uncertainty and disagreement

Under the auspices of the Intergovernmental Panel on Climate Change (IPCC), the international climate community has worked for more than 20 years to establish a scientific consensus on human-caused climate change. The IPCC consensus about dangerous anthropogenic climate change is portrayed as nearly total among scientists with prominence in the field of climate science, and the IPCC consensus has been endorsed by the relevant national and international science academies and scientific societies.

The IPCC consensus building process arguably played a useful role in the early synthesis of the scientific knowledge. However, I have argued that the ongoing process to negotiate a scientific consensus has had the unintended consequence of oversimplifying both the problem and its solution, introducing biases into the both the science and related decision making processes.

A scientist's job is to critically evaluate evidence and challenge and reassess conclusions drawn from the evidence. Disagreement and minority perspectives have an important and respected role to play in advancing science, as a mean for testing ideas and pushing the knowledge frontier forward. How then, and why, have climate scientists come to a scientific consensus about a very complex scientific problem that the scientists themselves acknowledge has substantial and fundamental uncertainties?

Climate scientists have become entangled in an acrimonious political debate that has polarized the scientific community and has resulted in political attacks on scientists on both sides of the debate. A scientist's 'side' is often defined by factors that are exogenous to the actual scientific debate. Scientific controversies surrounding evidence of climate change have become a proxy for political battles over whether

and how to react to climate change. Therefore, 'winning' a scientific debate means attaining a privileged position in political battle, hence providing motivation for defending the scientific consensus. The quality of both scientific and policy debate has suffered as a consequence.

A climate scientist making a statement about uncertainty or degree of doubt in the climate debate is categorized as a denier or a 'merchant of doubt,' whose motives are assumed to be ideological or motivated by funding from the fossil fuel industry. My own experience in publicly discussing concerns about how uncertainty is characterized by the IPCC has resulted in my being labeled as a 'climate heretic'[1] that has turned against my colleagues.

There is enormous pressure for climate scientists to conform to the so-called consensus. This pressure comes not only from politicians, but from Federal funding agencies, universities and professional societies, and scientists themselves who are green activists and advocates. Reinforcing this consensus are strong monetary, reputational, and authority interests.

As a result, I have become very concerned about the integrity of climate science. In the last 5 years, I have published a series of papers that address the inadequacies that I see in how climate scientists address the issue of uncertainty, and provide ways forward for improved reasoning about the complex problems in climate science:

- Climate science and the uncertainty monster[2]
- Reasoning about climate uncertainty[3]
- Nullifying the climate null hypothesis[4]
- Climate science: no consensus on consensus[5]

How to deal with the politicization of climate science is less obvious, but I regard it as highly important to shine some light on these problems. On my blog Climate Etc. at judithcurry.com, under the tags of 'Ethics'[6], 'Consensus' 1A[7] and 'Sociology of Science'[8], I have written a series of essays on biases, the problems of advocacy and partisanship among climate scientists, conflicts of interest, and suppressions of climate inquiry.

Unsettled climate science

Anthropogenic climate change is a theory in which the basic mechanism is well understood, but whose magnitude is highly uncertain owing to feedback processes. Scientists agree that surface temperatures have increased overall since 1880, humans are adding carbon dioxide to the atmosphere, and carbon dioxide and other greenhouse gases have a warming effect on the planet. However there is considerable disagreement about the most consequential issues: whether the warming has been dominated by human causes versus natural variability, how much the planet will warm in the 21st century, and whether warming is 'dangerous'.

Why do climate scientists disagree? The historical data is sparse and inadequate. There is disagreement about the value of different classes of evidence, notably the value of global climate models. There is disagreement about the appropriate logical framework for linking and assessing the evidence in this complex problem. Scientists disagree over assessments of areas of ambiguity and ignorance. And finally, belief polarization resulting from politicization of the science and the IPCC's consensus building process contributes substantially to the disagreement among scientists.

What is causing the warming?

The key conclusion of the 2013 IPCC AR5 Report[9] is that it is extremely likely that *more than half* of the warming since 1950 has been caused by humans, and climate model simulations indicate that *all* of this warming has been caused by humans.

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[1] *http://www.scientificamerican.com/article/climate-heretic/*
[2] *http://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS3139.1*
[3] *http://www.climateaccess.org/sites/default/files/Curry__Reasoning%20about%20climate%20uncertainty.pdf*
[4] *http://onlinelibrary.wiley.com/doi/10.1002/wcc.141/abstract?userIsAuthenticated=false&deniedAccessCustomisedMessage=*
[5] *http://curryja.files.wordpress.com/2012/10/consensus-paper-revised-final.doc*
[6] *http://judithcurry.com/category/ethics/*
[7] *http://judithcurry.com/category/consensus/*
[8] *http://judithcurry.com/category/sociology-of-science/*
[9] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5__SPM__FINAL.pdf*

Global surface temperature anomalies since 1850 are shown below.

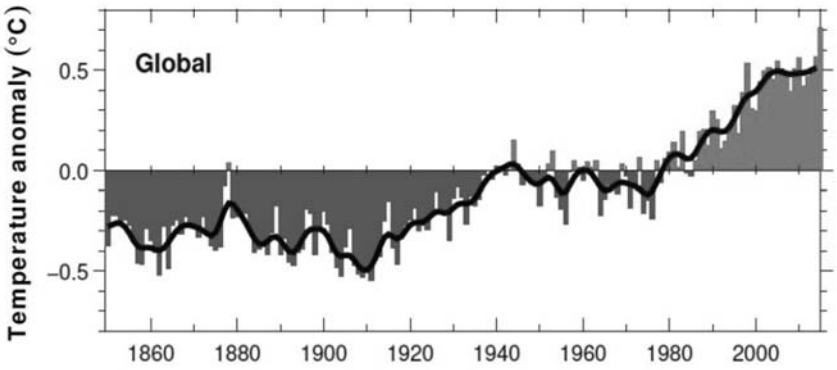

Figure 1: Global surface temperature anomalies from the UK HadCRUT4 dataset *http://www.cru.uea.ac.uk/cru/data/temperature/HadCRUT4.pdf*

If the warming since 1950 was caused by humans, what caused the warming during the period 1910—1945? The period 1910–1945 comprises over 40 percent of the warming since 1900, but is associated with only 10 percent of the carbon dioxide increase since 1900. Clearly, human emissions of greenhouse gases played little role in causing this early warming. The mid-century period of slight cooling from 1945 to 1975—referred to as the 'grand hiatus', also has not been satisfactorily explained.

Apart from these unexplained variations in 20th century temperatures, there is evidence that the global climate has been warming overall for the past 200 years, or even longer. While historical data becomes increasingly sparse in the 19th century, the Berkeley Earth Surface Temperature Project has assembled the available temperature data over land, back to 1750:

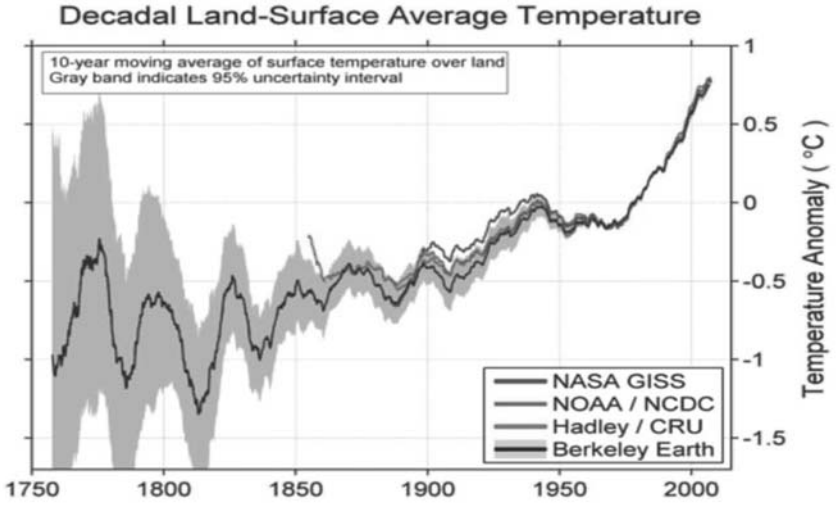

Figure 2: Global land surface temperature anomalies since 1750, smoothed with a 10 year filter [10].

The Berkeley Earth analysis shows a warming trend back to 1800, with considerable variability around the turn of the 19th century. Some of this variability around the turn of the 19th century can be attributed to large volcanic eruptions; this was also the time of the Dalton solar activity minimum (1791–1825). Paleoclimate reconstructions of Northern Hemisphere climate—such as from tree rings and boreholes—

[10] Rohde *et al.,* Geoinfor Geostat: An Overview 2013, 1:1 *http://dx.doi.org/10.4172/2327-4581.1000101*

indicate that overall warming may have occurred for the past 300–400 years.[11] Humans contributed little if anything to this early global warming.

What is the global warming hiatus, and why does it matter?

The warming hiatus, or 'pause', reflects a slowdown of the rate of warming in the early 21st century, relative to the rapid rate of warming in the last quarter of the 20th century. The 2013 IPCC AR5 Report[12] made the following statement: *"the rate of warming over the past 15 years . . . is smaller than the rate calculated since 1951"*.

The significance of a reduced rate of warming since 1998 is that during this period, 25 percent of human emissions of carbon dioxide have occurred. Most significantly, the observed rate of warming in the early 21st century was slower than climate model predictions. The growing discrepancy between climate model predictions and the observations has raised serious questions about the climate models that are being used as the basis for national and international energy and climate policies.

There has been a raging debate in recent months surrounding a new global temperature data set published by NOAA.[13] The new data set finds more warming in recent decades than other global surface temperature data sets. Media headlines touted the conclusion that science now shows that the recent hiatus in warming never existed. Other headlines accused NOAA of fiddling with the climate data to erase the warming hiatus.

As NOAA's new land temperature data set did not become publicly available until last month, independent scientists have not yet had the chance to fully assess or understand the new data set. The differences during the recent hiatus period between the new NOAA surface temperature data set and the other data sets is illustrated below.

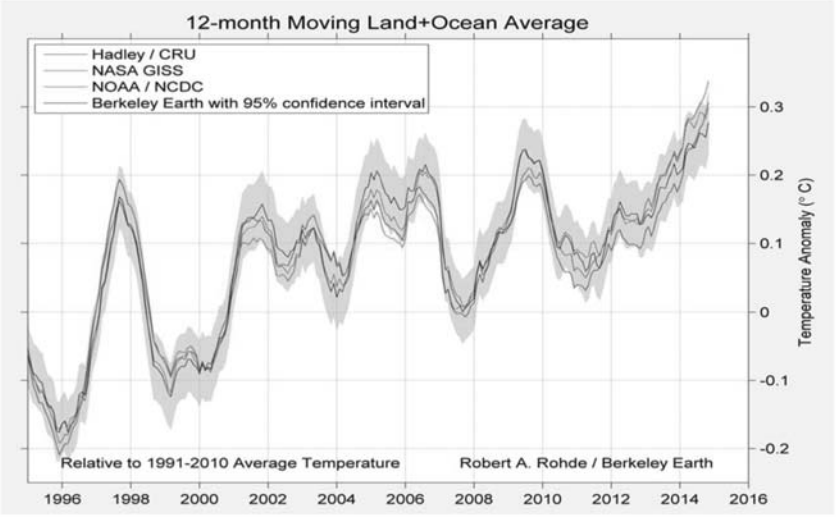

Figure 3: Global surface temperature anomalies since 1995, for four different data sets. Figure courtesy of Robert Rohde of the Berkeley Earth Surface Temperature Project

The new NOAA temperatures (red curve) are somewhat colder prior to 2007, and warmer since 2012. The largest discrepancies with other data sets are in the ocean data. Scientists are working to understand the reasons for these discrepancies. The trend of the new NOAA dataset of 0.1°C per decade for the period 1998–2014 is more than 50 percent larger than the trend of some of the other data sets. However, even the larger NOAA trend is at the bottom of the IPCC AR5 climate model projections for the early 21st century warming of 0.11 to 0.43 °C per decade[14].

The warming hiatus is most clearly revealed in the global satellite data sets of lower atmospheric temperature (Figure 4). Scientists disagree on the reasons for the

[11] *http://www.climatechange2013.org/report/reports-graphic/ch5-graphics/, Figure 5.7*
[12] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*
[13] *http://www.sciencemag.org/content/early/2015/06/03/science.aaa5632.full*
[14] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter11_FINAL.pdf*

discrepancies between the variations of surface temperature and the lower atmospheric temperatures. The presence of El Nino and La Nina events compounds the difficulty in interpreting trends.

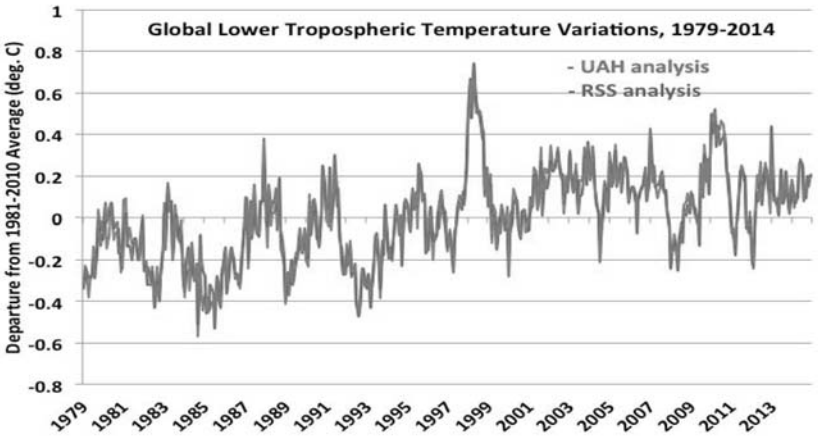

Figure 4: Lower atmospheric temperature anomalies determined from satellite, for two different analyses. Figure courtesy of Roy Spencer, University of Alabama Huntsville.

The U.S. media touted 2014 as the 'warmest year' in the historical record; however, given the uncertainties in the analyses, 2014 was in a statistical tie with 2010 and 2005. The UK dataset HadCRU, with perhaps a more realistic assessment of uncertainties, found 2014 to rank among the top 10 warmest years, all of which are since 1998. While the recent decade is the warmest in history, the ties for warmest year further reflect a plateau in the warming.

Scientists working with the global surface temperature datasets have predicted an 85 percent probability that 2015 will be the warmest year on record.[15] Declarations of 'warmest year' are already being made, before the end of the year, presumably to support the current UN climate negotiations in Paris. However, scientists working with the satellite data of lower atmospheric temperatures do not foresee 2015 as being among the warmest years.

Scientists continue to investigate the reasons for discrepancies among the data sets. It will likely be 5 years into the future before we have the perspective to identify whether the warming hiatus has ended with a resumption of a more rapid rate of warming, or whether the warming in 2015 from the large El Nino event will be followed by several cool years, as is often the case following El Nino events.

The oceans: sea ice and sea level rise

Among the greatest public concerns about climate change are sea level rise and melting of the polar ice. However, unless the recent changes are put in context with historical variations and an understanding of natural variability, it is easy to erroneously infer that any recent change is caused by humans.

Sea ice

The IPCC AR5 SPM [16] reports the following trends in sea ice:

> *"[T]he 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 percent per decade*
>
> *"It is very likely that the annual Antarctic sea ice extent **increased** at a rate of between 1.2 and 1.8 percent per decade between 1979 and 2012.*

Below are satellite observations of sea ice variability through early December 2015.

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[15] *http://berkeleyearth.org/berkeley-earth-temperature-update/*
[16] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*

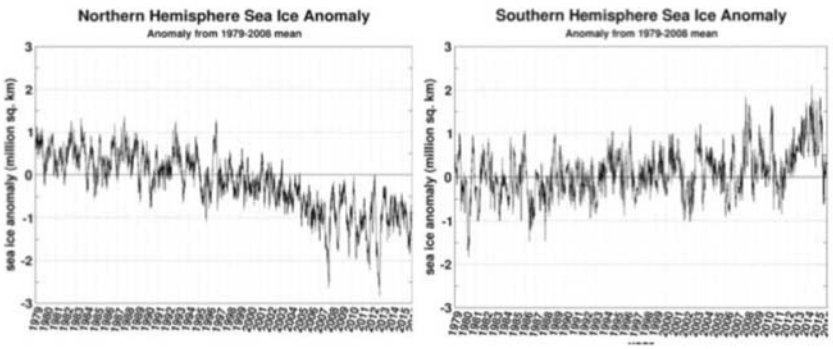

Figure 5. Sea ice extent anomalies from 1979 to present.
Source: *http://arctic.atmos.uiuc.edu/cryosphere/IMAGES/seaice.anomaly.arctic.png, http://arctic.atmos.uiuc.edu/cryosphere/IMAGES/seaice.anomaly.antarctic.png*

With regards to the most recent sea ice variability: since 2013, Arctic sea ice is recovering from its summertime minima during the period 2007–2012. Notably, Arctic sea ice volume (a metric that combines both horizontal extent and ice thickness) shows a continuing increase since 2012.[17] During 2014, Antarctic sea ice set a wintertime maximum record; whereas during 2015, the Antarctic sea ice extent has declined owing to the El Nino event.

Regarding the causes of the recent variations in sea ice, the AR5 Chapter 10[18] 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."*
>
> *"**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."*

The IPCC AR5 states that the increase in Antarctic sea ice is not understood and is not simulated correctly by climate models. Further, Arctic surface temperature anomalies in the 1930s were nearly as large as the recent temperature anomalies, and hence the IPCC uses the weak phrase 'contributed to' in reference to anthropogenic influences on Arctic sea ice.

A recent paper by Swart et al.[19] emphasized that internal climate variability can mask or enhance human-induced sea-ice loss on timescales ranging from years to decades or even a century. A recent paper by Zhang[20] clarifies the natural fluctuations that influence Arctic sea ice loss—heat transported by the Atlantic and Pacific, and wind patterns over the Arctic that drive sea ice out from the central Arctic, where it melts in the North Atlantic. In particular, the recent cooling in the high latitudes of the North Atlantic is associated with the current recovery of the sea ice in the Atlantic sector.

Wyatt and Curry (2014) interpret the multi-decadal natural variability component of the Arctic sea ice in context of a 'stadium wave'.[21] The stadium wave is a hypothesized low-frequency climate signal propagating across the Northern Hemisphere, whose tempo is set by the multidecadal component of Atlantic Ocean variability—the Atlantic Multidecadal Oscillation. Sea ice in the Eurasian Arctic shelf region, where sea ice is uniquely exposed to open ocean in the Northern Hemisphere,

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[17] *http://psc.apl.washington.edu/wordpress/wpcontent/uploads/schweiger/ice_volume/BPIOMASIceVolumeAnomalyCurrentV2.1.png*

[18] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter10_FINAL.pdf*

[19] Swart et al 2015 Influence of internal variability on Arctic sea-ice trends, *Nature climate Change,* 5, Pages: 86–89 DOI: doi:10.1038/nclimate2483

[20] Zhang, R. 2015. Mechanisms for low-frequency variability of summer Arctic sea ice extent, *Proceedings of the National Academy of Sciences,* doi:10.1073/pnas.1422296112

[21] 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*

bridges communication between the ocean and atmosphere that sustains propagation of the hemispheric signal. Ocean-ice-atmosphere coupling spawns a sequence of positive and negative feedbacks that convey persistence and quasi-oscillatory features to the signal. Further stabilizing the system are anomalies of co-varying Pacific-centered atmospheric circulations. The stadium wave hypothesis suggests that a transition to recovery of the natural variability component of the sea ice extent has begun in the European Arctic sector, and that the recovery will reach its maximum extent circa 2040.

Clearly, there is a lot going on with respect to variability in Arctic and Antarctic sea ice that cannot be explained solely by warming from human-caused greenhouse gases. Climate models do not simulate correctly the ocean heat transport and its variations. Scientists do not agree on the explanation for the increasing Antarctic sea ice extent, and the key issue as to whether human-caused warming is the dominant cause of the recent Arctic sea ice loss remains unresolved.

Nevertheless, the IPCC AR5 concluded:

- "[I]t is *very likely* that the Arctic sea ice cover will continue to shrink and thin all year round during the 21st century. It is also *likely* that the Arctic Ocean will become nearly ice-free in September before the middle of the century (*medium confidence*)."

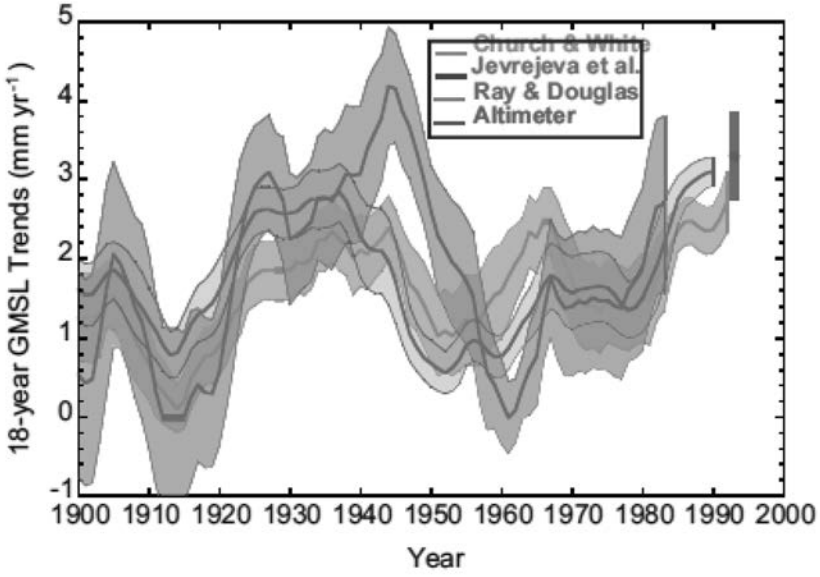
More convincing arguments regarding causes of recent sea ice variations in *both* hemispheres are required before placing any confidence in projections of future changes in Arctic sea ice cover.

Sea level rise

The IPCC AR5 SPM[22] makes the following statements regarding global sea level rise:

> "*Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m"* [about 7–8 inches]
>
> *"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 . . . 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.***"

The rate of global mean sea level rise as portrayed in the IPCC AR5 is shown in Figure 6 below.



[22] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*

Figure 6. 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 percent confidence. The estimate from satellite altimetry is also given, with the 90 percent confidence given as an error bar. [AR5 WGI Figure 3.14] [23]

The IPCC AR5 then concludes:

> *"It is **very likely** that there is a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s."*

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 1920–1950 was comparable to, if not larger than, the value in recent years (a period contributing less than 10 percent of the human caused CO_2 emissions since 1900). 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.

The IPCC AR5 then makes the following projections regarding sea level rise:

> *"Under all RCP scenarios the rate of sea level rise will very likely exceed that observed during 1971–2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets."*
>
> *"For RCP8.5, the rise by the year 2100 is 0.52 to 0.98 m [20 to 38 inches], with a rate during 2081–2100 of 8 to16 mm/yr (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."*

So, for a warming since 1900 that is approaching 1 °C, we have been unable to identify an unambiguous signal of human-caused sea level rise that exceeds the signal from natural variability (as evidenced by the large rates of sea level rise from 1920 to 1950). The extreme emissions scenario (RCP8.5) projects a sea level increase of 20 to 38 inches by the end of the 21st century; for the more realistic emissions scenario RCP6.0, the projected sea level rise is 13 to 25 inches. These projections were obtained using the same CMIP5 models that are arguably running too hot in their temperature projections, perhaps by a factor of two.

The largest concern about a potential catastrophic sea level rise is the possible collapse of the West Antarctic Ice Sheet (WAIS). The IPCC AR5 decided that there was insufficient evidence to make an assessment any more precise than the sea level rise contribution from WAIS "*would not exceed several tenths of a metre*" by the end of the 21st century. A recent paper in *Nature* [24] predicts that WAIS instability will most likely contribute 10 cm sea level rise by the end of the 21st century but is extremely unlikely to contribute more than 30 cm.

A recent paper [25] published by NASA scientists found that overall mass gains of the Antarctic ice sheet exceed losses, and that the growing accumulation of snow over Antarctic is *decreasing* global sea level by 0.23 mm/yr. This finding is in contrast to the IPCC AR5 conclusion that Antarctica was *adding* 0.27 mm/yr to sea level rise. The issues surrounding the current and potential future contributions of Antarctica to sea level rise continue to be debated.

The essential issue regarding sea level rise is that any dangers are local. Global warming (whether natural or anthropogenic) is only one factor that influences local sea level rise: other factors are geological sinking/rising, ground water withdrawal, and river and coastal engineering. Nearly all locales where sea level rise is regarded as dangerous have rates of sea level rise that far exceed the global rate of 3 mm/yr—U.S. examples [26] are the Louisiana coast (9.03 mm/yr) and Chesapeake Bay (6.02 mm/yr), and Bangladesh sea level is rising at a rate of 10.7 mm/yr [27]. A recent study by New Zealand scientists [28] found that 18 of 29 atoll islands in the tropical Pacific have actually grown over the past 60 years, in the presence of rising sea levels.

Summary

Anthropogenic climate change is a theory in which the basic mechanism is well understood, but whose potential magnitude is highly uncertain. What does the preceding analysis imply for IPCC's 'extremely likely' attribution of anthropogenically caused warming since 1950?

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[23] *https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spm.html*
[24] *http://www.nature.com/articles/doi:10.1038/nature16147*
[25] *http://www.ingentaconnect.com/content/igsoc/jog/pre-prints/content-ings_jog_15j071*
[26] *http://tidesandcurrents.noaa.gov/sltrends/sltrends.html*
[27] *http://www.sciencedirect.com/science/article/pii/S0921818113002191*
[28] *http://www.crossref.org/iPage?doi=10.1130%2FG36555.1*

1. 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 2007 IPCC AR4 Report[29], the rate of warming since 1998 is only 0.065 °C per decade (HadCRUT4 data set) or 0.1 °C per decade (new NOAA data set).
2. There have been large magnitude variations in global/hemispheric climate on timescales of 30 years, which are the same duration as the late 20th century warming. The IPCC does not have convincing explanations for previous 30 year periods in the 20th century, notably the warming 1910–1945 and the grand hiatus 1945–1975.
3. There is a secular warming trend at least since 1800 (and possibly as long as 400 years), that cannot be explained by CO_2, and is only partly explained by volcanic eruptions.

The combination of these three points substantially reduces the confidence that we should place in the IPCC's attribution of warming since 1950 to human causes.

With regards to the multidecadal variations, a recent paper by Tung and Zhou[30] argue that a natural multidecadal oscillation of an average period of 70 years with significant amplitude of 0.3–0.4°C is superimposed on the secular warming trend, which accounts for 40 percent of the observed warming since the mid-20th century. Tung and Zhou identify this oscillation with the Atlantic Multidecadal Oscillation (AMO), although the stadium wave[31] suggests a more complex multidecadal signal. The stadium wave provides a common explanation for both the mid 20th century warming hiatus (1945–1975) and the 21st century warming hiatus (since 1998). These oscillations are strongly reflected also in Arctic temperatures, Arctic sea ice extent and Greenland melting.

What could be the cause of a 200—400 year period of secular warming? The obvious places to look are to the sun and the ocean. Ocean circulation patterns influence climate also on century to millennial time scales. Sun-climate connections are receiving renewed interest, as evidenced by the National Academies Workshop Report "The Effects of Solar Variability on Earth's Climate".[32] Understanding and explaining the climate variability over the past 400 years, prior to 1950, has received far too little attention. Without this understanding, we should place little confidence in the IPCC's explanations of warming since 1950—it is too easy to get the 'right' answer for the wrong reasons.

Whither the 21st century climate?

The IPCC has made dire predictions that we can expect 4 °C or more of warming by the end of the 21st century if carbon dioxide emissions are not reduced. The climate models making these predictions are the same models that predicted too much warming in the early 21st century, and do not reproduce the warming from 1910–1945 or the mid 20th century grand hiatus. Further, the global climate models cannot predict future major volcanic eruptions or solar cycles, and do not adequately predict the long-term oscillations in the ocean.

Arguments for lower values of climate sensitivity to CO_2

Human-caused warming depends not only on increases in greenhouse gases but also on how 'sensitive' the climate is to these increases. Climate sensitivity is defined as the global surface warming that occurs when the concentration of carbon dioxide in the atmosphere doubles. If climate sensitivity is high, then we can expect substantial warming in the coming century as emissions continue to increase. If climate sensitivity is low, then future warming will be substantially lower.

The equilibrium climate sensitivity (ECS) is defined as the change in global mean surface temperature that is caused by a doubling of the atmospheric CO_2 concentration, allowing sufficient time for the climate to equilibrate. Table 1 compares the values of ECS determined by: the IPCC AR4 (2007)[33], the IPCC AR5 (2013)[34], the

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[29] *https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spm.html*

[30] Tung, KK and J Zhou, 2013: Using data to attribute episodes of warming and cooling in instrumental records. *PNAS http://www.pnas.org/content/early/2013/01/22/1212471110.abstract*

[31] Wyatt, MG and JA Curry 2014: Role for Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the 20th century. *Climate Dynamics,* 42, 2763–2782. *http://judithcurry.com/2013/10/10/the-stadium-wave/*

[32] *http://www.nap.edu/read/13519/chapter/1#xi*

[33] *https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spm.html*

[34] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*

CMIP5 climate models cited in the IPCC AR5 (2013)[35], the observational analysis of Lewis and Curry (2014)[36] and the update by Lewis (2015)[37] with lower aerosol forcing, and the U.S. IWG[38] (used to determine the social cost of carbon).

Table 1: Values of equilibrium climate sensitivity (ECS) (°C)

	Best Estimate	5th pctile	95th pctile
IPCC AR4 (2007)	3.0	1.5	—
IPCC AR5 (2013)	—	1.0	6.0*
CMIP5 models (2013)	3.22	2.1	4.7
Lewis & Curry (2014)	1.64	1.05	4.05
Lewis (2015)	1.45	1.05	2.2
US IWG	3.0	1.72	7.14

90th pctile

There are marked differences between the values of ECS determined by the IPCC AR5 versus the AR4. The nominal lower bound (5th percentile) has dropped from 1.5 °C (AR4) to 1.0 °C (AR5). The AR5 finds values of ECS exceeding 6°C to be very unlikely (90th percentile), whereas the AR4 did not have sufficient confidence to identify an upper bound at this confidence level. It is also significant that the AR5 does not cite a 'best estimate', whereas the AR4 cites a best estimate of 3 °C. 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).

Lewis and Curry (2014) found values of ECS approximately half that determined from the CMIP5 climate models. Using an observation-based energy balance approach, our calculations used the same data (including uncertainties) for changes in greenhouse gases, aerosols and other drivers of climate change given by the IPCC AR5. Our range for ECS is much narrower, with far lower upper limits, than reported by the IPCC AR5. Recent papers by Skeie et al[39] and Masters[40] also find comparably low values of ECS.

The latest research suggests even lower values of the equilibrium climate sensitivity. The greatest uncertainty in ECS estimates is accounting for the effects of small aerosol particles in the atmosphere, which have a cooling effect on the climate (partially counteracting the greenhouse warming). A new paper by Stevens[41] constrains the impact of aerosols on climate to be significantly smaller than assumed in the IPCC AR5. Nicholas Lewis has re-run the calculations used in Lewis and Curry (2014) using aerosol impact estimates in line with Stevens' paper.[42] Most significantly, the upper bound (95th percentile) is lowered to 2.2 °C (Table 1).

At the recent international Workshop on Earth's Climate Sensitivity,[43] concerns were raised about the upper end of the Lewis and Curry sensitivity being too low, owing to uncertainties in ocean heat uptake. Many of the climate model simulations used for the AR5 (CMIP5) are using values of aerosol forcing that are now known to be far too high. Climate model simulations that are re-assessed and re-calibrated to account for smaller values of aerosol forcing can be used to clarify the upper bound of ECS. In a presentation at the Workshop, IPCC lead author Bjorn Ste-

[35] *http://www.climatechange2013.org/images/uploads/WGIAR5__WGI-12Doc2b__FinalDraft__Chapter09.pdf*

[36] Lewis, N. and J.A. Curry, (2014) The implications for climate sensitivity of AR5 forcing and heat uptake. *Climate Dynamics http://link.springer.com/article/10.1007%2Fs00382-014-2342-y#page-1*

[37] *http://judithcurry.com/2015/03/19/implications-of-lower-aerosol-forcing-for-climate-sensitivity/*

[38] *https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf*

[39] Skeie, R. B., T. Berntsen, M. Aldrin, M. Holden, and G. Myhre, 2014. A lower and more constrained estimate of climate sensitivity using updated observations and detailed radiative forcing time series. *Earth System Dynamics, 5,* 139–175.

[40] Masters, T., 2013. Observational estimates of climate sensitivity from changes in the rate of ocean heat uptake and comparison to CMIP5 models. *Climate Dynamics,* doi:101007/s00382–013–1770–4

[41] Stevens, B (2015) Rethinking the lower bound on aerosol forcing. *J. Climate, http://journals.ametsoc.org/doi/abs/10.1175/JCLI–D–14–00656.1*

[42] Lewis, N, (2015) Implications of lower aerosol forcing for climate sensitivity. *http://judithcurry.com/2015/03/19/implications-of-lower-aerosol-forcing-for-climate-sensitivity/*

[43] *http://www.mpimet.mpg.de/en/science/the-atmosphere-in-the-earth-system/ringberg-workshop/ringberg-2014.html*

vens[44] argued for an upper bound to ECS of 3.5 °C based on analyses of climate models. Research continues to assess the methods used to estimate climate sensitivity. However, the reduced estimates of aerosol cooling lead inescapably to reductions in the estimated upper bound of climate sensitivity.

The discrepancy between observational and climate model-based estimates of climate sensitivity is substantial and of significant importance to policymakers—equilibrium climate 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. In spite of the IPCC AR5 assessment (where a 'best value' was not given) and this recent research on climate sensitivity, economists calculating the social cost of carbon and the impacts of emissions reductions on climate continue to use the 'best value' of ECS = 3 °C determined by the 2007 IPCC AR4 Report.

A particularly egregious example of this is the U.S. Social Cost of Carbon,[45] prepared by the InterAgency Working Group (IWG). In May 2013, the IWG produced an updated social cost of carbon model. However, the IWG did *not* update the equilibrium climate sensitivity (ECS) employed in the models, and this decision was reaffirmed by the IWG in July 2015. The values of ECS used by the U.S. IWG (Table 1) have lower and upper bounds that are indefensible in context of the IPCC values and most particularly in light of the recent research. The 95th percentile value is of particular importance, since the tail values of ECS drive the social cost of carbon.

In summary, there is a great deal of uncertainty in the values of climate sensitivity, and this is an active area of research. There is growing evidence in the published literature and recent assessments and workshops that a sensitivity of 1.0 °C is the appropriate lower bound to use in a 5 to 95 percentile range, and there is decreasing support for values of equilibrium climate sensitivity above 3.5°C. Not only are the U.S. IWG sensitivity values much higher than values suggested by the latest research, but the U.S. IWG values are indefensible even in context of both the IPCC AR4 and AR5 reports. The end result is that misleading values of the social cost of carbon being used to drive U.S. climate and energy policy.

Climate change in the 21st century

Chapter 11 of the IPCC AR5 Report[46] focused on near term climate change, through 2035. Figure 7 compares climate model projections with recent observations of global surface temperature anomalies.

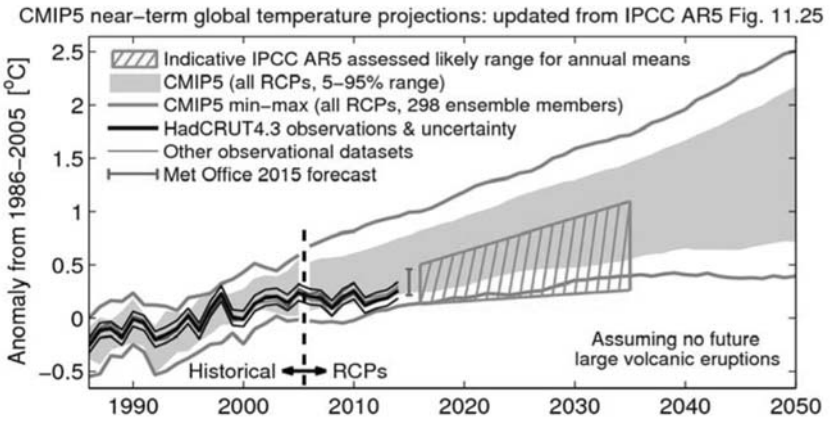

Figure 7. Comparison of CMIP5 climate model simulations of global surface temperature anomalies with observations through 2014 (HadCRUT4). Updated from Figure 11.25 of the IPCC AR5, to include observations through 2014. *http://www.climate-lab-book.ac.uk/comparing-cmip5-observations/*

The observed global temperatures for the past decade are at the bottom bound of the 5–95 percent envelope of the CMIP5 climate model simulations. Overall, the trend in the climate model simulations is substantially larger than the observed trend over the past 15 years.

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[44] *http://www.mpimet.mpg.de/fileadmin/atmosphaere/WCRP__Grand__Challenge__Workshop/Ringberg__2015/Talks/Stephens__24032015.pdf*

[45] *https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf*

[46] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5__Chapter11__FINAL.pdf*

Regarding projections for the period 2015–2035, the 5–95 percent range for the trend of the CMIP5 climate model simulations 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 in Figure 7):

> *"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."*

This lowering of the projections 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.

Multi-decadal ocean oscillations play a dominant role in determining climate on decadal timescales. The Atlantic Multidecadal Oscillation (AMO) is currently in its warm phase, with a shift to the cool phase expected to occur sometime in the 2020s.[47] Climate models, even when initialized with ocean data, have a difficult time simulating the amplitude and phasing of the ocean oscillations. In a paper that I coauthored, we found that most of CMIP5 climate models, when initialized with ocean data, show some skill out to 10 years in simulating the AMO.[48] Tung and Zhou[49] argue that not taking the AMO into account in predictions of future warming under various forcing scenarios may run the risk of over-estimating the warming for the next two to three decades, when the AMO is likely in its cool phase.

Projections for the year 2100

Climate model projections of global temperature change at the end of the 21st century are driving international negotiations on CO_2 emissions reductions, under the auspices of the UN Framework Convention on Climate Change (UNFCCC).[50] Figure 8 shows climate model projections of 21st century warming. RCP8.5 reflects an extreme scenario of increasing emissions of greenhouse gases, whereas RCP2.6 is a scenario where emissions peak around 2015 and are rapidly reduced thereafter.

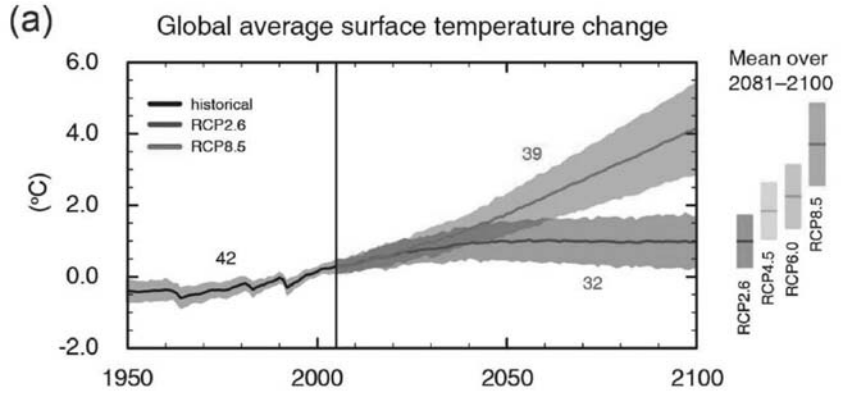

Figure 8: Figure SPM.7 of the IPCC AR5 WG1. CMIP5 multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (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.

Under the RCP8.5 scenario, the CMIP5 climate models project continued warming through the 21st century that is expected to surpass the 'dangerous' threshold of 2°C warming as early as 2040. It is important to note that the CMIP5 simulations only consider scenarios of future greenhouse gas emissions—they do not include consideration of scenarios of future volcanic eruptions, solar variability or long-term os-

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[47] *http://www.wyattonearth.net/images/9Wyatt__Curry__2013__author-version__manuscript.pdf*

[48] *http://webster.eas.gatech.edu/Papers/Kim__et__al.2012__GRL.pdf*

[49] Tung, KK and J Zhou, 2013: Using data to attribute episodes of warming and cooling in instrumental records. *PNAS http://www.pnas.org/content/early/2013/01/22/1212471110.abstract*

[50] *http://unfccc.int/2860.php*

cillations in the ocean. Russian scientists[51] argue that we can expect a Grand Solar Minima (contributing to cooling) to peak mid 21st century.

While the near-term temperature projections were lowered relative to the CMIP5 simulations (Figure 7), the IPCC AR5 SPM[52] states with regards to extended-range warming:

> *"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 percent model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding."*

There is a troubling internal inconsistency in the IPCC AR5 WG1 Report: the AR5 assesses substantial uncertainty in climate sensitivity and substantially lowered their projections for 2016–2035 relative to the climate model projections, versus the projections out to 2100 that use climate models that are clearly running too hot. Even more troubling is that the IPCC WG3 report—Mitigation of Climate Change—conducted its entire analysis assuming a 'best estimate' of equilibrium climate sensitivity to be 3.0 °C.

The IPCC AR5 declined to select a 'best estimate' for equilibrium climate sensitivity, owing to discrepancies between climate model estimates and observational estimates (that are about half the magnitude of the climate model estimates). Hence the CMIP5 models produce warming that is nominally twice as large as the lower values of climate sensitivity would produce. No account is made in these projections of 21st century climate change for the substantial uncertainty in climate sensitivity that is acknowledged by the IPCC.

Impact of reductions in CO_2 emissions

The current negotiations in Paris under the auspices of the UNFCCC COP21 are aimed at reducing emissions so as to avoid 'dangerous' human interference with climate change.[53] The definition of 'dangerous' has been rather arbitrarily set at 2°C warming since pre-industrial times.[54]

The world's nations have recently submitted to the UNFCCC their Intended Nationally Determined Contributions (INDCs).[55] Economists are beginning to assess the impact that these INDCs will have on the climate by the end of the 21st century. Danish economist Bjorn Lomborg recently published a paper[56] that assesses the impact of the climate policies implemented by 2030, and assuming these policies are extended out to 2100. Lomborg concluded that an optimistic estimate (assuming the targets are actually met) is that these emissions reductions would prevent 0.17 °C of warming by the end of the 21st century. Lomborg's estimate is consistent with a statement in the "MIT Energy and Climate Outlook 2015"[57] that projected about 0.2 °C less warming by the end of the 21st century.

The second, longer-term reduction commitments (*e.g.,* 80 percent reduction in both U.S. and EU emissions by 2050) were not included in Lomborg's analysis, because he regarded promises of what will happen in 2050 to be not as much actual policies but political hand waving. The International Energy Agency has issued a report[58] that estimated that full implementation of the path set by the global INDCs would be consistent with a global average temperature increase of 2.7°C by 2100. Other estimates[59] range higher, up 3.5 °C, although none of these estimates are documented in detail or published in a refereed journal. The bottom line is that all of these estimates from climate models are far from achieving the desired objective of keeping the warming below 2 °C.

All of these estimates are being conducted using the MAGICC climate model,[60] which allows specification of the value of equilibrium climate sensitivity. MAGICC's

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[51] Abdussamatov, H 2013: Current long-term negative energy balance of the earth leads to the new little ice age. *Journal of Geology and Geophysics http://omicsgroup.org/journals/grand-minimum-of-the-total-solar-irradiance-leads-to-the-little-ice-age-2329–6755.1000113.pdf*

[52] *https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf,* Table SPM.2

[53] *https://unfccc.int/resource/docs/convkp/conveng.pdf*

[54] *http://www.wbgu.de/en/special-reports/sr-1995-co2-reduction/*

[55] *http://unfccc.int/focus/indc_portal/items/8766.php*

[56] Lomborg, B, 2015: Impact of Current Climate Proposals, Global Policy *http://onlinelibrary.wiley.com/doi/10.1111/1758-5899.12295/full*

[57] *http://globalchange.mit.edu/research/publications/other/special/2015Outlook*

[58] *http://www.iea.org/media/news/WEO_INDC_Paper_Final_WEB.PDF*

[59] *http://www.climatescoreboard.com*

[60] *http://www.cgd.ucar.edu/cas/wigley/magicc/*

default value of ECS is 3 °C, and this number has become so ingrained that you see many analyses that do not even cite the value of ECS that was used.

Of particular note is a recent paper by Japanese economists Yoichi Kaya, Mitsutune Yamaguchi and Keigo Akimoto entitled "The uncertainty of climate sensitivity and its implications for the Paris negotiations".[61] The key conclusion from their paper:

> *"The outcome of our model shows global total emissions under major countries' INDCs in 2030 will not be on track to attain the 2 C target if climate sensitivity is 3 C. On the other hand, if climate sensitivity is 2.5 C, and if we allow a temporal overshoot of 580 ppmCO_2-eq, that the 2 C target is still within reach".*

If ECS is even lower, below 2 °C, then it is even easier to stay below the 2 °C 'danger' level. Further, for lower values of ECS, the planned emissions reductions will have an even smaller impact on temperatures in 2100. Policy makers meeting in Paris seem not to realize that there is large uncertainty in the values of equilibrium climate sensitivity, and that there is growing evidence in support of lower values.

Summary

The IPCC's projections of 21st century climate change explicitly assume that CO_2 is the control knob on global climate. Climate model projections of the 21st century climate are not convincing because of:

- Failure to predict the early 21st century hiatus in surface warming
- Inability to simulate the patterns and timing on multidecadal ocean oscillations
- Lack of account for future solar variations and solar indirect effects on climate
- Apparent oversensitivity to increases in greenhouse gases

There is growing evidence that climate models are running too hot and that climate sensitivity to CO_2 is on the lower end of the range provided by the IPCC—this is acknowledged in the IPCC AR5. Nevertheless, these lower values of climate sensitivity are not accounted for in IPCC's projections of temperature at the end of the 21st century or in estimates of the impact on temperatures of reducing CO_2 emissions.

While there is increasing evidence that the threat from human caused warming in the 21st century is overstated, the level of uncertainty is such that the possibly of dangerous human caused climate change remains. However, if the threat is not overstated by the IPCC, there are major shortfalls in solutions proposed by the UN, whereby proposed emissions reductions, even if actually successfully implemented, are insufficient to prevent what they regard as dangerous climate change.

The broken social contract between climate science and society

Working through Congress, the public has been generous with its funding for climate and the related sciences. However, recent stresses have frayed the fabric of the social contract between climate scientists and society.[62] Unfortunately, many climate scientists have responded by resorting to advocacy, both for increasing funding levels and for specific policies related to energy and climate. Even worse, too many climate scientists have abandoned any pretense at nonpartisanship and objectivity.

Scientists advocating for CO_2 emissions reductions is becoming the default, expected position for climate scientists; an example is this Huffington Post editorial "Curry Advocates Against Action on Climate Change"[63] that was signed by five climate scientists. This op-ed was a response to my arguments for values of climate sensitivity being on the low end of the IPCC spectrum. I am neither advocating for or against 'action' in terms of reducing CO_2 emissions. My writings on the policy response to climate change[64] address frameworks for decision making under deep uncertainty, including robust decision making and the concepts of resilience and anti-fragility.

In their efforts to promote their 'cause,' the scientific establishment behind the global warming issue has been drawn into the trap of seriously understating the uncertainties associated with the climate problem. This behavior risks destroying

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[61] Kaya *et al.,* 2015: The uncertainty of climate sensitivity and its implication for the Paris negotiations. Sustainability Science *http://link.springer.com/article/10.1007/s11625–015–0339-z?wt__mc=internal.event.1.SEM.ArticleAuthorOnlineFirst*

[62] Hooke, W. 2015: Reaffirming the social contract between science and society. *https://eos.org/opinions/reaffirming-the-social-contract-between-science-and-society*

[63] *http://www.huffingtonpost.com/michael-e-mann/judith-curry-climate-change__b__6000636.html*

[64] *https://curryja.files.wordpress.com/2015/04/house-science-testimony-apr-15-final.pdf*

science's reputation for honesty and objectivity—without this objectivity and honesty, scientists become regarded as merely another lobbyist group.

The biases of individuals are not an impediment to scientific progress if scholarly institutions work to counteract the errors and flaws of scientific research. A fair process of peer review and vigorous post-publication peer debate will quickly identify the most obvious errors and biases. Researchers having different perspectives (including their values and political identities) will conduct their own research and obtain opposing results, and the field will gradually sort out the truth.

This system works unless the institutions that support science—the professional societies that publish journals, organize conference and confer honors—are themselves biased. Nearly all of the relevant professional societies have issued policy statements about climate change, including statements such as *'Human-Induced Climate Change Requires Urgent Action'*[65] and *'call to support actions that will reduce the emissions.'*[66] Even more egregious is overt advocacy by journal editors, notably Marcia McNutt (editor of *Science*), who recently published this statement in an opinion piece in *Science*[67]: *"The time for debate has ended. Action is urgently needed."* Such official statements from the professional societies provide journal editors with a license to reject papers that challenge the consensus.

An even more insidious problem is when there is not a critical mass of scientists who think differently or who shrink from speaking up because they expect ostracism in response. Minority perspectives on climate science are effectively being squeezed out of the universities, and dissenting individuals choose to join the private sector, retire, join think tanks, or switch research topics. Climate science that dissents from the consensus is increasingly being relegated to retired professors and self-supported individuals from other fields, who are asking important questions that aren't 'relevant' to government research funding priorities.

While concerns about the behaviors and motives of scientists and the institutions that support science are well founded, the other side of the social contract is at least equally problematical. President Obama's administration is using climate science to support his political agenda, and is actively discouraging disagreement through consensus enforcement, *e.g.,* "Call Out The Climate Deniers."[68] So under the current administration, the social contract for climate science seems to be: support the consensus and promote alarmism, and you will receive plenty of research funding.

The potential for Federal funding to bias science is discussed in this recent report.[69] From my perspective, here is how research funding motivates what is going on. 'Success' to individual researchers, particularly at the large state universities, is driven by research dollars—big lab spaces, high salaries, institutional prestige, and career advancement. At the Program Manager level within a funding agency, 'success' is reflected in growing the size of their program (*e.g.,* more funding) and having some high profile results (*e.g.,* press releases). At higher levels, Divisional administrators are competing for budget dollars against the other Divisions; tying their research to a national policy priority helps in this competition. At the agency level, 'success' is reflected in growing, or at least preserving, the agency's budget. Aligning yourself, your program, your agency with the current political imperatives is a key to 'success'.

It is very difficult to obtain Federal research funding for dissenting science. Difficulty in the peer review process is only part of the problem. One problem is reflected in an e-mail[70] I recently received from a scientist employed at NASA:

> *"I was at a small meeting of NASA-affiliated scientists and was told by our top manager that he was told by his NASA boss that we should not try to publish papers contrary to the current global warming claims, because he (the NASA boss) would then have a headache countering the "undesirable" publicity".*

I hesitate somewhat to call out the NASA leadership here, since I think the bigger problems are with the NOAA leadership. The biggest problem, however, is that the call for proposals from the Federal funding agencies (notably NASA and NOAA) make an implicit assumption of the dominance of human caused global warming in the topics for which they are requesting research proposals.

Something is clearly wrong with the current contract between climate scientists and society that is biasing the science and breeding scientists who are advocates,

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[65] *http://sciencepolicy.agu.org/files/2013/07/AGU-Climate-Change-Position-Statement__August-2013.pdf*

[66] *http://www.aps.org/policy/statements/15__3.cfm*

[67] *http://www.sciencemag.org/content/349/6243/7.full*

[68] *https://www.barackobama.com/climate-change-deniers/#/*

[69] *http://object.cato.org/sites/cato.org/files/pubs/pdf/working-paper-29.pdf*

[70] *http://judithcurry.com/2015/10/12/conflicts-of-interest-in-climate-science-part-ii/*

partisans and alarmist. And the taxpayer foots the bill. How can we press the 'reset button' on all this?

First, we need to recognize that the politically driven push to manufacture a premature consensus on human caused climate change is biasing climate research, and in particular is resulting in the relative neglect of research on natural climate variability. Until we have a better understanding and predictive capability of natural climate variability, we don't have a strong basis for predicting the climate in the decades or century to come.

Second, we need to break the 'knowledge monopoly'[71] in climate science—the IPCC. As a result of this knowledge monopoly, there is insufficient intellectual and political diversity in assessments about climate change. To break this monopoly, we need to identify new frameworks for encouraging, publishing and publicizing independent ideas and assessments.

And finally, we need to find ways to fund a broader spectrum of research that challenges the politically preferred outcomes.

SHORT BIOGRAPHY

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Dr. Judith Curry is Professor and former 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 climate dynamics of the Arctic; climate dynamics of extreme weather events; cloud microphysics; and reasoning about climate uncertainty. She is a prominent public spokesperson on issues associated with the integrity of climate science, and is proprietor the weblog Climate Etc. judithcurry.com. Dr. Curry has recently served on the NASA Advisory Council Earth Science Subcommittee, the DOE Biological and Environmental Research Advisory Committee, the 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.

For more information:

http://curry.eas.gatech.edu/
http://www.cfanclimate.com/
http://judithcurry.com/about/

Senator CRUZ. Thank you very much, Dr. Curry.
Dr. Happer?
[Pause.]

STATEMENT OF WILLIAM HAPPER, PH.D., CYRUS FOGG BRACKET PROFESSOR OF PHYSICS, PRINCETON UNIVERSITY

Dr. HAPPER. My name is William Happer. I recently retired from a career of 50 years of teaching physics at Princeton and Columbia Universities.

As the Chairman mentioned, I served as Director of Energy Research, Office of Energy Research in Department of Energy from 1990 to 1993. And among the other projects I supported there was the Atmospheric Radiation Measurements Program, which is still going strong with facilities all over the world to measure basic climate data.

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[71] *https://www.esri.ie/publications/regulating-knowledge-monopolies-the-case-of-the-ipcc/*

After leaving the Department of Energy, I served as Princeton University's equivalent for vice president for research from 1995 to 2005. I guess I am best known in the scientific community for inventing the sodium guide star that is used on all modern telescopes to compensate for atmospheric turbulence. So I have been very involved with the atmosphere for a very long time.

There is all this talk about carbon pollution, which, of course, is meant carbon dioxide pollution, and I would like to set the record straight that carbon dioxide is not a pollutant. We are sitting in this room breathing out carbon dioxide at 40,000 parts per million with every breath.

We are fundamentally in a carbon dioxide famine, geologically speaking, now. If you look at the geological history of the Earth, most of the time CO_2 levels have been three times, four times what they are now. The Earth was just fine then.

And in fact, at the present time, you know, many plants are having a hard time performing as well as they are designed to perform because the CO_2 levels are too low, and the oxygen levels are too high. I won't go into the details, but there is not much dispute about that.

So the issue is not that CO_2 is a pollutant. It is actually very, very good for the world. The issue is what will it do to temperature? And Dr. Christy very clearly showed and a version of his display is reproduced here, which is a figure from *Nature* magazine. It is peer reviewed. *Nature* is anything but a skeptic journal.

But what it shows in dark bars are the predictions of various climate models of how much warming there would be over two time intervals, a 10-year interval, and a 20-year interval. The red bar is what is observed, and you notice that the observed warming is much, much less than the predictions of climate models.

Dr. Christy's chart was another version of that for the atmosphere, the lower atmosphere, and this is actually for surface data. But the message is the same for both sets of data, that the climate models on the basis of which we are making policy, do not work.

OK. So let me move on to the fact that CO_2 is a very important part of life on Earth.

This picture shows the greening of the planet from 1982 to 2010. And so this is satellite images of certain wavelength bands that allow you to tell how much plant life there is, and what you see is that over most of the Earth, contrary to what you might have heard, is that the Earth is getting greener.

And this is also clear from crop yields. Crop yields are going up. Some of that is fertilizer. Some of that is better cropping practices. But a good fraction of it is CO_2, 15 percent of the increase in crop yields is due to the 30 percent increase of CO_2 we have had in the past 100 years. So to call CO_2 a pollutant is just completely wrongheaded.

Now I would like to conclude by supporting Dr. Christy's urging that we have a red team. I call it a Team B. Science is often so complicated and controversial that unless you have some adversarial process, you really can't be sure who is right.

So, for example, when I was at Department of Energy, I didn't understand enough about nuclear weapons to know whether Livermore was right or Los Alamos was right. But I knew I could count

on Livermore to catch any error in Los Alamos or vice versa. That is the reason we had two labs. One could catch any mistakes made by the other.

We don't have two labs for climate. We have one organization, one world organization, the IPCC. And funding agencies follow the IPCC dogma. I would like to argue very strongly that we set aside some fraction of funding for climate research that is not constrained to follow IPCC dogma.

If you have some proposed research that might show that CO_2 is not such a big problem, you should be able to get funding. You shouldn't be last in line and turned away. That is the way it is in many other areas of human life. Even to become a saint in the Catholic Church, you have to pass a contested trial with a devil's advocate. You can't be sainted without that.

So every other region, every other aspect of human life has an adversarial process. This is the only area I know of where there is nothing adversarial in the science.

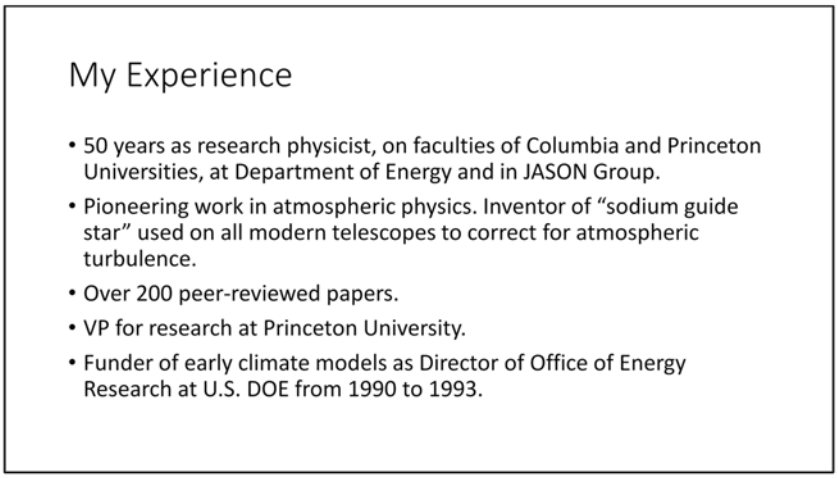
And so I would like to second Dr. Christy's request for a red team. A Team B also would be a good idea to provide a rigorous review of how well is science working. I know that there was review of how well science works, that both Dr. Christy and Dr. Curry took part in, by the American Physical Society. They did very well, and the review represented both sides of the debate. It was the only good review I know of. It was organized by Dr. Steve Koonin.

And I noticed that when the list of organizations supporting climate alarmism was read, the one that wasn't there was the American Physical Society. Maybe that was an oversight. I hope not. I hope it was partly due to Dr. Curry and Dr. Christy because it was a very informative workshop.

So let me conclude my testimony here, and thank you very much for the invitation.

[The prepared statement of Dr. Happer follows:]

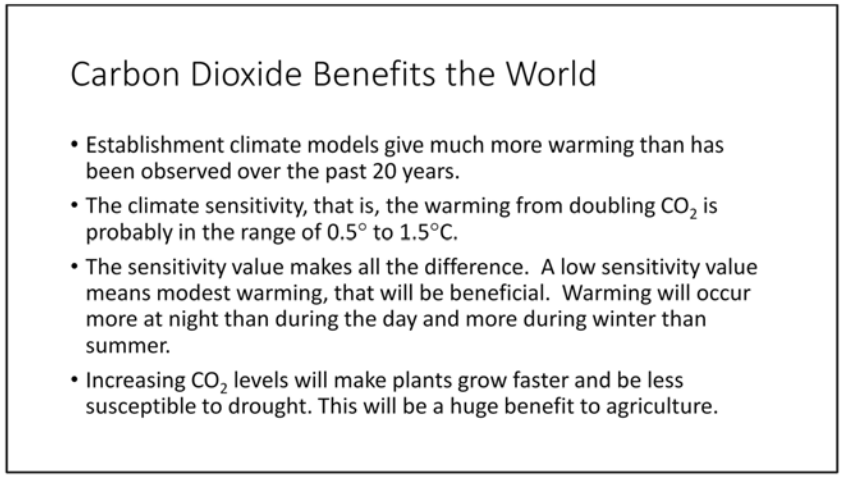
PREPARED STATEMENT OF WILLIAM HAPPER



I would like to express my thanks to Senator Cruz, Senator Thune, Senator Nelson and other members of this committee for inviting me to express my views at this hearing on climate science.

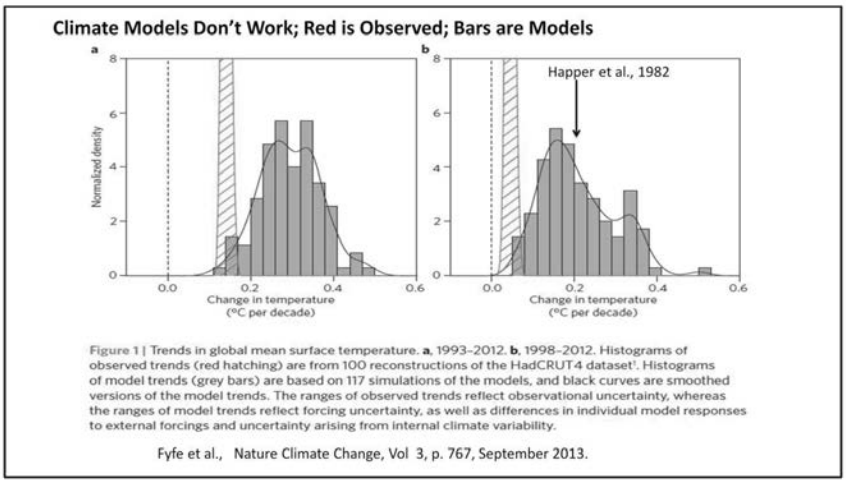
My name is William Happer. I recently retired from a career of over fifty years teaching physics at Princeton and Columbia Universities. I also served as the Director of the Office of Energy Research, now the Office of Science, in the U.S. Department of energy from the years 1990 to 1993, where I was responsible for all the non-weapons basic research of the Department of Energy. In addition to areas like high energy physics, materials science, the human genome and others, I had responsibility for DOE's work on climate science. During my time at DOE, my office established the Atmospheric Radiation Measurement (ARM) Climate Research Facility, with remote sensing observatories all around the world. The facility is still going strong and providing high quality observational data on atmospheric physics.

After leaving DOE, I served as Princeton University's equivalent of Vice President for Research from 1995 to 2005. I have published over 200 peer-reviewed scientific papers. Scientifically, I am probably best known for having invented the sodium guide star, used by modern ground based telescopes to remove much of the blurring of stellar images by atmospheric turbulence.



Along with other witnesses at this hearing, I hope to correct some misconceptions about the trace atmospheric gas, carbon dioxide or CO_2. In spite of the drumbeat of propaganda, CO_2 is not "carbon pollution." As part of my written testimony, I have submitted the document, *Carbon Dioxide Benefits the Word: See for Yourself.* This document summarizes the view of the CO_2 Coalition, a distinguished group of scientists, engineers, economists and others. The benefits that more CO_2 brings from increased agricultural yields and modest warming far outweigh any harm.

The key issue here is the equilibrium climate sensitivity: how much will the earth's surface eventually warm if the atmospheric concentration of CO_2 is doubled? This number has been drifting steadily downward from a youthful Arrhenius's first estimate of about 6 C to the estimate of the International Panel on Climate change (IPCC) of 1.5 C to 4.5 C. Observations of very small warming over the past 20 years suggest that the sensitivity is unlikely to be larger than 2 C. There are credible estimates that the sensitivity could be as small as 0.5 C.



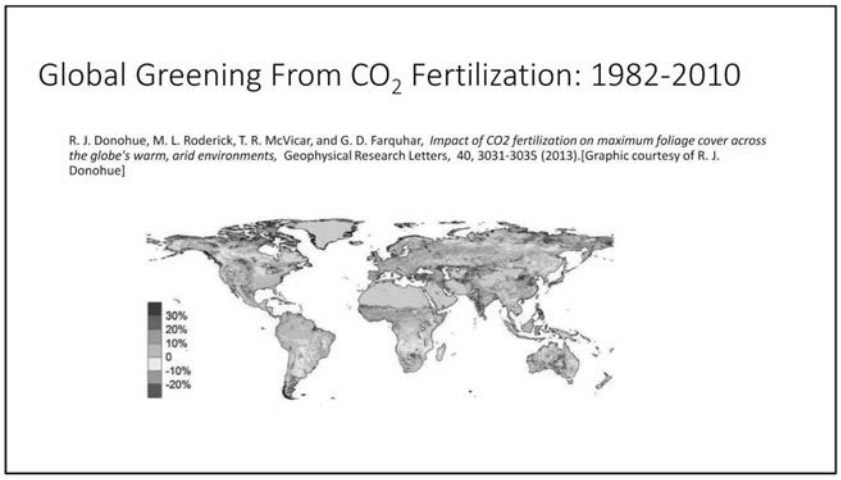
This slide shows that various mainstream climate models (the gray bars) have predicted much more warming than observed (the red bars). For full disclosure I add the warming predicted by me and my JASON colleagues in our book, *The Long-Term Impacts of Increasing Atmospheric Carbon Dioxide Levels,* edited by Gordon McDonald, Ballinger Publishing Company, Cambridge, MA (1982). My colleagues and I also predicted far too much warming. The models don't work. The most natural reason for this is that they have assumed climate sensitivities that are much too large. Most of the models in the figure use climate sensitivities of 3 C to 3.5 C.

Basic Facts Of CO_2 Fertilization Are Undisputed

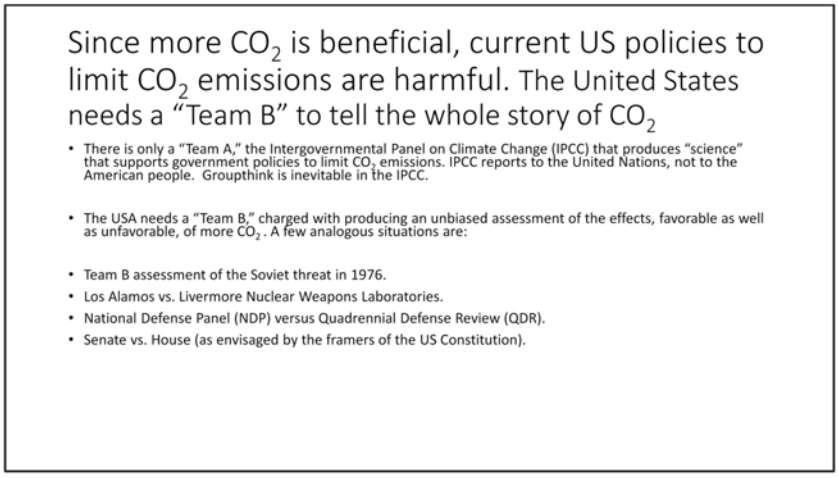
- Plants need CO_2 for photosynthesis. Plant growth rates and drought resistance would benefit significantly from additional CO_2.
- We can tell photosynthesis evolved during periods of much higher CO_2 concentrations, because the great majority of photosynthetic organisms (e. g., plants, algae) use the protein rubisco, which functions best when CO_2 concentrations are higher and O_2 concentrations are lower than those today.
- All trees, and many other plants, wheat, rice, soybeans, cotton, etc. are handicapped because, by historical standards, there currently is too little, not too much, CO_2 in the atmosphere.

Few realize that the world has been in a CO_2 famine for millions of years, a long time for us, but a passing moment in geological history. Over the past 550 million years since the Cambrian, when abundant fossils first appeared in the sedimentary record, CO_2 levels have averaged many thousands of parts per million (ppm) not today's few hundred ppm [R. A. Berner and C. Kothavala, *Geocarb: III, a revised model of atmospheric CO_2 over the Phanerozoic time,* American Journal of Science, *301,* 182 (2001). Pre-industrial levels of 280 ppm (parts per million), are not that far above the minimum level, around 150 ppm, when many plants die from CO starvation [J. K. Dippery, D. T. Tissue, R. B. Thomas and B. R. Strain, *Effects of low and elevated CO_2 levels on C3 and C4 annuals,* Oecologia, *101,* 13 (1995)].

Thousands of peer reviewed studies show that almost all plants grow better (and land plants are more drought resistant) at atmospheric CO_2 that are two or three times larger than those today.

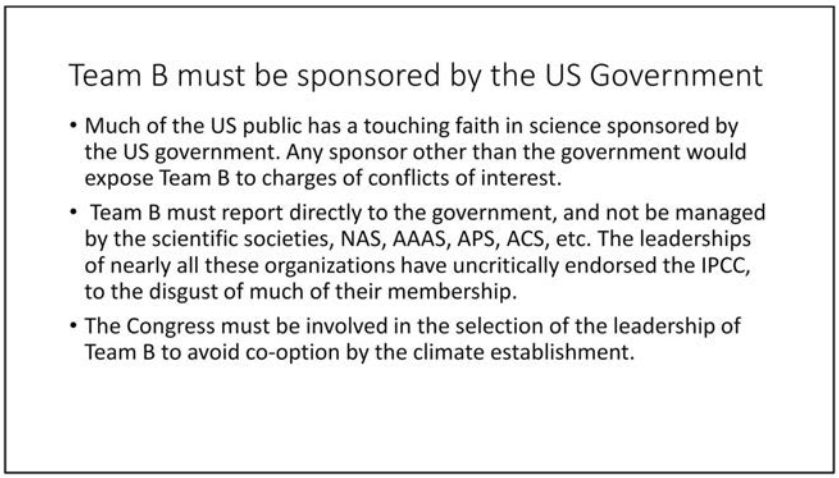


This slide summarizes satellite measurements of vegetation changes over the 28-year period from 1982 to 2010. The authors of the study have tried to eliminate any influences rainfall changes or other confounding factors during the measurement period. The earth is really getting greener, and an important part of the reason is more atmospheric CO_2.



For many decades the citizens of the USA and of much of the world have been flooded with the message that CO_2 is "carbon pollution." We are supposed to trust our government and selfless NGO's for instructions on how to save the planet. Much of the message is false, but its purveyors control key positions in the media, in the government, in scientific societies, in charitable foundations etc. This makes it difficult to get out the truth that climate science is far from "settled." To the extent it is settled, it indicates no cause for alarm or for extreme measures. Indeed, a dispassionate analysis of the science indicates that more CO_2 will bring benefits, not harm to the world.

The Congress could help by establishing a "Team B" to make a dispassionate review of climate science, with sponsorship by the Federal Government.



For credibility, it is essential that Team B be sponsored by the Federal Government. Otherwise there would be vigorous attempts to ignore any findings not considered politically correct, because the team members would be said to be working directly or indirectly for fossil fuel interests.

CARBON DIOXIDE BENEFITS THE WORLD: SEE FOR YOURSELF

Preface

This white paper summarizes the views of the CO_2 Coalition, a new and independent, non-profit organization that seeks to engage thought leaders, policy makers, and the public in an informed, dispassionate discussion of how our planet will be affected by CO_2 released from the combustion of fossil fuel. Available scientific facts have persuaded Coalition members that additional CO_2 will be a net benefit. Rather than immediately setting this document aside for promoting such a politically incorrect view, readers would do well to act on the ancient motto of Britain's prestigious Royal Society—*nullius in verba,* "don't take anyone's word for it," or more simply, "see for yourself."

Claims that "97 percent of scientists" agree that a climate catastrophe is looming because of the emission of CO_2 should be greeted with skepticism. Traditional science has advanced by comparing observations or experiments with theoretical predictions. If there is agreement with theory, confidence in the theory is increased. If there is disagreement, the theory is abandoned or it is modified and tested again against observations.

Scientific truth has *never* been established by consensus, for example, by "97 percent agreement." History reveals many instances when the scientific consensus of the day was later discredited. The widespread embrace and practice of eugenics in the early 1900s; opposition to the theory of plate tectonics in geology; and the dominance of Lysenkoist biology in the Soviet bloc, are a few recent examples. Given the frequency of mistaken consensus, citizens everywhere should heed the Royal Society's motto and learn as much as they can about how increasing CO_2 levels in the atmosphere will affect the planet.

1. Overview

Green plants grow faster with more CO_2. Many also become more drought-resistant because higher CO_2 levels allow plants to use water more efficiently. More abundant vegetation from increased CO_2 is already apparent. Satellite images reveal significant greening of the planet in recent decades, especially at desert margins, where drought resistance is critical. This remarkable planetary greening is the result of a mere 30 percent increase of CO_2 from its preindustrial levels. Still higher CO_2 levels will bring still more benefits to agriculture.

Plants use energy from sunlight to fuse a molecule of CO_2 to a molecule of water, H_2O, to form carbohydrates. One molecule of oxygen O_2 is released to the air for each CO_2 molecule removed. Biological machinery of plants reworks the carbohydrate polymers into proteins, oils and other molecules of life. Every living crea-

ture, from the blooming rose, to the newborn baby, is made of carbon from former atmospheric CO_2 molecules. Long-dead plants used CO_2 from ancient atmospheres to produce most of the fossil fuels, coal, oil, and natural gas that have transformed the life of most humans—moving from drudgery and near starvation before the industrial revolution to the rising potential for abundance today.

The fraction of the beneficial molecule CO_2 in the current atmosphere is tiny, about 0.04 percent by volume. This level is about 30 percent larger than pre-industrial levels in 1800. But today's levels are still much smaller than the levels, 0.20 percent or more, that prevailed over much of geological history. CO_2 levels during the past tens of millions of years have been much closer to starvation levels, 0.015 percent, when many plants die, than to the much higher levels that most plants prefer.

Basic physics implies that more atmospheric CO_2 will increase greenhouse warming. However, atmospheric processes are so complicated that the amount of warming cannot be reliably predicted from first principles. Recent observations of the atmosphere and oceans, together with geological history, point to very modest warming, about 1 C (1.8 F) if atmospheric CO_2 levels are doubled.

Observations also show no significant change in extreme weather, tornadoes, hurricanes, floods, or droughts. Sea levels are rising at about the same rate as in centuries past. A few degrees of warming will have many benefits, longer growing seasons and less winter heating expenses. And this will be in addition to major benefits to agriculture.

More CO_2 in the atmosphere is not an unprecedented experiment with an unpredictable outcome. The Earth has done the experiment many times in the geological past. Life flourished abundantly on land and in the oceans at much larger CO_2 levels than those today. Responsible use of fossil fuels, with cost-effective control of genuine pollutants like fly ash or oxides of sulfur and nitrogen, will be a major benefit for the world.

2. Introduction

Around the year 1861, John Tyndall, a prominent Irish physicist, discovered that water vapor (H_2O), carbon dioxide (CO_2), and many other molecular gases that are transparent to visible light can absorb invisible heat radiation—such as that given off by a warm tea kettle, the human body, or the Earth itself. Tyndall recognized that water vapor is the dominant greenhouse gases in the Earth's atmosphere, with CO_2 a less important contributor.[1]

Tyndall's discovery came as the combustion of coal in the Industrial Revolution was beginning to release substantial amounts of CO_2. These emissions have coincided with a steady increase of atmospheric CO_2, from around 285 ppm (parts-per-million) in the 1860s to around 400 ppm today.

Increased CO_2 levels have likely produced some warming of the Earth and will continue to do so in the future, although with ever decreasing efficiency because of the "logarithmic" dependence of warming on CO_2 concentrations, an important detail discussed more extensively below. At the same time, more CO_2 will have a hugely beneficial effect on agriculture, forests and plant growth in general. The benefits of more CO_2 will greatly exceed any harm.[2]

3. Key Findings

Mainstream warming forecasts have been wrong. Over the past two decades, the global warming predicted by climate models has mostly failed to materialize. The real "equilibrium climate sensitivity"—the amount of global warming to be expected for a doubling of atmospheric CO_2—is likely to be about three times smaller than what the models have assumed. Observational data suggest that doubling atmospheric CO_2 levels will increase the surface temperature by about 1 C, not the much larger values that were originally assumed in mainstream models. Using these much smaller, observationally based climate sensitivities, the projected warming from continued use of fossil fuels will be moderate and benign for the foreseeable future

Negative effects of more CO_2 have been exaggerated. Readily available data from governmental and reliable non-governmental sources confirm that extreme weather events in recent years have not occurred more frequently or with greater intensity. Such data also refute claims of ecologically damaging ocean acidification, accelerating sea-level rises, and disappearing global sea ice and other alleged dangers. If further observations confirm a small climate sensitivity, these realities will not change.

Higher carbon-dioxide levels will be beneficial. CO_2 is an essential nutrient for land-based plants. The Earth's biosphere has also experienced a relative CO_2 famine for many millennia—the recent increase in CO_2 levels has thus had a measurable,

positive effect on plant life. Future CO_2 increases will boost agricultural productivity and improve drought resistance, thereby bolstering food security and contributing to a greener, lusher planet.

4. Global Warming: The Neglected Facts

Most research that tries to project future climate has focused on developing and applying complex computer models that attempt to simulate the Earth's climate system. These models have sought to explain past climate and have been used to calculate various future global and regional climate scenarios. These future climate scenarios have, in turn, prompted policy proposals that would reduce future emissions—thereby, according to the models, limiting future global warming, though admittedly at the cost of reducing future global economic development.

This emphasis on computer model forecasts has been very costly, with many tens of billions of dollars invested but has failed to accurately *predict* the Earth's climate: the United Nations Intergovernmental Panel on Climate Change's (IPCC) estimates of the critical parameter, the equilibrium climate sensitivity, for example, have not become more precise over the past 25 years. *Figure 1* summarizes the IPCC's findings, as documented in its five comprehensive research reports released over more than three decades, as well as the findings of two major pre-IPPC research reports. Since scientific research is generally aimed at reducing uncertainty, the lack of progress over more than three decades is extremely unusual.

Figure 1. Key Findings, IPCC and Pre-IPCC Climate Reports*

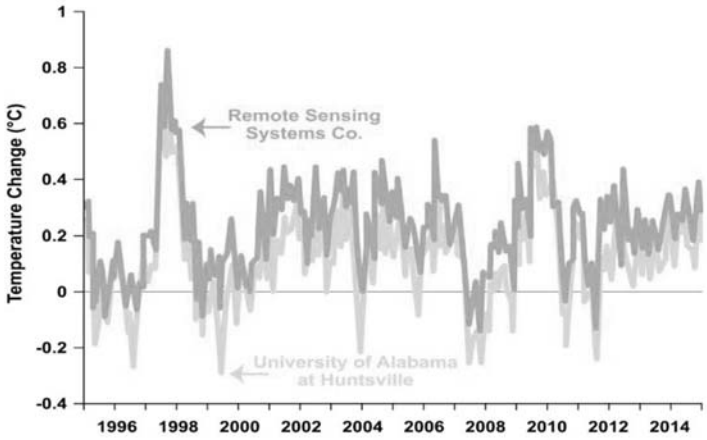
Date	Source	Confidence in Attribution	Equilibrium Climate Sensitivity (C)
1896 & 1938	Arrhenius / Callendar	------	2 – 5.5
1979	Charney Report	------	1.5 – 4.5
1990	IPCC FAR	No quantification of anthropogenic contribution to warming	1.5 – 4.5 (best guess = 2.5)
1996	IPCC SAR	*The balance of evidence suggests a discernible human influence on climate.*	1.5 – 4.5 (best guess = 2.5)
2001	IPCC TAR	*Human-emitted greenhouse gases are likely (67-90% chance) responsible for more than half of Earth's temperature increase since 1951.*	1.5 – 4.5
2007	IPCC AR4	*Human-emitted greenhouse gases are very likely (at least 90% chance) responsible for more than half of Earth's temperature increase since 1951.*	2 – 5.5 (>66% chance correct)
2013	IPCC AR5	*Human-emitted greenhouse gases are extremely likely (at least 95% chance) responsible for more than half of Earth's temperature increase since 1951.*	1.5 – 4.5

*In Figure 1, the far-right column lists successive estimates of the range of the equilibrium climate sensitivity (the "doubling sensitivity," in IPCC reports and two pre-IPCC reports). Extensive research over time nearly always reduces uncertainty; so this lack of progress is rare.

Source: American Physical Society Climate Change Statement Review framing document (2015), *http://www.aps.org/policy/statements/upload/climate-review-framing.pdf.*

In science, observational data are the ultimate test of theory and modeling. Climate data show significant divergence between computer predictions and the Earth's actual climate record. *Figure 2* shows average global temperature changes during 1995–2015, as provided by NASA satellite data: despite a 13 percent increase in atmospheric CO_2 levels during this period, there is no statistically discernible warming trend.[3] The climate record is thus at odds with the IPCC's Third (2001) and Fourth (2007) Assessment Reports' forecasts.[4] During this 20-year period, the Earth's atmosphere warmed by only 0.05 C;[5] but computer models predicted a far more dramatic 0.4 C rise in global temperature.[6]

Figure 2. Global Temperature Change as Measured by Satellite, 1995–2015*

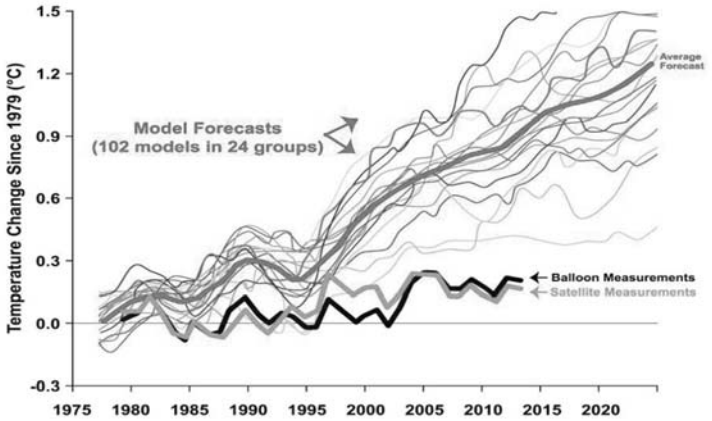


*NASA satellite data for the temperature of the Earth's lower troposphere for the 20-year period 1995–2014. Monthly global temperature is shown relative to the 1981–2010 base-period average. Despite month-to-month fluctuations, there has been little—or zero—global warming during this period.

Source: Roy W. Spencer, Earth Systems Science Center, University of Alabama at Huntsville.

Figure 3 compares various climate forecasts—specifically, 102 computer climate models used by the IPCC—with the actual change in average tropical atmospheric temperature during 1979–2013, as measured by balloon and satellite. Why focus on tropical atmospheric temperature? Because the Earth's tropical surface and troposphere, the lowest layer of the atmosphere, receive a major portion of the planet's incoming solar energy. The rising warm, humid air from the oceans and rain-forests that cover much of the tropics should lead to especially large warming of the middle troposphere. As Figure 3 demonstrates, actual temperature changes differ dramatically from those predicted by models: the average computer model forecast warming of a full 1 C for the period 1979–2013; in reality, only 0.2 C (at most) has been observed.

Figure 3. Average Change in Tropical Atmospheric Temperature, Forecasts v. Actual, 1979–2013*

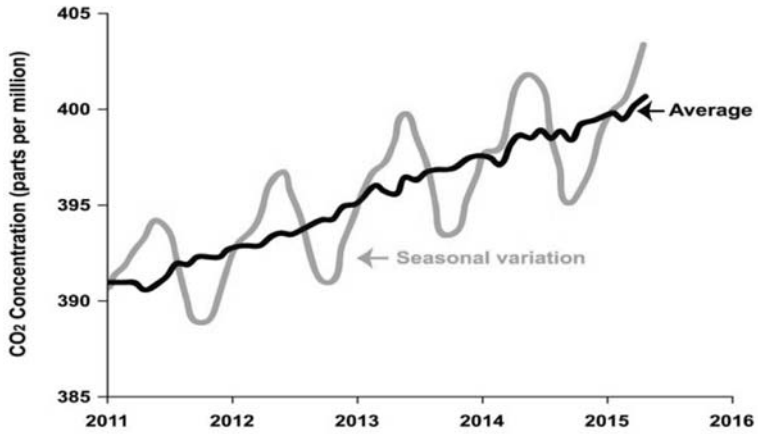


*As measured by satellite and balloon, from the Earth's surface to an altitude of 50,000 feet. Forecasts extend to 2024.

Source: *https://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-113-SY18-WState-JChristy-20131211.pdf*

Figure 4 shows CO_2 concentration measured at Hawaii's Mauna Loa: the long-term rise in CO_2 has seasonal oscillations caused mostly by removal of CO_2 from the air of the northern hemisphere by growing land plants during the summer; and by release of CO_2 during the winter, when respiration of CO_2 by the biosphere exceeds its removal by photosynthesis.

Figure 4. Atmospheric Concentration of CO_2, 2011–15*



*Annual CO_2 oscillations represent seasonal variations in the biosphere. The annual growth rate (black line) averages about 2 ppm annually. Annual growth, according to the IPCC, accounts for only about half of CO_2 emissions from human activities; the other half is naturally absorbed by oceans and land.

Source: National Oceanic and Atmospheric Administration

The failure of computer models to reliably predict future temperatures has created a growing awareness that such models are fundamentally flawed—and have greatly exaggerated past and future anthropogenic (man-made) global warming.[7] Indeed, there is good reason to believe that any future anthropogenic warming will be far smaller than projected by the IPCC's models. The best available evidence suggests that the equilibrium doubling sensitivity, the final warming of the surface in response to doubling atmospheric CO_2, is closer to 1 C than to the "most likely" 3 C of mainstream climate models.

The best available evidence also suggests that—despite two periods of 20th century warming, as well as a steady increase in atmospheric CO_2—the frequency of extreme weather events has not risen. And the rise in sea levels has been modest. "Ocean acidification," a slight decrease of the alkalinity of the oceans by a few tenths of a pH unit, will be much less than variations of pH with location, depth and time in today's oceans. Such facts do not support widespread predictions of imminent planetary catastrophe from rising CO_2 levels. Numerous studies suggest that a modestly warmer Earth with more atmospheric CO_2 will be good for all living things.[8]

4. Benefits of More Carbon Dioxide

Pure CO_2 gas is chemically inert, transparent, colorless, and odorless. On a cold winter day, chilled air often condenses the water vapor of human breath—of which 4 to 5 percent is CO_2—into visible fog. Such fog, however, is not CO_2. Similarly, water vapor often condenses into clouds of steam over fossil-fuel power plants, creating the impression of smoke. Such steam clouds are not CO_2, either.

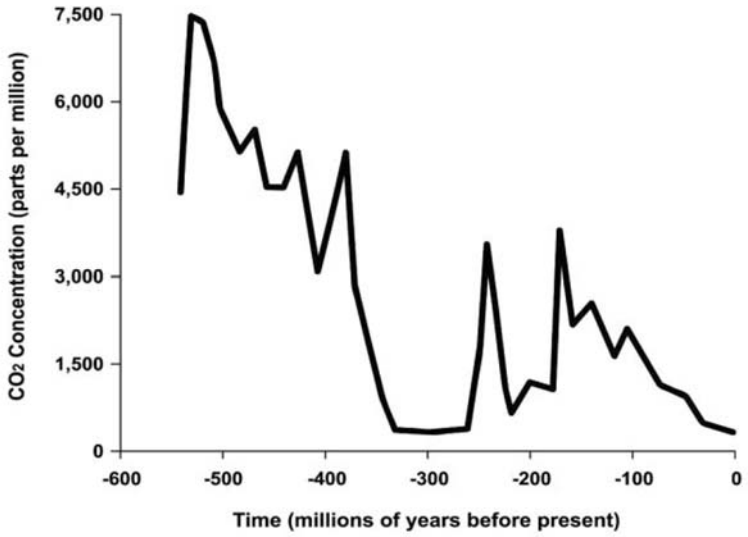
Of every million air molecules in today's atmosphere, 400 are CO_2. This average masks wide variation. For example, without strong ventilation, CO_2 levels in crowded indoor spaces, such as classrooms, courtrooms, and trains, commonly reach 2,000 ppm—with no clinically documented ill effects to people. The U.S Navy strives to keep CO_2 levels in its submarines below 5,000 ppm.[9]

On a calm summer day, CO_2 concentrations in a cornfield can drop to 200 ppm, as the growing corn consumes the available CO_2.[10] At a concentration of about 150 ppm or less, many plants die of CO_2 starvation.[11] The differences between the peak winter CO_2 levels and minimum summer CO_2 levels, measured at Hawaii's Mauna

Loa volcano (Fig. 4), have increased over the past 50 years. This is believed to be due a global expansion of forests and other plant life.

That Earth has experienced a CO_2 "famine" for millions of years is also not widely known. As illustrated in *Figure 5,* in the 550 million years since the Cambrian period—when abundant fossils first appeared in the sedimentary record—CO_2 levels have averaged many thousands of ppm, that is, much larger than the CO_2 level of 400 ppm today.[12]

Figure 5. CO_2 Levels on Earth: A Long View*



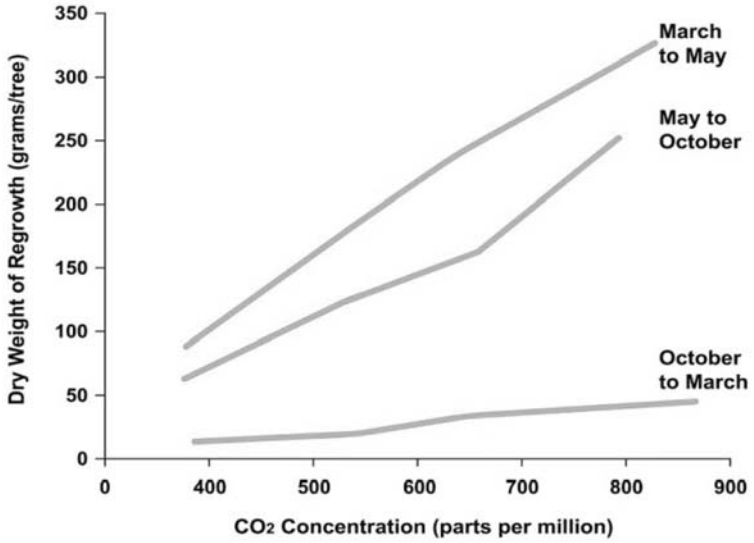
*CO_2 estimates during the Earth's Phanerozoic era are derived from fossil records in sedimentary rocks. A typical Phanerozoic CO_2 level is about 1,500 ppm, considerably higher than today's 400 ppm.

Source: Berner and Kothavala

All animals, including humans, owe their existence to green plants that use energy from sunlight to convert CO_2 and water molecules into carbohydrates, releasing oxygen into the atmosphere in the process. Land plants get the carbon they need from CO_2 in the air, and they obtain other essential nutrients from the soil. Just as plants grow better in fertilized, well-watered soils, they grow better with CO_2 concentrations several times higher than the Earth's current level.[13] For this reason, additional CO_2 is often pumped into greenhouses to enhance plant growth.[14]

Figure 6 illustrates the effect of various levels of CO_2 on the growth of sour orange trees. Because the growth rate of plants is proportional, on average, to the square root of CO_2 concentration, doubling atmospheric CO_2 will increase green plant growth by 40 percent—a boon for crop productivity and, thus, for global food security.

Figure 6. CO_2's Effect on Growth of Sour Orange Trees*



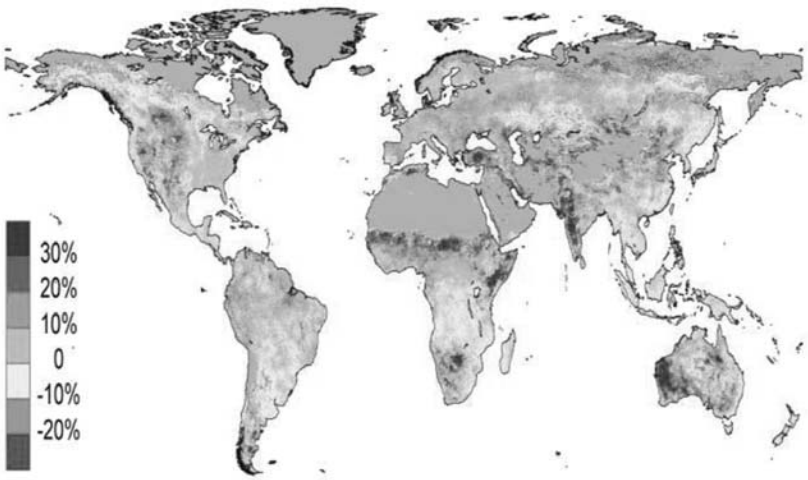
*Measured dry weight of above-ground biomass produced by sour orange trees between specified sequential coppicing dates; and mean atmospheric CO_2 concentration. Figure 6 is a particularly dramatic example of the CO_2 fertilization effect.
Source: Idso and Kimbal

CO_2's nutritional value is only part of its benefit for plants. No less important is CO_2's contribution to making plants more drought-resistant: plant leaves are perforated by stomata, surface holes that allow CO_2 to diffuse from the atmosphere into the leaf's interior, where they are photosynthesized into carbohydrates. Depending on the relative humidity of the outside air, as many as 100 H_2O molecules can diffuse out of the leaf for each CO_2 molecule that diffuses in. This is why most land plants need at least 100 grams of water to produce one gram of carbohydrate.

The 30 percent increase in atmospheric CO_2 during the 20th century boosted crop productivity by around 15 percent. Continued improvements in crop variety, fertilizer, and water management—coupled with higher CO_2 levels—will strengthen food security in large parts of Africa and Asia where hunger remains widespread.

Figure 7 shows how the Earth is getting greener. The study from which the image is drawn analyzed plant growth at desert margins and other semi-arid areas and found an 11 percent net growth in foliage ground cover during 1982–2006—growth attributed to improved water-use efficiency arising from higher atmospheric CO_2 levels.[15] The study's authors conclude: "Our results conﬁrm that the anticipated CO_2 fertilization effect is occurring alongside ongoing anthropogenic perturbations to the carbon cycle and that the fertilization effect is now a signiﬁcant land surface process." As CO_2 levels continue to rise, the Earth will grow greener and agricultural yields will continue to increase, with additional contributions from better varieties, improved cropping practices, more efficient use of fertilizer, and other factors.

Figure 7. Greening of the Earth, 1982–2006*



*Percentage change in foliage cover as revealed by satellite.
Source: Donohue et al

5. The Developing World

Developing nations in Asia, Africa, and Latin America will need enormous increases in low-cost energy to power their economic development and lift their citizens out of poverty. Fossil fuels—notably coal, natural gas, and oil—which currently supply more than 80 percent of the world's energy, will remain indispensable. As countries grow more affluent, they will also acquire greater means to reduce pollution. Indeed, it is precisely the wealth unleashed by industrialization that enables societies to invest in modern technologies and other practices that clean up the environment.

Further, the best available evidence suggests that current levels—and forseeable future increases—of carbon dioxide are not only harmless, but are indeed beneficial to plants and humans. Quixotic policies to supposedly limit global warming, by making fossil fuels prohibitively expensive, would condemn much of humanity to wretched conditions unimaginable in developed nations

6. Initial Members of the CO_2 Coalition

BELL, Larry: Launched the research and education program in space architecture at the University of Houston and author of *Climate of Corruption: Politics and Power Behind the Global Warming Hoax.*

COHEN, Roger, PhD in physics, Rutgers University, Fellow of the American Physical Society. Former Senior Scientist ExxonMobil

EVERETT, Bruce, Faculty Tufts University's Fletcher School, over forty years of experience in the international energy industry.

HAPPER, William is Cyrus Fogg Brackett Professor of Physics (emeritus) at Princeton University, former Director of the Office of Energy Research Director of Research, U.S. Department of Energy, Member National Academy of Sciences.

HARTNETT–WHITE, Kathleen: Distinguished Senior Fellow in Residence and the Director of the Armstrong Center for Energy and the Environment (CEE) at the Texas Public Policy Foundation.

IDSO, Craig: Founder and Chairman of the Center for the Study of Carbon Dioxide and Global Change, Member of the American Association for the Advancement of Science, American Geophysical Union, and the American Meteorological Society.

LINDZEN, Richard: emeritus, Alfred P. Sloan Professor of Meteorology, Member of National Academy of Sciences, author of numerous papers on climate and meteorology.

MICHAELS, Pat: director of the Center for the Study of Science at the Cato Institute, a past president of the American Association of State Climatologists, former Virginia state climatologist, program chair Committee on Applied Climatology of the American Meteorological Society.

MILLS, Mark: senior fellow Manhattan Institute, CE?O Digital Power Group, a tech-centric capital advisory group. He is also a Faculty Fellow McCormick School of Engineering and Applied Science at Northwestern University.

MOORE, Patrick: Co-founder, Chair, and Chief Scientist of Greenspirit Strategies, a Vancouver-based consulting firm on environmental and sustainability issues, founding member of Greenpeace (nine years as president of Greenpeace Canada and seven years as a director of Greenpeace International).

NICHOLS, Rodney: former President and Chief Executive Officer of the New York Academy of Sciences; Scholar-in-Residence at the Carnegie Corporation of New York, Executive Vice President of The Rockefeller University, R&D manager Office of the Secretary of Defense.

O'KEEFE, William: Chief Executive Officer of the George C. Marshall Institute; founder of Solutions; Executive Vice President and Chief Operating Officer American Petroleum Institute, Chief Administrative Officer of the Center for Naval Analyses.

ROGERS, Norman: founder of Rabbit Semiconductor Company, Policy Advisor to The Heartland Institute and a member of the American Geophysical Union and the American Meteorological Society.

SCHMITT, Harrison: PhD in Geology from Harvard University, Astronaut and last man to walk the moon (Apollo 17), Adjunct Professor of Physics at the University of Wisconsin-Madison, and former U.S. Senator from New Mexico.

SPENCER, Roy: Climatologist, Principal Research Scientist at the University of Alabama in Huntsville; served as Senior Scientist for Climate Studies at NASA's Marshall Space Flight Center; Co-Developer of satellite temperature measurement system.

STEWARD, Leighton: Geologist; Environmentalist; Author; Chairman of Plants Need CO_2.org; Chairman of the Board of The Institute for the Study of Earth and Man at SMU, past Chairman of the National Wetlands Coalition, twice Chairman of the Audubon Nature Institute.

YAPPS–COHEN, Lorraine: M.S. in chemistry and an M.B.A. in marketing, former communications & marketing manager ExxonMobil, columnist for the Examiner newspapers.

7. References

[1] J. Tyndall, *Heat, A Mode of Motion,* Longmans, Green and Company, London, 1875.

[2] See, *e.g.,* R. S. J. Tol, *The Economic Effects of Climate Change, Journal of Economic Perspectives,* Vol. 23,No. 2, pp. 29–51 (2009). Such studies do not fully account for the positive effects of CO_2 fertilization and water-efficiency gains.

[3] R. McKitrick, *HAC-Robust Measurement of the Duration of a Trendless Subsample in a Global Climate Time Series,* Open Journal of Statistics, Vol. 4, pp.527–535 (2014). doi:10.4236/ojs.2014.47050.

[4] See, eg., IPCC 4th Assessment Report WG1 (2007), *Summary for Policy Makers,* p12. *https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf*

[5] From the statistical trend lines of the UAH data set shown in Figure 2, for 1995–2014. *http://www.drroyspencer.com/2015/04/version-6–0-of-the-uah-temperature-dataset-released-new-lt-trend-0–11-cdecade/*

[6] IPCC 4th Assessment Report WG1 (2007), *Summary for Policy Makers,* p12, ibid; 3rd Assessment Report WG1 (2001), *Summary for Policy Makers,* p34; *https://www.ipcc.ch/ipccreports/tar/wg1/*

[7] J.C Fyfe et al, *Overestimated Global Warming over the Past 20 Years,* Nature Climate Change, Vol. 3, p. 767 (2013); P. Stott et al, *The Upper End of Climate Model Temperature Projections is Inconsistent with Past Warming,* Environ. Res. Lett. Vol. 8, 014024 doi:10.1088/1748–9326/8/1/014024.

[8] Indur Goklany, *Is a Richer-but-Warmer World Better than Poorer but Colder Worlds?* Energy & Environment, Vol. 18, Nos. 7–8, pp. 1023–1048 (2007). Detailed empirical studies of human mortality, in hundreds of communities around the world, show that in all countries and regions, minimum mortality is observed when temperatures are warmer than the median for that location. See, eg., Y. Guo et al, *Global Variation in the Effects of Ambient Temperature on Mortality,* Epidemiology, Vol. 25, No. 6, pp. 781–789 (2014).

[9] J. T. James and A. Macatangay, *Carbon Dioxide, Our Common "Enemy" http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090029352.pdf*

[10] H. W. Chapman, L. S. Gleason and W. E. Loomis, *The Carbon Dioxide Content of Field Air,* Plant Physiology, 29, 500 (1954).

[11] J. K. Dippery, D. T. Tissue, R. B. Thomas and B. R. Strain, *Effects of low and elevated CO_2* levels on C3 and C4 annuals, Oecologia, Vol. 101,p. 13 (1995).

[12] R. A. Berner and C. Kothavala, Geocarb:III, *A revised model of atmospheric CO_2* over the Phanerozoic time, American Journal of Science, 301, 182 (2001).

[13] S. B. Idso and B. A. Kimball, *Effects of the enrichment of CO_2* on regrowth of sour orange trees (Citrus aurantium; Rutacea) after copicing, Am. J. Bot. Vol. 81, p. 843 (1994).

[14] *http://www.ocap.nl/files/Ocap_Factsheet2012_UK.pdf.*

[15] R. J. Donohue, M. L. Roderick, T. R. McVicar, and G. D. Farquhar, *Impact of CO_2* fertilization on maximum foliage cover across the globe's warm, arid environments, Geophysical Research Letters Vol. 40, pp. 3031–3035 (2013).

Senator CRUZ. Thank you, Dr. Happer, for being here.

And I will say the one thing on which I think we can all agree is that no Members of Congress will be made saints at any time in the foreseeable future.

[Laughter.]

Senator CRUZ. And Mr. Steyn?

STATEMENT OF MARK STEYN,
INTERNATIONAL BESTSELLING AUTHOR

Mr. STEYN. Thank you. Thank you, Senator Cruz.

I am not a scientist. I am an author, and I am also one of the 7 billion people on this planet that the governments assembled in Paris currently are presuming to determine the future of. So I have an interest in that as much as anybody else.

I have listened to the examples that Senator Peters and Senator Nelson gave of toxic infestation in Michigan water and tidal flooding in the streets of Miami Beach. Nothing agreed at Paris is going to do anything for that.

If you expect the agreement at Paris to end the tidal flooding in Miami Beach, you are going to be waiting a long time. So if you want to do something about the tidal flooding in Miami Beach, the Mayor of Miami Beach and the Governor of Florida are the guys who should get together and do it.

This body is called the Subcommittee, I believe—the full name—on Science, Space, and Competitiveness. And the most important competitiveness in any healthy society is competitiveness in ideas. That is how ideas are tested, and that is how good ideas win out over bad. And only a very weak idea demands that it must be protected from any criticism.

Professor Ivar Giaever, the Nobel Prize winner—by the way, when I say he is a Nobel Prize winner, I mean he is a real one. He won the Nobel Prize in physics in 1973. Not a fraudulent Nobel Prize winner like, unfortunately, large members of Rear Admiral Titley's faculty—Michael Mann, Richard Alley, William Easterling—all of whom have falsely claimed to be Nobel Prize winners on an industrial scale, as have many other climate scientists.

There has never been a misrepresentation of credentials on this scale. It used to be a very serious business. But apparently, it is not when your cause is "saving the planet." But it is a revealing—it is this misrepresentation of credentials by people falsely claiming to be Nobel laureates is revealing. It gets to the heart of the problem here that they are attempting to cloak the science in an authority that it does not, in fact, possess.

At any rate, Professor Giaever compared the global warming orthodoxy to a hypothesis that you are not allowed to question. And it has gone beyond that in recent years. It is not only that you are not allowed to falsify the hypothesis, that the hypothesis is not, in fact, falsifiable, but that if you do, you suffer very serious consequences.

Professor Christy and Professor Curry are very brave individuals, and they were very mild in their remarks about what Congressman Grijalva did when he sent out a disgraceful letter that no citizen representative in a parliament of a free society should

be sending out to free individuals, demanding things like hotel expenses and e-mail communication going back a decade. It was an absolutely disgraceful letter, and it represents the next stage of big climate enforcement.

Your colleague Senator Whitehouse has called for the RICO laws, laws about racketeering, to be used against those who disagree with him on climate science. When you need that, you are not—you are not dealing with science. You are effectively enforcing a state ideology.

The Attorney General of New York is currently using securities law to do an end run around the First Amendment to chastise enemies of his who do not agree with him on the climate science. This—to take a milder example, Rear Admiral Titley has said that it is time—when it comes to global warming, it is time for the politicking to stop.

Well, when you are calling for the politicking to stop, that is itself politicking, such as the Democrats on this committee who appeared at a press conference a couple of hours ago under a sign saying, "The debate is ended." I learned from Canada in the battle I fought over free speech that Senator Cruz mentioned, I learned to always listen very carefully when someone is telling you to shut up.

And although Rear Admiral Titley and the Democrat Senators are doing it far more politely than Senator Whitehouse and Congressman Grijalva and the Attorney General of New York, what they are telling you is that this idea is so weak, it cannot be subjected to the normal vigorous debate of free society.

So I thank this subcommittee for allowing at least to recognize that there is a divergence of opinion. The science is not settled, and the climate system of this planet is too complex for the slogans of cartoon climatology we are currently seeing in Paris.

Thank you very much.

[The prepared statement of Mr. Steyn follows:]

PREPARED STATEMENT OF MARK STEYN, AUTHOR

My name is Mark Steyn. I am not a scientist. I am an author. My main interest in climate science is that Michael E Mann, the inventor of one of its most notorious artifacts, is suing me for "defamation of a Nobel Prize winner"—a crime that I was not aware existed, especially in his case, as according to the Nobel Institute he is not a Nobel Prize winner. So I recently edited a book about it called *"A Disgrace to the Profession": The World's Scientists—in Their Own Words—On Michael E Mann, His Hockey Stick, and Their Damage to Science, Volume One*—which I'm proud to say was Number One on the Climatology Hit Parade. I have been Number Four on the Amazon books chart, and Number Seven on the Amazon easy-listening chart, and earlier this very month the Number One Amazon jazz vocalist, but I had no idea there was also a climatological bestseller list. Still, I'm happy my book was credible enough to get to the top of it.

That said, at a hearing on "Data or Dogma?", given the distinguished scientists here to address the data, I thought I should confine myself mostly to the dogma.

The Climate of Fear

In the three years that I have been ensnared in the dysfunctional court system of the District of Columbia, I have come to know well what I call the "climate of fear" within climate science. Professors Christy, Curry and Happer are sufficiently eminent that they can, just about, bear the assault the Big Climate enforcers mount on those who dissent from the dogma—although that assault is fierce and unrelenting. If you're a professor emeritus, you're told you're senile. If you're one of the few women in this very male field, you're told you're whoring for Big Oil: The aforementioned Michael Mann of Penn State, who is too cowardly to be here today and has

instead sent his proxy, approvingly linked to an Internet post accusing Dr Curry of sleeping with me. This is how a supposedly distinguished climate scientist treats those who disagree with him. On May 13th last year I wrote:

It's always fun in a legal battle to have something bigger at stake than a mere victory. In Canada, we put the 'human rights' system itself on trial, to the point where the disgusting and indefensible 'hate speech' law Section 13 was eventually repealed by Parliament. It seems to me that in this particular case the bigger issue is the climate of fear that Mann and his fellow ayatollahs of alarmism have succeeded in imposing on an important scientific field.[1]

The very next day the distinguished 79-year-old Swedish climatologist Lennart Bengtsson was forced to resign from a dissident climate group after the Big Climate enforcers took the hockey stick to him in the back alley. He had agreed to participate in a group headed by Nigel Lawson. Some of you may know Lord Lawson personally. He was Chancellor of the Exchequer in Mrs Thatcher's ministry in the United Kingdom. He's nobody's idea of a fringe madman: He's a member of the House of Lords, a Privy Counselor; his daughter is a popular celebrity chef on America's Food Network; his fellow trustees include a bishop of the Church of England, a former private secretary to the Queen, and an advisor to two Prime Ministers from the Labour Party. But they disagree with the tight little coterie of climate alarmists, and so Lennart Bengtsson could not be permitted to meet with them. As Professor Bengtsson wrote:

> *I have been put under such an enormous group pressure in recent days from all over the world that has become virtually unbearable to me. If this is going to continue I will be unable to conduct my normal work and will even start to worry about my health and safety. I see therefore no other way out therefore than resigning from GWPF. I had not expecting such an enormous world-wide pressure put at me from a community that I have been close to all my active life. Colleagues are withdrawing their support, other colleagues are withdrawing from joint authorship etc. I see no limit and end to what will happen. It is a situation that reminds me about the time of McCarthy. I would never have expecting anything similar in such an original peaceful community as meteorology. Apparently it has been transformed in recent years.*[2]

Because it's no longer about "meteorology", it's about saving the planet. Bengtsson was a former director of the Max Planck Institute of Meteorology, winner of the Descartes Prize and a WMO prize for groundbreaking research, and even a friend and collaborator of Mann's at scientific conferences. But he made the mistake of, ah, seeking to expand his circle of climate acquaintances, and so Michael Mann now sneeringly dismisses him as "junk science."[3] Nate Silver is the hipster statistician who correctly predicted the 2012 election and then set up his own "538" website dedicated to "data journalism"—just the data, the facts, the numbers, the analysis . . . But, when Mr Silver made the mistake of hiring Professor Roger Pielke Jr, then Michael Mann and Kevin Trenberth were obliged to explain to him that these considerations do not apply to climate science.[4] So Nate Silver fired Professor Pielke—who has now withdrawn from all climate research. When Professor Willie Soon co-authored a paper earlier this year on why the turn-of-the-century climate models all turned out wrong, the Big Climate heavies did not attempt to refute the paper, but instead embarked on a campaign to get him fired from the Harvard-Smithsonian Center for Astrophysics.

For every Judith Curry or Willie Soon or Lennart Bengtsson, there are a thousand lesser names who see what happens to even the most distinguished people in their field and decide to keep their heads down. Professor Ivar Gievar recently spoke out against, among other things, the recent adjustment of figures by NASA—an agency overseen by this sub-committee—at the annual meeting of Nobel Laureates in Lindau. Professor Gievar is a Nobel Laureate. A real Nobel Laureate, I mean, not a fake one like Michael Mann, Kevin Trenberth and many other climate scientists who falsely claim to be Nobel Prize winners on the grounds that the IPCC was awarded the Nobel Peace Prize in 2007, and they once contributed to an IPCC report. Mann falsely claimed to be a Nobel Prize winner on his book jacket, on his website, in his court complaint about me—even though the Nobel Institute told him he wasn't a Nobel Prize winner and he should cut it out. But this serial misrepresentation of credentials by Mann, Trenberth and others is also part of their intimidation technique. If you're a real Nobel Laureate like Ivar Giaever, who won the

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[1] *http://www.steynonline.com/6333/michael-e-mann-liar-cheat-falsifier-and-fraud*
[2] *http://klimazwiebel.blogspot.com.au/2014/05/lennart-bengtsson-leaves-advisory-board.html*
[3] *https://twitter.com/MichaelEMann/status/467310861237760000*
[4] *http://judithcurry.com/2014/03/20/nate-silvers-538-inconvenient-statistics/*

1973 Nobel Prize in Physics, or if you're older, tenured and sufficiently eminent, you can just about withstand the Big Climate enforcers jumping you in the parking lot and taking the hockey stick to you.

But, if you're a younger scientist, you know that, if you cross Mann and the other climate mullahs, there goes tenure, there goes funding, there goes your career. I've been stunned to learn of the very real fear of retribution that pervades the climate world.

When I look at what has happened to those who speak out, I recall the wise words of Stephen McIntyre:

> *As a general point, it seems to me that, if climate change is as serious a problem as the climate 'community' believes, then it will require large measures that need broadly based commitment from all walks of our society.*[5]

Mr McIntyre is exactly right: If we take Big Climate at their word that the entire global economy needs massive re-orientation on a scale never before contemplated, it will require the largest societal consensus—left and right and center, in America, in Canada, in Britain, in Europe . . . Yet all Big Climate does is retreat ever deeper into its shrinking echo chamber and compile ever longer lists of people who are beyond the pale—Professor Curry, Professor Christy, Professor Bengtsson, Professor Pielke, Professor Soon, Lord Lawson, the Bishop of Chester, the winner of the 1973 Nobel Prize in Physics, the winner of the 1998 Nobel Prize in Physics. . .It might be quicker for Mann, Trenberth, Gavin Schmidt and the other climate enforcers to make a short list of those to whom they are prepared to grant a say in the future of the planet.

In shoring up this cartoon climatology, the alarmism industry is now calling on courts and legislatures to torment their opponents. I shall outline my own particular experience, and then the general climate.

Mann vs Steyn et al

On July 12, 2012, former FBI Director and special investigative counsel Louis Freeh issued a devastating report regarding the behavior of Pennsylvania State University and its most senior figures, as they ignored, abetted and covered up the systemic and brutal child sexual abuse conducted by Gerald A Sandusky, longtime football coach at the university.

The following day Rand Simberg posted an article on the Competitive Enterprise Institute's website entitled "The Other Scandal in Happy Valley", which suggested that, in light of the revelations regarding the "rotten and corrupt culture" at Penn State under the presidency of Graham Spanier, it might be worth revisiting the other sham "investigation" on Spanier's watch—of Dr Michael E Mann, creator of the famous global-warming "hockey stick".

The very same day *The Chronicle of Higher Education* also tied together the sham Sandusky and Mann investigations in a piece titled "Culture of Evasion."[6] As you know, after the Freeh Report was published, criminal charges were filed against Penn State President Graham Spanier and other senior administrators. Spanier is currently under indictment for grand-jury perjury, obstruction of justice, child endangerment, conspiracy and failure to report child abuse.

Two days later, I wrote a 270-word blog post for the opinion page of National Review Online[7] referencing the Freeh Report and Mr Simberg's piece. That post appears below in its entirety:

> *In the wake of Louis Freeh's report on Penn State's complicity in serial rape, Rand Simberg writes of Unhappy Valley's other scandal:*
>
> *'I'm referring to another cover up and whitewash that occurred there two years ago, before we learned how rotten and corrupt the culture at the university was. But now that we know how bad it was, perhaps it's time that we revisit the Michael Mann affair, particularly given how much we've also learned about his and others' hockey-stick deceptions since. Mann could be said to be the Jerry Sandusky of climate science, except that instead of molesting children, he has molested and tortured data in the service of politicized science that could have dire economic consequences for the Nation and planet.'*
>
> *Not sure I'd have extended that metaphor all the way into the locker-room showers with quite the zeal Mr Simberg does, but he has a point. Michael Mann was the man behind the fraudulent climate-change 'hockey-stick' graph, the very ringmaster of the tree-ring circus. And, when the East Anglia e-mails came out, Penn*

[5] *http://climateaudit.org/2014/05/14/the-cleansing-of-lennart-bengtsson*
[6] *http://chronicle.com/blogs/innovations/a-culture-of-evasion/33485*
[7] *http://www.nationalreview.com/corner/309442/football-and-hockey-mark-steyn*

> *State felt obliged to "investigate" Professor Mann. Graham Spanier, the Penn State president forced to resign over Sandusky, was the same cove who investigated Mann. And, as with Sandusky and Paterno, the college declined to find one of its star names guilty of any wrongdoing. If an institution is prepared to cover up systemic statutory rape of minors, what won't it cover up? Whether or not he's 'the Jerry Sandusky of climate change', he remains the Michael Mann of climate change, in part because his 'investigation' by a deeply corrupt administration was a joke.*

I asked what I thought was quite an obvous question: If an institution is prepared to cover up the systemic ongoing rape of minors, what won't it cover up?

It's a legitimate question for an institution that receives taxpayer funding, a certain portion of which falls under the oversight of this committee. Penn State has a representative here today, and perhaps he will address some of these questions about his institution and its integrity.

Graham Spanier, the now disgraced president of Penn State who presided over the joke investigations of both Sandusky and Mann, remains the President Emeritus of Penn State, and a professor of family studies. His absolution of Michael Mann was widely regarded at the time as a total joke even by many who are by no means "climate deniers"—for example, the venerable American institution *The Atlantic Monthly:*

> *The Penn State inquiry exonerating Michael Mann—the paleoclimatologist who came up with 'the hockey stick'—would be difficult to parody.*[8]

Professor Harold Lewis, one of the most distinguished members of the American Physical Society, resigned from the organization over the whitewashing of Mann, writing:

> *When Penn State absolved Mike Mann of wrongdoing, and the University of East Anglia did the same for Phil Jones, they cannot have been unaware of the financial penalty for doing otherwise.*[9]

In other words, Spanier's depraved regime at Penn State turned a blind eye to Mann for the same reason it turned a blind eye to the Sandusky rape epidemic: they couldn't afford to take the financial hit.

In this case, unlike football revenue, the money comes in large part from taxpayers, via you and the agencies you preside over—such as the National Science Foundation. Given Penn State's refusal to disclose materials relating to the Mann investigation under the corrupt Spanier regime, it would be appropriate for you to put a hold on all NSF funding of Penn State, including Mann's two current grants totaling half a million dollars. And I hope this sub-committee will ask the witness here today representing this deeply corrupt institution whether he will join in a call for Spanier's successor to let the sunlight in on all the dank, fetid corners of Spanier's legacy.

Dr Mann did not want the world to be reminded that the same man who turned a blind eye to Sandusky also turned a blind eye to him. He filed suit against me and three other parties in the Superior Court of the District of Columbia, where neither Mann nor I work or reside. Indeed, I never set foot in this benighted jurisdiction except to come here for matters arising from the court case, such as this hearing. The case was assigned to Natalia Combs Greene, a since reprimanded landlord-and-tenant judge appointed by President Clinton and confirmed by this honorable Senate. After a botched ruling in which she confused the parties, she said the case was "complicated" and shuffled it off on a colleague, but not before procedurally mangling it so that, for a while, two different trial judges were ruling on the case simultaneously—something that's a big no-no in functioning jurisdictions, but which was partly caused here by Michael Mann falsely claiming in his complaint to be a Nobel Laureate and then, after the Nobel Institute told him he wasn't, having to file an amended complaint.

At this point, my fellow defendants chose to test the DC Anti-SLAPP statute, which was assented to by this U.S. Senate in 2010, but was so poorly written as to leave unanswered such basic questions as the standard for dismissal and whether or not that decision is immediately appealable to the DC Court of Appeals. The ACLU, *The Washington Post,* NBC News, *The Los Angeles Times,* and various other media bigfeet all filed amici briefs opposed to Mann—not because they disagree with

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[8] *http://www.theatlantic.com/politics/archive/2010/07/climategate-and-the-big-green-lie/59709/*

[9] *http://wattsupwiththat.com/2010/10/16/hal-lewis-my-resignation-from-the-american-physical-society/*

him on global warming (most of them are as hot for climate change as he is) but because they understand that putting climate science beyond criticism and into the courtroom would inflict the greatest damage on the First Amendment in over 50 years. Not a single amicus brief was filed on Dr Mann's behalf.

Oral arguments were heard over one year ago, yet judges Vanessa Ruiz, Corinne Beckwith and Catharine Easterly, all confirmed to the DC court by this Senate, have failed to rule. I note that, in writing to President Obama recommending a second 15-year term for Judge Ruiz, the Commission on Judicial Disabilities and Tenure nevertheless observed:

> *The Commission would be remiss if it did not address the serious issue of Judge Ruiz's backlog of opinions . . . Of crucial importance to the proper functioning of the Court of Appeals is the timely resolution of disputes. The public's confidence in the Court is eroded when litigants must wait multiple years for decisions to be rendered. The Commission believes that this problem is not only about the pace of opinion production, but also about a less than fully adequate appreciation on the part of Judge Ruiz as to how her backlog adversely affects the litigants, the Court, and her colleagues.*[10]

As a result, an interlocutory appeal has dragged on for almost two years. Judge Ruiz is an activist judge who is, inter alia, a trustee of the Carnegie Endowment for International Peace, which aspires to be the first global think-tank and is very active on the transnational climate scene. All very fascinating. But she's supposed to be a DC judge first and a condition of the Commission in exchange for recommending her for a second term was that her obligation to clear her appalling backlog of cases took precedence over her "outside activities, no matter how worthy they may be". A dissenting member of the Commission, Noel J Francisco, was shrewder about Judge Ruiz's failings:

> *It should go without saying that an appellate judge's primary duty—if not her sole duty—is to decide cases. On this score, as my colleagues have described, Judge Ruiz's backlog is 'the highest by far of any of the appellate judges on the DC Court of Appeals' and, as a result, litigants often 'must wait multiple years for decisions to be rendered' by her . . . As the old adage goes, 'justice delayed is justice denied'.*

The purpose of anti-SLAPP laws is to prevent the use of litigation to chill free speech—on climate change and many other issues. When it takes up to three years to get a ruling (as it apparently does with Judge Ruiz), there is no point to anti-SLAPP legislation. Indeed, when it takes three years to get a ruling, the case is not the issue, the judge is. When it takes three years from oral arguments to ruling, it may be that the judge is just an incompetent sloth who's spending far too much time with the Carnegie Endowment working on world peace. Or it may be that a sclerotic and incompetent DC court system has three-year backlogs because it accepts cases from venue tourists like Michael Mann who have no connection whatsoever with this jurisdiction—and, as a result, the court system is incapable of serving the people it's meant to serve.

Nevertheless, this Senate confirmed Judge Ruiz. Under the Home Rule Act, the District of Columbia operates in a constitutional no-man's-land whereby it enacts legislation for which this honorable body is ultimately responsible. In practice, that means they pass slapdash, poorly drafted laws, and you guys rubber-stamp them. The constitutional limbo allows serial plaintiffs like Michael Mann to use the DC courts to torture non-DC residents: this is a disgrace, and ultimately it is the responsibility of you and your colleagues.

I responded to Mann's discovery requests almost two years ago. He has yet to respond to mine. No court around the world within the Common Law tradition to which this country is heir has ever presumed to adjudicate science. Judge Natalia Combs Greene is not competent to rule on landlord-and-tenant cases, never mind the extent of the Medieval Warm Period. Judge Vanessa Ruiz is so lethargic that, by the time she does rule on the science, global warming will have kicked in and the rising sea levels will have washed away the Maldives, Tuvalu and, with luck, the District of Columbia. My three years in the stagnant swamp of DC "justice" demonstrate why science in particular and public policy disputes in general are beyond the competence of the judges you confirm and the courts you fund. They belong properly in what the eminent jurist Lord Moulton called "the domain of manners".

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[10] *http://legaltimes.typepad.com/files/commission-on-judicial-disabilities-and-tenure-report-vanessa-ruiz.pdf*

Big Climate vs Everyone

Why is this relevant beyond the travails of one obscure immigrant? Because too many people within the climate cartel are demanding that dissent from the alleged "consensus" should be not merely a civil offense but a criminal one—and far too many legislators and bureaucrats are willing to entertain it. Your colleague, Senator Whitehouse, is among those who favor criminal penalties for those who disagree with him on climate policy. Earlier this year, you, Senator Markey, were rebuked by the President of the Cato Institute for "an obvious attempt to chill research into and funding of public policy projects you don't like . . . You abuse your authority when you attempt to intimidate people who don't share your political beliefs." [11]

Likewise, Raúl Grijalva, the Congressman from Arizona and Ranking Member of the House UnEnvironmental Activities Committee, earlier this year sent a letter to seven scientists, including professors Curry and Christy—a quite disgraceful letter that no citizen-legislator in a representative parliament has any business sending to anybody, demanding among other things details of speaking fees, travel expenses, and e-mail communications stretching back a decade [12]. Commissar Grijalva presumed to be able to do this because these scientists had voluntarily testified before his committee, and thus, as he saw it, had submitted to his jurisdiction over every aspect of their lives. I hope this Senate sub-committee will distance itself from Commissar Grijalva's deformed understanding of his role. But, in the event that, following my voluntary appearance here today, any Senator demands in five years' time to see my e-mails and know what hotel I stayed in in Cleveland or Copenhagen, I might as well give you my answer now: You ain't getting' nuthin'.

It takes quite a lot to stand up to powerful congressmen and senators threatening to plunge you into half-a-decade of investigative torture for exercising your free-speech and public-advocacy rights. The ultimate verdict of such inquiry is largely irrelevant: The process is the punishment.

The Attorney General of New York, Eric Schneiderman, is presently using securities law to do an end run around the First Amendment and sue Exxon for not holding the same views on climate change as the more pliable oil companies have been forced to adopt in public.

Recently, a group of scientists mainly from George Mason University wrote to the President to demand that climate dissenters be prosecuted under the RICO laws. RICO, as you know, is supposed to be used against racketeers and mobsters and, granted the unfortunate tendency of sloppily drawn Federal laws to metastasize under opportunist U.S. Attorneys, one marvels nevertheless that such an absurd and ideological expansion of this legislation could ever be seriously entertained.

Needless to say, as with the Spanier regime at Penn State, it is in fact George Mason's climate community that most closely approximates a mob racket. The first signatory on that letter demanding RICO be applied to his enemies is Professor Jagadish Shukla of George Mason, who additionally controls a "non-profit" the Institute for Global Environment and Security, Inc. which is part of George Mason's College of Science. In 2014 alone, this "institute" received over half a million dollars in Federal climate grants, including from bodies you oversee. As you know, the NSF and other Federal agencies have supposedly strict rules about enriching oneself from grant monies. As a general principle, during college vacation you're allowed to earn no more than your monthly salary in research grants. So if you're paid, say, $100,000 per year, you're allowed to top that up to 20 grand of grant money during the summer. Instead, Professor Shukla essentially tripled his income, and since 2001 has taken some 63 million dollars in Federal science grants for a "non-profit" that employed him as president, his wife as business manager and his daughter as assistant business manager. There's a little bit of congressional oversight just waiting to be done, don't you think? Sixty-three million bucks! But instead Commissar Grijalva wants to know whether Judith Curry got upgraded to a junior suite at the airport Hilton in 2007.

This climate of intimidation, led by influential legislators of the most lavishly funded government in the world, sends a powerful signal to others. Professor Curry has noted the latest stage in the grim descent of the journal *Science,* whose editor Marcia McNutt recently published a statement confirming her journal's wholesale embrace of advocacy over science: "The time for debate has ended. Action is urgently needed." The other most prominent science journal on the planet, *Nature,* appears to be going even further, publishing a statement by three climate scientists arguing that "climate justice" is "more vital than democracy":

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[11] *http://www.cato.org/blog/message-catos-center-study-science*
[12] *http://www.steynonline.com/6831/the-warmish-inquisition*

Democracy emphasizes the mutual roles of actors: all preferences are treated as equal. In many regions of the world, however, the results of democratic choices can be strongly influenced by power relations and inequitable social arrangements, owing to differences in economic development, access to technology and knowledge.

Elites may use democratic processes to entrench their status or encroach on other social goals. This can lead to incremental or undesirable results, which might explain why ***large democratic nations such as the United States continue to oppose progressive climate legislation.***

In our view, sound climate and energy planning should not treat all stakeholders in the same way. Instead, preferences and roles should be weighted to consider criteria related to equity, due process, ethics and other justice principles.[13]

So the fake 97 per cent consensus is no longer enough. These scientists are saying that, because there's a supposed 97 per cent consensus among climate scientists, they don't need a 51 per cent consensus from the electorate.

The relationship between government and science today would be unrecognizable to real scientists—to Sir Isaac Newton, to Charles Babbage, to the Curies. The creation of the IPCC in particular has led to the establishment of a closed, largely Anglo-American climate jet set that, as demonstrated in the Climategate e-mails, has had a wholly corrupting effect on peer review among other things. In this culture, what is the proper role of the political class? Is it to do as Senator Whitehouse, Congressman Grijalva and Attorney General Schneiderman are doing, and make climate alarmism a state ideology from which it is forbidden to dissent? Or is it time for legislators to exercise their responsibility to ensure that the people's money is used in the service of science and not propaganda?

In that respect, let me close by turning to my area of expertise. I am not a climate scientist, but I am an acknowledged expert in the field of musical theatre.[14] Last year, a show called *The Great Immensity* opened off-Broadway. It ran a week and then closed after largely stinking reviews from *The New York Times* et al. It had received a direct grant of $700,000 from the agency for which you are responsible, the National Science Foundation. There is no science in putting on a musical: If there were, the Broadway adaptation of the Tom Hanks film *Big* would not have lost its entire investment, nor the Stephen King musical *Carrie,* nor the supposed blockbuster of America's bicentennial year *1600 Pennsylvania Avenue,* by Leonard Bernstein and Alan Jay Lerner, which closed after five days and led Bernstein to conclude that he never wanted to get mixed up with Broadway again. If only the National Science Foundation was that savvy. The difference between those shows and *The Great Immensity* is that, with your blessing, only the last had American taxpayers' money in it. The Government of the United States is the brokest entity in the history of brokeness. It has to pay back $20 trillion just to get back to having nothing at all. Which nobody in human history has ever done. Yet it apparently is not so broke that it can't throw down the toilet 700 grand of funds marked for science on a lousy musical.

I have been around the theatre my entire adult life, and once in a while one runs into an example of an official government musical. There was the celebrated socialist operetta, *The State Department Store,* which was produced in Hungary and other Warsaw Pact countries after the Communist regimes banned all the old-school operettas for having too many singing princes and countesses as the principal characters. There was also *Zabibah and the King,* a musical version of Saddam Hussein's allegorical novel in which the nubile virginal heroine represents Iraq and her manly yet tender expert lover the King represents Saddam. Unlike the NSF-funded *Great Immensity,* it got rave reviews from the Baghdad critics—because, if you gave it two thumbs down, you got one head off. The National Science Foundation does not yet enjoy that power, although clearly Dr Mann, Senator Whitehouse, Congressman Grijalva, Attorney General Schneiderman, and those scientists demanding that climate justice trump democracy are moving in that direction.

And in fairness neither the Communist regimes of Eastern Europe nor the Baathist tyranny of Saddam Hussein had their scientific bodies invest in musicals. That grotesque innovation came from an agency for which you are responsible. If you click on the YouTube link below.[15] which I hope we might listen to during the hearing, you will see just how little American taxpayers got for their $700,000. Even if the show were not total garbage, it would be tainted and disfigured by the

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[13] *http://www.nature.com/nature/journal/v526/n7573/full/526323a.html*

[14] *http://www.amazon.com/Broadway-Babies-Say-Goodnight-Musicals/dp/0415922879/ref=sr__1__1?ie=UTF8&qid=1449452540&sr=8-1&keywords=Steyn+Broadway+Babies*

[15] *https://www.youtube.com/watch?v=EASpzOX2UNQ*

$700,000 in direct funding from a government agency. That moves it into the same realm of state propaganda as Saddam Hussein's musical and *The State Department Store.* Propaganda can only disfigure art and science, and it has no place in either. The National Science Foundation has no more business sinking three-quarters of a million bucks into *The Great Immensity* than it would have into my cat album, released this month—although, in the latter case, the American people would at least have got a return on their involuntary investment.

In the world of arts funding, bureaucrats and administrators often talk of the "arm's length" principle. There is no "arm's length" between government bureaucracies and contemporary climate science: They are entwined like Saddam Hussein and his lush, curvaceous lover in that boffo Baghdad smash, and it has done untold damage throughout most of the western world. As a final thought—and here I stray from dogma to my colleagues' field of data—it seems to me that there are more similarities between musical theatre and IPCC climate science than there ought to be. As Irving Caesar, the celebrated lyricist of *No, No, Nanette,* characterized Broadway to me many years ago: "Remember, kid. No one knows nothing." You hire the greatest composer, the hottest choreographer, the biggest star, the best orchestrator, and, when you put 'em all together, it just lies there and it dies there. Likewise, as I have come to learn, with climate science: when someone's up in northern Finland collecting lake sediment, that's science; when someone's taking tree rings from the Gaspé peninsula in Québec, that's science; when someone's up to his neck in ice cores in Antarctica, that's science. But, when Michael Mann feeds them all into his magic processor and tells you here's the planet's temperature for the last two millennia, that's not science. When the IPCC distills it further into "This is the hottest year of the hottest decade of the hottest century in, like, forever", that is way beyond the realm of science. And, when politicians distill that further still into "Give us all your money or the planet gets it", we have flown the coop of science and are free-floating through clouds of totalitarian fantasy.

Climate alarmism is going nowhere. The two-decade global-warming pause, which no late 1990s climate model foresaw, led the public to doubt Big Climate's confident predictions for the future. In response, Federal bodies such as NOAA and NASA have adjusted the past to make the present appear hotter, and thus supposedly demonstrated that in fact there is no such "pause". As a result, public opinion, which no longer trusts the Big Climate enforcers to tell them what the climate will be like in 2050, now no longer trusts them to tell them what it was like in 1950. A recent poll found that, notwithstanding the urgings of the President and the Secretary of State and others, only three per cent of Americans regard climate change as their major concern. Three per cent. There is your 97 per cent consensus, gentlemen.

At exactly the time when climate science needs to acknowledge its own failings, and the uncertainties of which Dr Curry speaks, and the inability of cartoon climatology and fraudulent gimmicks like the hockey stick to capture the complexities of the planet's climate system, a narrow unrepresentative group of activists is demanding ever more brutal penalties against those who refuse to toe the line.

There is certainly a role for the state to play in this—not in prosecuting climate dissenters under RICO laws or in dumping taxpayer money into unwatchable propaganda musicals, or in having feckless lethargic judges in the District of Columbia reward serial plaintiffs for nuisance suits, but rather in standing firm for the most expansive definition of free speech, which is vital to scientific inquiry and sorely overdue in this particular field, and against the abuse of government funds, which has been disastrous for it.

Senator CRUZ. Thank you, Mr. Steyn.

Dr. Titley?

STATEMENT OF DAVID W. TITLEY, REAR ADMIRAL USN (RET.), PH.D., PROFESSOR OF PRACTICE AND DIRECTOR, CENTER FOR SOLUTIONS TO WEATHER AND CLIMATE RISK, PENNSYLVANIA STATE UNIVERSITY

Admiral TITLEY. Thank you for Chairman Thune to extend this invitation to me.

Chairman Cruz, Ranking Member Peters, Ranking Member Nelson, distinguished members of the Committee, thank you.

This is an important hearing on an important subject. I am here today as a private citizen. My views are my own.

I got involved in climate in 2009. I was minding my own business as a one-star admiral, ran the Navy's oceanography and operational weather forecasting. Got a call while driving to the New Orleans airport across the causeway in Lake Pontchartrain, and it was the Chief of Naval Operations, Admiral Gary Roughead.

He basically said, "Hey, Titley, figure out what is going on in the Arctic. Is this an issue or not? What is going on with climate? Do I need to deal with this? Come up to the Pentagon and figure this out."

So I was a one star. He is a four star. So I said, "Aye aye, sir." And that is what we did.

And kind of what I looked at it as is really dropping back to the training. I was a navigator on an old guided missile destroyer, and we didn't have GPS. So you had to look at all the data, but not believe any one piece of data entirely.

And that is kind of how I have looked at this because, actually, I wasn't really convinced one way or the other what was going on. So that is what I did. And the more we looked at the data, the more we saw that not only were the air temperatures coming up, but the ocean temperatures were coming up. The sea level was coming up. The glaciers were retreating. The oceans were acidifying. And as I said, the sea levels were actually rising.

So when you put all of those independent lines of evidence together, coupled with a theory that was over 100 years old and had stood the test of time, it kind of made sense. Does it mean we know everything? No. But does it mean that we know enough that we should be considering this and acting? Yes. It is called risk management, and that is what we are here doing.

So that is kind of where, you know, the science in general works there. Can you test your hypothesis? What is the cumulative weight of error? Can you replicate? What is the discovery?

You know, and over time, you can identify what is known with confidence. Not every publication is correct. That is OK. But it informs what we need to study over the next few years.

So, you know, basically, what do we know today about climate science? We know that the Earth's climate is changing at an unusual pace compared to the natural changes that the Earth has experienced in the past. We know emissions of greenhouse gases from human activities—primarily, but not exclusively fossil fuels—are the principal drivers.

We know it is already causing harm, as Senator Nelson has pointed out. Will continue for some time, that harm will continue because there is inertia in the system. There is inertia in the physical system. There is inertia in the world's energy system. And we can limit that harm, though, by remedial action.

In the military, you don't always have perfect information. In fact, you hardly ever have perfect information. But you still make decisions based on what you know, and we know a lot.

General Sullivan, who serves with me on the CNA Military Advisory Board, famously said that if you wait for 100 percent certainty on the battlefield, you will probably be dead. Let us not do that.

We know in 2014 the CNA Military Advisory Board put out another report that talked about the climate risks are accelerating, the threats are being magnified, and the complex, cascading con-

sequences can lead to a failure of imagination. We have already experienced that in the last 15 years in this country. We don't need to do that again.

So what do we do? We are already paying today a de facto carbon tax, one that nobody voted on. You look at the cost of the New Orleans levees. You look at the cost of Sandy. You look at the cost of Florida. You look at the cost of relocating communities in Alaska. Those are all carbon taxes, and we are paying those today.

These are the impacts to society, not necessarily mid-tropospheric corrections to MSU data. These are the kinds of things that we have got to figure out.

So what can we do? I will use my last little bit of time here to really plead to the Congress that your leadership is essential. Big things happen in the United States with the Congress. The Executive Branch can do some things. It can't do a ton.

We have seen this in the Department of Defense. Goldwater-Nichols, that was a big change for the Department of Defense.

Nuclear power. The way nuclear power came into the Navy is because the Congress made it happen. The Congress is massively important.

Ultimately, we need to decarbonize our energy system. It is going to happen anyways, but the speed of that transition is important. And as has been mentioned, there are 190 countries right now in Paris. So that energy system is going to transform. They are talking about this. Why don't we lead it?

We have already heard the Ranking Member talk about that. Why don't we—why don't we lead it?

So here is my belief. I believe that we are still the exceptional country that much of the world looks to for leadership. I believe we all want a better life for ourselves, our children, our grandchildren. Please let us not pull a "Thelma and Louise." Let us get a better future. Let us start it today.

Thank you very much. I look forward to your questions.

[The prepared statement of Admiral Titley follows:]

PREPARED STATEMENT OF DAVID W TITLEY, REAR ADMIRAL USN (RET.), PH.D., PROFESSOR OF PRACTICE AND DIRECTOR, CENTER FOR SOLUTIONS TO WEATHER AND CLIMATE RISK, PENNSYLVANIA STATE UNIVERSITY

Thank you Chairman Cruz, Ranking Member Peters, distinguished members of the U.S. Senate Committee on Commerce, Science, and Transportation for the opportunity to come before you today and discuss this very important topic.

I am David Titley and currently serve as the Founding Director of the Center for Solutions to Weather and Climate Risk at the Pennsylvania State University. I had the honor of serving in the United States Navy for 32 years and retired last year as a Rear Admiral and Assistant Deputy Chief of Naval Operations for Information Dominance. When I retired, I was also the Oceanographer and Navigator of the Navy, and Director of U.S. Navy Task Force Climate Change. Subsequent to my time in the Navy, I served as the Chief Operating Officer position of the National Oceanic and Atmospheric Administration (NOAA). My Center at Penn State currently receives no Federal Funding. Although I have consulted with many distinguished climate scientists in preparation for this testimony, my views are my own—any mistakes are my responsibility.

I am here today because I believe coming to a consensus on how to develop policies that address the challenge of a changing climate is a very important discussion for our Nation's leadership to have. Thank you for holding this hearing.

In the Navy we have a saying, to just give me the 'Bottom Line Up Front' or BLUF. So here's my BLUF for today's hearing:

- *We know how to do Science:* Science is not a simple linear process, performed in an isolated, sterile environment, but rather an iterative process with continual interaction between exploration and discovery, feedback and input from peers, inputs from society, but most importantly, testing ideas, called hypotheses and theories, with evidence. New evidence can change existing ideas. The better ideas fit actual observations, disparate or seemingly unrelated observations or previously unknown observations, the more likely the idea is to be accepted widely by science. Results are provided in many venues, but peer-reviewed journals are especially important. Peer-review does not guarantee the ideas being published are correct, but the process does ensure the work acknowledges previous work in that field, the experiments and methods were well-designed, the evidence cited logically leads to the conclusion. If new evidence becomes available, or subsequent researchers find errors in the methods published, the original ideas are modified. Science is based on the cumulative weight of the evidence available. If initially published contrarian results stand the test of independent confirmation and corroboration, these initially contrarian (or even revolutionary) results become part of the accepted body of science.
- *The climate is changing more rapidly than has been observed in the past; we understand why that is so, and we understand that those changes will continue, absent meaningful action in reducing Greenhouse Gas emissions:* The change in the climate, and therefore the change in the weather, is real. Multiple independent sources of data show a rise in temperatures and rise in the ratio of record high temperatures to record low temperatures; an increase in the intensity of precipitation events—that is, the hardest rains are getting harder; the continued collapse in the area and amount of summer-time sea ice in the Arctic Ocean; an acceleration of sea level rise; acidifying oceans; and ecosystems moving poleward and up in elevation where possible. We understand why the climate is changing, based on science extending back to the mid-19th century. The basic concept of greenhouse gasses trapping heat and keeping the atmosphere warmer than it would be in the absence of these gasses is extremely well understood. This idea explains not only the temperature of the Earth, but the same concept also applies to understanding the temperatures of Venus and Mars.[1]
- *We know how to succeed even when the future is not perfectly known:* Traditional risk planning takes the chance or probability of an event and multiplies it by the impact. But even when it is difficult to assess the likelihood of a specific event, there are still available methods by which risk planning and mitigation can be accomplished. Our national security teams frequently have to account for these "deep uncertainties" and they have a variety of tools to assist them. Rich scenario planning, assumptions-based planning and similar methods can be used with the goal of identifying all plausible vulnerabilities and their subsequent impacts. National Security and strategic military planners have used these tools successfully for decades—we can apply these methods and adapt them to the climate change challenge.

The earth's climate has naturally varied for millions of years (Figure 1—From John Englander "High Tide on Main Street"; it will continue to do so for millions more (*e.g.,* . However, humans, primarily through the release of greenhouse gases, also have the capability to modify the earth's climate in a way that previously could occur only by nature. If the climate has always changed in the past and will do so in the future, then why do we care? We care because we are forcing a change to a system that has been remarkably stable in the past 8–12 thousand years (Figure 2—From John Englander "High Tide on Main Street"); the time when humans developed agriculture, civilization and our modern way of life. It's not that the climate of the past few thousand years is optimal *per se,* but its stability allowed us to base a civilization on an overall predictability of where our coasts would be, when the rains would come, and the length of the growing seasons. Later on we would construct our buildings, towns, and cities all based on a historical understanding of the averages and extremes of our historical climate. And most importantly, we made a fundamental assumption that the future climate would be like the past. That assumption no longer holds.

[1] MacCracken, M. "Climate Change in Six Well-Documented Findings". *http://www.climate.org/topics/climate-change/science-in-six-findings.html*

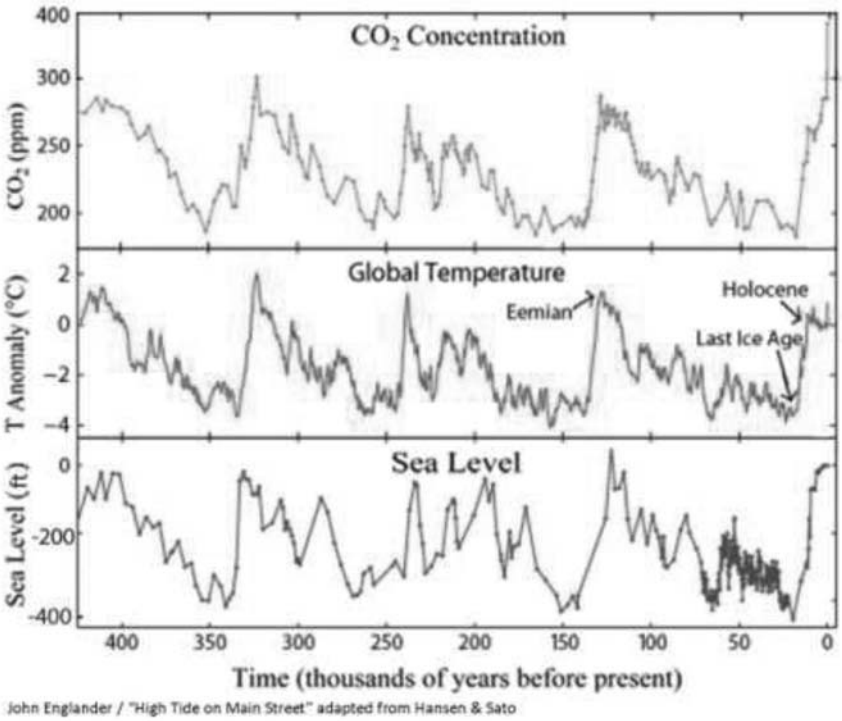

Figure 1—From John Englander "High Tide on Main Street"

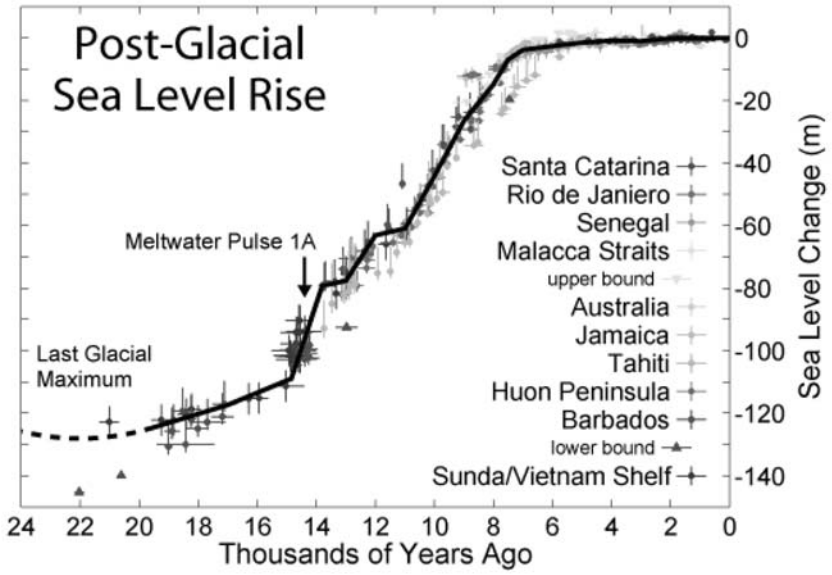

Figure 2—From John Englander "High Tide on Main Street"

Dr. John Holdren, Director of the White House Office of Science and Technology Policy, provided extensive written testimony on the subject of climate change data

and evidence to the U.S. House of Representatives Committee on Science, Space and Technology in September 2014. While I have no ties to the current administration I believe Dr. Holdren describes accurately the state of climate science today. The following is an extract of his written statement:

> "There is an immense amount of [climate science] primary, peer-reviewed, published research . . . carried out by a wide variety of competent national and international bodies (including Federal agencies and scientific advisory boards and committees reporting to them). Important examples include the comprehensive reviews by the U.S. National Academies [2] and the Intergovernmental Panel on Climate Change (IPCC),[3] the recent joint review by the U.S. National Academy of Sciences and the U.K.'s Royal Society of London,[4] the Second and Third U.S. National Climate Assessments,[5] the annual State of the Climate reports of the U.S. National Oceanic and Atmospheric Administration,[6] the periodic synthesis and assessment reports of the U.S. Global Change Research Program,[7] and the first Quadrennial Energy Technology Review of the U.S. Department of Energy.[8] Notably, the U.S. National Climate Assessments, which are required under the Global Change Research Act of 1990, reflect substantial input from the public, outside experts and stakeholders. The most recent such Assessment, which was released in May of 2014, was the result of a three-year analytical effort by a team of over 300 climate scientists and experts, informed by inputs gathered through more than 70 technical workshops and stakeholder listening sessions held across the country. The resulting product was subjected to extensive review by the public and by scientific experts inside and outside of government.

The Natural Science of Anthropogenic Climate Change

Decades of observation, monitoring, and analysis have demonstrated beyond reasonable doubt that:

(1) the Earth's climate is changing at an unusual pace compared to natural changes in climate experienced in the past;

(2) emissions of carbon dioxide and other greenhouse gases from human activities, principally the combustion of fossil fuels but also land-use change, are the principal drivers of the recent and ongoing changes in climate;

(3) climate change is already causing harm in many parts of the world (and many parts of the United States);

(4) this harm will continue to grow for some time to come, because of the time lags and inertia built into the Earth's climate system and the inertia in civilization's energy system (which prevents drastically reducing the offending emissions overnight); but

(5) there is a large difference between the amount of additional harm projected to occur in the absence of vigorous remedial action versus that expected if such action is taken promptly.

The recent measured changes in climate include a multi-decade increase in the year-round, global-average air temperature near Earth's surface, but they are not limited to that. The changes also include increased temperatures in the ocean; increased moisture in the atmosphere; increased numbers of extremely hot days; changed patterns of rainfall and snowfall; and, in some regions, increases in droughts, wildfires, and unusually powerful storms.

In consequence of the temperature increase, moreover, glaciers are melting, the Greenland and Antarctic ice sheets are losing mass, and sea level is rising. While

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[2] The National Academies reports on climate change include the four-volume set, *America's Climate Choices* (2010) and a host of other reports completed since 2010, all accessible at: *http://nas-sites.org/americasclimatechoices/*

[3] Intergovernmental Panel on Climate Change (IPCC) 2007 and 2013–2014 IPCC Fourth and Fifth Assessments, accessible at: *http://www.ipcc.ch/publications__and__data/publications__and__data__reports.shtml#1*

[4] Climate Change: Evidence and Causes—An Overview from the Royal Society and the U.S. National Academy of Sciences, 2014: *http://dels.nas.edu/resources/static-assets/exec-office-other/climate-change-full.pdf*

[5] *Global Climate Change Impacts in the United States,* 2009: *http://nca2009.globalchange.gov* and *Climate Change Impacts in the United States,* 2014: *http://nca2014.globalchange.gov.*

[6] National Oceanic and Atmospheric Administration (NOAA) State of the Climate reports, accessible at: *http://www.ncdc.noaa.gov/sotc/*

[7] *http://www.globalchange.gov/browse/reports*

[8] Department of Energy (DOE) 2011 Quadrennial Technology Review: *http://energy.gov/sites/prod/files/QTR__report.pdf*

the pace of sea-level rise is relatively slow—the current rate would produce an increase of about a foot over a century—there are three main reasons that the problem should not be underestimated:

(1) The rate appears to be increasing and is now about twice the average for the 20th century; increases as high as 1 to 2 meters (3.3 to 6.6 feet) above the pre-industrial value by 2100 cannot be ruled out.[9]

(2) Even modest amounts of sea-level increase constitute a significant threat to ecosystems and infrastructure in low-lying coastal areas, not least because of the amplification of storm surges and increased intrusion of salt water into coastal aquifers.

(3) The momentum in the processes driving sea-level rise is such that it is expected to continue for centuries even under the most optimistic scenarios for climate-change mitigation; it can be slowed, but it cannot be stopped on any time scale of practical interest.

The "fingerprint" of human responsibility for most of the climate change observed over the past few decades is unmistakable: science has established persuasively that the atmospheric build-up of the key greenhouse gases has resulted from human activities; and the spatial and temporal patterns as well as the magnitudes of the observed changes in temperature are consistent with what theory and models predict would result from that build-up, after allowance is made for the partially offsetting effect of increased atmospheric concentrations of reflective and cloud-forming particulate matter (also of human origin).

Civilization's emissions of carbon dioxide, in particular, have led not only to a build-up of the stock of this important heat-trapping gas in the atmosphere (where it's responsible for close to half of the total warming influence of all the heat-trapping substances humans have added over time); those emissions have also led to an increase in the dissolution of carbon dioxide into the surface layer of the ocean. There the dissolved CO_2 forms carbonic acid (H_2CO_3) and thus lowers the pH (increases the acidity) of ocean waters. This ongoing acidification increasingly puts at risk coral reefs and other marine organisms that build their shells or skeletons from calcium carbonate (including clams, oysters, and some plankton).

The foregoing conclusions are based on an immense number of observations and measurements made by thousands of scientists at both governmental and non-governmental institutions around the world, as well as on fundamental understandings about atmospheric physics and increasingly sophisticated computer models of ocean-atmosphere-ecosystem interactions, all recorded in tens of thousands of peer-reviewed scientific publications. These key findings about climate change have been endorsed by every major national academy of sciences in the world, including those of [the United Kingdom], China, India, Russia, and Brazil as well as that of the United States, and by nearly every U.S. scientific professional society, by the World Meteorological Organization and the UN's Inter-governmental Panel on Climate Change (IPCC), and by the recently released Third U.S. National Climate Assessment."

(I have attached additional, more technical parts of Dr. Holdren's statement providing evidence of changes in our climate in Attachment A, submitted with this testimony.)

I would be remiss if I did not address the so-called 'pause' in global surface temperatures. Dr. Holdren provides additional details (submitted as part of Attachment A). It is easy to find arbitrary 5–15 year periods when, with careful choosing of the start and stop dates, one can claim there has been no change in global temperatures. This method of analysis though does not account for the longer-term upward trend that persists through the relatively short-term variations. As an analog, I drive west on Interstate 70 from Washington DC back to Penn State. However, for nearly the first 25 miles in Pennsylvania, I–70 runs north, or even northeast. But even with that short-term variation (to account for the mountains) the road, overall, still takes me from east to west. Likewise, due to natural variability, there are short-term ups and downs in year-to-year temperature. But this structure does not remove the long-term, and upward, trend. A recent graphic (Figure 3) from Dr.

[9] Note: The highest value cited by the IPCC's 2013 climate-science synthesis is 1.25 meters, but a December 2012 NOAA report put the upper limit at 2 meters (see Parris, A., P. Bromirski, V. Burkett, D. 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 U.S. National Climate Assessment.* NOAA Tech Memo OAR CPO–1: *http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf*)

Kevin Trenberth of the National Center for Atmospheric Research [10] shows this trend, and also shows how 2015 is very likely to be the warmest year recorded in the modern record—and by a significant margin.

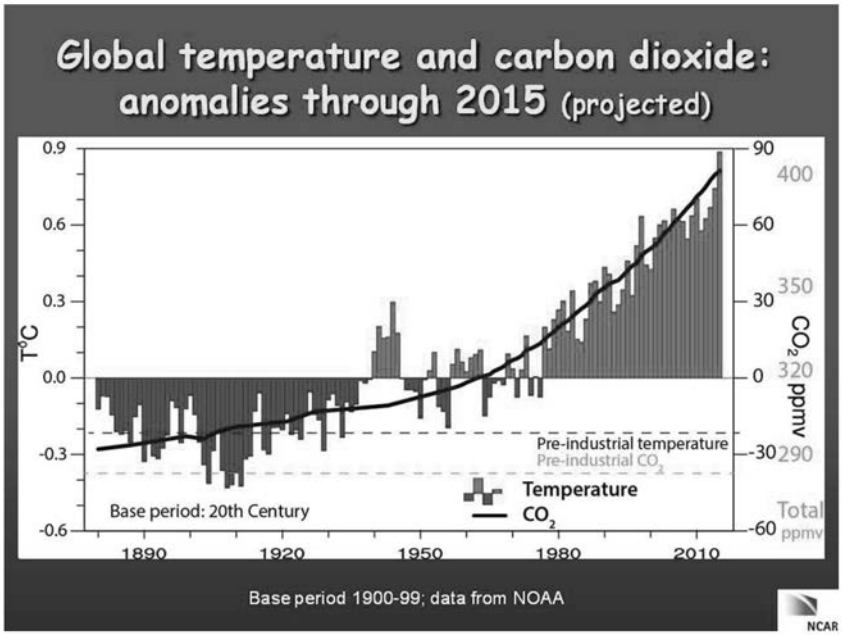


Figure 3—Global Temperature change and CO_2 concentration

In summary, a combination of multiple, independent sources of data provide the basis to the latest conclusion from the Intergovernmental Panel on Climate Change: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. . .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." [11] We should not be surprised; these conclusions rest on science discovered in the 19th century by Fourier, Tyndall, Arrhenius and their colleagues [12] and validated by many scientists in the subsequent decades.

It is worth noting that private industry independently arrived at these same conclusions decades ago. Recently released documents [13] show that in 1980 Exxon researchers projected the impacts on global temperature due to increasing greenhouse gasses with astonishing accuracy (*e.g.,* Figure 4). Again, the basis of the science of climate change is exceptionally well-understood and can be—and has been—applied by many researchers inside and outside the government.

[10] *http://www.huffingtonpost.com/dr-kevin-e-trenberth/fact-not-opinion-climate-__b__8703012.html*

[11] Summary for Policy Makers of the Working Group I contribution to the IPCC Fifth Assessment Report (2013)

[12] *http://www.aip.org/history/climate/co2.htm*

[13] *http://insideclimatenews.org/news/01122015/documents-exxons-early-co2-position-senior-executives-engage-and-warming-forecast*

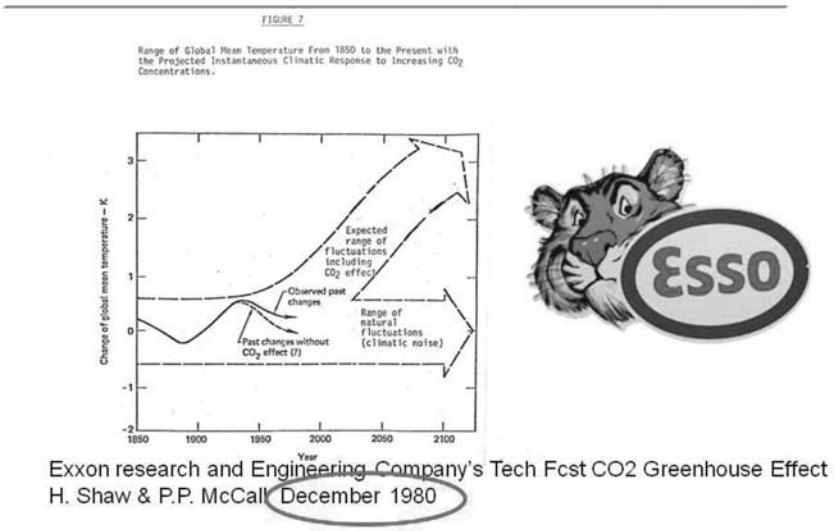


Figure 4—Exxon Projection of global temperatures

So what should we do? I recommend we take a risk-management approach, similar to how the CNA Military Advisory Board (MAB) has done in their most recent report on the risks of climate change to security.[14] Although most of the CNA MAB members are not scientists, their positions as former senior three-and four-star leaders in the United States Military trained them to seek and assess technical advice from many different fields of expertise. They have accepted the overwhelming evidence of the mainstream, international science community, and understand that if significant new and compelling evidence is discovered, the conclusions may need to be adjusted accordingly. Climate risks and security risks share another trait in common: "The worst matters much more than the bad"[15]. In other words: What are the near-term and future risks to our way of life—and what policies and structures should we put in place to manage and mitigate those risks?

How might we meet this challenge? One way might be to start with these four recommendations, consistent in broad goals with the President's Climate Action Plan[16]:

- Set up and support a monitoring system that will allow the U.S. and the world to detect and assess changes to future climate. Assign specific responsibilities. Many National Academies of Science (NAS) reports have called for such a monitoring system. As a recent example, the NAS 'Abrupt Climate Changes' report calls for such a monitoring system.
- Adjust policies today for what we know—and for what we might reasonably expect in the coming decades. Ensure we do not simply plan for the best case or even the most likely, but also consider seriously the most damaging and harmful scenarios (think 'Katrina' and 'Sandy'). We learned in the military a long time ago that hope by itself is rarely a good strategy.
- Invest in better understanding—and ultimately prediction—at the boundary between weather and climate. While scientifically this is very challenging, it is also very important for people and a myriad of decisions. From a security, economic, agricultural, infrastructure and policy perspective, greater climate knowledge of the next few seasons to the next decade or two would be extremely useful. While we should not use today's uncertainty as an excuse to defer action, better understanding of the climate over the next 2–20 years would be very useful in allocating scarce resources. The Department of the Navy is funding today

[14] "National Security and the Accelerating Risks of Climate Change.", CNA Corporation, May 2014. *https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf*

[15] Burroughs, William "Climate Change in Prehistory: The End of the Reign of Chaos", Cambridge University Press, 2005

[16] *http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf*

the 'Earth System Prediction Capability' or ESPC—an interagency program designed to provide our country the next-generation of integrated air-ocean-ice-land prediction system.[17] Navy is working with other components of the DoD, as well as NOAA, NASA and the Department of Energy to ensure our Nation has the world's best operational weather and climate prediction tools at our disposal. This national imperative must be a national priority.

- As we work on adapting to our changing climate we should not lose sight of the big picture: how to move the world's energy system to a predominantly non-carbon based energy source to power the world. How can we unleash the innovation and energy that makes our country great to solve one of the grand challenges of the 21st Century? The United States has responded to grand challenges of the past, in part by investing for the future. As seen in Figure 5, we responded to President Kennedy's call to go to the moon and President Nixon's response to the 1973 Arab Oil Embargo. To date though, there has been no serious response to the need to transforming our energy system. We are the country that is developing a self-driving car and whose private companies can send satellites to geosynchronous orbit. With the right policies and encouragement from the Federal Government I am sure our private sector can develop—and profit from—energy solutions that will power the world in a sustainable fashion into the future.

In closing, our country is dealing with a significant change in the world's climate; it is a very serious challenge and if we do not manage this risk climate change, unchecked, will make many of our existing threats worse. But our country has met challenges of this magnitude before and succeeded—and we will do so again. While we don't know everything—and we never will—we do know more than enough to act now. By focusing our efforts in a risk-based framework on meeting the climate challenge, we can prepare for the short-term while shaping our longer-term future. We can provide the policies, stability and guidance our country needs to unleash our country's energy, creativity and initiative. I am convinced we will be proud and amazed at what we can accomplish.

Thank you very much for your time and attention; I look forward to taking your questions.

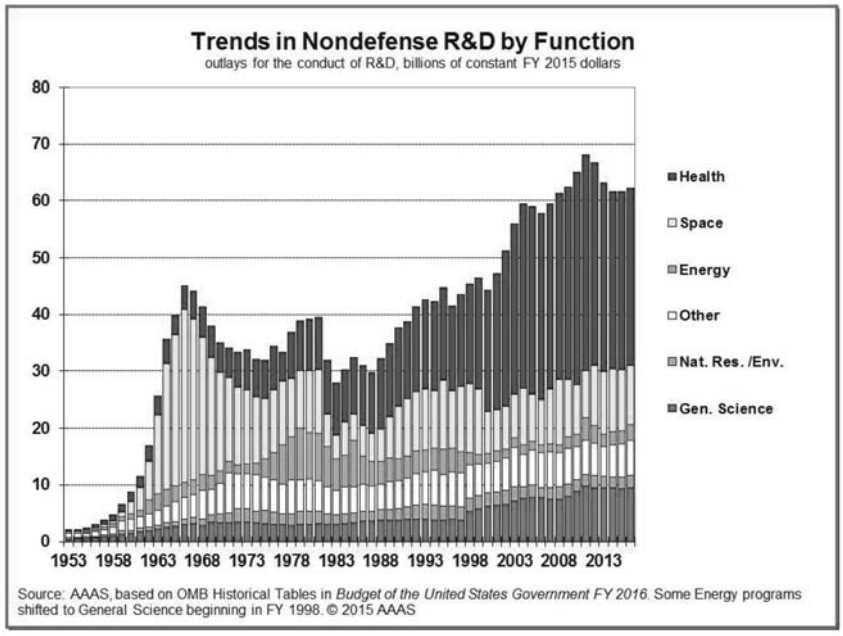


Figure 5—Non-Defense U.S. R&D 1953–2015

[17] *http://espc.oar.noaa.gov/*

ATTACHMENT A

Additional excerpts from Dr. John Holdren's (Director, Office of Science and Technology Policy, Executive Office of the President of the United States) written statement to the U.S. House of Representatives Committee on Science, Space, and Technology, given 17 September 2014

Elaboration on the human drivers of global climate change

Scientists have developed good estimates of the magnitudes of both human-caused and natural influences on the global climate (called "forcings" in climate science) since the start of the Industrial Revolution around 1750. The results show that the human influences in this period have far outweighed the natural forcings, as well as internal variability of the climate system. The 2013 IPCC report found, specifically, that the positive forcing (warming influence) attributable to human-caused emissions over the period 1750–2011 was about 80 times as large as the positive forcing from changes in solar irradiance (the largest natural influence) over that period. Studies going back 20 years and more show that increases in globally-averaged temperatures over the last several decades have been too rapid and too sustained to be a result of internal climate variability.

Carbon dioxide (CO_2) is the most important greenhouse gas emitted by humans. Emissions of CO_2 between 1750 and 2011 accounted for 42 percent of the total positive forcings resulting from all human emissions over this period; and current CO_2 emissions are responsible for around 75 percent of the century-scale Global Warming Potential (GWP) of all current human emissions of heat-trapping substances.[18]

In 2012, about 90 percent of global anthropogenic CO_2 emissions came from fossil-fuel combustion and cement production (40 percent coal, 30 percent oil, 16 percent natural gas, 4 percent cement) and 10 percent from deforestation and other land-use change. Of the "industrial" (fossil fuel and cement) emissions in that year, China accounted for about 29 percent, the United States for about 15 percent, the 27 countries of the European Union for about 11 percent, India for about 6 percent, Russia for about 5 percent, and Japan for about 4 percent. These relatively few countries alone, then, accounted for about 70 percent of global industrial CO_2 emissions in 2012.

The second most important greenhouse gas emitted by humans is methane (CH_4). It has a far shorter atmospheric lifetime than that of carbon dioxide, but methane emissions between 1750 and 2011 nonetheless accounted for about 24 percent of the total positive forcings resulting from all human emissions over this period. Part of this contribution is because chemical reactions involving CH_4 lead to increases in tropospheric ozone and stratospheric water vapor. The activities responsible for civilization's methane emissions are, approximately: fossil-fuel production, processing and transport, 30 percent; animal husbandry, 27 percent; waste management, 23 percent; rice cultivation, 10 percent; and biomass burning, 10 percent.[12]

Emissions of halogen gases (leaked from a variety of commercial products and industrial uses) accounted for another 9 percent of the total positive forcing as of 2011, compared to 1750, but about 40 percent of the positive forcing from the halogen gases was cancelled out by the reduction in the stratospheric concentration of ozone caused by their emissions. Emissions of nitrous oxide (from combustion and fertilizer use) contributed about 4 percent of the total positive forcing up to 2011.

The other major contributor to positive forcing since the beginning of the Industrial Revolution is not a greenhouse gas at all but "black carbon"—heat-absorbing particles emitted primarily by biomass burning and by many two-stroke and diesel engines. Although the atmospheric lifetime of these particles is only days to weeks, their emissions had contributed about 16 percent of all positive forcing as of 2011, compared to 1750.

The positive forcings from the sources just mentioned are currently being partially offset by negative forcing that comes from reflective and cloud-forming particles that also have increased in concentration in the industrial era. The main sources of these

[18] Note: The GWP of an initial emissions pulse of a greenhouse gas is calculated by summing its warming effects over a specified number of years into the future. Because different greenhouse gases have different lifetimes in the atmosphere, the relative importance of their respective emissions at a given time—as measured by GWP—depends on the length of time chosen for those sums. One hundred years is a common choice. Note also that the IPCC's new approach to allocating the responsibility for forcing (as of the 2013–14 assessment) is based on the contribution of emissions of the heat-trapping substances and their precursors between 1750 and 2011, not on the changes in concentrations of the heat-trapping substances as was the approach in the IPCC's previous assessments. The two approaches to allocation give somewhat different numbers because emissions of some substances affect not only their own concentrations but also the concentrations of others.

particles are certain oxides of sulfur and nitrogen emitted by fuel combustion. There are strong incentives to reduce those emissions for reasons of public health and the protection of ecosystems from acid precipitation, however, and when this happen the resulting reduction of negative forcing by the associated reflective and cloud-forming particles will "unmask" some of the warming that currently is being offset.

Elaboration on the "hiatus" in global warming

A number of climate-change contrarians have been propagating the claim that there has been no global warming since 1998. This is not correct.

Although the rate of increase in the globally and annually averaged temperature of the atmosphere near the surface has *slowed* since around 2000 [19] compared to the rate of increase over the preceding three decades, near-surface warming of the atmosphere has indeed continued. The 2000s were warmer than the 1990s, and the 2010s so far have been warmer than the 2000s.

Thirteen of the 14 warmest years since decent thermometer records became available (around 1880) have occurred since 2000. During the recent period in which the rate of increase of the average surface air temperature has slowed, moreover, other indicators of a warming planet—shrinkage of Arctic sea ice and mountain glaciers, increased discharges from the Greenland and Antarctic ice sheets, increased ocean temperatures, and sea-level rise—have been proceeding at or above the rates that characterized the preceding decades.

The long-term warming trend resulting from the build-up of heat-trapping gases and particles in the atmosphere is superimposed on a considerable amount of variability—year-to-year and decade-to-decade ups and downs in the global-average atmospheric temperature resulting from variations in solar output, in volcanic activity that injects reflecting particles into the strato-sphere, and in ocean circulation patterns that govern how much of the trapped heat goes into the oceans as opposed to staying in the atmosphere. Scientists therefore do not *expect* the rate of atmospheric warming, which results from the combination of human and natural influences, to be uniform from year to year and decade to decade. Climate models show short periods of slow warming and even cooling within long-term warming epochs, much as we see recently in observations.

The reduced rate of warming since around 2000 is thought to be the result of a partial offsetting, by a combination of natural factors that tended to cool the atmosphere in this period, of the warming influence of the continuing greenhouse-gas build-up. An increase in emissions of sunlight-reflecting particles from an increase in global coal use may also have contributed. Among the natural factors thought to be involved, oceans are likely to have played a major role in slowing atmospheric warming in this period. The oceans normally take up more than 90 percent of the excess heat trapped by anthropogenic greenhouse gases; thus, a small percentage increase in what goes into the ocean can take a large share away from what otherwise would have gone into the atmosphere.

When the variability that has lately slowed surface-atmosphere temperature trends next shifts to contributing warming, of course, it will then reinforce rather than offset the warming influence of the build-up of greenhouse gases. The rate of increase of the global-average surface temperature will then rebound, becoming more rapid, rather than less rapid, than the long-term average.

It is not clear, finally, that all of what has long been called "natural variability" is completely free of human influences. It's known that the geographic unevenness of anthropogenic global warming (amplified in the Northern Hemisphere by the shrinkage of Arctic sea ice, among other factors), affects atmospheric and oceanic circulation patterns. There is considerable evidence that the El Niño/La Niña cycle, as well as other patterns that affect how much trapped heat ends up in the oceans rather than in the atmosphere, are being influenced to some extent by anthropogenic global warming.

It has been suggested that the slow rate of recent warming calls into question our understanding of the importance of CO_2 in determining Earth's climate. There is no reason to believe this. Short periods of slow warming and even cooling amidst longer warming epochs are expected and are seen in instrumental records, geologic temperature reconstructions, and in climate-model output. Internal redistributions of energy (as are suspected to be responsible for most of the recent slowdown in atmos-

[19] Note: The one year in the top 14 that occurred prior to 2000 was 1998. It was the third or fourth warmest year since 1880 as a result of an unusually powerful El Niño, which boosted the global-average surface temperature well above the trend line. The recent rate of temperature increase can be made to look smaller by "cherry-picking" the 1998 spike as the new start date for one's trend line, as a number of contrarians have done to bolster their claim that global warming has stopped.

pheric warming) in no way conflict with our understanding of CO_2 as a dominant driver of long-term changes in Earth's climate.

Senator CRUZ. Thank you, Dr. Titley. And thank you to each of the witnesses for testifying.

Dr. Happer, I want to start with you, and I want to just make sure I understood your testimony correctly. As I understood what you told this committee, you had a series of facts. That CO_2 is not a pollutant. That CO_2 is good for the planet. That CO_2 is good for plant life in particular. That the world right now is currently greening. And that for much of our history, there has been substantially more CO_2 in the atmosphere than there is right now.

Am I correct in understanding each of those facts?

Dr. HAPPER. That is completely correct. But by history, I mean for since the last 500 million years, you know, since the Cambrian.

Senator CRUZ. And I would note that the history with markedly more CO_2 predated the Industrial Revolution. So it didn't come from automobiles or the burning of carbon fuels. Is that correct?

Dr. HAPPER. That is correct.

Senator CRUZ. OK. So those are facts we are beginning with. I would note those facts are directly contrary to what the global warming alarmists tell us day in and day out and to what the media, which echoes their concerns, say day in and day out.

I want to pull up charts number 1 and number 2. I guess the bias on the charts of the computer models is causing the chart to fall over.

[Laughter.]

Senator CRUZ. So, Dr. Christy, this first chart here, the bright red line, do I understand it correctly that the bright red line is what the computer models—and this is an average of quite a many—quite a significant number of computer models, what the computer models said should be happening with our temperature, that we should see warming spiking like crazy. Is that correct?

Dr. CHRISTY. Yes, and that is the bulk atmosphere, where the biggest signal of greenhouse warming is supposed to be seen. So that is precisely where you want to measure it.

Senator CRUZ. So we see the computer models, and if that were fact, we might have something to talk about. But the bottom line there, the blue and green, those are the actual measurements of what is, in fact, happening in the atmosphere. Is that correct, Dr. Christy?

Dr. CHRISTY. Yes, and I think the nice thing about that chart is there are seven different datasets involved in that observations there, not just one.

Senator CRUZ. So when you compare alarmist theories, the red line, to actual facts, the blue and green dots, you see that the facts don't back up the theories. And we are being asked as a Congress to act and impose trillions of dollars of cost on humanity because of the red-line theory that is not backed up by the facts. Is that correct?

Dr. CHRISTY. I think so. In fact, going along with your hearing, you might want to say dogma is the red line. Data is the blue and the green.

Senator CRUZ. I think that is very well said. I would note this chart on the right, which shows for the last 18 years that there has

been no significant warming whatsoever. Now that is directly contrary to what the dataset showed.

Now, Dr. Titley, I noticed in your written testimony that you took a moment to address what you described as the so-called "pause" in global temperatures. By the pause, are you referring to the last 18 years of no significant recorded warming?

Admiral TITLEY. Well, unlike your previous witness, I am not referring to the 1940s. It is—I thought you would like that.

Senator CRUZ. Indeed.

Admiral TITLEY. Yes. The pause is very interesting. As you know, sir, 1998, big El Niño. So it is kind of interesting we start at 18 years. We don't look at a 15-year dataset or a 10-year dataset or a 20-year dataset. We look at an 18-year dataset.

But even if you do that, that is fine. Let us look at that. We have—this is low budget here. I have got to do my own charts.

[Laughter.]

Admiral TITLEY. Thanks, Amanda.

Senator CRUZ. Well, let me take a moment on——

Admiral TITLEY. So here, sir, just to answer your question, Senator. Here was 1998, and here is today.

So, on me, I mean, I am just a simple sailor. But it is hard for me to see the pause on that chart. So I think the pause has kind of come and gone.

Senator CRUZ. Do you dispute the satellite measurement?

Admiral TITLEY. Let us not talk about the satellite. Here is——

Senator CRUZ. But, sir—sir, I am asking, do you—I understand that the global warming alarmists don't want to talk about the satellite data, but I am asking——

Admiral TITLEY. OK, sure. I will talk about the satellite. Let us talk about the satellite measurements. Let us talk about orbital decay. Let us talk about overlapping satellite records. Let us talk about stratospheric temperature contamination.

I think Dr. Christy and Dr. Spencer, when they put this out, they had been wrong I think at least four consecutive times. Each time the data record has had to be adjusted upwards. There have been several sine errors.

So when—with all due respect, sir, I don't know which data exactly your staff has, whether it is the first or second or third or fourth correction to Dr. Christy's data. We used to have a negative trend, then we had no trend, and now we begrudgingly have an upward trend.

So looking at those data, you know, it is OK. But here is where we live——

Senator CRUZ. Let me see if—let me see if I can understand. The first argument you gave in response to this, and it is an argument that a number of the global warming alarmists use is they say, well, 18 years ago was El Niño, and it is arbitrary to begin there. And I will confess I don't understand that argument because we have 18 years of no significant warming. So if you don't like an 18-year window, we can start in 1999. There is no significant warming for 17 years.

If you don't like a 17-year window, we can start in 2000. Then we don't have a significant warming. It is true for any date across those 18 years. So I fail to see the significance——

Admiral TITLEY. Actually, Senator, it is not. If you take off that top really big spike and you take that out, you start getting the upward bias, and this is what people do when you start looking at these relatively arbitrary times is you start with a really high number at the left-hand side, and that kind of influences basically your linear trend.

So when you start looking at things like every decade, you have an upward trend in the data, and that is from the World Meteorological Organization.

Senator CRUZ. And I would note you asked about the source of the data on the right chart. It is actually not Dr. Christy's data. It is the Remote Sensing Systems, the RSS data that is up there.

At this point, my time has expired. But we are going to have another round.

Admiral TITLEY. Thank you, sir.

Senator CRUZ. And we will return to questions on these topics.

Senator Peters?

Senator PETERS. Thank you, and again, thank you to our panelists for your testimony here today.

Now it was interesting as I heard the testimony from folks and some of the comments that were being made, that this is the so-called consensus of climate change and warming. I heard one of the panelists say the argument is so weak that it can't stand up to any other scrutiny.

As I look at the facts, I don't understand where those—where those comments are coming from. My understanding is that—and this is in a number of peer-reviewed journals that have looked at where scientists are, particularly those who are climate scientists—roughly 97 percent of those folks in the profession believe that the climate is, indeed, changing and that humans had a significant aspect to it.

But it is not just in the scientific community. We have got, in fact, just recently a letter of 150 of the leading companies in this country who are having to make business decisions and are concerned about changing climate. Companies important to me in Michigan like General Motors and Kellogg, but also Coca-Cola, Walmart, UPS. It is a list of the "who's who" of companies in this country who believe this is a concern.

We have some of my colleagues who are in Paris. Nearly 190 countries have come together, realizing this is something that we have to deal with. So, and we hear those numbers, that seems like there is overwhelming amount of scientific support.

That is not to discredit the folks who are testifying here. Certainly your view is important, and we need to hear that. And I think, as, Dr. Titley, you mentioned, nothing is ever 100 percent. And I want to pick up on that, and you mentioned it briefly in your comments as well, particularly as someone who is an admiral in the Navy and as a military person.

We expect our Department of Defense to evaluate potential threats that we face to our national security, threats that we face as a country. If we are in—if we have to go to war, our commanders have to make constant assessments of threats, and they rely on the intelligence community to give them data before they

commit men and women into harm's way. People's lives could be at stake.

These are huge decisions, serious decisions, ones that I know commanders agonize about. But they know if they make the wrong decision, the consequences could be even more significant.

So, and I spent some time in the Navy as well, and I don't know that an intelligence report will ever give you 100 percent certainty. In fact, they will give you all sorts of caveats in providing any kind of intelligence assessment.

So speaking as a man from the military, if you are an operational commander and someone said we can give you 97 percent confidence, but not 100, is that going to be enough? And really, what is—speak to what sort of certainty you are going to need.

Admiral TITLEY. Senator, thanks for the question, sir.

If somebody could tell me with 97 percent certainty what is going to happen on the battle space or in the operating environment, I mean, you would take that in a heartbeat. Our intelligence community does wonders. They have been supported by the Congress, supported by the administration, tremendous hard-working men and women.

But if the intelligence community could tell you as much as the climate community could about the state of the world 50 years from now, we would find General Clapper, whatever he is doing today, stop him. Fly him to the White House and give him the Presidential Medal of Freedom this afternoon because that would be just an outstanding feat.

Now this is not a knock on the intelligence community. They are dealing with people. They are trying to deal with people who deceive us. We are just dealing with physics. The physics isn't trying to deceive anyone, and we understand the basic theory.

We certainly don't understand everything, and we certainly do understand that there are short- and medium-term variations, ups and downs, some of which we do pretty well on, others not so much. That is why we need research. That is why we need better observations.

But the degree of certainty that you ask for, sir, we—we would love to have that for operational commanders making military decisions.

Senator PETERS. And certainly that is in weather decisions. You are a part of the meteorologic or for part of meteorology with the Navy. As a meteorologist, what level of certainty on weather forecasts is acceptable to mission commanders who make operational decisions? Obviously, they don't go into battle without checking with you and other meteorologists.

Admiral TITLEY. Yes, sir. Usually they would say, "Shut up, Titley. Don't give me that weather stuff. Just tell me what is going to happen."

So what they are looking for—but they do understand risk. In all seriousness, people do understand risk. Sometimes weather forecasts are taken to the bank. It is going to start snowing at whatever time.

Other times, like hit-and-miss showers, like the Ranking Member, you know, in Florida, trying to figure out where that thunderstorm is and is not is pretty tricky. But you can communicate that

in terms of risk, in terms of probabilities, and that is really when you extend into climate. This is all we are doing.

I think anybody who says, you know, you have 100 percent of whatever, you probably don't. But if you start having significant numbers and you look at the impacts, I mean, that is the other part of risk is what is the impact if you are wrong? You know, and then how do you buy that down? How do you manage that risk so that it becomes acceptable? And that is what we are trying to do.

Senator PETERS. And that is the thing is the risk that could be potentially catastrophic or go anywhere from bad to catastrophic. But you mentioned and I mentioned the short-term weather effects. If you would just briefly—or my time is about up, but briefly, there is a difference between weather events and climate. And I think that is oftentimes confusing to folks. It is to me.

Could you elaborate why short-term weather events, we shouldn't spend too much time focusing on those and instead need to be looking at the long-term impact of climate change?

Admiral TITLEY. Yes, sir. I mean, I often tell people you live in weather and you plan for climate. Climate is simply this amalgamation or it is put together in space and time, over decades over large regions. Those are the trends. That is climate, up, down, whatever it is.

Weather is day-to-day, you know, and even out to a week, 2 weeks, 3 weeks. And then in between is where it gets interesting, and you know, when we talk about 18 years, this is an interesting time. You have some ocean pieces, but also climate. And you get these—get these interactions here, and this is the interesting time.

Long-term, though, we know where the climate is going.

Senator PETERS. Thank you, sir.

Admiral TITLEY. Thanks.

Senator CRUZ. Senator Daines?

STATEMENT OF HON. STEVE DAINES,
U.S. SENATOR FROM MONTANA

Senator DAINES. Thank you, Mr. Chairman. Thank you for holding this hearing today.

Ranking Members Peters, Nelson, thank you.

I do not have a Nobel Prize, just for the record to be clear. I do have a degree in chemical engineering. I am the only chemical engineer on the Hill. So I very much appreciate and I like being on this science kind of debate and on this committee.

My home state of Montana is well known for its beautiful landscapes, pristine environment, and clearly, we have a moral responsibility to be good stewards of that environment. But Montana families also rely on our natural resources. We are called the Treasure State for a reason. And it is not because of elk antler furniture and huckleberry jam, as much as we enjoy those things. We are called the Treasure State because of our natural resources, which includes coal.

These are good-paying jobs, that coal creates. It is reliable, affordable energy. And I believe Montanans and most Americans believe we can achieve a balanced approach of protecting our environment, as well as ensuring we have affordable energy.

I can tell you there is a lot of concern about the regulations that are coming out of the debates like we are having here today and the magnitude of the devastating impacts on families. The University of Montana, which is not a conservative think tank—my dad is a proud graduate of the University of Montana. But I will tell you they just published a study on the Clean Power Plan, which probably should be called the unaffordable energy plan.

And that study stated that the Clean Power Plan could potentially be the largest economic event to occur in Montana in more than 30 years. Here is what the study said, coming out of the EPA's Clean Power Plan.

It will cost us 7,000 jobs, $500 million a year in annual income, and the loss of $145 million in state tax revenues for our schools and for our teachers. Two weeks ago, I held a telephone town hall. We had thousands of Montanans participating with concerns about these regulations.

What do we do? What do we tell the boilermaker union workers back in Montana who will lose their jobs? What do we tell senior citizens and the working poor who are on fixed incomes and looking at significant and huge increases in energy costs as a result of these regulations from Washington, D.C.?

Let us remember the facts and the data. The United States consumes 10 percent of the coal in the world, 10 percent. Said another way, 90 percent is consumed outside of our country. In Montana, 51 percent of our electricity comes from coal.

I love Tesla automobiles. I have a friend who has a Tesla. It is great to see him plug that into the charging station there in Bozeman. But the reality is in the back of that Tesla, let us just say this Tesla is powered by coal. That is where the electricity is coming from to power that Tesla.

But you think about the United States, about 40 percent of our electricity comes from coal. Look at the numbers—27 percent from natural gas, 19 percent nuclear, 6 percent hydro, 4 percent wind, and 0.4 percent solar.

Now with that as background, as we think about the global challenges that we face as we look at carbon and so forth, with 10 percent coming from the United States and 90 percent outside, we ought to be making sure this is a global conversation and not unilaterally disarming our economy through these regulations coming out of Washington, D.C.

China is building a new coal-fired plant every 10 days. Japan—I used to have an office in Tokyo. I had a private sector job for 28 years before I came to Congress a few years ago. I had an office in Tokyo. Japan is building 43 coal-fired plants as we speak, looking to the future.

And yet these regulations, coming out of the EPA, are going to absolutely kill our economy and kill our natural resources industry.

Dr. Christy, in your testimony, you mentioned the importance of affordable and accessible energy and the importance to human health and welfare. I remind everybody in this room that over 1.3 billion people in the world today do not have access to electricity. What impact will the Clean Power Plan have on greenhouse gases, and what impact will it have on the well-being of families?

Dr. CHRISTY. First of all, I lived in Africa, and I can assure you that without energy, life is brutal and short. The effect that these regulations will have will be negligible on both the carbon dioxide concentrations in the atmosphere and on whatever the climate might do as a result. And we calculated many scenarios in that regard.

Senator DAINES. And so if it is negligible, negligible—now we can quantify the impact on tax revenues, on jobs, on energy prices and what that means for, as you said, a negligible impact, and we have heard similar kinds of conversations and comments actually from the EPA on that very point. Do you realize China—and the New York Times was reporting here just a month ago that China has been underreporting their emissions by a quantity equivalent to 70 percent of the total U.S. emissions. That is what their underreporting has been.

Should we consider such costly remedies as what is going on right now with this Clean Power Plan for merely symbolic changes?

Dr. CHRISTY. Well, if you are asking a State climatologist who deals with economic development of poor State, basically, I would say no. There is no consequence that is positive that I see in regulating the energy in this way.

Senator DAINES. Dr. Curry, in your testimony, you explain how funding motivates research. The Clean Power Plan not only harms workers, but it stifles investments that could lead to innovation and make coal cleaner. I would hope that the U.S. would be leaders in innovation. Because as we lead in innovation and cleaner technologies, we can not only lead our country, we can lead the world as we look at the environment here.

What can be done, in your opinion, to incentivize objective research that can make affordable energy sustainable?

Dr. CURRY. Well, that is a topic—I mean, I applaud the goal that you state. We need to—we need more research and development on advanced energy technologies. How to effect that, private sector-Government, you know, is a challenge for politicians. I don't have any particular insight as a scientist as to how that might work.

But in terms of having—you have to allow people to have opportunity to fail. And if you are going to look for blue sky technologies and something really innovative, you have to have a mechanism that allows people to fail. You need maybe three good ideas, and this may mean, you know, 50 or 100 of them have to be tried before you find a few good ones that are going to work.

And so pretending that wind energy and at least the current solar technology are going to solve the problems is fairly ludicrous.

Senator DAINES. Thank you, Mr. Chairman. I am out of time.

Senator CRUZ. Thank you, Senator Daines.

Senator Nelson?

Senator NELSON. Could you call on Senator Schatz? He has got a meeting to go to.

Senator CRUZ. Sure. Senator Schatz?

STATEMENT OF HON. BRIAN SCHATZ,
U.S. SENATOR FROM HAWAII

Senator SCHATZ. Thank you, Mr. Chairman.

Thank you, Ranking Members Nelson and Peters.

Thank you for having this hearing. It gives us an opportunity to clarify that climate change is real, it is caused by humans, and it is solvable. And only in the four corners of the United States Capitol is that still being debated.

It is ironic that we are holding this hearing in the Committee with jurisdiction over science because this committee is turning its back on the real science. Now I suppose that it is possible that what the four people on the left-hand side of this dais are saying is true, which is that basically everybody else is wrong, that everybody else is wrong.

But I think it is more likely that 97 percent of the scientists have come independently to the same conclusion. Scientists should and do receive Federal research dollars based on the merit of their work, not on their conclusions. The only reason that so few climate deniers or skeptics, whichever you prefer, as a percentage of the whole receive Federal support for their research is because the vast majority of scientists independently come to the same conclusions that the climate is changing due to human activity.

A review of nearly 12,000 peer-reviewed journal articles over 20 years found that 97 percent of those articles and 98 percent of scientists agree that humans are influencing the climate. The vast majority of climate scientists around the world will tell you that greenhouse gas emissions, primarily from the burning of fossil fuels, have increased the concentration of carbon in the atmosphere, which, in turn, has raised average global temperatures.

Now I suppose everybody could be wrong. In fact, the American Academy for the Advancement of Science has said the science linking human activities to climate change is analogous to the science linking smoking to lung and cardiovascular diseases. There may be a doctor out there who doesn't believe there is a connection between smoking and lung cancer, but I would keep that doctor away from me and my family.

Just as there is no genuine scientific debate over whether we are responsible for changing the climate, there is also no global conspiracy to manufacture data. The skeptics do not know more than the National Academies of Science, NASA, the DOD, the CIA, the American Chemical Society, the American Physical Society, the American Medical Association, the American Geophysical Union, the American Meteorological Society, the American Society of Plant Biologists, and the National Academies of Science from 80 countries, the World Health Organization, NATO, and a litany of other organizations.

I, for one, believe that the Department of Defense has to contend with what is, not with how we view—how we wish things would be. And my question is for Admiral Titley.

Could you please describe the relationship between CO_2 and the atmosphere and global temperature?

Admiral TITLEY. Senator, thank you for the question, sir.

I give some talks to the public on this, and basically, what I tell people is what you have asked me is cutting-edge 19th century science here. A bunch of old dead white guys figured this stuff out, starting with Fourier, Arrhenius, Tyndall. By the time you get to 1896, we were actually doing calculations of global warming. Now

it was with stubby pencil and paper, but we actually kind of figured it out.

So in, you know, basic terms, energy comes in at one wavelength. Energy comes back out through the atmosphere at a different wavelength. The carbon dioxide and other greenhouse gases actually re-radiate that longer wavelength. The short stuff comes in from the Sun. The long stuff gets basically bounced around, reabsorbed, readmitted, and that is really good for us.

If we did not have greenhouse gases, we wouldn't all be here because we would be living on an ice cube. It would be about 59 degrees Fahrenheit colder than it is right now. So greenhouse gases provide life on Earth.

But there can be too much of a good thing, and we have literally formed human civilization in a period of wonderful climate stability, where we have not been varying either the greenhouse gases or much of the other part of the atmosphere. So we have had this stability.

Now as we inject a whole lot of extra greenhouse gases, they are just doing what physics does. So they are re-radiating, warming the atmosphere, as you talked about, sir.

Senator SCHATZ. And tell me about the observations on page 3 of your testimony. It seems to me that there is a nearly one-to-one relationship between global temperatures, CO_2, fossil fuel consumption, and sea level and ocean temperature. Is that about right?

Admiral TITLEY. Yes, sir. Everybody here at this table knows that correlation doesn't necessarily mean causality, but there has been a lot of work shown——

Senator SCHATZ. How would you establish causality in an experiment involving our planet?

Admiral TITLEY. We only have one planet. That makes it kind of tough to run the control case, if you will. So this is what the computer models help you with.

Senator SCHATZ. Thank you.

Admiral TITLEY. But we only have one planet. Thank you, sir.

Senator SCHATZ. Thank you very much.

Mr. STEYN. Senator Schatz, could I comment on that? You said that the four people——

Senator SCHATZ. Mr. Chairman, I do have a meeting at 4:30 p.m., and I did not ask a question of Mr. Steyn. I apologize. I do have to go.

Thank you.

Mr. STEYN. Well, I would like to make a comment on what he——

Senator CRUZ. You are welcome to give a response, sure.

Mr. STEYN. I would like to make a comment on what he said because he said these people represent a tiny minority point of view. The 97 percent consensus from these papers does not argue for the kind of measures that are being discussed here today.

We are talking about the greatest—just to take the pro-climate people at their word, we are talking about the greatest shift in the global economy that has ever been contemplated. We hear a lot of talk about risk management. This is a hell of a risk. And it requires—if we are to take these pro-climate people at their word, it

would require the greatest societal consensus—left, right, and center—across North America, Europe, and the developing world.

So to exclude, if you exclude Professor Christy, if you exclude Professor Curry, if you exclude Professor Happer, if you exclude the French weatherman who basically just lost his job for writing a book countering climate change, if you refuse Professor Lennart Bengtsson, whose career was destroyed because he wanted to meet with a skeptic think tank—the great Swedish climatologist—if you exclude the Nobel Prize winner in physics from 1973 and the Nobel Prize winner in physics from 1988, you wind up with what has happened to climate alarmism, where the polls show the real 97 percent consensus that only 3 percent of Americans view this as their overriding priority.

The point that Admiral Titley made about things we could do, he brought up—he brought up Superstorm Sandy as an example of climate change. You know what would have stopped Sandy? If they would have built the same storm barrier that the Dutch coast has, that the Russians have in St. Petersburg, and that London has with the Thames barrier.

For a couple of billion dollars, you wouldn't have had water in the New York subway. But instead, when we talk about all the saving the planet stuff, the flood barrier never gets built. And that is what elected legislators should focus on, the real issues involving them now, not the pie in the sky stuff.

Senator CRUZ. Thank you, Mr. Steyn. And I would note Dr. Titley made reference to dead white guys, and in response to Senator Schatz's question about 97 percent of scientists and this one bogus and discredited study, in the year 1615, I suspect if you asked, 97 percent of scientists at the time would have said categorically that the Sun rotates around the Earth.

And yet an individual named Galileo dared to actually be a scientist and take measurements and stand up to that enforced consensus. And I would note it was the Roman Inquisition that brought heretics before it who dared to say that the Earth rotates around the Sun, and today the global warming alarmists have taken the language of the Roman Inquisition, going so far as labeling anyone who dares point to the actual science as a denier, which is, of course, the language of religion. It is calling someone a heretic.

And anytime you hear people saying scientists should not question the conventional wisdom, you are hearing someone advocating essentially for the abolition of science.

Senator Udall?

STATEMENT OF HON. TOM UDALL,
U.S. SENATOR FROM NEW MEXICO

Senator UDALL. Chairman Cruz, thank you very much.

And you know, today we are having a hearing on climate change science. And while this is an extremely important topic and great for Senators to engage on, I am disheartened by the frame here. It is called "data or dogma" is part of this title of this hearing.

And quite clearly, this hearing was called to inject controversy and skepticism into the issue of climate science and research, to cast doubt on the work of many scientists, including those at Amer-

ican universities in all of our States, the National Laboratories—New Mexico has two of those National Laboratories—and the National Academy of Sciences, who have been researching the effects of climate change and the impacts that humans are having on the climate.

This year is almost over. It will likely be the warmest year on record, and the current record holder, last year, 2014. The impact is clear, and people are seeing it all over the world with rising sea levels that increase drought.

The Southwest is in the eye of the storm. In New Mexico, temperatures are rising 50 percent faster than the global average not just this year or last year, but for decades. Through all of this, Congress has been slow to act. We could be using this time right now to push forward on strong, comprehensive energy policies that curb greenhouse gas emissions.

So I want to turn to you, Dr. Titley. I was really interested in your role as the lead oceanographer for the U.S. Navy and your history of 32 years of service in the Navy. And I have a simple question for you.

Do we have time to waste, in your opinion?

Admiral TITLEY. Senator, thanks, sir.

There is a saying in the Navy, in naval aviation that the two things that are of no use to you is altitude above you or runway behind you. Right now, we are putting runway behind us.

Now how much more there is, that is hard to say. But we are certainly taking time that we should be using to start mitigating this, and actually, some of the other witnesses have brought up some things. I think Dr. Curry talked about more research and development for energy.

We need to transform our energy system. The Federal Government, the Congress can be very, very helpful on that. So, but we are not doing that right now, sir, because we have these debates that—which is fine. But at some point, we need to do something.

Senator UDALL. And you believe, I think, that it would be very prudent to look at the science, which is overwhelming, and we have heard the 97, 98 percent and proceed to do something in a bipartisan way that is constructive and find solutions.

Were you always convinced that climate change is occurring?

Admiral TITLEY. I was—I think there is a YouTube video out there or a TEDx talk I did. I talked about I was kind of a skeptic, as I think—as the chair introduced me, I have—my degrees were in meteorology. You see a lot of day-to-day variation in weather, and you also see, when you take a look at weather models, back when I started back in the dark ages of the 1970s, after about 3 days they weren't really worth very much.

So it took me, honestly, a while to realize that in weather, it really matters about how do you start those models. It is called initial conditions, for the science folks. Whereas the climate models really work on boundary conditions. It is like how much energy is coming in? How many greenhouse gases do we have? Where are the continents? Where are the oceans?

And you realize that, and this is why the climate models are useless at telling you what it is going to be like today or tomorrow, things like that. But they are pretty good at the overall trend.

So when I looked at that and when, frankly, I was asked by the Chief of Naval Operations, Admiral Gary Roughead, to look at this for the Navy, I just said, well, what does the evidence show? And that is where it really—I came to it.

So, you know, I am probably like the reformed smoker. But it was really just simply looking at all these independent lines of evidence. That, to me, said we have got an issue here, and we are going to have to do something.

Senator UDALL. And Doctor, the evidence is right behind you on that chart. That is the evidence you are talking about.

Admiral TITLEY. Just one——

Senator UDALL. Yes, one data point, but——

Admiral TITLEY—to have a chart like that for the rising seas and for many, many other lines. Yes, sir.

Senator UDALL. And do you believe science has progressed on climate, on climate change?

Admiral TITLEY. I think the evidence has shown that science in many fields and including climate, it is not a nice linear process, but fits and starts. So when you take things like, you know, whether it is different observation techniques, I mean, there is a paper that just came out—I think I saw a day or two ago—from NASA measurements, talking about maybe more snow in Antarctica. We are going to have look at that, but that is interesting.

So we get these ups and downs. But overall, and we have seen this in the IPCC and many other conclusions that the level of confidence that the basic theory of greenhouse gases from the 19th century is, in fact, correct.

Senator UDALL. Thank you.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Udall.

Senator Markey?

STATEMENT OF HON. EDWARD MARKEY,
U.S. SENATOR FROM MASSACHUSETTS

Senator MARKEY. Thank you, Mr. Chairman, very much for having this hearing.

And hopefully, this will go better than Galileo because Galileo was put under house arrest, Dr. Titley, in 1633. And the Catholic Church did not issue an apology to Galileo until 1992. So we wish you a long life so that 359 years from now, you can get the apology you deserve for actually using scientific data to back up your arguments here today.

2014 is the warmest year ever recorded. Is that correct, Dr. Titley?

Admiral TITLEY. Yes, Senator. That is what I understand.

Senator MARKEY. That is what you understand. Now what would that be based on? Science?

Admiral TITLEY. A whole lot of thermometers, yes, sir.

Senator MARKEY. Whole bunch of thermometers. A very, very sophisticated technology. So this is going back to the beginning of the measurement of the temperature of the planet using thermometers. So that goes back to 1880, 1870.

Now I am told that the first 6 months of this year are the warmest 6 months ever recorded on the history of the planet. Is that correct?

Admiral TITLEY. Yes, sir. And I think that now extends to the warmest November as well. So we are up to 11 months and counting.

Senator MARKEY. The warmest October and the warmest November now ever recorded using thermometers, the same measurement for about 150 years right now. Very clear calculations that have been made. And so, so I guess we are pretty much 150 years into the 359 years to getting kind of the apology from those who are the deniers.

Now, you know, in Paris right now we have got just about every single scientist in the world, every country in the world is there, all saying the planet is dangerously warming and that the cause of it is human activity. Even the Pope said that it is dangerous, to name a Jesuit who taught high school chemistry. You actually get somebody who says that, you know, it is happening, and it is caused by human beings and that there is a moral responsibility to do something about it.

So this panel that we have in this committee, this last redoubt of denial on the planet, of all the countries on the planet, this last place, you know, has the flip of witnesses that have every other place. We have four here who deny it and one who believes in the science.

And so we clearly here are at a historic moment, and there will be a day when you get your apology, Dr. Titley, for being kind of the sacrificial lamb here, like Galileo, standing up for actual science. And so what we have here is just one of the clear national security challenges of our time. Just as we were focused on protecting the planet from the threat of Communism in the 1950s, we need to be focused on protecting the planet from the threat of climate change now.

We sit here in the Space, the Science, and the Competitiveness Subcommittee, which has oversight over NASA. We should all be cognizant of the fact that NASA was established in 1958 when this country felt the very real threat of Communism. If we had ignored that threat in the 1950s, America wouldn't be the leader it is today.

And it was in response to the threat of Communist domination in space when 53 years ago President Kennedy announced the ambitious goal of sending an American safely to the Moon. He told us that we would need a giant rocket made of new metal alloys, some of which had not yet been invented. It would have to be fitted together with a precision better than the finest watch, and it would have to be returned to Earth safely at speeds never before reached by humans. And it would all have to be done in less than 8 years.

President Kennedy urged us to be bold, and America responded to his call not by saying it couldn't be done, not by denying the threat, but by boldly putting our scientists and our engineers to work protecting our Nation and the world.

Today, a growing global danger lies in the cascading impacts of climate change. Temperatures are increasing. Sea levels are rising. More extreme rains are falling. The ocean is becoming more acidic.

And all of this has consequences for people, public health, and for prosperity.

That is why our national security, military, and intelligence leaders have warned that a changing climate can worsen the tensions that are fueling terrorism and conflicts around the world. More than 50 years ago, we looked to the scientific community to help protect our Nation from Communism. Today, the same scientific rigor we used to send astronauts to space is used to evaluate our changing climate.

And just as President Kennedy urged our Nation to be bold in the space race, the global community is meeting in Paris right now to hold bold action to protect our climate. But the Republicans' message to the world is, Houston, we do not have a problem. And that is the wrong scientific message.

They are once again questioning the integrity of the scientific community and the basic scientific principles behind climate change. The truth is the only thing that requires a serious scientific investigation is why we are holding today's hearing in the first place.

Climate science stands on a foundation of more than 150 years of research, laboratory experiments, demonstrated carbon dioxide traps heat in the same year that Charles Darwin published on the Origin of the Species. So we should listen to the planet's doctors. The more fossil fuels we burn, the more carbon pollution we put in the air, the higher the risk for catastrophic climate consequences.

But the Republicans' response to this existential challenge is to insist that the brightest minds of the United States of America who once figured out how to send a man to the Moon and bring him back safely can't possibly figure out how to generate energy from anything other than burning the cane plants that have been sitting underground since the time of the dinosaurs.

But we all know that failure is not an option. There is no planet B. We must solve this problem. The science dictates that we solve this problem. It is time to stop denying the science and start deploying the climate solutions.

Admiral Titley, we have heard a lot about temperature measurements today. When I am feeling sick and I go to the doctor, she takes my temperature. But the doctor always checks my blood pressure, listens to my heart and lungs, and looks at my ears, eyes, and throat to get a broader assessment of my health.

This chart behind me is NOAA's assessment of the Earth's climatic vital signs. Yes, temperatures are going up, but so is the heat in the ocean, the sea level, and the humidity. And snow and glaciers and Arctic Sea ice are going down.

Do you agree, Dr. Titley, that a wide range of independent observations indicate that the planet is warming and the climate is changing and that there are no emergency rooms for planets, and we have to engage in preventive care?

Admiral TITLEY. Yes, sir.

Senator MARKEY. What would you say is the basis for your decision? Is it based on data, or is your answer based on dogma?

Admiral TITLEY. It is based on the evidence, sir.

Senator MARKEY. It is based on the evidence. And I agree with you, Admiral, and I thank you so much for your service to our country, both in the active Navy and here today before this committee.

Thank you, Mr. Chairman. I yield back.

Senator CRUZ. Thank you, Senator Markey.

Senator Nelson?

Mr. STEYN. Dr. Curry wanted to respond to the Senator——

Dr. CURRY. Is it possible for me to respond? You basically——

Senator MARKEY. I did not ask for—ask you a question.

Mr. STEYN. Really? Why can't she respond, Senator?

Dr. CURRY. Yes, I was——

Senator CRUZ. Dr. Curry, you are welcome to——

Mr. STEYN. You impugned her integrity. I think she is entitled to——

Senator CRUZ. You are welcome to respond, Dr. Curry.

Dr. CURRY. I was basically called a denier, that I am denying science. Did you read my written testimony? Are you aware that the IPCC and the consensus has no explanation for the increase of ice in the Antarctic? Are you aware that they have no explanation for the fact that the rate of sea level rise from 1920 to 1950 was as large, if not larger, as it currently is?

Are you aware that temperatures have been warming for more than 200 years and that in the 20th century, 40 percent of the warming occurred before 1950, when carbon dioxide was not a factor in the warming. OK. And I could go on and on. Many of these issues are raised in my written testimony.

And most of it is pulled from the IPCC itself. The IPCC has an explanation for—so it says, for warming during the period 1975 to 2000. It doesn't have an explanation for the flat period since 2000. It doesn't have an explanation for the early century——

Senator MARKEY. Dr. Mair, as I just said in my—Doctor, as I just said in my testimony, corroborated by Dr. Titley, this is the warmest year ever recorded. Last year is the warmest year ever recorded until this year. This is the warmest November ever recorded. October is the warmest October ever recorded.

You do not have an answer for that, Dr. Mair. You continue to ignore the chart, which Dr. Titley has over his left shoulder. He has documented for this committee the warming trend, which is inexorable, inevitable in terms of its consequences unless we take action here.

That is the science you are having a hard time in responding to——

Dr. CURRY. No, the issue——

Senator MARKEY.—here, Dr. Mair——

Dr. CURRY. The issue is what is causing the warming? Is it natural variability, or is it humans?

Senator MARKEY. Like Galileo, he said, no, the science——

Dr. CURRY. Are you aware——

Senator MARKEY. The science—the science is clear. You are depending upon something that perhaps is God made rather than dependent upon something that is manmade, which is anthropogenic and documented by 97 percent of all of the scientists——

Mr. STEYN. Are you saying there is no natural variability, Senator?

Senator MARKEY. What I am——

Mr. STEYN. There were alligators at the North Pole. What was that? Was that you in your SUV?

Senator MARKEY. What I am saying is that this warming is something that while it may have a variability year to year in specific parts of the planet, that the trend is straight up.

Mr. STEYN. Yes, do you know what—do you know what the Little Ice Age was, Senator?

Senator MARKEY. And again, it is climate change. We had 110 inches of snow in Boston last year, with measurements of water 21 degrees warmer than normal off of the coast of Massachusetts, OK? This was an unusual event for us.

The warming of the ocean intensifies the amount of precipitation when Arctic air hits that water. Now if you want to deny that, if you want to ignore that these changes are taking place and that they are having a dramatic impact, then you are in the right place. You are in the right——

Mr. STEYN. Do you know what the winters were like at Plymouth Rock? Do you know what the winters were like at Plymouth Rock, Senator?

Senator MARKEY. Well, here is the thing. We——

Mr. STEYN. You don't. How long has your family been in Massachusetts?

Senator MARKEY. We are new arrivals, and I have to admit——

Mr. STEYN. You should have been there in 1750.

Senator MARKEY. The Irish weren't arriving in 1750. So I apologize for being late to the country, and I will have to chastise my grandparents for not leaving until the economic conditions in 1902 forced them here.

But that notwithstanding, there is as much consensus that man is causing climate change as there is in Galileo's original theory, and all which——

Mr. STEYN. What percentage of climate change is man causing, Senator?

Senator MARKEY. Excuse me, sir?

Mr. STEYN. What percentage of climate change is anthropogenic?

Senator MARKEY. Well, according to the scientists who are in Paris right now, which would fill pretty much the entire space of the building in which we are in right now, and the number of deniers would still be the ones who are——

Dr. CURRY. Are you aware——

Mr. STEYN. What percentage, Senator?

Dr. CURRY. Are you aware of a recent survey of the professional members of the American Meteorological Society? When asked the question how much is the recent changes natural versus human caused, 52 percent of the membership said it was majority human caused.

Senator MARKEY. Dr. Titley? Dr. Titley, could you respond to that question in terms of what you believe is the amount of warming that is relatable to human activity?

Admiral TITLEY. Thanks, Senator.

Right now, there is—as has been pointed out, there are natural variations, things like volcanoes, things like changes in sunlight. And then there is something called internal variations, and these are the oscillations or basically the back-and-forths of the ocean currents. So even if you had no change and forcing.

But what we are doing is we are changing and forcing, and I think the IPCC has come down pretty strong, along with multiple, multiple National Academy panels, saying that the human-caused forcing is very, very significant. That doesn't mean there isn't natural variability. It doesn't mean there is not internal variability.

But the human-caused forcing is very significant, and that is, I think, what we need to deal with.

Senator CRUZ. Thank you, Dr. Titley.

Senator Nelson?

Senator MARKEY. And could I just make—I agree with you, and I agree with this Pope. I disagree with the Pope in 1632. This Pope is correct, and we have a moral responsibility to act.

Thank you, Mr. Chairman.

Senator CRUZ. Senator Nelson?

Senator NELSON. Thank you, Mr. Chairman.

My approach to this is a little more "coolly aloof" and look at facts. Admiral, the chart behind you, is that a measurement of surface temperature?

Admiral TITLEY. Senator, thank you, sir.

It is near surface temperatures. Basically, it is about 10 feet above the—you know, 6 to 10 feet above the surface. So for all intents and purposes, it is surface temperatures.

Senator NELSON. That surface temperature would reflect that heat, most of which is absorbed by the oceans. Why don't you give us your perspective on that as an admiral?

Admiral TITLEY. Thanks, sir.

The oceans are absorbing roughly 90 percent, nine zero percent of the excess heat. What I have told people is that if you think of the—you know, when you study climate, try to get more and more oceanographers involved, and the oceanographers are certainly involved because that is where the action is, that is where the heat is. It is sort of like why did Willie Sutton rob banks? It is where the money was.

So the heat is in the oceans, and then the atmosphere is sort of the tail on the dog. The atmosphere gets sort of driven, ups and downs, depending on what the ocean is doing. So the heat is in the ocean, sir.

Senator NELSON. And when water is heated, what happens to it?

Admiral TITLEY. It expands.

Senator NELSON. Right. And therefore, that would indicate a reason why we are seeing sea level rise?

Admiral TITLEY. Yes, sir.

Senator NELSON. Not just the melting of glaciers and that additional displacement of water, but mainly from the absorption of the oceans, which cover two-thirds of the Earth, of the heat—the absorption of the heat. Is that right?

Admiral TITLEY. Yes, sir. The scientists would call it thermal expansion. It is the expanding of the water.

Senator NELSON. Are you familiar with the satellite, it is really not a satellite, it is a spacecraft named Discover that was put up earlier this year at a Lagrange point a million miles from Earth between the Earth and the Sun?

Admiral TITLEY. Yes, sir. I think it is at what the scientists would call L1.

Senator NELSON. That is correct. There is an instrument—there are four main instruments on that spacecraft, but there is an instrument that looks back continuously at Earth to measure the heat in and heat out.

If in addition to our surface temperatures and other instruments that measure, if we get the total amount of heat being radiated into the Earth's atmosphere and we measure the total amount of heat coming out and subtract one from the other, we should be able to have a very precise measurement of the amount of heat that is trapped in the Earth's atmosphere?

Admiral TITLEY. Yes, sir.

Senator NELSON. OK. Now this heat that is trapped in the atmosphere, the Sun's rays come in, and normally, when they hit the Earth's surface, some are absorbed, but some radiate back out into space. Is that correct?

Admiral TITLEY. Yes, sir.

Senator NELSON. If there is something trapping that heat from being radiated back out into space, you naturally would start to have the heating up of the Earth's atmosphere, and you, as a climatologist, would you speculate that that would be gases such as CO_2 and SO_2?

Admiral TITLEY. Senator, yes. I mean not as a climatologist, but just basic—basic physics. There are greenhouse gases that re-radiate or trap, as you said, the heat, and that actually allows us to have life on Earth. Yes, sir.

Senator NELSON. So that could be another reason that reflects why the surface measurements are showing the chart that you have?

Admiral TITLEY. As we increase the greenhouse gases, the temperature should come up. And that is what we are seeing. Yes, sir.

Senator NELSON. Would you answer one more question, and we have not covered this today. The Department of Defense is quite concerned about the heating up of the Earth because of the implications for our national security. Would you trace a few of those for us?

Admiral TITLEY. Yes, sir. So the Department of Defense, in their 2014 Quadrennial Defense Review, they talk about climate change really in three ways. They talk about increasing risk of conflict and instability overseas, the impacts of Department of Defense operations on operations people in installations, and also the impact of stability, development, human security, and other nations. So that was in 2014.

Later on in 2014, the Department of Defense, they released their Climate Change Adaptation Roadmap. Really, that assessed climate change. It directed the department to assess climate change impacts on infrastructure, commissions, and activities; fully integrate climate considerations across a full range of department missions and activities; collaborate with partners internal and external

to better understand what is going on; and also a bureaucratic part, they designate a climate change officer.

If I may, sir, just one more thing. Just a few months ago, the geographic combatant commanders released an assessment, a report to the Congress. So these are the four-star admirals and generals who have direct control over the operating forces. They report to the Secretary of Defense and President.

They had four issues, primarily issues. Persistently recurring conditions, such as flooding, drought, higher temperatures. More frequent and more severe extreme weather events that may require more humanitarian assistance and disaster relief, or support—defense support of civil authorities here in the United States.

The sea level rise and the temperature change, greater chance of flooding in coastal communities, adverse effects impacting navigation safety, damages to infrastructure, displaced populations. And then, finally, the Arctic. As the Arctic changes, that is a whole category to itself.

I will stop there, sir. But those are just some of the more recent documents that the Department of Defense has released concerning climate change.

Senator CRUZ. Thank you, Senator Nelson.

All right. We are going to have a second round, and then the hearing will conclude.

I want to start with Dr. Curry. When Senator Markey was haranguing you, he said that you had no response to his assertion that 2014 was the hottest year on record. Am I correct that NASA stated that that assertion, that 2014 was the hottest year on record, that they had a 38 percent level of confidence in that, which means that 62 percent or substantially more likely than not 2014 was not the hottest year on record? Is that an accurate statement?

Dr. CURRY. Yes, basically, 2014 was, according to the NASA/NOAA datasets, in a statistical tie with 2010 and 2005. The U.K. dataset, which has, I think, more credible error bars on their dataset, found that it was in the top 10 warmest years. They couldn't fine-tune it anymore than that, given the great uncertainties in the reconstruction of global surface temperature data.

And I think the uncertainty levels are really too low on all of those estimates, in my opinion.

Senator CRUZ. And indeed, NOAA included 2014, 2010, 2005, 2013, and 1998, five different years as potentially being tied for being the warmest?

Dr. CURRY. Correct.

Senator CRUZ. The last hearing I chaired when Mr. Mair, who should have been sitting next to you, testified, he told the Subcommittee, "Our planet is cooking and heating up and warming."

Does the evidence and data we have been discussing support the assertion that the planet is cooking?

Dr. CURRY. Not cooking, no.

Senator CRUZ. And indeed, another reference was made by Senator Markey to the measurements. Now I would note none of the Democratic Senators who participated in a press conference earlier today saying how dare you ask the data, not a single Democratic Senator addressed the satellite data. Not a single Democratic Sen-

ator addressed the fact that for 18 years there has been no significant warming recorded.

Because, I suppose, it is contrary to their computer model and to their political desire to massively increase Government control of the economy and impose trillions of dollars of cost on people who can't afford it. But let us turn to the different measurements, not the satellite data, and if we can put up the next two charts?

These next two charts are from the United States Historical Climate Network. These are the measurements of the thermometers that are measuring climate change. And these in particular record the adjustments that NOAA has done to the climate data.

Chart on the left you can see that between 1900 and 1960, NOAA made relatively few adjustments, and they were relatively minor. And then we see that for the more recent years, they have been adjusting them upwards. And the adjustments consistently are upwards. They are never adjusting downward.

Now the chart on the right likewise looks at the raw numbers are on the top. The raw numbers demonstrate a fair degree of uniformity. But the adjusted numbers, the old temperatures are cooler, and the new temperatures are warmer.

Dr. CURRY. Well, the different—there is a number of different groups who do global temperature datasets, and they have different methods for dealing with spatial representativeness, missing data, changes in temperature, measuring instrumentation, adjusting for the time of day, all sorts of different adjustments that they make. And the adjustments, as you can see, are rather huge, OK?

So should we—so, to me, the error bars should really be much bigger if they are making such a large adjustment. So we really don't know too much about what is going on in terms of, you know, it is a great deal of uncertainty. Yes, I do believe that we have overall been warming, but we have been warming for 200, maybe even 400 years, OK? And that is not caused by humans.

OK. There is natural variability involved. And this is exactly what has not been sorted out.

Now the ocean—the ocean temperature is the current focus of controversy. I mean, the land datasets are sort of starting to agree, but there is a great deal of controversy and uncertainty right now in the treatment of the ocean temperatures. And that has not been sorted out.

And so especially looking in the recent period, if we are trying to sort out what is going on with the hiatus or the pause, we need to look at the satellite data. I mean, this is the best data that we have and is global, and we need to sort out the differences between the satellite and the surface observations. And then there is the numerical weather prediction reanalysis data simulation systems that give us a global view, and we haven't been really using that for climate purposes, and I think we need to.

So the work is just starting in terms of trying to sort this out. And we don't have——

Senator CRUZ. Now, Dr. Curry, you said something very important there in that you said the satellite data are the best data we have. Can you explain, as a scientist, why that is the case?

Dr. CURRY. Well, it is global coverage. It is not a simple measurement. You have to do, you know, a retrieval and weighting func-

tions, and it is a complex problem. But it is reasonably well calibrated and consistent over the last 30-ish years.

Senator CRUZ. And not a single Democratic Senator had any response to the satellite data that demonstrates their entire theory of global warming for 18 years hasn't been happening?

Dr. CURRY. Yes. I mean, we need to sort this out rather than ignore it. I mean, this is what I am concerned about.

Senator CRUZ. And Mr. Steyn, you look like you want to make a comment.

Mr. STEYN. Yes, I——

Senator CRUZ. I want to ask a question on this because you also are quite familiar with the cooking of the books——

Mr. STEYN. Right.

Senator CRUZ.—of the hockey stick, and indeed, Dr. Curry, you mentioned Climategate and the scientists receiving a whole lot of funding to conclude global warming was occurring and then adjusting their results to reflect that. I would note if you systematically add, adjust the numbers upwards for more recent temperatures, wouldn't that, by definition, produce a dataset that proves your global warming theory is correct?

And the more you add, the more warming you can find, and it just—you don't have to actually bother looking at what the thermometer says. You just add whatever number you want?

Mr. STEYN. No. That is what is fascinating about this. Could you just tell me the left-hand data on your chart, Senator? What is it? I can't quite see it from here.

Senator CRUZ. On the left——

Mr. STEYN. On the right-hand chart, the blue and red line, what is the——

Senator CRUZ. In both of them, it is 1900.

Mr. STEYN. 1900. So you look at the blue line, you look at the red line, this is the adjustment of figures that is going on.

Senator CRUZ. Yes.

Mr. STEYN. What has happened since the global warming pause is that the public does not trust the alarmist establishment to tell them what the climate will be like in the year 2050. What that chart shows is why the public is moving to a new position now where it doesn't even trust these Federal agencies to tell them what the climate was like in 1950 or 1920 or 1900.

And that is interesting. If these adjustments are merited, if an adjustment in the official recorded observed temperature because Gavin Schmidt at NASA wasn't standing out by the thermometer in the year 1920, but he suddenly decides a century on—what are we now, 95 years on—the 1920s temperature needs adjusting, that tells you how uncertain the science is.

I would also like, Senator, just to say a word about this whole national security thing because I have never heard anything quite so ridiculous. We are a country in which we have an enemy overseas who so-called radicalizes suburban couples in California who go out and kill people. But we are planning now for global security threats a century hence because the Maldives might have been swept away by water by then.

The entire population of the Maldives are all Sunni Muslim. So they will fit in perfectly fine if they all move to this Brussels suburb that produced the shooters in Paris.

But the biggest—climate change is irrelevant to the long-term patterns. And I cannot tell you how absurd it is to be talking about climate change as a security threat compared to, say—just to pluck at random—population. In 1920, the British Isles and British West Africa had the same population, about 45 million people for England, Scotland, Ireland, Wales on the one hand and what are now Nigeria, Sierra Leone, Ghana, the Gambia on the other hand.

Now the British Isles has a combined population—England, Scotland, Ireland, Wales—about 69 million, and British West Africa has a population of 250 million. So the security threat is exactly what we see in Europe at the moment that Niger, a country that can't—that has increased its population by 50 percent in this century, since the year 2000, and had millions of starving people already that it couldn't feed and is expected to increase its population tenfold by the end of the century, and all those people are just going to get on a boat and walk into Italy, Greece, Spain, Portugal.

And the idea that somehow climate changes impact on that is absolutely trivial to the remorselessness of those numbers. And I understand that governments find it easier to deal with cloud-cuckoo fantasyland, saving the planet type issues. But this is a complete waste of time for an already-beleaguered Defense Department having difficulty fighting the wars it is actually in right now in Afghanistan and Iraq and elsewhere suddenly dealing with sea levels in the Maldives in the 22nd century.

It is completely preposterous and complete waste of time.

Senator CRUZ. So I will leave that aside for a moment.

[Laughter.]

Senator CRUZ. And simply observe if we look to the satellite data, we see for 18 years no significant recorded warming. We see no response from the Democratic Senators.

If we look to the raw data, according to the raw data, 1940, it appears from this chart, the 5-year mean temperature was higher than it is in recent time. But once you adjust it, if you subtract from the old temperatures and add to the new ones, then you can have measurements that reflect your theory.

Dr. Happer, you wanted to comment on this?

Dr. HAPPER. Yes, I just wanted to say one more thing about the satellite data, and that is that they are cross-calibrated with weather balloons all over the world. And so it is not simply a couple groups measuring satellites. There is a quality check that goes on, and there is no similar check for the surface data that I know of.

Senator CRUZ. It is a very good point, and indeed, Dr. Christy's chart, as he described, was an average of several measurements of both the satellites and the weather balloon.

If we could move to the next two charts, I want to—the final line of questioning I want to address is the effect of censorship, of dogmatism, of intimidation. So both of these come from *barack obama.com,* a website I will admit I don't spend a lot of time perusing.

On *barackobama.com,* the President of the United States is issuing a call, "Call out the climate deniers. Too many of our elected officials deny the science of climate change. Along with their polluter allies, they are blocking progress in the fight against climate change. Find the deniers near you. Find the heretics and call them out today."

And indeed, they show a number. And I will say when I first looked at that chart, I was quite disappointed. I thought I was omitted, but then I discovered I am, indeed, included, along with a number of other elected officials. Indeed, I might note, a number of elected officials.

What does it do to scientific debate when anyone who dares question political ideology is branded a denier and a heretic? What are the consequences in the academic world when that occurs? Dr. Curry?

Dr. CURRY. There is a chilling effect, OK? People keep their heads down. They look for opportunities just to do something else and to move on, retire, get out of the business. I have talked to any number of scientists who have done this, recent Ph.D. recipients on up to very senior scientists. It has a very chilling effect.

As a tenured scientist who is relatively senior, I felt sufficiently secure to speak out. But younger scientists, scientists who are not tenured, fear for their jobs. They have mortgage payments, whatever, and you know—and kids to support. They can't afford to speak out.

The social contract currently between the Obama Administration and climate scientists is if you say alarming things, you will get plenty of funding. That seems to be how it is working. And that is very, very pernicious for science.

Senator CRUZ. And do you get funded——

Dr. CURRY. I am——

Senator CRUZ.—if you are researching anything other than the orthodoxy of global warming alarmists?

Dr. CURRY. I am no longer applying for government grants. I can't get funded to do anything I want.

Senator CRUZ. Let me speak more in the aggregate. Does one get funded? If one is a scientist and one—you know, I recall being back in high school and studying science, the scientific method that you started with a hypothesis, and then you look to evidence to prove or disprove the hypothesis. And often disproving it is the more useful thing to try to do.

Do those who are actually trying to disprove the hypotheses—mind you, the hypotheses that will drive up the electric bills and the cost of living for millions of Americans, will hurt people who are struggling, will hurt single moms, will hurt Hispanics, will hurt African Americans. Does anyone doing any research that might contradict the political dogma, are they at all likely to get funding?

Dr. CURRY. OK. The funding—the issue is this. The funding agencies do a call for proposals or an announcement of opportunity, and they are already implicitly assuming that human-caused climate change is dangerous. There is not even an opportunity or something that even makes sense to submit a proposal.

Senator CRUZ. All right.

Dr. CURRY. So that is the real problem. So a lot of the skeptical research is really being conducted by independent scientists who are not asking for any Government funding.

Senator CRUZ. OK. So my final two questions. One of the letters that the minority has submitted into the record is a letter from the American Association for the Advancement of Science. A sentence within that letter.

"We are committed to the principle that scientific inquiry and open scientific communication, regardless of field of study, should proceed unhampered by intrusions on academic freedom."

Now that is a noble-sounding statement and one that I—with which I agree emphatically. I want to ask the members of the panel, how does that noble sentiment comport with the call from our colleague Democratic Senator Sheldon Whitehouse that anyone who dares dispute the global warming alarmist orthodoxy should face criminal prosecution under RICO?

Are those two statements somehow compatible, that you can have academic freedom and robust debate when you have got politicians saying we will criminally prosecute you as a racketeer if you dispute our political orthodoxy?

Dr. CURRY. Well, that statement by Science, the AAAS is really a myth because about 2 months ago, well, maybe 3 months ago, the editor of *Science,* Marcia McNutt, had an op-ed in *Science* that said the debate is over. Urgent action needed, essentially. And this was the editor of *Science,* which is the flagship journal of the American Association for the Advancement of Science.

When an editor of a scientific journal makes a statement like that, it gives all of the editors a license to completely ignore any publication that is submitted that questions a consensus, and this is the real pernicious thing that is going on. So right now we are more ruled by the RICO mentality than we are by those lofty sentiments expressed by the American Association for the Advancement of Science.

Mr. STEYN. Senator, you said your parents were, I think, mathematicians, statistical modelers. We have had a lot of talk today about climate science. I compiled a book that you were kind enough to mention the title of, and what was fascinating to me about that book was that climate science evolves. Twenty years ago, it was basically a branch of—30 years ago, physical geography. Now it is basically computer modeling.

Yet at the same time, the majority of statisticians who look at the climate models think they are grossly unprofessional. Mathematicians and statisticians who look at the—at the way these climate models and the way the hockey stick were constructed are not onboard with it at all. A majority of engineers are not onboard with it. A majority of physicists, non-climate physicists are not onboard with this.

So this idea that climate science is this hermetically sealed specialty that is sealed off from the rest of the world is nonsense. Climate science, there is—you have dendrochronology types. You have statistical modeling types. And there are elements of all in the work that they do. But certain people—mathematicians, engineers, statisticians—are not onboard with this.

And Judith mentioned—Judith mentioned Science magazine. Nature magazine went even further. They are the two most prestigious science journals on the planet, Nature and Science. And Nature printed a statement recently from a group of climate scientists who said, "Climate justice," climate justice is more important than democracy.

So that the fake 97 percent consensus is no longer enough. The fake 97 percent consensus of so-called climate scientists now has to trump the 51 percent of the electorate.

No science in history has conducted itself like this, and it would be unrecognizable to Sir Isaac Newton or Charles Babbage or the Curies to see a self-sustaining, malign, politico science nexus supporting itself and excluding all other voices. It is at odds with scientific inquiry across the centuries.

Senator CRUZ. Let me—in 2009, August 31, 2009, then-Senator John Kerry, as I discussed in my opening, said, "Scientists project that the Arctic will be ice free in the summer of 2013. Not in 2050, but 4 years from now." The nice thing about this is, unlike theories that can't necessarily be disproven, this is actually a statement that can be tested by actual facts and evidence.

Dr. Happer, was it, in fact, accurate in the summer of 2013 the Arctic was ice free?

Dr. HAPPER. No, it certainly wasn't ice free. But if I could follow up on something my colleague just said, this dogmatism is not unprecedented. If you look at the Soviet Union, for 30 years, Lysenko had complete control over biology. You got fired or worse if you didn't agree with his brand of biology.

And that was finally brought to an end, partly because of people from other fields. For example, Andrei Sakharov, the inventor of the Soviet hydrogen bomb, led some of the opposition because he had enough stature to stand up and push back.

But most people were afraid. So there was a state of fear that was actually quite a bit worse than that associated with climate science right now. It is a good lesson to remember.

Senator CRUZ. And my final question, Dr. Titley, based on your three decades serving in the Navy, do you agree with President Obama, who said holding a global warming summit in Europe was a powerful rebuke to the ISIS terrorists who just committed a horrific act of terrorism in Paris and, indeed, likewise in San Bernardino?

Admiral TITLEY. Senator, thanks, sir, for the question.

The way I describe these geostrategic risks of climate change, climate is the risk, and it makes the threats, threats such as ISIS worse. So this doesn't—this is not an either/or. It is not a false——

Senator CRUZ. But I am asking your judgment as a military man if you agree with President Obama that holding a global warming summit was a powerful rebuke to the ISIS terrorists? I find that statement absurd on its face.

I am asking, based on your military judgment, do you agree with the President?

Admiral TITLEY. We have to address both, sir. Thank you.

Senator CRUZ. From your declining to answer, I take it that the inference of that is that your answer is no?

Admiral TITLEY. My answer is, sir, we have to address both the risk of climate change and the threat of ISIS.

Thank you.

Senator CRUZ. Thank you.

Senator Peters?

Senator NELSON. Mr. Chairman, I am going to go first, with your permission.

Senator CRUZ. Senator Nelson?

Senator NELSON. And Mr. Chairman, I might say, just supporting the Admiral, sea level rise is a threat to an area such as Bangladesh. It would cause a huge—it will cause a huge displacement of population, which will cause turmoil, which is the conditions that are ripe for extremists to exploit.

So there are answers to that, and I would just conclude my remarks by saying, you know we have been talking about censorship here. Mr. Chairman, you are my friend, and as you know, I am respectful to you and the other Senators. I find it somewhat ironic that we are talking about censorship against those that speak against climate change when, in fact, it has been exactly the opposite over and over.

And it was so much so that we saw examples where various levels of government said that you couldn't even use the term "climate change" that I offered an amendment in March in front of the full Senate. A majority voted for my amendment, including two Republican members of this committee, Senator Rubio and Senator Ayotte.

And so when we start talking about muzzling of scientists, I think we better watch out how we are talking about which side is trying to do the muzzling because that amendment to prevent muzzling of scientists on the subject of climate change, it actually had a majority, and it was a bipartisan majority that voted for it in the Senate.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Nelson.

Senator Peters?

Senator PETERS. Thank you, Mr. Chairman.

And I certainly have enjoyed the hearing and the testimony, but actually, to pick up on comments by Senator Nelson about muzzling, certainly that didn't occur in this hearing. We heard from three witnesses, scientific witnesses, as well as the political commentator about issues related to climate change that represented a particular point of view that is not shared by the vast majority of the scientific community, has been very clearly demonstrated in numerous documented studies, the 97 percent figure, for example, that has been documented by a number of studies.

So I was curious. We had three folks testifying with concerns about the science. And if you look at it in a ratio of 97 folks, we had 3 scientists who had some questions who represent not 60 percent of the scientific consensus. We have Mr. Steyn, the political commentator, which I know if we had all the political commentators on both sides of the issue, it would be a lot more than one out of five, I am sure. It would probably fill several rooms here.

Dr. Titley, you were here by yourself. But if we put it in perspective, we had the three that took this perspective, and I think there

is probably—I don't know if there is 100 people in this room, but probably everybody else in this room would have a different position.

Certainly, as policymakers, this is about leadership. It is about making decisions. It is about someone who has to make decisions that are going to impact the country.

Dr. Titley, we talked about military commanders that have to make decisions based on intelligence reports and best estimates of the risk involved and then weigh that against the potential consequences. That is exactly what we have to do here in this committee. It is what we have to do as U.S. Senators is that we have to listen to experts.

I am not a climatologist. I rely on climatologists to give me information and then make policy decisions based on that. And oftentimes, it is—this is about weighing, weighing the opinions of folks, and in this case, the scales of justice are weighing are clearly on a side different than what we have heard from four of the five witnesses.

So today you had that opportunity to present that view and in a very unbalanced way. It would have been great if we could have had 100 scientists and had 97 telling us one thing and the 3 of you something else. That is not what we had, but I think it is important to keep that image in mind.

And if we are going to be serious policymakers that are going to make decisions that are going to impact this country and are going to impact the world, we have to make decisions based on expertise from those who understand this science better than anyone. And that is where I come. I try to come from a dispassionate side. Let us listen to the science. Let us listen to folks who are experts.

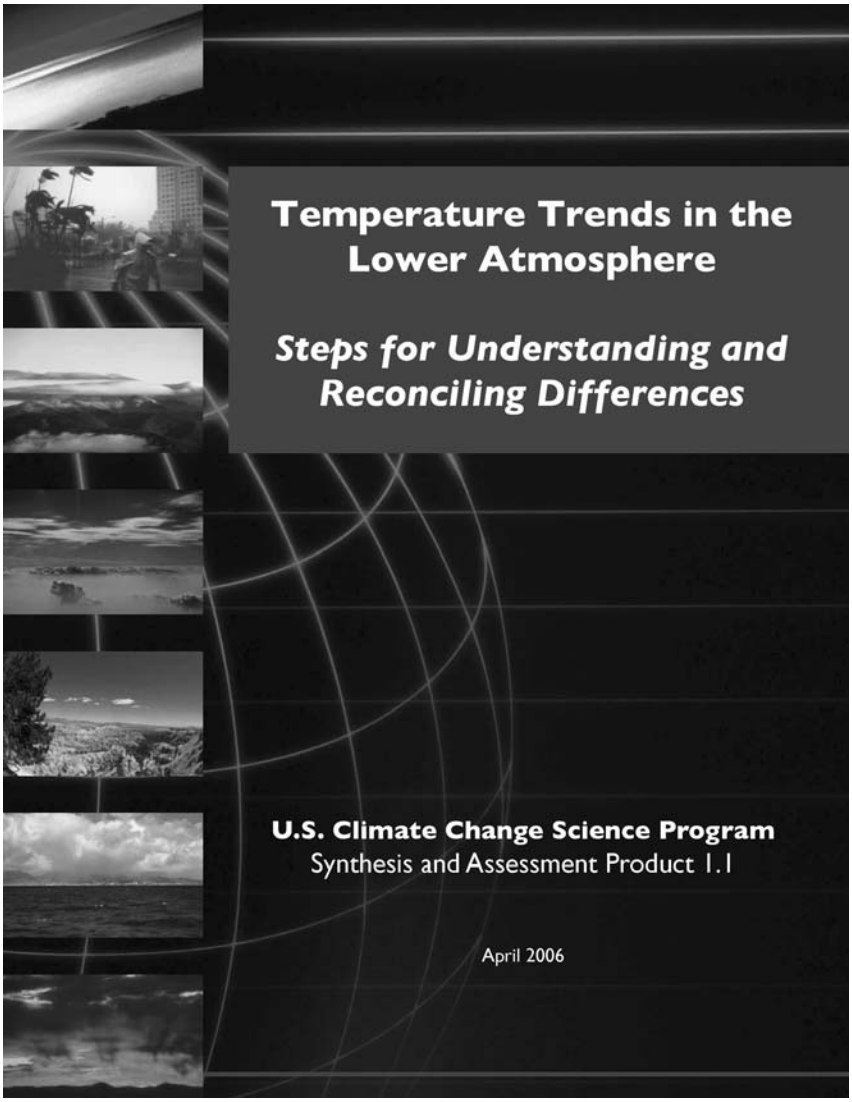
And that is why I am disappointed that we didn't have a more balanced hearing, but I certainly appreciate your testimony, Dr. Titley. And I would like to just ask you a few questions related to that because we heard quite a bit about satellite data. And Chairman Cruz had a line of questioning related to that.

And I am concerned that from listening to that, people might think that satellites are just basically thermometers in space running around. We know that that is not the case. In fact, I would like to enter into the record, Mr. Chairman, this report that is a 2006 Synthesis and Assessment Report of the U.S. Climate Change Science Program.

And it really underscores the difficulty in using satellite data in that it is a complex numerical model that converts satellite observations to—in order to determine temperature. If we could put that in, I would appreciate it.

Senator CRUZ. Without objection, it will be entered in the record.

[The information referred to follows:]


Temperature Trends in the Lower Atmosphere
Steps for Understanding and Reconciling Differences
U.S. Climate Change Science Program
Synthesis and Assessment Product 1.1
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This document, the first of the Synthesis and Assessment Products described in the U.S. Climate Change Science Program (CCSP) Strategic Plan, was prepared in accordance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and the information quality act guidelines issued by the Department of Commerce and NOAA pursuant to Section 515 <http://www.noaanews.noaa.gov/stories/iq.htm>). The CCSP Interagency Committee relies on Department of Commerce and NOAA certifications regarding compliance with Section 515 and Department guidelines as the basis for determining that this product conforms with Section 515. For purposes of compliance with Section 515, this CCSP Synthesis and Assessment Product is an "interpreted product" as that term is used in NOAA guidelines and is classified as "highly influential". This document does not express any regulatory policies of the United States or any of its agencies, or provide recommendations for regulatory action.

Temperature Trends in the Lower Atmosphere

Steps for Understanding and Reconciling Differences

Synthesis and Assessment Product 1.1
Report by the U.S. Climate Change Science Program
and the Subcommittee on Global Change Research

EDITED BY:
Thomas R. Karl, Susan J. Hassol,
Christopher D. Miller, and William L. Murray

April 2006

Members of Congress:

We are pleased to transmit to you this report, *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*, the first of a series of Synthesis and Assessment Products produced by the U.S. Climate Change Science Program (CCSP). This series of 21 reports is aimed at providing current evaluations of climate change science to inform public debate, policy, and operational decisions. These reports are also intended to help inform CCSP's consideration of future program priorities.

CCSP's guiding vision is to empower the Nation and the global community with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems. The Synthesis and Assessment Products are important steps toward that vision, helping translate CCSP's extensive observational and research base into informational tools that directly address key questions that are being asked of the research community.

This first Synthesis and Assessment Product addresses previously identified discrepancies between observations and simulations of surface and atmospheric temperature trends. It was developed with broad scientific input and reviewed by the National Research Council. Public comments were solicited and carefully reviewed at multiple stages in the process. It was prepared in accordance with the Information Quality Act and the Federal Advisory Committee Act. Further information on the process for preparing Synthesis and Assessment products and the CCSP itself can be found at www.climatescience.gov.

We commend the report's authors for both the thorough nature of their work and their adherence to an inclusive review process. This product sets a high standard for quality for subsequent Synthesis and Assessment Products.

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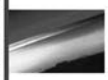

CHAPTER

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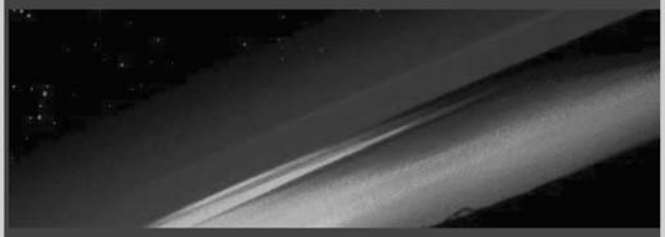
ABSTRACT



Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human-induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite and radiosonde data showed little or no warming above the surface. This significant discrepancy no longer exists because errors in the satellite and radiosonde data have been identified and corrected. New data sets have also been developed that do not show such discrepancies.

This Synthesis and Assessment Product is an important revision to the conclusions of earlier reports from the U.S. National Research Council and the Intergovernmental Panel on Climate Change. For recent decades, all current atmospheric data sets now show global-average warming that is similar to the surface warming. While these data are consistent with the results from climate models at the global scale, discrepancies in the tropics remain to be resolved. Nevertheless, the most recent observational and model evidence has increased confidence in our understanding of observed climatic changes and their causes.

RECOMMENDED CITATIONS

For the Report as a whole:
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For Chapter 2:
Christy, J.R., D.J. Seidel, S.C. Sherwood, 2006: What kinds of atmospheric temperature variations can the current observing systems detect and what are their strengths and limitations, both spatially and temporally? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 3:
Lanzante, J.R., T.C. Peterson, F.J. Wentz, K.Y. Vinnikov, 2006: What do observations indicate about the change of temperatures in the atmosphere and at the surface since the advent of measuring temperatures vertically? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 4:
Mears, C.A., C.E. Forest, R.W. Spencer, R.S. Vose, R.W. Reynolds, 2006: What is our understanding of the contribution made by observational or methodological uncertainties to the previously reported vertical differences in temperature trends? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 5:
Santer, B.D., J.E. Penner, P.W. Thorne, 2006: How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

For Chapter 6:
Folland, C.K., D. Parker, R.W. Reynolds, S.C. Sherwood, P.W. Thorne, 2006: What measures can be taken to improve the understanding of observed changes? in *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, editors. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

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PREFACE

Report Motivation and Guidance for Using this Synthesis/Assessment Report

Authors:
Thomas R. Karl, NOAA; Christopher D. Miller, NOAA; William L. Murray, STG, Inc.

A primary objective of the U. S. Climate Change Science Program (CCSP) is to provide the best possible scientific information to support public discussion and government and private sector decision-making on key climate-related issues. To help meet this objective, the CCSP has identified an initial set of 21 synthesis and assessment products that address its highest priority research, observation, and decision-support needs. This Synthesis/Assessment Report, the first of the 21 Reports, focuses on understanding the causes of the reported differences between independently produced data sets of atmospheric temperature trends from the surface through the troposphere to the lower stratosphere.

This topic is relevant to policy-makers because previous discrepancies between surface and tropospheric temperature observations challenged the correctness of climate model simulations and the reality of greenhouse gas-induced global warming. As described in the Executive Summary, considerable progress has been made in resolving many of these earlier discrepancies.

Background

Measurements of global surface air temperature show substantial increases over the past several decades. In the early 1990s, data from the National Oceanic and Atmospheric Administration's (NOAA's) polar orbiting satellites were analyzed for multi-decadal trends. These initial analyses indicated that global-mean temperatures in the troposphere showed little or no increase, in contrast with surface air measurements from ships, land-based weather stations, and ocean buoys. This result led some to question the reality and/or the cause of reported global-mean surface temperature increases, on the basis that human influences, thought to be important contributors to observed change, were expected to increase temperatures both at the surface and in the troposphere, with the largest increases expected in the tropical troposphere. This led to an intensive effort by climate scientists to better understand the causes of the apparent differences in the reported rates of temperature changes between the surface and the troposphere.

Scientists analyzing the data knew that there were complex and unresolved issues related to inadequacies of observing systems that could lead to misleading impressions or misinterpretation of the data. There were also uncertainties in our understanding of how the climate might respond to various forcings, as is often assessed through the use of climate models. In an attempt to resolve these issues, in 2000 the National Research Council (NRC) specifically addressed the issue of temperature trends in the troposphere and at the surface. In its Report, the NRC concluded that "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the twentieth century. The disparity between surface and upper air trends in no way invalidates the conclusion that surface temperature has been rising." The NRC further found that corrections in the Microwave Sounding Unit (MSU) processing algorithms brought the satellite data record into slightly closer alignment with surface temperature trends. They concluded that the substantial disparity that remained probably reflected a less rapid warming of the troposphere than the surface in recent decades due to both natural and human-induced causes.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report devoted additional attention to new analyses of the satellite, weather balloon, and surface data to evaluate the difference in temperature trends between the surface and the troposphere. Similar to the NRC, the IPCC concluded that it was very likely that the surface temperature increases were larger and differed significantly from temperature increases higher in the troposphere. They concluded, "during the past two decades, the surface, most of the troposphere, and the stratosphere have responded differently to climate forcings because

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different physical processes have dominated in each of the regions during that time." (IPCC, Climate Change 2001: The Scientific Basis, Chapter 2, p. 122-123; Cambridge University Press).

Focus of this Synthesis/Assessment Report

The efforts of the NRC and IPCC to address uncertainties about the temperature structure of the lower atmosphere (*i.e.*, from the surface through the lower stratosphere) have helped move us closer to a comprehensive understanding of observed trends of temperature. Although these documents provided a great deal of useful information, full resolution of the issue was hampered by the complexities of the climate system coupled with shortcomings of the available observing systems. To more fully address remaining fundamental questions, a broader examination has been undertaken here to answer the following questions:

1) Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time?

2) What kinds of atmospheric temperature variations can the current observing systems measure and what are their strengths and limitations, both spatially and temporally?

3) What do observations indicate about the changes of temperature in the atmosphere and at the surface since the advent of measuring temperatures vertically?

4) What is our understanding of the contribution made by observational or methodological uncertainties to the previously reported vertical differences in temperature trends?

5) How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes?

6) What measures can be taken to improve the understanding of observed changes?

These questions provide the basis for the six main chapters in this Synthesis/Assessment Report (the chapter numbers correspond to the question numbers above). They highlight several of the fundamental uncertainties and differences between and within the individual components of the existing observational and modeling systems. The responses to the questions are written in a style consistent with major authoritative international scientific assessments (*e.g.*, IPCC assessments, and the Global Ozone Research and Monitoring Project of the World Meteorological Organization [WMO]). The Executive Summary, which presents the key findings from the main body of the Report, is intended to be useful for those involved with policy-related global climate change issues. The Chapters supporting the Executive Summary are written at a more technical level suitable for non-climate specialists within the scientific community and well-informed lay audiences.

The Synthesis/Assessment Report is structured so as to compartmentalize, as much as possible, the answers to each of the six questions (above). However, given the interconnected nature of the questions, this is not entirely possible, or desirable. Occasionally topics extraneous to a particular chapter are mentioned in passing to make an important point or alert the reader to some issue(s) covered elsewhere in the report. However, as a general rule, in the interest of brevity this report does not always explicitly refer the reader to another chapter. The reader is advised to keep this in mind and refer to Table 1 (next page.) for guidance on locating the discussion of particular issues.

To help answer the questions posed, climate model simulations of temperature change based on time histories of important forcing factors have been compared with observed temperature changes. It is recognized that in a system containing internally generated variations, it is unrealistic to expect models to exactly replicate observed changes. If the ensemble of simulations replicates important aspects of the observed temperature changes (*e.g.*, global mean, tropical mean) this increases confidence in our understanding of the observed temperature record and reduces uncertainties about projected changes. If not, then this implies that the time histories of the important forcings are not adequately known, all of the important forcings are not included, the processes being simulated in the models have flaws, the observational record is incorrect, or some combination of these factors is present.

This CCSP Synthesis/Assessment Report assesses the uncertainties associated with the data used to determine changes of temperature, and whether such changes are consistent with our understanding of climate processes. This requires a detailed comparison of observations and climate models used to simulate observed changes, including an appreciation of why temperatures might respond differently at the surface compared to various layers higher in the atmosphere.

This CCSP Report also addresses the accuracy and consistency of the temperature records and outlines steps necessary to reconcile differences between individual data sets. Understanding exactly how and why there are differences in temperature trends reported by several analysis teams using different observation systems and analysis methods is a nec-

Table 1. Guide to readers to identify Chapter emphasis. The Executive Summary ties together all these aspects of the Synthesis/Assessment Report.

Report Section	Observations	Observational Uncertainty	Processes	Models	Comparing Model Simulations & Observations	Statistical Analysis
Chapter 1	secondary		primary			
Chapter 2		primary				
Chapter 3	primary					
Chapter 4		primary				
Chapter 5			secondary	primary	primary	secondary
Chapter 6		primary			secondary	
Appendix	secondary					primary

essary step in resolving previously identified discrepancies between observations and model simulations.

New observations and analyses since the IPCC and NRC Reports

Since the IPCC and NRC assessments, there have been intensive efforts to create new satellite and weather balloon data sets using a range of approaches. Having multiple tropospheric temperature data sets provides the opportunity for much greater understanding of observed changes and their uncertainty than was possible in the previous assessments. In addition, for the first time, a suite of models simulating observed climate since 1979 (when satellite data began) has provided a unique opportunity to inter-compare observed trends from various data sets with model simulations using various scenarios of historical climate forcings. Taken together, these advances lead to a greater understanding of the issues. The process of producing this Report has stimulated additional research and analysis on these topics, and helped to move the science forward.

This Report includes recent analyses of and corrections to data sets that have helped resolve inconsistencies among observational data sets and between observations and models. The science of upper air temperatures is a rapidly evolving field. During the preparation of this Report, new findings were published and are now included in the current draft. For example, a recent article demonstrated an error in the method used in the original satellite data set to correct for diurnal cycle errors due to satellite orbital drift. When corrected, the data set yielded greater warming in the lower troposphere. Since it was possible for the error to be rectified fairly quickly, a new version of this data set was available for this Report. At the same time, another research team produced its first version of satellite-derived lower tropospheric temperatures, and yet another team updated its tropospheric temperature time series. All these results are included in this Report and are compared to a suite of recent climate model simulations. The authors certainly expect that new data and discoveries that follow the release of this Report will further improve our understanding.

Factors that guided the authors in the selection of the climate records considered extensively in this Report were: (a) publication heritage, (b) public availability, (c) use by the scientific community at-large, (d) updates on a monthly basis, and (e) period of record beginning in 1979 or earlier. The climate records considered in this Report are also global in scope.[1]

[1] Most analyses undertaken to date have considered temperature trends at the global scale or large-regional scale *(e.g.,* the tropics). Because this report was charged with assessing the current state of the science, it also necessarily focuses on these large scales. It is at these scales that the apparent discrepancies in temperature trends were first reported. We also currently have most capability in simulating climate at these scales. Until we can reconcile our understanding on the very large scales, little scientific value will be added by considering finer regional details. This does not imply that future analyses should not consider finer regional scales for a complete understanding of relative temperature trends at the surface and in the troposphere.

The three surface analyses that were used have many publications that describe their construction methods. These data sets are readily available and are widely used. Two of the three satellite data sets used, while relatively recent, are based on a heritage of published versions that have incorporated new adjustments as discoveries have been made. Each of these data sets allows ready access to the public and has been used in several research publications. A third, more recently developed data set has been updated during the preparation of this Report. Two data sets used were based on weather balloon data. One of these data sets publicly appeared in 2005, but the authors had made the preliminary versions and methodology available to scientists as early as 2002 and have built upon the extensive experience acquired from previous versions of these data sets. Another data set has a heritage dating back several decades and was recently updated.

The models selected for comparison with observations were those models available to the author team during the course of this assessment. They represent the state-of-the-science from every major global climate modeling center in the world. The model simulations selected include a large fraction of those that were run for the Fourth Assessment Report of the IPCC, due to be published in 2007. The simulations are freely available, and details regarding access to the model data can be obtained from the Program for Climate Model Diagnosis and Intercomparison (http://www.pcmdi.llnl.gov/ipcc/about_ipcc.php). The data used in this report are also openly available and a list of web sites where they can be obtained is included in Chapter 3.

How to use this Synthesis/Assessment Report

This Report promises to be of significant value to decision-makers, and to the expert scientific and stakeholder communities. Readers of this Report will find that new observations, data sets, analyses, and climate model simulations enabled the Author Team to resolve many of the issues noted by the NRC and the IPCC in their earlier Reports. This Synthesis/Assessment Report already has had an important impact on the content of the draft to the Fourth Assessment Report of the IPCC, due to be published in 2007.

This Synthesis/Assessment Report exposes the remaining differences among different observing systems and data sets related to recent changes in tropospheric and stratospheric temperature. Discrepancies between the data sets and the models have been reduced and our understanding of observed climate changes and their causes has increased. Given this, there is no longer sufficient evidence to conclude that there exists any notable discrepancy between our understanding of recent global average temperature changes and model simulations of these changes. This represents a change from conclusions of earlier reports (see above) and should constitute a valuable source of information to policymakers.

In addition, we expect the information generated here will be used both nationally and internationally, *e.g.*, by the Global Climate Observing System (GCOS) Atmospheric Observation Panel to help identify effective ways to reduce observational uncertainty. The findings regarding observations and comparisons between models and observations of lower stratospheric temperature trends may also be useful for future WMO/United Nations Environment Programme (UNEP) Ozone Assessments.

Some terms used in the Report may be unfamiliar to those without training in meteorology; a glossary and list of acronyms is included at the end of the Report. In addition, Table 2 on page X defines the terminology used in this Report for the layers of the atmosphere.

To integrate a wide variety of information, this Report also uses a lexicon of terms (See Fig. 1) to express the team's considered judgment about the likelihood of results. Confidence in results is highest at each end of the spectrum. Unless qualified by these expressions of likelihood, all statements are implied to be certain.

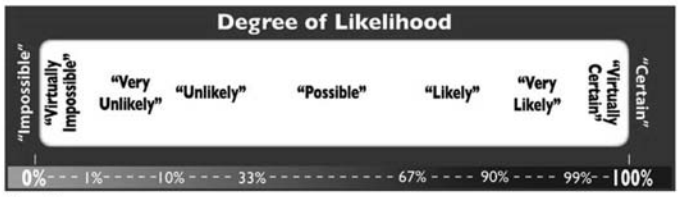

Figure 1.

The Synthesis/Assessment Product Team

A full list of the Author Team (in addition to a list of lead authors provided at the beginning of each Chapter) is provided on page II of this Report. The Author Team Convening Lead Authors (CLAs), Lead Authors (LAs), and Chief Editor were constituted as a Federal Advisory Committee that was charged with advising the CCSP on the scientific and technical content of the Report. Contributing Authors (CAs) provided relevant input used in the development of the report, but CAs who were not also LAs or CLAs did not participate in the Federal Advisory Committee (FAC) committee deliberations upon which this Synthesis and Assessment Product was developed. The remainder of the Editorial Staff reviewed the scientific/technical input and managed the assembly, formatting and preparation of the Report. The focus of this Report follows the Prospectus guidelines developed by the Climate Change Science Program and posted on its website at http://www.climatescience.gov.

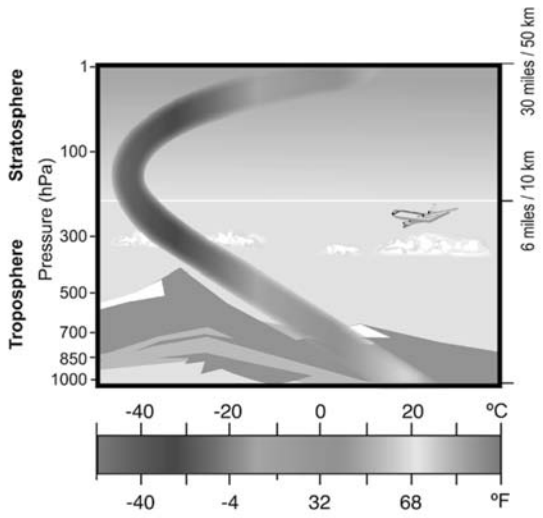

Figure 2. The illustration shows the layers of the atmosphere of primary interest to this Synthesis/Assessment Report. The multi-colored line on this diagram indicates the variations in temperature with altitude. The table on the following page defines the terminology used in this Report for the layers of the atmosphere.

Table 2. Abbreviated terms: Subscript "S," refers to the Surface. Subscripts "2" and "4" refer to MSU data from channels 2 and 4. Subscript "2LT" refers to a modification of channel 2 data to focus more directly on the °ower Troposphere and reduce the influence of stratospheric temperatures on channel 2 data. Subscripts "850–300" and "100–50" are specific atmospheric layers sampled by radiosondes. Subscript "*G" refers to a combination of channel 2 and channel 4 data derived by Fu and co-workers, applicable to global averages, and "*T" refers to applicable tropical averages. For the model-observation comparisons, the observation-based definitions were used as listed in the Table.

Terms for Layers of the Atmosphere Used in this Report				
Common Term	**Abbreviated Term for the temperature of that layer**	**Main region of Influence**	**Approximate altitude. (For satellite products: altitude range of bulk (90%) of layer measured)**	**Lower and upper pressure level boundaries**
Surface	T_S	Air: Just above surface Water: Shallow depth	Surface Air: Land: 1.5 m above surface; Ocean: ship deck-height (5 – 25 m) above surface (NMATs). Surface Water: 1 - 10 m depth in ocean (SSTs)	Surface (or ~1000 hPa at sea level)
Lower Troposphere	T_{2LT}	Lower to Mid-Troposphere	Sfc – 8 km	Sfc – 350 hPa
Troposphere (radiosonde)	$T_{(850-300)}$	Troposphere	1.5 – 9 km	850 – 300 hPa
Troposphere (satellite)	T^*_G	Troposphere	Sfc – 13 km	Sfc – 150 hPa
Tropical Troposphere (satellite)	T^*_T	Troposphere (tropics only)	Sfc – 16 km	Sfc – 100 hPa
Mid Troposphere to Lower Stratosphere	T_2	Mid and Upper Troposphere to Lower Stratosphere[2]	Sfc – 18 km	Sfc – 75 hPa
Lower Stratosphere (satellite)	T_4	Lower Stratosphere	14 – 29 km	150 – 15 hPa
Lower Stratosphere (radiosonde)	$T_{(100-50)}$	Lower Stratosphere	17 – 21 km	100 – 50 hPa

[2] Only about 10% of this layer extends into the lower stratosphere.

EXECUTIVE SUMMARY

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Abstract

Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human-induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite and radiosonde data showed little or no warming above the surface. This significant discrepancy no longer exists because errors in the satellite and radiosonde data have been identified and corrected. New data sets have also been developed that do not show such discrepancies.

This Synthesis and Assessment Product is an important revision to the conclusions of earlier reports from the U.S. National Research Council and the Intergovernmental Panel on Climate Change. For recent decades, all current atmospheric data sets now show global-average warming that is similar to the surface warming. While these data are consistent with the results from climate models at the global scale, discrepancies in the tropics remain to be resolved. Nevertheless, the most recent observational and model evidence has increased confidence in our understanding of observed climatic changes and their causes.

NEW RESULTS AND FINDINGS

This Report is concerned with temperature changes in the atmosphere, differences in these changes at various levels in the atmosphere, and our understanding of the causes of these changes and differences. Considerable progress has been made since the production of reports by the NRC and the IPCC in 2000 and 2001. Data sets for the surface and from satellites and radiosondes (temperature sensors on weather balloons) have been extended and improved, and new satellite and radiosonde data sets have been developed[1]. Many new model simulations of the climate of the 20th century have been carried out using improved climate models[2] and better estimates of past forcing changes, and numerous new and updated comparisons between model and observed data have been performed. The present Report reviews this progress. A summary and explanation of the main results is presented first. Then, to address the issues in more detail, six questions that provide the basis for the six main chapters in this Synthesis and Assessment Report are posed and answered in Sections 1 through 5 below.

The important new results presented in this Report include:

Global Average Temperature Results

- For observations since the late 1950s, the start of the study period for this Report, the most recent versions of all available data sets show that both the surface and troposphere have warmed, while the stratosphere has cooled[3]. These changes are in accord with our understanding of the effects of radiative forcing agents[4] and with the results from model simulations.

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1 For details of new observed data see Table 3.1 in Chapter 3.

2 For details of new models and model simulations see Chapter 5 and http://www-pcmdi.llnl.gov/ipcc/model.documentation.

3 We use the words "warming" and "cooling" here to refer to temperature increases or decreases, as is common usage. Technically, these words refer to changes in heat content, which may occur through changes in either the moisture content and/or the temperature of the atmosphere. When we say that the atmosphere has warmed (or cooled) over a given period, this means that there has been an overall positive (or negative) temperature change based on a linear trend analysis. For more on the use of linear trends, including a discussion of their strengths and weaknesses, see Appendix A.

4 The main natural forcing agents are changes in solar output and the effects of explosive volcanic eruptions. The main human-induced ("anthropogenic") factors are: the emissions of greenhouse gases (e.g., carbon dioxide [CO_2], methane [CH_4], nitrous oxide [N_2O]); aerosols (tiny droplets or particles such as smoke) and the gases that lead to aerosol formation (most importantly,

- Since the late 1950s, all radiosonde data sets show that the low and mid troposphere have warmed at a rate slightly faster than the rate of warming at the surface. These changes are in accord with our understanding of the effects of radiative forcing agents on the climate system and with the results from model simulations.

- For observations during the satellite era (1979 onwards), the most recent versions of all available data sets show that both the low and mid troposphere have warmed. The majority of these data sets show warming at the surface that is greater than in the troposphere. Some of these data sets, however, show the opposite - tropospheric warming that is greater than that at the surface. Thus, due to the considerable disagreements between tropospheric data sets, it is not clear whether the troposphere has warmed more than or less than the surface.

- The most recent climate model simulations give a range of results for changes in global-average temperature. Some models show more warming in the troposphere than at the surface, while a slightly smaller number of simulations show the opposite behavior. There is no fundamental inconsistency among these model results and observations at the global scale.

- Studies to detect climate change and attribute its causes using patterns of observed temperature change in space and time show clear evidence of human influences on the climate system (due to changes in greenhouse gases, aerosols, and stratospheric ozone).

- The observed patterns of change over the past 50 years cannot be explained by natural processes alone[5], nor by the effects of short-lived atmospheric constituents (such as aerosols and tropospheric ozone) alone.

Tropical Temperature Results (20°S to 20°N)

- Although the majority of observational data sets show more warming at the surface than in the troposphere, some observational data sets show the opposite behavior. Almost all model simulations show more warming in the troposphere than at the surface. This difference between models and observations may arise from errors that are common to all models, from errors in the observational data sets, or from a combination of these factors. The second explanation is favored, but the issue is still open.

sulfur dioxide); and changes in land cover and land use (see Chapter 1, Table 1.1). Since these perturbations act to drive or "force" changes in climate, they are referred to as "forcings". Tropospheric ozone [O_3], which is not emitted directly, is also an important greenhouse gas. Tropospheric ozone changes occur through the emissions of gases like carbon monoxide, nitrogen oxides and volatile organic compounds, which, by themselves, are not important directly as greenhouse gases.

[5] "Natural processes" here refers to the effects of natural external forcing agents such as volcanic eruptions and solar variability, and/or internally generated variability.

EXPLANATION OF FINDINGS

These results for the globe and for the tropics characterize important changes in our understanding of the details of temperature changes at the surface and higher in the troposphere. In 2000 and 2001, the NRC and the IPCC both concluded that global-average surface temperature increases were larger and differed significantly from temperature increases in the troposphere. The new and improved observed data sets and new model simulations that have been developed require modifications of these conclusions.

The issue of changes at the surface relative to those in the troposphere is important because larger surface warming (at least in the tropics) would be inconsistent with our physical understanding of the climate system, and with the results from climate models. The concept here is referred to as "vertical amplification" (or, for brevity, simply "amplification"): greater changes in the troposphere would mean that changes there are "amplified" relative to those at the surface.

For global averages, observed changes from 1958 through 2004 exhibit amplification: i.e., they show greater warming trends in the troposphere compared with the surface. Since 1979, however, the situation is different: most data sets show slightly greater warming at the surface.

Whether or not these results are in accord with expectations based on climate models is a complex issue, one that we have been able to address more comprehensively now using new model results. Over the period since 1979, for global-average temperatures, the range of recent model simulations is almost evenly divided among those that show a greater global-average warming trend at the surface and others that show a greater warming trend aloft. The range of model results for global average temperature reflects the influence of the mid- to high-latitudes where amplification results vary considerably between models. Given the range of model results and the overlap between them and the available observations, there is no conflict between observed changes and the results from climate models.

In the tropics, the agreement between models and observations depends on the time scale considered. For month-to-month and year-to-year variations, models and observations both show amplification (*i.e.*, the month-to-month and year-to-year variations are larger aloft than at the surface). This is a consequence of relatively simple physics, the effects of the release of latent heat as air rises and condenses in clouds. The magnitude of this amplification is very similar in models and observations. On decadal and longer time scales, however, while almost all model simulations show greater warming aloft (reflecting the same physical processes that operate on the monthly and annual time scales), most observations show greater warming at the surface.

These results could arise either because "real world" amplification effects on short and long time scales are controlled by different physical mechanisms, and models fail to capture such behavior; or because non-climatic influences remaining in some or all of the observed tropospheric data sets lead to biased long-term trends; or a combination of these factors. The new evidence in this Report favors the second explanation.

1. HOW DO WE EXPECT VERTICAL TEMPERATURE PROFILES TO CHANGE?

Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time?

When all forcings are considered, we expect the troposphere to have warmed and the stratosphere to have cooled since the late 1950s.

This question is addressed in both Chapter 1 and Chapter 5 of this Report.

In response to this question, Chapter 1 notes:

(1) TEMPERATURES VARY VERTICALLY

- The global temperature profile of the Earth's atmosphere reflects a balance between radiative, convective and dynamical heating and cooling processes in the surface-atmosphere system. Radiation from the Sun is the source of energy for the Earth's climate. Physical properties of the atmosphere and dynamical processes mix heat vertically and horizontally, yielding the highest temperatures, on average, at the surface, with marked seasonal and spatial variations. In the atmosphere above the surface, the distribution of moisture and the lower air pressure at progressively higher altitudes result in decreasing temperatures with height up to the tropopause (marking the top of the troposphere, *i.e.*, the lower 8 to 16 km of the atmosphere, depending on latitude). Above this, the physical properties of the air produce a warming with height through the stratosphere (extending from the tropopause to ~50 km).

(2) TEMPERATURE TRENDS AT THE SURFACE CAN BE EXPECTED TO BE DIFFERENT FROM TEMPERATURE TRENDS HIGHER IN THE ATMOSPHERE BECAUSE:

- The physical properties of the surface vary substantially according to location and this produces strong horizontal variations in near-surface temperature. Above the surface, on monthly and longer time scales, these contrasts are quickly smoothed out by atmospheric motions so the patterns of change in the troposphere must differ from those at the surface. Temperature trend variations with height must, therefore, vary according to location.
- Changes in atmospheric circulation or modes of atmospheric variability (*e.g.*, the El Niño-Southern Oscillation [ENSO]) can produce different temperature trends at the surface and aloft.
- Under some circumstances, temperatures may increase with height near the surface or higher in the troposphere, producing a "temperature inversion." Such inversions are more common at night over continents, over sea ice and snow in winter, and in the trade wind regions. Since the air in inversion layers is resistant to vertical mixing, temperature trends can differ between inversion layers and adjacent layers.
- Forcing factors, either natural or human-induced, can result in differing temperature trends at different levels in the atmosphere, and these vertical variations may change over time.

As noted above, temperatures in the atmosphere vary naturally as a result of internal factors and natural and human-induced perturbations ("forcings"). These factors are expected to have different effects on temperatures near the surface, in the troposphere, and in the stratosphere, as summarized in Table 1. When all forcings are considered, we expect the troposphere to have warmed and the stratosphere to have cooled since the late 1950s (and over the whole 20th century). The relative changes in the troposphere and stratosphere provide information about the causes of observed changes.

Within the troposphere, the relative changes in temperature at different levels are controlled by different processes according to latitude. In the tropics, the primary control is the thermodynamics of moist air *(i.e.*, the effects of evaporation at the surface and the release of latent heat through condensation that occurs in clouds as moist air rises due to convection), and the way these effects are distributed and modified by the atmospheric circulation. Thermodynamic principles require that temperature changes in the tropics will be larger in the troposphere than near the surface ("amplification"), largely independent of the type of forcing. In mid to

Table 1: Summary of the most important global-scale climate forcing factors and their likely individual effects on global-, annual-average temperatures; based on Figure 1.3 (which gives temperature information) and Table 1.1 (which gives information on radiative forcing) in Chapter 1, and literature cited in Chapter 1. The stated effects are those that would be expected if the change specified in column 1 were to occur. The top two rows are the primary natural forcing factors, while the other rows summarize the main human-induced forcing factors. The relative importance of these different factors varies spatially and over time. For example, volcanic effects last only a few years in the stratosphere, and slightly longer in the troposphere; while the effects of well-mixed greenhouse gases last for decades to centuries.

	Theoretically expected change in annual-global-average temperature		
Forcing Factor	**Surface**	**Low to Mid Troposphere**	**Stratosphere**
Increased solar output	Warming	Warming	Warming
Volcanic eruptions	Cooling	Cooling	Warming
Increased concentrations of well-mixed greenhouse gases (CO_2, CH_4, N_2O, halocarbons)	Warming	Warming	Cooling
Increased tropospheric ozone (O_3)	Warming	Warming	Slight cooling
Decreased stratospheric ozone	Negligible except at high latitudes	Slight cooling	Cooling
Increased loading of tropospheric sulfate (SO_4) aerosol – sum of direct plus indirect effects	Cooling	Cooling	Negligible
Increased loading of carbonaceous aerosol (black carbon [BC] and organic matter [OM]) in the troposphere – sum of direct plus indirect effects	Regional cooling or warming – possible global-average cooling	Warming	Uncertain
Land use and land cover changes	Regional cooling or warming – probably slight global-average cooling	Uncertain	Negligible

high latitudes, the processes controlling how temperature changes in the vertical are more complex, and it is possible for the surface to warm more than the troposphere. These issues are addressed further in Chapter 1 and Chapter 5.

2. STRENGTHS AND LIMITATIONS OF THE OBSERVATIONAL DATA

What kinds of atmospheric temperature variations can the current observing systems detect and what are their strengths and limitations, both spatially and temporally?

This question is addressed in Chapter 2 of this Report. Chapter 2 draws the following main conclusions:

(1) The observing systems available for this Report are able to detect small surface and upper air temperature variations from year to year as well as trends[6] in climate since the late 1950s (and over the last century for surface observations), once the raw data are successfully adjusted for changes over time in observing systems and practices, and micro-climate exposure. Measurements from all systems require such adjustments. This Report relies solely on adjusted data sets.

[6] Many of the results in this Report (and here in the Executive Summary) are quantified in terms of linear trends, *i.e.*, by the value of the slope of a straight line that is fitted to the data. A simple straight line is not always the best way to describe temperature data, so a linear trend value may be deceptive if the trend number is given in isolation, removed from the original data. Nevertheless, used appropriately, linear trends provide the simplest and most convenient way to describe the overall change over time in a data set, and are widely used. For a more detailed discussion, see Appendix A.

All data sets require careful examination for instrument biases and reliability, and adjustments are made to remove changes that might have arisen for non-climatic reasons.

(2) Independently performed adjustments to the land surface temperature record have been sufficiently successful that trends given by different data sets are reasonably similar on large (*e.g.*, continental) scales, despite the fact that spatial sampling is uneven and some errors undoubtedly remain. This conclusion holds to a lesser extent for the ocean surface record, which suffers from more serious sampling problems and changes in observing practice.

(3) Adjustments for changing instrumentation are most challenging for upper-air data sets. While these show promise for trend analysis, and it is very likely that current upper-air climate records give reliable indications of directions of change (*e.g.*, warming of the troposphere, cooling of the stratosphere), some questions remain regarding the accuracy of the data after adjustments have been made to produce homogeneous time series from the raw measurements.

- Upper-air data sets have been subjected to less scrutiny than surface data sets.
- Adjustments are complicated, can be large compared to the linear trend signal, involve expert judgments, and cannot be stringently evaluated because of lack of traceable standards.
- Unlike surface trends, reported upper-air trends vary considerably between research teams beginning with the same raw data owing to their different decisions on how to remove non-climatic factors.

Many different methods are used to measure temperature changes at the Earth's surface and at various levels in the atmosphere. Near-surface temperatures have been measured for the longest period, over a century, and are measured directly by thermometers. Over land, these data come from fixed meteorological stations. Over the ocean, measurements are of both air temperature and sea-surface (top 10 meters) temperature taken by ships or from buoys.

The next-longest records are upper-air data measured by radiosondes (temperature sensors carried aloft by weather balloons). These have been collected routinely since 1958. There are still substantial gaps in radiosonde coverage.

Satellite data have been collected for the upper air since 1979 with almost complete global coverage. The most important satellite records come from Microwave Sounding Units (MSU) on polar orbiting satellites. The microwave data from MSU instruments require calculations and adjustments in order to be interpreted as temperatures. Furthermore, these satellite data do not represent the temperature at a particular level, but, rather, the average temperature over thick atmospheric layers (see Figure 2.2 in Chapter 2). As such, they cannot reveal the detailed vertical structure of temperature changes, nor do they completely isolate the troposphere from the stratosphere. Channel 2 data (mid troposphere to lower stratosphere, T_2) have a latitudinally dependent contribution from the stratosphere, while Channel 4 data (lower stratosphere, T_4) have a latitudinally dependent contribution from the troposphere, factors that complicate their interpretation. However, retrieval techniques can be used both to approximately isolate specific layers and to check for vertical consistency of trend patterns.

All measurement systems have inherent uncertainties associated with: the instruments employed; changes in instrumentation; and the way local measurements are combined to produce area averages. All data sets require careful examination for instrument biases and reliability, and adjustments are made to remove changes that might have arisen for non-climatic reasons. We refer to these as "adjusted" data sets. The term "homogenization" is also used to describe this adjustment procedure.

Reanalyses[7] and other multi-system products that synthesize observational data with model results to ensure spatial and inter-variable consistency have the potential for addressing issues of surface and atmospheric temperature trends by making better use of available information and allowing analysis of a more comprehensive,

[7] Reanalyses are mathematically blended products based upon as many observing systems as practical. Observations are assimilated into a global weather forecasting model to produce globally comprehensive data sets that are most consistent with both the available data and the assimilation model.

internally consistent, and spatially and temporally complete set of climate variables. At present, however, these products contain biases, especially in the stratosphere, that affect trends and that cannot be readily removed because of the complexity of the data products.

3. WHAT TEMPERATURE CHANGES HAVE BEEN OBSERVED?

What do observations indicate about the changes of temperature in the atmosphere and at the surface since the advent of measuring temperatures vertically?

What is our understanding of the contribution made by observational or methodological uncertainties to the previously reported vertical differences in temperature trends?

These questions are addressed in Chapters 3 and 4 of this Report. The following conclusions are drawn in these chapters. Supporting information is given in Figure 1 and Figure 2.

(1) Surface temperatures: For global-average changes, as well as in the tropics (20°S to 20°N), all data sets show warming at the surface since 1958, with a greater rate of increase since 1979. Differences between the data sets are small.

- Global-average temperature increased at a rate of about 0.12°C per decade since 1958, and about 0.16°C per decade since 1979. In the tropics, temperature increased at about 0.11°C per decade since 1958, and about 0.13°C per decade since 1979.

- Systematic local biases in surface temperature trends may exist due to changes in station exposure and instrumentation over land[8], or changes in measurement techniques by ships and buoys in the ocean. It is likely that these biases are largely random and therefore cancel out over large regions such as the globe or tropics, the regions that are of primary interest to this Report.

(2) Tropospheric temperatures: All data sets show that the global- and tropical-average troposphere has warmed from 1958 to the present, with the warming in the troposphere being slightly more than at the surface. For changes from 1979, due to the considerable disagreements between tropospheric data sets, it is not clear whether the troposphere has warmed more than or less than the surface.

- Global-average tropospheric temperature increased at a rate of about 0.14°C per decade since 1958 according to the two radiosonde data sets. For the period from 1979, temperature increased by 0.10°C to 0.20°C per decade according to the two radiosonde and three satellite data sets. In the tropics, temperature increased at about 0.13°C per decade since 1958, and between 0.02°C and 0.19°C per decade since 1979.

- Errors in observed temperature trend differences between the surface and the troposphere are more likely to come from errors in tropospheric data than from errors in surface data.

- It is very likely that estimates of trends in tropospheric temperatures are affected by errors that remain in the adjusted radiosonde data sets. Such errors arise because the methods used to produce these data sets are only able to detect and remove the more obvious causes, and involve many subjective decisions. The full consequences of these errors for large-area averages, however, have not yet been fully resolved. Nevertheless, it is likely that a net spurious cooling corrupts the area-averaged adjusted radiosonde data in the tropical troposphere, causing these data to indicate less warming than has actually occurred there.

- For tropospheric satellite data, a primary cause of trend differences between different versions is differences in how the data from different satellites are merged together. Corrections required to account for drifting measurement times are also important.

Errors in observed temperature trend differences between the surface and the troposphere are more likely to come from errors in tropospheric data than from errors in surface data.

[8] Some have expressed concern that land temperature data might be biased due to urbanization effects. Recent studies specifically designed to identify systematic problems using a range of approaches have found no detectable urban influence in large-area averages in the data sets that have been adjusted to remove non-climatic influences (*i.e.*, "homogenized").

- Comparisons between satellite and radiosonde temperatures for the mid troposphere to lower stratosphere layer (MSU channel 2; T_2) are very likely to be corrupted by excessive stratospheric cooling in the radiosonde data.

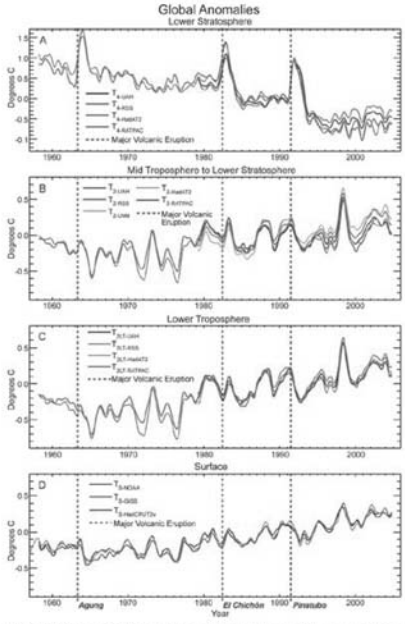

Figure 1: Observed surface and upper air global-average temperature records. From top to bottom: **A**, lower stratosphere (denoted T_4) records from two satellite analyses (**UAH** and **RSS**) together with equivalently weighted radiosonde records based on **HadAT2** and **RATPAC** data; **B**, mid-troposphere to lower stratosphere (T_2) records from three satellite analyses (**UAH**, **RSS** and **UMd**) together with equivalently weighted radiosonde records based on **HadAT2** and **RATPAC**; **C**, lower troposphere (T_{2LT}) records from **UAH** and **RSS** (satellite), and from **HadAT2** and **RATPAC** (equivalently weighted radiosonde); **D**, surface (T_S). All time series are based on monthly-average data smoothed with a 7-month running average, expressed as departures from the **Jan. 1979 to Dec. 1997** average. Note that the T_2 data (panel **B**) contain a small contribution (about **10%**) from the lower stratosphere. Information here is from **Figures 3.1, 3.2** and **3.3** in **Chapter 3.**

(3) Lower stratospheric temperatures: All data sets show that the stratosphere has cooled considerably from 1958 and from 1979 to the present, although there are differences in the linear trend values from different data sets.

- The largest differences between data sets are in the stratosphere, particularly between the radiosonde and satellite-based data sets. It is very likely that the discrepancy between satellite and radiosonde trends arises primarily from uncorrected errors in the radiosonde data.

Figure 1 shows the various temperature time series examined in this Report.

For the lower stratosphere, the cooling trend since the late 1950s (which is as expected due to the effects of greenhouse-gas concentration increases and stratospheric ozone depletion) is punctuated by short-term warming events associated with the explosive volcanic eruptions of Mt. Agung (1963), El Chichón (1982) and Mt. Pinatubo (1991).

Both the troposphere and the surface show warming since the late 1950s. For the surface, most of the temperature increase since 1958 occurs starting around 1976, a time coincident with a previously identified climate shift. For the balloon-based tropospheric data, a major part of the temperature increase since 1958 also occurs around 1976, in the form of a relatively rapid rise in temperature. The shift in 1976 is important because it occurs just before the start of the satellite era.

The dominant shorter time scale fluctuations are those associated with the El Niño-Southern Oscillation phenomenon (ENSO). The major ENSO warming event in 1998 is obvious in all records. Cooling following the eruptions of Mt. Agung and Mt. Pinatubo is also evident, but the cooling effect of El Chichón is masked by an ENSO warming that occurred at the same time. The changes following volcanic eruptions *(i.e.,* surface and tropospheric cooling and stratospheric warming) are consistent with our physical understanding and with model simulations.

Global-average temperature changes over the periods 1958 through 2004 and 1979 through 2004 are shown in Figure 2 in degrees Celsius and degrees Fahrenheit.

4. ARE MODEL SIMULATIONS CONSISTENT WITH THE OBSERVED TEMPERATURE CHANGES?

Computer-based climate models encapsulate our understanding of the climate system and the driving forces that lead to changes in climate. Such models are the only tools we have for simulating the likely patterns of response of the climate system to different forcing mechanisms. The crucial test of our understanding is to compare model simulations with observed changes to address the question:

How well can the observed vertical temperature changes be reconciled with our understanding of the causes of these changes?

In addressing this question, Chapter 5 draws the following conclusions ...

FINGERPRINT PATTERN STUDIES

(1) Results from many different pattern-based "fingerprint"[9] studies (see Box 5.5 in Chapter 5) provide consistent evidence for human influences on the three-dimensional structure of atmospheric temperature changes over the second half of the 20th century.

- Fingerprint studies have identified greenhouse gas and sulfate aerosol signals in observed surface temperature records, a stratospheric ozone depletion signal in stratospheric temperatures, and the combined effects of these forcing agents in the vertical structure of atmospheric temperature changes.

(2) Natural factors (external forcing agents like volcanic eruptions and solar variability and/or internally generated variability) have influenced surface and atmospheric temperatures, but cannot fully explain their changes over the past 50 years.

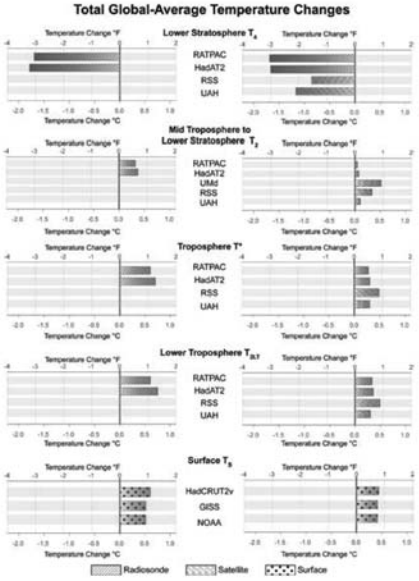

Figure 2: Total global-average temperature changes for the surface and different atmospheric layers, from different data sets and over two periods, 1958 to 2004 and 1979 to 2004. The values shown are the total change over the stated period in both degrees Celsius (°C; lower scales) and degrees Fahrenheit (°F; upper scales). All changes are statistically significant at the 5% level except RSS T_4 and RATPAC, HadAT2 and UAH T_2. Total change in °C is the linear trend in °C per decade (see Tables 3.2 and 3.3 in Chapter 3) times the number of decades in the time period considered. Total change in °F is this number times 1.8 to convert to °F. For example, the Table 3.2 trend for NOAA surface temperatures over January 1958 through December 2004 is 0.11°C/decade. The total change is therefore 0.11 times 4.7 decades to give a total change of 0.53°C. Multiplying this by 1.8 gives a total change in degrees Fahrenheit of 0.93°F. Warming is shown in red, and cooling in blue.

[9] Fingerprint studies use rigorous statistical methods to compare the patterns of observed temperature changes with model expectations and determine whether or not similarities could have occurred by chance. Linear trend comparisons are less powerful than fingerprint analyses for studying cause-effect relationships, but can highlight important differences and similarities between models and observations.

When models are run with natural and human-induced forcings, simulated global-average temperature trends for individual atmospheric layers are consistent with observations.

Linear Trend Comparisons

(3) When models are run with natural and human-induced forcings, simulated global-average temperature trends for individual atmospheric layers are consistent with observations.

(4) Comparing trend differences between the surface and the troposphere exposes potentially important discrepancies between model results and observations in the tropics.

- In the tropics, most observational data sets show more warming at the surface than in the troposphere, while almost all model simulations have larger warming aloft than at the surface.

Amplification of Surface Warming in the Tropical Troposphere

(5) Amplification means that temperatures show larger changes aloft than at the surface. In the tropics, on monthly and inter-annual time scales, both models and observations show amplification of temperature variability in the troposphere relative to the surface. This amplification is of similar magnitude in models and observations. For multi-decadal trends, models show the same amplification that is seen on shorter time scales. The majority of the most recent observed data sets, however, do not show this amplification.

- This inconsistency between model results and observations could arise either because "real world" amplification effects on short and long time scales are controlled by different physical mechanisms, and models fail to capture such behavior; or because non-climatic influences remaining in some or all of the observed tropospheric datasets lead to biased long-term trends; or a combination of these factors. The new evidence in this Report - model-to-model consistency of amplification results, the large uncertainties in observed tropospheric temperature trends, and independent physical evidence supporting substantial tropospheric warming (such as the increasing height of the tropopause) - favors the second explanation. However, the large observational uncertainties that currently exist make it difficult to determine whether or not models still have significant errors. Resolution of this issue requires reducing these uncertainties.

Other Findings

(6) Because of differences between different observed data sets and differences between models, it is important to account for both model and observational uncertainty in comparisons between modeled and observed temperature changes.

- Large "construction" uncertainties in observed estimates of global-scale atmospheric temperature change can critically influence the outcome of consistency tests between models and observations.

(7) Inclusion of previously ignored, spatially variable forcings in the most recent climate models does not fundamentally alter conclusions about the amplification of warming in the troposphere relative to the surface.

- Changes in sulfate aerosols and tropospheric ozone, which have spatially variable forcings, have been incorporated routinely in climate model experiments for a number of years. It has been suggested that the spatially heterogeneous forcing effects of black carbon aerosols and land use/land cover changes may have had significant effects on regional temperatures that might modify previous conclusions regarding vertical temperature changes. These forcings have been included for the first time in about half of the global model simulations considered here. Within statistical uncertainties, model simulations that include these forcings show the same amplification of warming in the troposphere relative to the surface at very large spatial scales (global and tropical averages) as simulations in which these forcings are neglected.

Chapter 5 analyzes state-of-the-art model simulations from 19 institutions from around the world, run using combinations of the most important natural and human-induced forcings. The Chapter compares the results of these simulations with a number of different observational data sets for the surface and different atmospheric layers, resulting in a large number of possible model/observed data comparisons.

Figures 3 and 4 summarize the new model results used in this Report, together with the corresponding observations. Figure 3 gives results for global-average temperature, while Figure 4 gives results for the tropics (20°S to 20°N). Model and observed results are compared in these Figures using linear trends over the period January 1979 through December 1999[10] for the surface, for individual layers, and (right-hand panels) for surface changes relative to the troposphere. Rectangles are used to illustrate the ranges of both model trends (red rectangles) and observed trends (blue rectangles). Individual observed-data trends are also shown.

Since statistical uncertainties (see Appendix A) are not shown in these Figures, the rectangles do not represent the full ranges of uncertainty. However, they allow a useful first-order assessment of similarities and differences between observations and model results. Overlapping rectangles in the Figures indicate consistency, while rectangles that either do not overlap or show minimal overlap point to potential inconsistencies between observations and model results.

For global averages (Fig. 3), models and observations generally show overlapping rectangles. A potentially serious inconsistency, however, has been identified in the tropics. Figure 4G shows that the lower troposphere warms more rapidly than the surface in almost all model simulations, while, in the majority of observed data sets, the surface has warmed more rapidly than the lower troposphere. In fact, the nature of this discrepancy is not fully captured in Fig. 4G as the models that show best agreement with the observations are those that have the lowest (and probably unrealistic) amounts of warming (see Chapter 5, Fig. 5.6C). On the other hand, as noted above, the rectangles do not express the full range of uncertainty, as they do not account for the large statistical uncertainties in the individual model trends or the large constructional and statistical uncertainties in the observed data trends.

The potential discrepancy identified here is a different way of expressing the amplification discrepancy described in Section 4, item (5) above. It may arise from errors that are common to all models, from errors in the observational data sets, or from a combination of these factors. The second explanation is favored, but the issue is still open.

A potentially serious inconsistency has been identified in the tropics. The favored explanation for this is residual error in the observations, but the issue is still open.

[10] This is the longest period common to all model simulations.

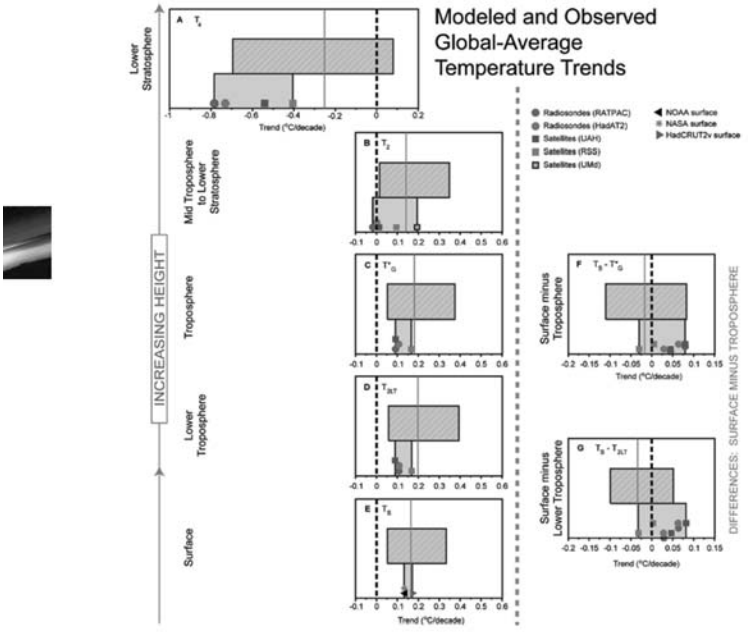

Figure 3: Comparison of observed and model-simulated global-average temperature trends (left-hand panels) and trend differences (right-hand panels) over January 1979 through December 1999, based on Table 5.4A and Figure 5.3 in Chapter 5. The upper red rectangles in each box show the range of model trends from 49 model simulations. The lower blue rectangles show the range of observed trends, with the individual trends from different data sets indicated by the symbols. From bottom to top, the left-hand panels show trends for the surface (T_S), the lower troposphere (T_{2LT}), the troposphere (T^*), the mid troposphere to lower stratosphere (T_2), and the lower stratosphere (T_4). The right-hand panels show differences in trends between the surface and either the troposphere or the lower troposphere, with a positive value indicating a stronger warming at the surface. The red vertical lines show the average of all model results. The vertical black dashed lines show the zero value. For the observed trend differences, there are eight values corresponding to combinations of the four upper-air data sets (as indicated by the symbols) and either the HadCRUT2v surface data or the NASA/NOAA surface data (which have almost identical trends).

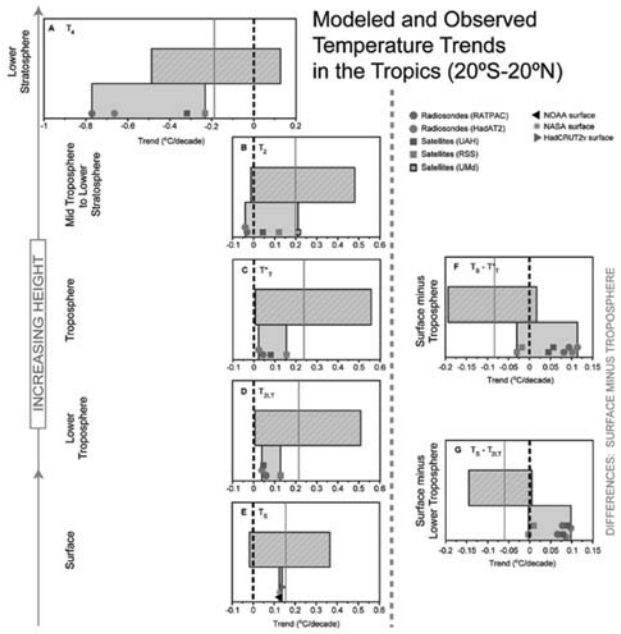

Figure 4: As Figure 3, but for the tropics (20°S to 20°N), based on Table 5.4B and Figure 5.4 in Chapter 5. Note that, in the tropics, the tropospheric radiosonde data (green and purple filled circles in panels **C** and **D**) may have a cooling bias and that it is unlikely that this bias has been completely removed from the adjusted data used here. Note also that the (small) overlap in panel **G** is deceptive because the models in this overlap area have unrealistically small amounts of warming. On the other hand, the rectangles do not express the full range of uncertainty, as they do not account for uncertainties in the individual model or observed data trends.

5. RECOMMENDATIONS

What measures can be taken to improve the understanding of observed changes?

In answer to this question, drawing on the material presented in the first five chapters of this Report, a set of primary recommendations has been developed and is described in detail in Chapter 6. The items described in Chapter 6 expand and build upon existing ideas, emphasizing those that are considered to be of highest utility. The seven inter-related recommendations are:

(1) The independent development of data sets and analyses by several scientists or teams will help to quantify structural uncertainty. In order to encourage further independent scrutiny, data sets and their full metadata (*i.e.*, information about instrumentation used, observing practices, the environmental context of observations, and data-processing procedures) should be made openly available. Comprehensive analyses should be carried out to ascertain the causes of remaining differences between data sets and to refine uncertainty estimates.

(2) Efforts should be made to archive and make openly available for independent analysis surface, balloon-based, and satellite data and metadata that have not previously been exploited. Emphasis should be placed on the tropics and on the recovery of satellite data before 1979 (which may allow better characterization of the climate shift in the mid-1970s).

(3) Efforts should be made to develop new or reprocess existing data to create climate quality data sets[11] for a range of variables other than temperature (*e.g.* atmospheric water vapor content, ocean heat content, the height of the tropopause, winds and clouds, radiative fluxes, and cryospheric changes). These data sets should subsequently be compared with each other and with temperature data to determine whether they are consistent with our physical understanding. It is important to create several independent estimates for each variable in order to assess the magnitude of construction uncertainties.

(4) Efforts should be made to create several homogeneous atmospheric reanalyses. Particular care needs to be taken to identify and homogenize critical input climate data. Identification of critical data requires, in turn, observing system experiments where the impacts and relative importance of different observation types from land, radiosonde, and space-based observations are assessed.

(5) Models that appear to include the same forcings often differ in both the way the forcings are quantified and how these forcings are applied to the model. Hence, efforts are required to separate more formally uncertainties arising from model structure from the effects of forcing uncertainties. This requires running multiple models with standardized forcings, and running the same models individually under a range of plausible scenarios for each forcing.

(6) The GCOS (Global Climate Observing System) climate monitoring principles should be fully adopted. In particular, when any type of instrument for measuring climate is changed or re-sited, there should be a period of overlap between old and new instruments or configurations that is sufficient to allow analysts to adjust for the change with small uncertainties that do not prejudice the analysis of climate trends. The minimum period is a full annual cycle of the climate. Thus, replacement satellite launches should be planned to take place at least a year prior to the expected time of failure of a key instrument.

(7) A small subset (about 5%) of the operational radiosonde network should be developed and implemented as reference sites for all kinds of climate data from the surface to the stratosphere.

[11] Climate quality data sets are those where the best possible efforts have been made to identify and remove non-climatic effects that might produce spurious changes over time.

CHAPTER 1

Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time?

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SUMMARY

Temperatures Vary Vertically

The global temperature profile of the Earth's atmosphere reflects a balance between the radiative, convective and dynamical heating/cooling of the surface-atmosphere system. Radiation from the Sun is the source of energy for the Earth's climate, with most of it absorbed at the surface. Combined with the physical properties of the atmosphere and dynamical processes, the heat is mixed vertically and horizontally, yielding the highest temperatures, on average, at the surface, with marked seasonal and spatial variations. In the atmosphere, the distribution of moisture and the lower air pressure at progressively higher altitudes result in decreasing temperatures with height up to the tropopause, with the rate of decrease depending on geographical factors and meteorological conditions. The tropopause marks the top of the troposphere, i.e., the lower 8 to 16 km of the atmosphere (see Preface, Fig. 2), and varies with latitude and longitude. Above this altitude, the physical properties of the air produce a warming with height through the stratosphere (extending from the tropopause to ~50 km).

Temperature trends at the surface can be expected to be different from temperature trends higher in the atmosphere.

Temperature trends at the surface can be expected to be different from temperature trends higher in the atmosphere because:

- Surface types (sea, snow, ice, and different vegetative covers of land) differ considerably in their physical properties. Near the surface, these differing conditions can produce strong horizontal variations in temperature. Above the surface layer, these contrasts are quickly smoothed out by the atmospheric motions, contributing to varying temperature trends with height at different locations.
- Changes in atmospheric circulation or modes of atmospheric variability (e.g., El Niño-Southern Oscillation [ENSO]) can produce different temperature trends at the surface and aloft.
- Under some circumstances, temperatures may increase with height near the surface or higher in the troposphere, producing a "temperature inversion." Such inversions are more common at night; over continents, sea ice and snow during winter; and in the trade wind regions. Since the air in inversion layers is resistant to vertical mixing, temperatures trends can differ between inversion layers and adjacent layers.
- Forcing factors, either natural (e.g., volcanoes and solar) or human-induced (e.g., greenhouse gas, aerosols, ozone, and land use) can result in differing temperature trends at different altitudes, and these vertical variations may change over time. This can arise due to spatial and temporal changes in the concentrations or properties of the forcing agents.

Senator PETERS. Thank you, Mr. Chairman.

And given that thought, Admiral Titley, if you could explain briefly, a little bit expand on that, how satellites is a complex mechanism in order to do that, as well as if you could briefly explain the corrections that have been made over time to UAH satellite datasets since the original estimates were published.

These datasets are revised on a regular basis because of the difficulty in correlating. Is that correct?

Admiral TITLEY. Senator, thank you. Thank you, sir.

I mean, kind of the bottom line, it is not rocket science. It is actually harder. Once you get the satellite up in the air, then you have to do something with the data.

And as has been talked about I think several times in this committee, they are not thermometers in space. There is all different types of frequencies, all the way from visible, the pictures that you see on the TV, infrared, and there is also some things called micrometer. So it is basically almost like radar. It is not exactly, but some of them are.

And what you do is you are trying to look down through the atmosphere. But of course, the atmosphere doesn't say, oh, here is the low part, and then there is a nice dividing, and here is the middle. So you have different frequencies that are mostly sensitive, but not entirely sensitive to those different parts. And then you have to put all of that stuff together, and it is. It is complicated.

A lot of work in meteorology was done in this, and it was one of the real big advances when we figured out how to use these data directly and not make them like thermometers. That happened around the turn of—around the year 2000 or so, and it was a big advance.

As you have mentioned, sir, there have been just a number of corrections that have had to be made to the UAH dataset. Merging overlapping satellite records. So when you have satellite A and satellite B, how do you, in fact, cross-calibrate? How do you compare them?

As the satellites go around and around, they actually start falling back to Earth. Very slightly, but they fall back to Earth. You have to account for that orbital decay.

You have to account for the stratosphere, the air up above what we have been talking about, this where we live or near where we live, and is that contaminated? And then there is even things like the diurnal heating correction. So like when the satellite is in where the Sun, you have to account for that.

And those have—it has taken other people, such as Mears and Wentz from Remote Sensing Systems and other external scientists, to help with those datasets to get them corrected. And again, it is not easy stuff to do. It is hard stuff to do, but there have been a number of errors.

Senator PETERS. So I get from that testimony that satellite data alone may be inadequate. We need to look at a variety of other measurements of climate indicators. So how do climate models compare with these measurements and observations in the aggregate when we are looking at a variety of tools to measure what is happening on our planet?

Admiral TITLEY. There is a saying certainly in the weather community and other communities as well that all models are wrong, but some are useful. And in a technical sense, it is really hard to find a weather or a climate model that is exactly right all the time. But they can tell you very useful things.

So even back in 1979, Jim Hansen of NASA published in Nature—it was published, I think, in May 1980—his climate model. This is from 35 years ago, when probably his computer system was not even as powerful as our iPhones today. And what that showed in published record, anybody can look it up, is the temperature was going to start going up.

And then when you overlay the actual temperatures on there, he was wrong. But he was wrong because he was actually slightly too cold. But it was very useful because it said, guys, we are going to get on this escalator and we are going to start going up.

So the climate models are useful. They are certainly getting better. Are they perfect? No. Could we use more research and development, better computers? Yes. Could we use better observations? Yes.

But they are very useful, and they do help us understand the future.

Thank you, sir.

Senator PETERS. Well, thank you, Dr. Titley.

One, another question here. We have heard about or had testimony that folks sometimes have difficulty getting their positions heard. If you could explain to us the importance of skepticism in the scientific process, that that is, indeed, very important and specifically how the peer review process works, which leads to these academic journals and studies?

Admiral TITLEY. I mean, skepticism is what drives science. I mean, very frankly, it is what drives science. It is people who ask different questions in different ways. They either get inspired. They come up with a new dataset. They see a way to use a new dataset. And that can sometimes challenge the very orthodoxy. I mean, you look at Darwin, who challenged the very orthodoxy.

As far as the peer review, the peer review doesn't mean that this is the final settled science, but it does mean there is a logical flow. It means that the scientist or the author has, in fact, correctly taken a look at his or her field previously and documented that. The methods are clear, and the conclusions are consistent with the evidence that was presented.

It may not be the final word, but it is sort of that Good Housekeeping Seal of Approval, if you will. So that if you are reading from another field or if you are policymaker, if you understand it is peer reviewed, there is some sort of certification or quality control. It may not be perfect, but over time, it is a pretty good process.

Senator PETERS. So these papers aren't based on dogma. It is a very robust scientific process that has significant review by peers who have expertise in the area?

Admiral TITLEY. Senator, in my opinion, the vast majority of papers are based on data and not dogma.

Senator PETERS. Doctor—or Admiral Titley as well, what do we understand about the natural phenomena that has contributed to

warming from the last 150 years versus effect of carbon that humans have released? We have heard that from some of our other panelists that there is other natural phenomena. Could you kind of dive into that a little more and give us a better sense of what we know about humans' impact?

Admiral TITLEY. Yes, sir. The humans' impact is really primarily, although not exclusively, from greenhouse gases. Land use also has an impact. Agriculture has an impact. But primarily, it is our energy uses, fossil fuels. And what they are doing is putting billions of tons of greenhouse gases into the atmosphere.

So even though in absolute terms, 400 parts per million doesn't sound like that much, compared to where we started the pre-Industrial Revolution at about 275, 280 parts per mission, it is a significant increase. And we are seeing those effects. We are seeing the temperatures come up, but we are also seeing the rainfall come up. A warmer atmosphere has a potential to hold, if you will, more water vapor. So when it rains, it can rain harder.

The temperatures are melting the ice. We have already talked about, I believe, with Senator Schatz, the sea level or the thermal expansion. So we are seeing all these different independent lines of evidence. And since we built human civilization based on climate stability, that is the challenge that we have.

We now have to adapt. And I think I have heard some of the other panelists say we need to adapt. So we are going to have to adapt to the climate changes that are coming that we cannot stop, but at the same time, we need to figure out how not to drive over the cliff, how to change ourselves so that all we have is a bumpy ride, put your seatbelts on, and we will be OK.

But if we don't get serious with this, we could have a very, very rough ride, indeed.

Senator PETERS. Well, hopefully, that is where we will spend time in this committee in the future is thinking through how do we adapt, how do we design policy prescriptions to what is a complex, but potentially dangerous change in the climate.

I want to go back because I didn't hear the response, I think Dr. Happer talked about carbon dioxide, and I just want to have opportunity for you to respond, Dr. Titley. Is that we know that there have been periods in Earth's history prior to the evolution of photosynthesis, I believe, when carbon dioxide levels in the atmosphere were much higher than they are now.

Can you talk about what the Earth was like in times past when carbon dioxide levels were much higher and what that might mean for us now? And you heard Dr. Happer's testimony. Perhaps your response would be helpful now.

Admiral TITLEY. Yes, sir. There certainly have been times in the past where carbon dioxide levels have been much, much higher, but there weren't modern humans, and there certainly weren't billions of humans. So our challenge is how do we deal with these new rises in carbon dioxide with 7, 8 billion people onboard?

The plants—certainly, in general, plants do better, but so do the weeds. So if you are looking at agriculture, what you have to deal with is not only are the plants that you want to grow are going to do better, the weeds are going to grow better, but they are going to do so in a hotter environment.

Do you start crossing thresholds, either not only daytime thresholds, nighttime thresholds? Does it mess up with the germination? Does it mess up with the pollination? Where are you going to get the water from if you have changed the basic water cycle?

So all of those issues become a great challenge, and you need to be able to look at the entire system of agriculture in a changing climate to see where the risks are and where the challenges are.

Senator PETERS. Well, I think those are important points, Dr. Titley, and I would actually like to enter in the record two studies, one in 2006 by Stephen Long and another study here by Samuel Myers, also has a little different perspective on CO_2 levels than what we heard in testimony today.

If I could introduce that in the record, Mr. Chairman?

Senator CRUZ. Without objection, they will be made part of the record.

[The information referred to follows:]

LETTER

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Increasing CO_2 threatens human nutrition

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Dietary deficiencies of zinc and iron are a substantial global public health problem. An estimated two billion people suffer these deficiencies[1], causing a loss of 63 million life-years annually[2,3]. Most of these people depend on C_3 grains and legumes as their primary dietary source of zinc and iron. Here we report that C_3 grains and legumes have lower concentrations of zinc and iron when grown under field conditions at the elevated atmospheric CO_2 concentration predicted for the middle of this century. C_3 crops other than legumes also have lower concentrations of protein, whereas C_4 crops seem to be less affected. Differences between cultivars of a single crop suggest that breeding for decreased sensitivity to atmospheric CO_2 concentration could partly address these new challenges to global health.

In the 1990s, several investigators found that elevated atmospheric CO_2 concentration (hereafter abbreviated to $[CO_2]$) decreased the concentrations of zinc, iron and protein in grains of wheat[4–7], barley[5] and rice[8] grown in controlled-environment chambers. However, subsequent studies failed to replicate these results when plants were grown in open-top chambers and free-air CO_2 enrichment (FACE) experiments. A previous study[9] found no effect of $[CO_2]$ on the concentrations of zinc or iron in rice grains grown under FACE and suggested that the earlier findings had been influenced by 'pot effects', by which a small rooting volume led to nutrient dilution at the root–soil interface. Of the more recent studies[10–13], most have indicated lower elemental concentrations in soybeans[10], sorghum[10], potatoes[11], wheat[12] or barley[13] grown at elevated $[CO_2]$, but with the exception of iron in one study on wheat[12], these results were statistically insignificant, perhaps because of small sample sizes.

Small sample sizes have limited the statistical power of individual studies of many aspects of plant responses to elevated $[CO_2]$, and meta-analyses involving larger samples of genotypes, environmental conditions and experimental locations have been important in resolving which elements of plant function respond reliably to altered $[CO_2]$[14,15]. A recent meta-analysis of published data concluded that only sulphur is decreased in grains grown at elevated $[CO_2]$[16].

Here we report findings from a meta-analysis of newly acquired data from 143 comparisons of the edible portions of crops grown at ambient and elevated $[CO_2]$ from seven different FACE experimental locations in Japan, Australia and the United States involving six food crops (see Table 1). We tested the nutrient concentrations of the edible portions of rice (*Oryza sativa*, 18 cultivars), wheat (*Triticum aestivum*, 8 cultivars), maize (*Zea mays*, 2 cultivars), soybeans (*Glycine max*, 7 cultivars), field peas (*Pisum sativum*, 5 cultivars) and sorghum (*Sorghum bicolor*, 1 cultivar). In all, forty-one genotypes were tested over one to six growing seasons at ambient and elevated $[CO_2]$, where the latter was in the range 546–586 p.p.m. across all seven study sites. Collectively, these experiments contribute more than tenfold more data regarding both the zinc and iron content of the edible portions of crops grown under FACE conditions than is currently available in the literature. Consistent with earlier meta-analyses of other aspects of plant function under FACE conditions[14,15], we considered the response comparisons observed from different species, cultivars and stress treatments and from different years to be independent. The natural logarithm of the mean response ratio (r = response in elevated $[CO_2]$/response in ambient $[CO_2]$) was used as the metric for all analyses. Meta-analysis was used to estimate the overall effect of elevated $[CO_2]$ on the concentration of each nutrient in a particular crop and to determine the significance of this effect (see Methods).

We found that elevated $[CO_2]$ was associated with significant decreases in the concentrations of zinc and iron in all C_3 grasses and legumes (Fig. 1 and Extended Data Table 1). For example, wheat grains grown at elevated $[CO_2]$ had 9.3% lower zinc (95% confidence interval (CI) −12.7% to −5.9%) and 5.1% lower iron (95% CI −6.5% to −3.7%) than those grown at ambient $[CO_2]$. We also found that elevated $[CO_2]$ was associated with lower protein content in C_3 grasses, with a 6.3% decrease (95% CI −7.5% to −5.2%) in wheat grains and a 7.8% decrease (95% CI −8.9% to −6.8%) in rice grains. Elevated $[CO_2]$ was associated with a small decrease in protein in field peas, and there was no significant effect in soybeans or C_4 crops (Fig. 1 and Extended Data Table 1).

In addition to our own observations, we obtained data from 10 of 11 previously published studies investigating nutrient changes in the edible portion of food crops (Extended Data Table 6) and combined these data with our own observations in a larger meta-analysis. Analysis of our results combined with previously published FACE data (Extended Data Table 2), or combined with previously published data from both FACE and chamber experiments (Extended Data Table 3), was consistent with the results obtained using only our new data. Combining our data with previously published data did not alter the significance or substantially alter the effect size of the nutrient changes for any crop or any nutrient.

In addition to nutrient concentrations, we also measured phytate, a phosphate storage molecule present in most plants that inhibits the absorption of dietary zinc in the human gut[17]. We had no a priori reason to assume that phytate concentrations would change in response to rising $[CO_2]$. However, formulae for calculating absorbed, or bioavailable, zinc depend on both the amount of dietary zinc and the amount of dietary phytate consumed[17], making it important to interpret changes in zinc concentration in the context of possible changes in phytate. Phytate content decreased significantly at elevated $[CO_2]$ only in wheat ($P < 0.01$). This decrease might offset some of the declines in zinc for this particular crop, although the decrease was slightly less than half of the decrease in zinc. For other crops examined, however, the lack of a concurrent decrease in phytate may further exacerbate problems of zinc deficiency.

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Table 1 | Characteristics of agricultural experiments

Crops	Country	Treatments used	Years grown	Number of replicates	Number of cultivars	CO_2 ambient/elevated (p.p.m.)
Wheat						
Site 1	Australia	2 water levels, 2 nitrogen treatments, 2 sowing times	2007–2010	4	8	382/546–550
Site 2	Australia	1 water level, 1 nitrogen treatment, 2 sowing times	2007–2009	4	1	382/546–550
Field peas	Australia	2 water levels	2010	4	5	382/546–550
Rice						
Site 1	Japan	1 nitrogen treatment, 2 warming treatments	2007–2008	3	3	376–379/570–576
Site 2	Japan	3 nitrogen treatments, 2 warming treatments	2010	4	18	386/584
Maize	United States	2 nitrogen treatments	2008	4	2	385/550
Soybeans	United States	1 treatment	2001, 2002, 2004, 2006–2008	4	7	372–385/550
Sorghum	United States	2 water levels	1998–1999	4	1	363–373/556–579

'Number of replicates' refers to the number of identical cultivars grown under identical conditions in the same year and location but in separate FACE rings.

The global $[CO_2]$ in the atmosphere is expected to reach 550 p.p.m. in the next 40–60 years, even if further actions are taken to decrease emissions[18]. At these concentrations, we find that the edible portions of many of the key crops for human nutrition have decreased nutritional value when compared with the same plants grown under identical conditions but at the present ambient $[CO_2]$. Analysis of the United Nations' Food and Agriculture Organization food balance sheets reveals that in 2010 roughly 2.3 billion people were living in countries whose populations received at least 60% of their dietary zinc and/or iron from C_3 grains and legumes, and 1.9 billion lived in countries that received at least 70% of one or both of these nutrients from these crops (Extended Data Table 5). Reductions in the zinc and iron content of the edible portion of these food crops will increase the risk of zinc and iron deficiencies across these populations and will add to the already considerable burden of disease associated with them.

The implications of decreased protein concentrations in non-leguminous C_3 crops are less clear. From a study of adult men and women in the United States, there is strong evidence that the substitution of dietary carbohydrate for dietary protein increased the risk of hypertension, lipid disorders, and 10-year coronary heart disease risk[19]. For the developing world, minimum protein requirements for different demographic groups are an area of active research and debate[20]. For countries such as India, however, in which up to one-third of the rural population is thought to be at risk of not meeting protein requirements[21] and in which most protein comes in the form of C_3 grains[21], decreased protein content in non-leguminous C_3 crops may have serious consequences for public health.

Whereas zinc and iron were significantly decreased in all C_3 crops tested, only iron in maize was observed to decrease among the C_4 crops. No changes were found in sorghum. That zinc and iron declines were notable in C_3 crops but less so in C_4 crops is consistent with differences in physiology. C_4 crops concentrate CO_2 internally, which results in photosynthesis being CO_2-saturated even under ambient $[CO_2]$ conditions, leading to no stimulation of photosynthetic carbon assimilation at elevated $[CO_2]$ levels under mesic growing conditions[22]. Our finding that protein content was less affected in legumes than in other C_3 crops is also physiologically consistent with the general ability of leguminous crops to match the stimulation of photosynthetic carbon gain at elevated $[CO_2]$ with greater nitrogen fixation, to maintain tissue carbon:nitrogen (C:N) ratios[23]. In contrast, most temperate non-legume C_3 crops are generally unable to extract and assimilate sufficient nitrogen from soils to maintain tissue C:N ratios[24,25].

Little is known about the mechanism(s) responsible for the decline in nutrient concentrations associated with elevated $[CO_2]$. Some authors have proposed 'carbohydrate dilution', by which CO_2-stimulated carbohydrate production by plants dilutes the rest of the grain components[26]. To test this hypothesis, we measured concentrations of additional elements for all crops except wheat (Extended Data Table 4). Our findings were inconsistent with carbohydrate dilution operating alone. If only

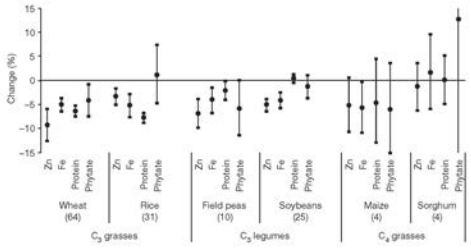

Figure 1 | Percentage change in nutrients at elevated $[CO_2]$ relative to ambient $[CO_2]$. Numbers in parentheses refer to the number of comparisons in which replicates of a particular cultivar grown at a specific site under one set of growing conditions in one year at elevated $[CO_2]$ have been pooled and for which mean nutrient values for these replicates are compared with mean values for identical cultivars under identical growing conditions except grown at ambient $[CO_2]$. In most instances, data from four replicates were pooled for each value, meaning that eight experiments were combined for each comparison (see Table 1 for details of experiments). Error bars represent 95% confidence intervals of the estimates.

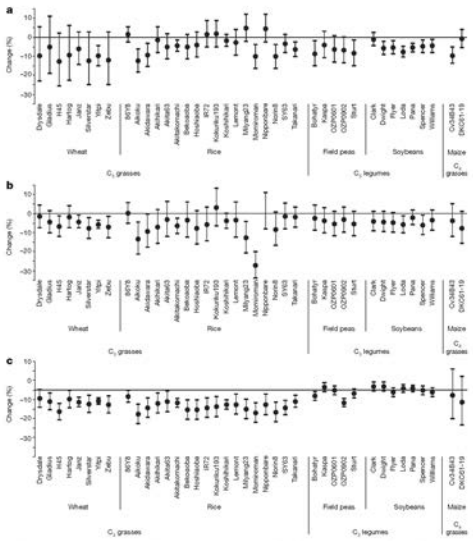

Figure 2 | Percentage change (with 95% confidence intervals) in nutrients at elevated [CO_2] relative to ambient [CO_2], by cultivar. **a**, Zinc; **b**, iron; **c**, protein.

passive dilution of nutrients were occurring, we would have expected to see very similar changes in the concentration of each nutrient tested for a given crop. In contrast, we found that elemental changes in the individual crops are distinct from each other. For example, in rice grains (Extended Data Table 4) the decrease in zinc concentrations associated with elevated [CO_2] was significantly different from the decreases in the concentrations of copper ($P \leq 0.001$), calcium ($P \leq 0.001$), boron ($P \leq 0.001$) and phosphate ($P = 0.010$). This heterogeneous response was also observed in recent analyses reviewing possible mechanisms for nutrient changes in both edible and non-edible plant tissues grown at elevated [CO_2][27]. It also seems that the mechanism(s) causing these changes operate distinctly in different species. In one instance, for example, we found boron to be significantly decreased in soybeans ($P \leq 0.001$), whereas it was significantly elevated in rice grains ($P \leq 0.001$). Although these differences may, in part, have derived from different environmental conditions, they suggest that the mechanism is more complex than carbohydrate dilution alone. Of all the elements, changes in nitrogen content at elevated [CO_2] have been the most studied, and inhibition of photorespiration and malate production[24], carbohydrate dilution[26], slower uptake of nitrogen in roots[23] and decreased transpiration-driven mass flow of nitrogen[7] may all be significant.

We also examined the effects of elevated [CO_2] on zinc, iron and protein content as a function of cultivar when data were available (Fig. 2). Whereas most crops showed negligible differences across cultivars, concentrations of zinc and iron across rice cultivars varied substantially ($P = 0.04$ and $P = 0.03$, respectively; Fig. 2a, b). Such differences between cultivars suggest a basis for breeding rice cultivars whose micronutrient levels are less vulnerable to increasing [CO_2]. Similar effects may occur in other crops, given that the statistical power of many of our other intercultivar tests was limited by sample size. We note, however, that such breeding programmes will not be a panacea for many reasons including the affordability of improved seeds and the numerous criteria used by farmers in making planting decisions that include taste, tradition, marketability, growing requirements and yield. In addition, as has been noted previously, there are likely to be trade-offs with respect to yield and other performance characteristics when breeding for increased zinc and iron content[28].

The public health implications of global climate change are difficult to predict, and we expect many surprises. The finding that raising atmospheric [CO_2] lowers the nutritional value of C_3 food crops is one such surprise that we can now better predict and prepare for. In addition to efforts to limit increases in [CO_2], it may be important to develop breeding programmes designed to decrease the vulnerability of key crops to these changes. Nutritional analysis of which human populations are most vulnerable to decreased dietary availability of zinc, iron and protein from C_3 crops could help to target response efforts, including breeding decreased sensitivity to elevated [CO_2], biofortification, and supplementation.

METHODS SUMMARY

We examined the response of nutrient levels to elevated atmospheric [CO_2] for the edible portions of rice (*Oryza sativa*, 18 cultivars), wheat (*Triticum aestivum*, 8 cultivars), maize (*Zea mays*, 2 cultivars), soybeans (*Glycine max*, 7 cultivars), field

peas (*Pisum sativum*, 5 cultivars) and sorghum (*Sorghum bicolor*, 1 cultivar). The six crops were grown under FACE conditions; in all six experiments the elevated $[CO_2]$ was in the range 546–586 p.p.m.

In accordance with methods described previously[2,8,13], the natural logarithm of the response ratio (r = response in elevated $[CO_2]$/response in ambient $[CO_2]$) was used as the metric for analyses and is reported as the mean percentage change ($100 \times (r - 1)$) at elevated $[CO_2]$. Consistent with these earlier analyses of multiple species grown under FACE conditions, the responses of different species, cultivars and stress treatments and from different years of the FACE experiments were considered to be independent and suited to meta-analytic analysis[14].

The meta-analysis was designed to estimate the effect of elevated $[CO_2]$ on the concentration of each nutrient in a particular crop and to determine the significance of this effect relative to a null hypothesis of no change. All tests were conducted as two-sided; that is, not specifying which direction the nutrient concentrations were expected to change under elevated $[CO_2]$. Meta-analysis was conducted with a linear mixed model.

Parameter estimates were obtained by the restricted maximum-likelihood method, a standard approach for analysing repeated measurements[29] that, in our case, were of nutrient concentrations at the time of harvest. Results for all analyses are reported as the best estimate of percentage changes in the concentration of nutrients along with the 95% confidence intervals associated with each estimate. Two tailed P values are also reported.

Online Content Any additional Methods, Extended Data display items and Source Data are available in the online version of the paper; references unique to these sections appear only in the online paper.

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1. Tulchinsky, T. H. Micronutrient deficiency conditions: global health issues. *Public Health Rev.* **32,** 243–255 (2010).
2. Caulfield, L. E. & Black, R. E. in *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attribution to Selected Major Risk Factors* (eds Ezzati, M., Lopez, A. D., Rodgers, A. & Murray, C. J. L.) Vol. 1, Ch. 5 (World Health Organization, 2004).
3. Stoltzfus, R. J., Mullany, L. & Black, R. E. in *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attribution to Selected Major Risk Factors* (eds Ezzati, M., Lopez, A. D., Rodgers, A. & Murray, C. J. L.) Vol. 1, Ch. 3 (World Health Organization, 2004).
4. De la Puente, L. S., Pérez, P. P., Martínez-Carrasco, R., Morcuende, R. M. & Del Molino, I. M. M. Action of elevated CO_2 and high temperatures on the mineral chemical composition of two varieties of wheat. *Agrochimica* **44,** 221–230 (2000).
5. Manderscheid, R., Bender, J., Jäger, H. J. & Weigel, H. J. Effects of season long CO_2 enrichment on cereals. II. Nutrient concentrations and grain quality. *Agric. Ecosyst. Environ.* **54,** 175–185 (1995).
6. Fangmeier, A., Grüters, U., Högy, P., Vermehren, B. & Jäger, H.-J. Effects of elevated CO_2, nitrogen supply and tropospheric ozone on spring wheat. II. Nutrients (N, P, K, S, Ca, Mg, Fe, Mn, Zn). *Environ. Pollut.* **96,** 43–59 (1997).
7. Pleijel, H. *et al.* Effects of elevated carbon dioxide, ozone and water availability on spring wheat growth and yield. *Physiol. Plant.* **108,** 61–70 (2000).
8. Seneweera, S. P. & Conroy, J. P. Growth, grain yield and quality of rice (*Oryza sativa* L.) in response to elevated CO_2 and phosphorus nutrition. *Soil Sci. Plant Nutr.* **43,** 1131–1136 (1997).
9. Lieffering, M., Kim, H.-Y., Kobayashi, K. & Okada, M. The impact of elevated CO_2 on the elemental concentrations of field-grown rice grains. *Field Crops Res.* **88,** 279–286 (2004).
10. Prior, S. A., Runion, G. B., Rogers, H. H. & Torbert, H. A. Effects of atmospheric CO_2 enrichment on crop nutrient dynamics under no-till conditions. *J. Plant Nutr.* **31,** 758–773 (2008).
11. Högy, P. & Fangmeier, A. Atmospheric CO_2 enrichment affects potatoes. 2. Tuber quality traits. *Eur. J. Agron.* **30,** 85–94 (2009).
12. Högy, P. *et al.* Effects of elevated CO_2 on grain yield and quality of wheat: results from a 3-year free-air CO_2 enrichment experiment. *Plant Biol.* **11,** 60–69 (2009).
13. Erbs, M. *et al.* Effects of free-air CO_2 enrichment and nitrogen supply on grain quality parameters and elemental composition of wheat and barley grown in a crop rotation. *Agric. Ecosyst. Environ.* **136,** 59–68 (2010).
14. Ainsworth, E. A. & Long, S. P. What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytol.* **165,** 351–372 (2005).
15. Curtis, P. S. & Wang, X. A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. *Oecologia* **113,** 299–313 (1998).
16. Duval, B. D., Blankinship, J. C., Dijkstra, P. & Hungate, B. A. CO_2 effects on plant nutrient concentration depend on plant functional group and available nitrogen: a meta-analysis. *Plant Ecol.* **213,** 505–521 (2012).
17. Miller, L. V., Krebs, N. F. & Hambidge, M. K. A mathematical model of zinc absorption in humans as a function of dietary zinc and phytate. *J. Nutr.* **137,** 135–141 (2007).
18. Fisher, B. S. *et al.* in *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change* (eds Metz, B. *et al.*) 169–250 (Cambridge Univ. Press, 2007).
19. Appel, L. J. *et al.* Effects of protein, monounsaturated fat, and carbohydrate intake on blood pressure and serum lipids: results of the OmniHeart randomized trial. *J. Am. Med. Assoc.* **294,** 2455–2464 (2005).
20. Millward, D. Joe. Identifying recommended dietary allowances for protein and amino acids: a critique of the 2007 WHO/FAO/UNU report. *Br. J. Nutr.* **108,** S3–S21 (2012).
21. Swaminathan, S., Vaz, M. & Kurpad, A. V. Protein intakes in India. *Br. J. Nutr.* **108,** S50–S58 (2012).
22. Leakey, A. Rising atmospheric carbon dioxide concentration and the future of C_4 crops for food and fuel. *Proc. R. Soc. Lond. B* **276,** 2333–2343 (2009).
23. Rogers, A., Ainsworth, E. A. & Leakey, A. D. Will elevated carbon dioxide concentration amplify the benefits of nitrogen fixation in legumes? *Plant Physiol.* **151,** 1009–1016 (2009).
24. Bloom, A. J. *et al.* CO_2 enrichment inhibits shoot nitrate assimilation in C_3 but not C_4 plants and slows growth under nitrate in C_3 plants. *Ecology* **93,** 355–367 (2012).
25. Leakey, A. D. *et al.* Elevated CO_2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *J. Exp. Bot.* **60,** 2859–2876 (2009).
26. Gifford, R., Barrett, D. & Lutze, J. The effects of elevated $[CO_2]$ on the C:N and C:P mass ratios of plant tissues. *Plant Soil* **224,** 1–14, 10.1023/A:1004790612630 (2000).
27. McGrath, J. M. & Lobell, D. B. Reduction of transpiration and altered nutrient allocation contribute to nutrient decline of crops grown in elevated CO_2 concentrations. *Plant Cell Environ.* **36,** 697–705, 10.1111/pce.12007 (2013).
28. Monasterio, I. & Graham, R. D. Breeding for trace minerals in wheat. *Food Nutr. Bull.* **21,** 392–396 (2000).
29. Searle, S. R., Casella, G. & McCulloch, C. E. *Variance Components* (Wiley, 1992).

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Author Contributions S.S.M. conceived the overall project and drafted the manuscript. A.Z., I.K., J.S. and P.H. performed statistical analyses. P.H. and A.D.B.L. provided substantial input into methods descriptions. A.J.B., E.C. and V.R. analysed grain samples for nutrient content. G.F., T.H., A.D.B.L., R.L.N., M.J.O., H.S., S.S., M.T. and Y.U. conducted FACE experiments and supplied grain for analysis. N.M.H. and P.H. assisted with elements of experimental design. K.A.S. and L.H.D. assisted with data collection and analysis. All authors contributed to manuscript preparation.

Author Information Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to S.S.M. (smyers@hsph.harvard.edu).

METHODS

We examined the response of nutrient levels to elevated atmospheric [CO_2] for the edible portions of rice (*Oryza sativa*, 18 cultivars), wheat (*Triticum aestivum*, 8 cultivars), maize (*Zea mays*, 2 cultivars), soybeans (*Glycine max*, 7 cultivars), field peas (*Pisum sativum*, 5 cultivars) and sorghum (*Sorghum bicolor*, 1 cultivar). The six crops were grown under FACE conditions; in all six experiments, the elevated [CO_2] was in the range 546–586 p.p.m. (see the Agricultural Methods section below for details associated with individual trials).

Statistics. In accordance with methods described previously[14,15], the natural logarithm of the response ratio (r = response in elevated [CO_2]/response in ambient [CO_2]) was used as the metric for analyses and is reported as the mean percentage change ($100 \times (r - 1)$) at elevated [CO_2]. Consistent with these earlier analyses of multiple species grown under FACE conditions, the responses of different species, cultivars and stress treatments and from different years of the FACE experiments were considered to be independent and suited to meta-analytic analysis[14].

The meta-analysis was designed to estimate the overall effect of elevated [CO_2] on the concentration of each nutrient in a particular crop and to determine the significance of this effect relative to a null hypothesis of no change. All tests were conducted as two-sided—not specifying which direction the nutrient concentrations were expected to change under elevated [CO_2]—to make the analysis as general as possible. Meta-analysis was conducted with a linear mixed model. A random intercept was included for each comparison, representing nutrient level variability unrelated to [CO_2] that was common to both treatment groups. Additional analyses indicated that the effect of [CO_2] on zinc concentration in rice was modified by cultivar and amount of nitrogen application, suggesting systematic variations across the pooled analysis of rice, and for these samples it was shown that the effect on zinc concentration was still significant when including interactions terms for cultivar and nitrogen. No other significant modifications of the [CO_2] effect were identified. We tested whether changes in different nutrients for particular crops were statistically different from each other, as has been described[30]. To address the issue of multiple comparisons when testing for differences between cultivars within a crop, we multiplied the P value by the number of independent comparisons. This approach follows the so-called Bonferroni correction and is conservative in the sense of biasing the P values high, but still shows that individual test results are significant despite their having been selected from multiple tests.

Parameter estimates were obtained by the restricted maximum-likelihood method, a standard approach for analysing repeated measurement data[29] that, in our case, were of nutrient concentrations at time of harvest. Results for all analyses are reported as the best estimate of percentage changes in the concentration of nutrients along with the 95% confidence intervals associated with each estimate. Two-tailed P values are also reported.

When combining our data with previously published data, we defined outliers as pairs in which the difference between an observation at ambient [CO_2] and elevated [CO_2] was at least three times the standard deviation from the mean differences for that crop and nutrient type when calculated using all observations. Using this criterion, we excluded a total of two pairs of previously published data from all analyses; these included one observation of iron in rice and one observation of zinc in potato.

Agricultural methods. Rice (*Oryza sativa*, 18 cultivars), wheat (*Triticum aestivum*, 8 cultivars), maize (*Zea mays*, 2 cultivars), soybeans (*Glycine max*, 7 cultivars), field peas (*Pisum sativum*, 4 cultivars) and sorghum (*Sorghum bicolor*, 1 cultivar) were grown under FACE conditions during daylight hours. The experiments were conducted in Australia, Japan and the United States between 1998 and 2010. Ambient [CO_2] ranges were between 363 and 386 p.p.m.; elevated [CO_2] was between 546 and 584 p.p.m. With the exception of soybeans, each experiment involved multiple cultivars of each crop and more than one set of growing conditions. Each experiment for each cultivar and set of treatments was replicated four times, with the exception of one of the rice sites, for which three replicates were performed. These data are summarized in Table 1, and additional details of the soil and growing conditions, FACE methods and experimental designs have been published for rice[31], wheat[32], maize[33], soybeans[34], field peas[35] and sorghum[35].

Minerals method. Samples were analysed for minerals by heated closed-vessel digestion/dissolution with nitric acid and hydrogen peroxide followed by quantification with an inductively coupled plasma atomic emission spectrometer[36]. Nitrogen content was measured by flash combustion of the sample coupled with thermal conductivity/infrared detection of the combustion gases (N_2, NO_x and CO_2) with a LECO TruSpec CN Analyzer[37]. Protein values are based on measurement of nitrogen and conversion to protein with the equation below, where $k = 5.36$ (ref. 38):

$$\text{protein (weight \%)} = k \times \text{nitrogen (weight \%)}$$

For phytic acid determination, a modified version of the method of ref. 39 was used. The accuracy of the method was monitored by the inclusion of tissue standards of known and varying levels of phytic acid[40].

Dietary calculations. The United Nations Food and Agriculture Organization (UNFAO) publishes annual Food Balance Sheets, which provide country-specific data on the quantities of 95 'standardized' food commodities available for human consumption. Data, expressed in terms of dietary energy (kilocalories per person per day) were downloaded for 210 countries and territories with available information for the period 2003–2007 (available at http://faostat.fao.org). The percentage of dietary energy available from C_3 grasses (wheat, barley, rye, oats, rice and 'cereals, other' (excluding *Eragrostis tef*)) was calculated globally with estimates weighted by national population size (188 countries available; UN 2011; 2012 revision available at http://esa.un.org/wpp/).

Dietary intake data from the UNFAO Food Balance Sheets (to year 2000) and food composition data from the United States Department of Agriculture National Nutrient Database for Standard Reference were used to calculate per-person nutrient intake for 95 food items; these were shared with us with permission[41]. This data set was used to calculate the contribution of each food item to total dietary zinc and iron intake, and the proportions of all food items derived from C_3 grains and legumes were summed to identify countries that are highly dependent on plant sources of iron and zinc (Extended Data Table 5).

30. Schenker, N. & Gentleman, J. F. On judging the significance of differences by examining the overlap between confidence intervals. *Am. Stat.* **55,** 182–186 (2001).
31. Hasegawa, T. *A. et al.* Rice cultivar responses to elevated CO_2 at two free-air CO_2 enrichment (FACE) sites in Japan. *Funct. Plant Biol.* **40,** 148–159 (2013).
32. Mollah, M., Norton, R. & Huzzey, J. Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facility: design and performance. *Crop Pasture Sci.* **60,** 697–707 (2009).
33. Markelz, R., Strellner, R. & Leakey, A. Impairment of C_4 photosynthesis by drought is exacerbated by limiting nitrogen and ameliorated by elevated CO_2 in maize. *J. Exp. Bot.* **62,** 3235–3246 (2011).
34. Gillespie, K. *et al.* Greater antioxidant and respiratory metabolism in field-grown soybean exposed to elevated O_3 under both ambient and elevated CO_2. *Plant Cell Environ.* **35,** 169–184 (2012).
35. Ottman, M. J. *et al.* Elevated CO_2 increases sorghum biomass under drought conditions. *New Phytol.* **150,** 261–273 (2001).
36. Sah, R. N. & Miller, R. O. Spontaneous reaction for acid dissolution of biological tissues in closed vessels. *Anal. Chem.* **64,** 230–233 (1992).
37. *AOAC* Official Method 972.43. in *Official Methods of Analysis of AOAC International, 18th edition, Revision 1, 2006* Ch. 12 5–6 (AOAC International, 2006).
38. Mosse, J. Nitrogen to protein conversion factor for ten cereals and six legumes or oilseeds. A reappraisal of its definition and determination. Variation according to species and to seed protein content. *J. Agric. Food Chem.* **38,** 18–24 (1990).
39. Haug, W. & Lantzsch, H. J. Sensitive method for the rapid determination of phytate in cereals and cereal products. *J. Sci. Food Agric.* **34,** 1423–1426 (1983).
40. Raboy, V. *et al.* Origin and seed phenotype of maize *low phytic acid 1-1* and *low phytic acid 2-1*. *Plant Physiol.* **124,** 355–368 (2000).
41. Wuehler, S. E., Peerson, J. M. & Brown, K. H. Use of national food balance data to estimate the adequacy of zinc in national food supplies: methodology and regional estimates. *Public Health Nutr.* **8,** 812–819 (2005).

Extended Data Table 1 | Percentage change in nutrient content at elevated [CO_2] relative to ambient [CO_2]

	N* (number of pairs)	Zn (µg/g)			Fe (µg/g)			Protein (mg/g)			Phytate (g/100g)		
		%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value
C3 grasses													
Wheat	64	-9.3	(-12.7,-5.9)	<.0001	-5.1	(-6.5,-3.7)	<.0001	-6.3	(-7.5,-5.2)	<.0001	-4.2	(-7.5,-0.8)	0.009
Rice	31	-3.3	(-5.0,-1.7)	<.0001	-5.2	(-7.6,-2.9)	<.0001	-7.8	(-8.9,-6.8)	<.0001	1.2	(-4.6,7.4)	0.697
C3 legumes													
Field peas	10	-6.8	(-9.8,-3.8)	0.002	-4.1	(-6.7,-1.4)	0.003	-2.1	(-4.0,-0.1)	0.039	-5.8	(-11.5,0.1)	0.055
Soybeans	25	-5.1	(-6.4,-3.9)	<.0001	-4.1	(-5.8,-2.5)	<.0001	0.5	(-0.4,1.3)	0.267	-1.3	(-3.7,1.2)	0.303
C4 grasses													
Maize	4	-5.2	(-10.7,0.6)	0.077	-5.8	(-10.9,-0.3)	0.038	-4.6	(-13.0,4.5)	0.312	-6.1	(-15.0,3.7)	0.215
Sorghum	4	-1.3	(-6.2,3.8)	0.603	1.6	(-5.8,9.7)	0.674	0.0	(-4.9,5.2)	0.993	12.8	(-15.8,51.1)	0.418

* 'Number of pairs' refers to the number of comparisons in which replicates of a particular cultivar grown at a specific site under one set of growing conditions in one year at elevated [CO_2] have been pooled and mean nutrient values for these replicates were compared with mean values for identical cultivars under identical growing conditions except grown at ambient [CO_2]. In most instances, data from four replicates were pooled for each value, meaning that eight experiments were combined for each comparison (see Table 1 for details of experiments).

Extended Data Table 2 | Original data combined with previously published FACE data from studies 3, 4, 6 and 7

	N* (number of pairs)	Zn (µg/g)			Fe (µg/g)			Protein (mg/g)		
		%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value
C3 grasses										
Wheat	70	-8.8	(-11.9,-5.6)	<.0001	-5.5	(-6.8,-4.1)	<.0001	-6.5	(-7.5,-5.4)	<.0001
Rice	32	-3.1	(-4.8,-1.5)	<.0001	-4.9	(-7.3,-2.6)	<.0001	-8	(-9.0,-6.9)	<.0001
Barley	4	-11.4	(-19.3,-2.7)	0.012	-10.5	(-12.2,-8.7)	<.0001	-11.9	(-13.1,-10.7	<.0001
C3 legumes										
Field peas	10	-6.8	(-9.8,-3.8)	0.002	-4.1	(-6.7,-1.4)	0.003	-2.1	(-4.0,-0.1)	0.039
Soybeans	25	-5.1	(-6.4,-3.9)	<.0001	-4.1	(-5.8,-2.5)	<.0001	0.5	(-0.4,1.3)	0.267
C_3 tubers										
Potato	2	-3.9	(-12.9,6.2)	0.440	2.3	(-3.8,8.7)	0.472	-4.6	(-7.7,-1.4)	<.0001
C4 grasses										
Maize	4	-5.2	(-10.7,0.6)	0.077	-5.8	(-10.9,-0.3)	0.038	-4.6	(-13.0,4.5)	0.312
Sorghum	4	-1.3	(-6.2,3.8)	0.603	1.6	(-5.8,9.7)	0.674	0.0	(-4.9,5.2)	0.993

See Extended Data Table 6 for a list of experiments. Percentage change in nutrient content at elevated [CO_2] relative to ambient [CO_2].
* 'Number of pairs' refers to the number of comparisons in which replicates of a particular cultivar grown at a specific site under one set of growing conditions in one year at elevated [CO_2] have been pooled and mean nutrient values for these replicates were compared with mean values for identical cultivars under identical growing conditions except grown at ambient [CO_2]. In most instances, data from four replicates were pooled for each value, meaning that eight experiments were combined for each comparison (see Table 1 for details of experiments).

Extended Data Table 3 | Original data combined with previously published FACE and chamber data from studies 1–10

	N* (number of pairs)	Zn (µg/g)			Fe (µg/g)			Protein (mg/g)		
		%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value
C3 grasses										
Wheat	78	-9.1	(-12.1,-6.1)	<.0001	-5.9	(-7.8,-4.0)	<.0001	-7.2	(-8.6,-5.8)	<.0001
Rice	32	-3.1	(-4.8,-1.5)	<.0001	-4.9	(-7.3,-2.6)	<.0001	-8	(-9.0,-6.9)	<.0001
Barley	6	-13.6	(-19.3,-7.6)	<.0001	-10.0	(-12.4,-7.4)	<.0001	-15.0	(-19.1,-10.7	<.0001
C3 legumes										
Field peas	10	-6.8	(-9.8,-3.8)	<.0001	-4.1	(-6.7,-1.4)	0.003	-2.1	(-4.0,-0.1)	0.039
Soybeans	28	-5.0	(-6.1,-3.9)	<.0001	-5.2	(-7.9,-2.5)	<.0001	0.1	(-0.8,0.9)	0.865
C_3 tubers										
Potato	5	-10.0	(-20.9,2.4)	0.110	-4.1	(-16.6,10.3)	0.555	-9.7	(-15.9,-3.1)	0.005
C4 grasses										
Maize	4	-5.2	(-10.7,0.6)	0.077	-5.8	(-10.9,-0.3)	0.038	-4.6	(-13.0,4.5)	0.312
Sorghum	7	-0.6	(-4.5,3.4)	0.764	33.8	(-10.2,99.3)	0.153	-5.6	(-12.7,2.1)	0.150

See Extended Data Table 6 for a list of experiments. Percentage change in nutrient content at elevated [CO_2] relative to ambient [CO_2].
* 'Number of pairs' refers to the number of comparisons in which replicates of a particular cultivar grown at a specific site under one set of growing conditions in one year at elevated [CO_2] have been pooled and mean nutrient values for these replicates were compared with mean values for identical cultivars under identical growing conditions except grown at ambient [CO_2]. In most instances, data from four replicates were pooled for each value, meaning that eight experiments were combined for each comparison (see Table 1 for details of experiments).

Extended Data Table 4 | Percentage change in nutrient content at elevated [CO_2] compared with ambient [CO_2] for all nutrients

	C3 grasses						C3 legumes						C4 grasses					
	Wheat			Rice			Field Peas			Soybean			Maize			Sorghum		
	%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value	%	95% CI	P-value
Zinc (ppm)	-9.3	(-12.7,-5.9)	<.0001	-3.3	(-5.0,-1.7)	<.0001	-6.9	(-9.6,-3.8)	<.0001	-5.1	(-6.4,-3.9)	<.0001	-5.2	(-10.7,0.4)	0.077	-1.3	(-6.2,3.8)	0.603
Iron (ppm)	-5.1	(-6.5,-3.7)	<.0001	-5.2	(-7.6,-2.9)	<.0001	-4.1	(-6.7,-1.4)	<.0001	-4.1	(-5.8,-2.5)	<.0001	-5.8	(-10.9,-0.5)	0.036	1.6	(-5.8,9.7)	0.674
Phytate (mg/g)	-4.2	(-7.5,-0.8)	0.019	1.2	(-4.6,7.4)	0.7	-5.8	(-11.5,0.1)	0.055	-1.3	(-3.7,1.2)	0.303	-6.1	(-15.0,3.7)	0.215	12.0	(-15.8,51.1)	0.418
Protein	-6.3	(-7.5,-5.2)	<.0001	-7.8	(-9.8,-5.8)	<.0001	-2.1	(-4.0,-0.1)	0.039	0.5	(-0.4,1.5)	0.267	-4.6	(-13.0,4.5)	0.312	0.0	(-4.9,5.2)	0.995
Mn (ppm)				-7.5	(-12.0,-2.8)	<.0001	-2.5	(-4.2,-0.8)	0.005	-1.4	(-3.5,0.8)	0.204	-4.2	(-10.5,2.5)	0.215	1.7	(-4.5,8.3)	0.596
Mg (%)				-0.9	(-2.3,0.6)	0.24	0.0	(-1.3,1.4)	0.960	-3.5	(-4.3,-2.8)	<.0001	-5.7	(-9.9,-1.3)	0.011	-0.2	(-5.1,4.9)	0.944
Cu (ppm)				-10.6	(-13.8,-7.1)	<.0001	-2.3	(-5.1,-0.3)	0.025	-5.7	(-8.0,-3.4)	<.0001	-9.9	(-19.3,0.7)	0.066	-2.9	(-7.1,1.5)	0.190
Ca (%)				2	(-0.8,4.9)	0.16	-0.5	(-4.2,3.3)	0.787	-5.0	(-7.3,-4.2)	<.0001	-2.7	(-14.3,13.9)	0.734	11.2	(-5.2,30.3)	0.190
S (ppm)				-7.8	(-8.8,-6.8)	<.0001	-2.2	(-3.6,-0.7)	0.003	-2.9	(-3.5,-2.2)	<.0001	2.1	(-2.2,6.7)	0.342	-0.2	(-5.4,5.2)	0.956
K (%)				1.1	(-0.3,2.5)	0.13	2.2	(0.4,3.9)	0.008	0.1	(-0.8,1.0)	0.857	-2.7	(-5.1,-0.2)	<.0001	3.0	(-2.7,9.1)	0.308
B (ppm)				5.1	(1.9,8.4)	0.002	-1.9	(-3.9,0.1)	0.057	-6.4	(-9.1,-3.6)	<.0001	4.9	(-1.0,11.1)	0.107	-0.3	(-9.3,9.4)	0.952
P (%)				-3.0	(-12.4,6.4)	0.560	-3.7	(-6.6,-0.5)	0.023	-0.7	(-2.2,0.9)	0.379	-7.1	(-9.9,-4.1)	<.0001	0.3	(-4.0,4.9)	0.881

Sample sizes for each crop type are identical to those listed in Table 1.

Extended Data Table 5 | Countries whose populations receive at least 60% of dietary iron and/or zinc from C_3 grains and legumes

Country	% Iron from C_3 grains & legumes	% Zinc from C_3 grains & legumes	Population (in thousands)
Afghanistan	78%	78%	31,412
Algeria	76%	79%	35,468
Iraq	74%	83%	31,672
Bangladesh	72%	88%	148,692
Iran, Islamic Rep of	72%	77%	73,974
Pakistan	70%	72%	173,593
Tunisia	70%	77%	10,481
Jordan	69%	73%	6,187
Morocco	69%	78%	31,951
Syrian Arab Republic	67%	71%	20,411
Libya	67%	71%	6,355
Yemen	66%	75%	24,053
Myanmar	65%	81%	47,963
Tajikistan	62%	56%	6,879
India	59%	71%	1,224,614
Egypt	54%	65%	81,121
Indonesia	52%	65%	239,871
Sierra Leone	51%	70%	5,868
Cambodia	49%	68%	14,138
Sri Lanka	46%	69%	20,860
Laos	44%	66%	6,201
Viet Nam	43%	61%	87,848
Total			2,329,612

Source: United Nations Food and Agriculture Organization food balance sheets and 2010 United Nations estimated population.

Extended Data Table 6 | Literature reporting nutrient changes in the edible portion of crops grown at elevated and ambient [CO_2]

Study	Experimental Method	Associated Citations
1	Growth Chambers	Conroy , J., Seneweera, S. P., Basra, A., Rogers, G. & Nissen-Wooller, B. Influence of rising atmospheric CO_2 concentrations and temperature on growth, yield and grain quality of cereal crops. Australian Journal of Plant Physiology 21, 741-758 (1994).
		Seneweera , S., Milham, P. & Conroy, J. Influence of elevated CO_2 and phosphorus nutrition on the growth and yield of a short-duration rice. Australian Journal of Plant Physiology 21, 281-292 (1994).
		Seneweera, S. P. & Conroy, J. P. Growth, grain yield and quality of rice (Oryza sativa L.) in response to elevated CO_2 and phosphorus nutrition (Reprinted from Plant nutrition for sustainable food production and environment, 1997). Soil Sci. Plant Nutr. 43, 1131-1136 (1997).
2	Temperature Gradient Tunnels	De la Puente, L. S., Perez, P. P., Martinez-Carrasco, R., Morcuende, R. M. & Del Molino, I. M. M. Action of elevated CO_2 and high temperatures on the mineral chemical composition of two varieties of wheat. Agrochimica 44, 221-230 (2000).
3	Open Top Chambers & FACE	De Temmerman L et al. Effect of climatic conditions on tuber yield (Solanum tuberosum L.) in the European 'CHIP' experiments. European Journal of Agronomy 17, 243-255 (2002).
		De Temmerman, L., Hacour, A. & Guns, M. Changing climate and potential impacts on potato yields and quality 'CHIP': introduction, aims and methodology. European Journal of Agronomy 17, 233-242 (2002).
		Fangmeier, A., De Temmerman, L., Black, C., Persson, K. & Vorne, V. Effects of elevated CO_2 and/or ozone on nutrient concentrations and nutrient uptake of potatoes. European Journal of Agronomy 17, 353-368 (2002).
		Högy, P. & Fangmeier, A. Atmospheric CO_2 enrichment affects potatoes: 2. Tuber quality traits. European Journal of Agronomy 30, 85-94 (2009).
4	FACE	Erbs, M. et al. Effects of free-air CO_2 enrichment and nitrogen supply on grain quality parameters and elemental composition of wheat and barley grown in a crop rotation. Agriculture, Ecosystems and Environment 136, 59-68 (2010).
5	Open Top Chambers	Fangmeier, A. et al. Effects of elevated CO_2, nitrogen supply and tropospheric ozone on spring wheat. I. Growth and yield. Environmental Pollution 91, 381-390 (1996).
		Fangmeier, A., Grüters, U., Högy, P., Vermehren, B. & Jäger, H.-J. Effects of elevated CO_2, nitrogen supply and tropospheric ozone on spring wheat – II. Nutrients (N, P, K, S, Ca, Mg, Fe, Mn, Zn). Environmental Pollution 96, 43-59 (1997).
		Fangmeier, A. et al. Effects on nutrients and on grain quality in spring wheat crops grown under elevated CO_2 concentrations and stress conditions in the European, multiple-site experiment 'ESPACE-wheat'. European Journal of Agronomy 10, 215-229 (1999).
		Jäger , H.-J., Hertstein, U. & Fangmeier, A. The European Stress Physiology and Climate Experiment – project 1: wheat (ESPACE-wheat): introduction, aims and methodology. European Journal of Agronomy 10, 155-162 (1999).
6	FACE	Högy, P. & Fangmeier, A. Effects of elevated atmospheric CO_2 on grain quality of wheat. Journal of Cereal Science 48, 580-591 (2008).
		Högy, P. et al. Does elevated atmospheric CO_2 allow for sufficient wheat grain quality in the future? . Journal of Applied Botany and Food Quality 82, 114-121 (2009).
		Högy, P. et al. Effects of elevated CO_2 on grain yield and quality of wheat: results from a 3-year free-air CO2 enrichment experiment. Plant Biology 11, 60-69 (2009).
		Högy, P., Zörb, C., Langenkämper, G., Betsche, T. & Fangmeier, A. Atmospheric CO_2 enrichment changes the wheat grain proteome. Journal of Cereal Science 50, 248-254 (2009).
7	FACE	Kim , H., Lieffering, M., Miura, S., Kobayashi, K. & Okada, M. Growth and nitrogen uptake of CO_2-enriched rice under field conditions. New Phytologist 150, 223-229 (2001).
		Kim , H. et al. Effects of free-air CO_2 enrichment and nitrogen supply on the yield of temperate paddy rice crops. Field Crops Research 83, 261-270 (2003).
		Lieffering, M., Kim, H.-Y., Kobayashi, K. & Okada, M. The impact of elevated CO_2 on the elemental concentrations of field-grown rice grains. Field Crops Research 88, 279-286 (2004).
8	Open Top Chambers	Pleijel, H. et al. Effects of elevated carbon dioxide, ozone and water availability on spring wheat growth and yield. Physiologia Plantarum 108, 61-70 (2000).
		Pleijel, H. & Danielsson, H. Yield dilution of grain Zn in wheat grown in open-top chamber experiments with elevated CO_2 and O3 exposure. Journal of Cereal Science 50, 278-282 (2009).
9	Open Top Chambers	Prior, S. A., Runion, G. B., Rogers, H. H., Torbert, H. A. Effects of atmospheric CO_2 enrichment on crop nutrient dynamics under no-till conditions. Journal of Plant Nutrition 31, 758-773 (2008).
10	Open Top Chambers	Weigel, H., Manderscheid, R., Jäger, H.-J. & Mejer, G. Effects of season-long CO_2 enrichment on cereals. I. Growth performance and yield. Agriculture, Ecosystems and Environment 48, 231-240 (1994).
		Manderscheid, R., Bender, J., Jager, H., J & Weigel, H., J. Effects of season long CO_2 enrichment on cereals. II. Nutrient concentrations and grain quality. Agriculture, Ecosystems & Environment 54, 175-185 (1995).
11	FACE	Yang, L., Wang, Y., Dong, G., Gu, H., Huang, J., Zhu, J., Yang, H., Liu, G., Han, Y. The impact of free-air CO_2 enrichment (FACE) and nitrogen supply on grain quality of rice. Field Crops Research 102, 128-140 (2007).
	Meta-Analyses	Loladze, I. Rising atmospheric CO_2 and human nutrition: toward globally imbalanced plant stoichiometry? Trends in Ecology and Evolution 17 (10), 457-461 (2002). [Uses data from studies 1, 2, 5, and 10 as well as numerous other studies on non-edible tissues and plants other than food crops].
		McGrath, J. M. and Lobell, D. B. Reduction of transpiration and altered nutrient allocation contribute to nutrient decline of crops grown in elevated CO_2 concentrations. Plant, Cell, & Environment 36, 697-705 (2013). [Uses data from studies 1, 5, and 10 as well as numerous other studies on non-edible tissues and plants other than food crops].
		Duval, B.D., Blankinship, J. C., Dijkstra, P., Hungate, B. A. CO2 effects on plant nutrient concentration depend on plant functional group and available nitrogen: a meta-analysis. Plant Ecology 213, 505-521 (2012). [Uses data from studies 1,2, 3, 5, 6, and 9 as well as numerous other studies on non-edible tissues and plants other than food crops].

Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations

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Model projections suggest that although increased temperature and decreased soil moisture will act to reduce global crop yields by 2050, the direct fertilization effect of rising carbon dioxide concentration ($[CO_2]$) will offset these losses. The CO_2 fertilization factors used in models to project future yields were derived from enclosure studies conducted approximately 20 years ago. Free-air concentration enrichment (FACE) technology has now facilitated large-scale trials of the major grain crops at elevated $[CO_2]$ under fully open-air field conditions. In those trials, elevated $[CO_2]$ enhanced yield by ~50% less than in enclosure studies. This casts serious doubt on projections that rising $[CO_2]$ will fully offset losses due to climate change.

Much effort has been put into linking models of climate and crop growth to project future changes in crop yields and food supply across the globe (*1*–*4*). Projections reviewed by the Intergovernmental Panel on Climate Change (IPCC) suggest that increased temperature and decreased soil moisture, which would otherwise reduce crop yields, will be offset by the direct fertilization effect of rising carbon dioxide concentration ($[CO_2]$) (*5*–*7*). The IPCC projections suggest that total crop yield may rise when averaged across the globe, but this net gain will result from generally lower yields in the tropics and increased yields in temperate zones. The accuracy of these projections and thus future food security depend critically on the magnitude of the CO_2 fertilization effect under actual growing conditions.

Atmospheric $[CO_2]$ has risen from ~260 parts per million (ppm) approximately 150 years ago to 380 ppm today (*8*). Yet $[CO_2]$ is markedly uniform across the globe; so, in contrast to temperature and soil moisture, there is no consistent spatial variation on which to estimate yield responses to increasing $[CO_2]$. Similarly, it is not easy to alter $[CO_2]$ experimentally around a crop in the field. As a result, most information about crop responses to elevated $[CO_2]$ is obtained from studies in greenhouses, laboratory controlled-environment chambers, and transparent field chambers, where released CO_2 may be retained and easily controlled. These settings have provided the basis for projecting CO_2 fertilization effects on the major food crops: maize, rice, sorghum, soybeans, and wheat.

Crops sense and respond directly to rising $[CO_2]$ through photosynthesis and stomatal conductance, and this is the basis for the fertilization effect on yield (*9*). In C_3 plants, mesophyll cells containing ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) are in direct contact with the intercellular air space that is connected to the atmosphere via stomatal pores in the epidermis. Hence, in C_3 crops, rising CO_2 increases net photosynthetic CO_2 uptake because RuBisCO is not CO_2-saturated in today's atmosphere and because CO_2 inhibits the competing oxygenation reaction leading to photorespiration. RuBisCO is highly conserved across terrestrial plants, so instantaneous responses to increased $[CO_2]$ may be generalized across C_3 plants, including rice, soybeans, and wheat. In theory, at 25°C, an increase in $[CO_2]$ from the present-day value of 380 ppm to that of 550 ppm, projected for the year 2050, would increase C_3 photosynthesis by 38% (*9*). In contrast, in C_4 crops such as maize and sorghum, RuBisCO is localized to bundle sheath cells in which CO_2 is concentrated to three to six times atmospheric $[CO_2]$ (*10*). This concentration is sufficient to saturate RuBisCO and in theory would prevent any increase in CO_2 uptake with rising $[CO_2]$. Although C_4 crops may not show a direct response in photosynthetic activity, an indirect increase in the efficiency of water use via reduction in stomatal conductance may still increase yield (*9*).

How have CO_2 fertilization factors been derived? Most models used to predict future crop yields, including those within the IPCC (*5*), are from two families: the Decision Support System for Agrotechnology Transfer (DSSAT) (*6*, *11*, *12*) and the Erosion Productivity Impact Calculator (EPIC) (*13*–*15*). Studies using DSSAT assume CO_2 fertilization factors based on the method of Peart *et al.* (*3*), which used summaries for soybeans (*16*), maize (*17*), wheat (*18*), and rice (*18*). Studies using EPIC (*13*–*15*) assume CO_2 fertilization factors based on the method of Stockle *et al.* (*4*), which parameterized a CO_2 response function to reproduce the mean yield stimulations reported for elevated $[CO_2]$ by Kimball (*18*). Tracing DSSAT and EPIC methods back reveals that the magnitude of the CO_2 fertilization effects in these models is primarily based on data from three literature reviews from the 1980s (*16*–*18*). The CO_2 fertilization effects reported in these reviews for the major crops are given in Table 1

Table 1. Percentage increases in yield, biomass, and photosynthesis of crops grown at elevated $[CO_2]$ (550 μmol mol^{-1}) relative to ambient $[CO_2]$ in enclosure studies versus FACE experiments. Data for enclosure studies were summarized by Kimball (*18*), Cure and Acock (*17*), and Allen *et al.* (*16*) and in Fig. 2. Mean response ratios from these reviews were adjusted to an elevated $[CO_2]$ of 550 μmol mol^{-1} by means of the nonrectangular hyperbolic functions for C_3 and C_4 species from Fig. 2. The values that summarize all chamber studies shown in Fig. 2 are given in the row entitled "enclosure studies." Percentage increases for FACE studies were generated by meta-analysis [see supporting online material (SOM) and table S2] (*37*).

Source	Rice	Wheat	Soybeans	C_4 crops
		Yield		
Kimball (1983)	19	28	21	–
Cure and Acock (1986)	11	19	22	27
Allen *et al.* (1987)	–	–	26	–
Enclosure studies	–	31	32	18
FACE studies	12	13	14	0*
		Biomass		
Cure and Acock (1986)	21	24	30	8
Allen *et al.* (1987)	–	–	35	–
FACE studies	13	10	25	0*
		Photosynthesis		
Cure and Acock (1986)	35	21	32	4
FACE studies	9	13	19	6

*Data from only 1 year in Leakey *et al.* (*30*).

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after adjustment to estimate crop performance at a common [CO_2] of 550 ppm. Collectively, the fertilization factors averaged across the C_3 crops (rice, wheat, and soybeans) are 24% for yield, 27% for biomass, and 29% for photosynthesis. The responses for maize were lower except for yield, which was reported to increase by 27% (Table 1). All studies included in the reviews used enclosures, such as controlled environmental chambers, transparent field enclosures, or open-top chambers. Since the 1980s, many further chamber studies have been conducted. When these are compiled for wheat and soybeans, an even larger yield fertilization factor of 31% is suggested (Table 1). Although this is a wealth of data on which to project a CO_2 fertilization effect for crops across the globe, no agrochemical or plant-breeding company would base its business plan for a new chemical or variety solely on greenhouse studies without rigorous field trials (*19*, *20*). Yet our current projections of future world food supply are based on such potentially inadequate data.

Why might chamber studies be inadequate for predicting future yields? Many chamber studies used plants grown in pots, which are now known to alter the response of plants to elevated [CO_2] (*21*). Most of the field studies used open-topped and transparent-walled chambers, up to 2 m in diameter. Despite being partially open to the atmosphere, important environmental differences remain. In a chamber carefully designed to minimize environmental differences, receiving ~75% of full sunlight, the temperature inside the chamber was 4.3°C warmer and the water vapor pressure deficit was 0.8 kPa higher (*22*) than outside the chamber. The transmission of sunlight into the chambers was lower and the ratio of diffuse to direct sunlight increased. Other chamber types would cause even greater perturbation of the natural environment. All chambers alter air flow and intercept rainfall. Access by pests and diseases is restricted, but if they gain access, higher humidity and more shelter may accentuate epidemics. As a result, the effect of the chamber on plants is often greater than that of elevated [CO_2] (*23*). In agronomic trials, buffer rows are used between treatments; typically the width of this zone is twice the height of the crop. Because of the small practical size of chambers, most or all of the treated crop will be within this zone, which could exaggerate the response to elevated [CO_2] (*23*). To overcome these limitations, free-air concentration enrichment (FACE) was developed.

How does FACE work? A typical FACE apparatus consists of a 20-m-diameter plot within the crop field (Fig. 1A), in which CO_2 is released just above the crop surface on the upwind side of the plot. Wind direction, wind velocity, and [CO_2] (or ozone concentration) are measured at the center of the plot. Fast-feedback computer control then adjusts the positions and amount of CO_2 released at different points around the plot. These systems have been engineered so that they can operate continuously from sowing to harvest and maintain [CO_2] within the plot to within ±10% of the target level, either 550 or 600 ppm, for ~90% of the time (*9*, *24*–*26*) (Fig. 1B). Elevated [CO_2] decreases transpiration and therefore evaporative cooling, so that in sunlight the crop is warmer. This can serve to illustrate the uniformity of treatment (Fig. 1B).

Mini-FACE systems as small as 1 m in diameter have been developed and have proved invaluable in ecosystem studies where the focus is on the effect of increased input of carbon (CO_2 fertilization factor for crops. Our analysis has therefore been limited to full-size FACE systems of plots >8 m in diameter, investigating the five major global food crops and managed pasture systems (table S1): wheat at Maricopa, Arizona, USA, in 1992, 1993, 1996, and 1997; managed grassland at Eschikon, Switzerland, from 1993 to 2002; managed pasture at Bulls, New Zealand, from 1997 to 2002; sorghum at Maricopa, Arizona, USA, in 1998 and 1999; rice at Shizukuishi, Japan, from 1998 to 2000; and soybeans at Urbana-Champaign, Illinois, USA, from 2001 to 2005 and maize at the same location in 2002 and 2004 (*26*, *28*).

What have we learned from the FACE experiments? The response of plant production to [CO_2] is approximately hyperbolic, increasing linearly at subambient concentration and saturating at around 800 to 2000 ppm. The ratio of yield at treatment [CO_2] to yield at atmospheric [CO_2] was calculated for over 340 independent chamber studies. Hyperbolas of the response of yield to [CO_2] were then fit for wheat, soybeans, and C_4 grains (maize and sorghum combined) (Fig. 2). Only one replicated FACE experiment was conducted with each of these crops, but these experiments were repeated over 2 to 5 years. It was notable that for each crop, the stimulation of yield observed in FACE experiments fell well below (about half) the value predicted from chambers (Fig. 2). This was apparent for total biomass and most marked for photosynthesis. Notably, the stimulation of photosynthesis by elevated [CO_2] in enclosure studies of rice was four times the value observed in the rice FACE experiment (Table 1). With so few FACE studies, it might be thought that these lower values are the result of chance. Table 1 shows that for three key production measures in four crops, only 1 of the 12 items is not lower than the chamber equivalent. The probability of this outcome being attributed to chance is remote ($P = 0.003$).

Results from FACE experiments with C_4 crops are consistent with CO_2 having no direct effect on photosynthesis, but there may be an indirect effect through the amelioration of drought stress by reduced stomatal conductance at elevated [CO_2] (*29*–*31*). This fits the theoret-

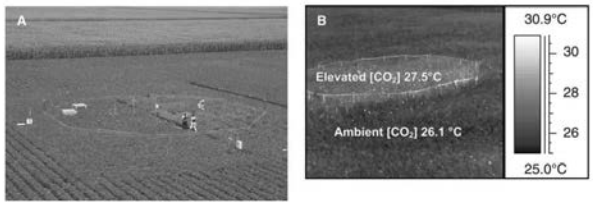

Fig. 1. (**A**) One of the 16 FACE plots of soybeans at the University of Illinois SoyFACE facility. CO_2 is released into the wind from nozzles in the green pipe, on the upwind side of the plot. Release rate is determined by wind speed and [CO_2], which is measured at the center of each ring. (**B**) The false-color infrared image provides a simple visualization of the uniformity of CO_2 treatment within a FACE plot. Here the atmosphere around a maize crop within the octagonal plot is maintained at 550 ppm [CO_2], whereas the rest of the field is at the current ambient [CO_2] of ~380 ppm. Maize growing inside an elevated [CO_2] plot was warmer in full sunlight than maize growing under ambient [CO_2] outside the plot at 15:30 on 15 July 2004. At that time, the average canopy temperature inside the four elevated [CO_2] plots at SoyFACE was 27.9 ± 0.2°C, significantly higher than canopy temperatures under ambient [CO_2] outside the plots (26.8 ± 0.3°C; $P = 0.03$). Because the pipes surrounding the plot are dry, they are warmer and so appear as white or light yellow. Greater canopy temperatures under elevated [CO_2] result from lower stomatal conductance, reducing latent heat loss by evapotranspiration and leading to lower crop water use, as described in Leakey *et al.* (*30*).

ical expectation that C_4 photosynthesis is CO_2-saturated at current atmospheric $[CO_2]$ (*10*); therefore, no yield increase would be expected for well-watered crops. Under drought, elevated $[CO_2]$ increased midday photosynthesis by 23% in sorghum (*31*). This failed to translate into a significant yield increase (*32*). On average, no significant yield increase has been observed for C_4 crops or C_4 wild grasses at elevated $[CO_2]$ in FACE studies (*28*). This is in sharp contrast to the large stimulation of yield for well-watered plants in chambers (Fig. 2B) used to parameterize models. This suggests that the consistent stimulation of C_4 crop yield by elevated $[CO_2]$ currently applied in models is inappropriate. At best, yield will in all probability be enhanced by elevated $[CO_2]$ only in times and places of drought.

Wheat and rice FACE experiments included nitrogen treatments. At the lowest [N] (15 to 70 kg of N ha^{-1}), the average yield increase with elevated $[CO_2]$ was only 9% (*28*), just over one-third of that of the chamber response (Table 1). Although this N input treatment was considered low by the standards of intensive agriculture in the European Union and United States, these levels exceed the world average and may therefore be closer to the stimulation factor for crop yields across the globe. Lower-than-expected yields under elevated $[CO_2]$ are not just confined to grain crops. For example, the major C_3 herbage grass, *Lolium perenne*, also showed a yield increase of only 9% at two locations; and at the lowest [N] (100 to 140 kg of N ha^{-1}), the yield increase was an insignificant 1% (table S2) (*28*). Although the data here apply to a single species, *L. perenne* is one of the most important and widely grown herbage grasses in the temperate zone.

No FACE experiment has been conducted in the tropics, but two factors emerging from temperate studies have particular implications for tropical crops. First, the CO_2 fertilization effect may be small without large additions of N. Second, FACE experiments with the major grain crops of sub-Saharan Africa, sorghum and maize, have so far failed to show any yield increase from elevated $[CO_2]$. Parry *et al.* (*7*) projected that yield losses in these countries due to climate change could be 10 to 30% by 2050, but these would be ameliorated to only 2.5 to 5% when the CO_2 fertilization effect is added (*7*). The FACE experiments suggest that this amelioration may be far less than expected.

Rising surface ozone. Increased combustion of fuels will increase not only atmospheric $[CO_2]$ but also atmospheric nitrogen oxide concentrations, which, when coupled with climate change, will result in a continued increase in surface ozone concentration ($[O_3]$). Many rural areas in the temperate zone of the Northern Hemisphere, as well as in the tropics, are forecast to see increases in $[O_3]$ of ~20% by midcentury (*8*). Ozone is toxic to plants at concentrations as low as 30 parts per billion (ppb). Although chamber studies have shown large yield losses owing to elevated $[O_3]$ (*33*), these effects are not incorporated in current projections of future yields (*2*, *8*).

Until very recently, the only studies of the effects of elevated $[O_3]$ on crops were conducted in chambers, and it was unclear whether similar losses would occur under conditions of normal canopy/atmosphere coupling in the field. Morgan *et al.* (*34*) used a FACE system adapted to elevate $[O_3]$ rather than $[CO_2]$ to examine whether the decreases in yield for soybeans in central Illinois projected from chamber experiments occurred in the open air. A 23% increase in $[O_3]$ from an average daytime ambient concentration of 56 to 69 ppb over two growing seasons decreased soybean yield by 20%. How does this compare with the expectations established from chamber studies? Based on a prior compilation of chamber studies (*33*), the expected decrease was 8%. If the effects of $[CO_2]$ and $[O_3]$ observed in FACE studies are additive, then the net effect of simultaneous increases in $[O_3]$ and $[CO_2]$, as forecast by the IPCC A1B scenarios, would be a 5% decrease in yield, compared with the 23% increase used to parameterize current models (Table 1). Chamber studies suggest that elevated $[CO_2]$ may provide some protection against elevated $[O_3]$ and therefore the effects will not be additive, but this has yet to be verified for any crop under open-air field conditions.

What is needed? The CO_2 fertilization effects, derived from chamber experiments, currently used in crop models forecast substantial increases in future crop production under conditions associated with climate change. The FACE experiments, conducted in open fields, are not without their limitations (*26*, *35*), but represent our best simulations of the future elevated $[CO_2]$ environment. Our meta-analytic summary of the FACE experiments indicates that there will be a much smaller CO_2 fertilization effect on yield than currently assumed, and possibly little or no stimulation for C_4 crops.

The average yield increase at elevated $[CO_2]$ for crops in FACE studies fell well short of the

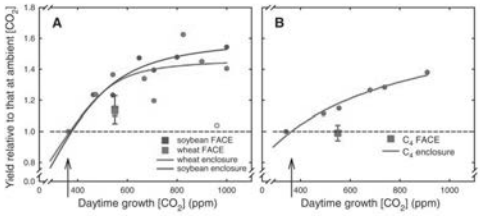

Fig. 2. Effects of elevated $[CO_2]$ on crop yield. Data are yields at elevated $[CO_2]$ relative to those at ambient $[CO_2]$ (arrow) for (**A**) soybeans in chambers (solid blue circles) and FACE (blue square, hidden behind red square) and wheat in chambers (red circles) and FACE (red square); and (**B**) C_4 crops (maize and sorghum combined) in chambers (green circles) and FACE studies (green square). Error bars indicate mean ± 90% confidence intervals around the means for the FACE studies. The chamber studies included 115 independent measures of soybeans (*21*), 211 of wheat (*36*), and 14 of maize and sorghum (table S3). These measures were divided into 10 classes of growth $[CO_2]$ in 100-ppm increments. Plotted values are the class means of growth $[CO_2]$ and yield. Solid lines are the least-squares fits for the nonrectangular hyperbolic response of yield to growth $[CO_2]$ from these enclosure studies of soybeans (blue line, $r^2 = 0.98$), wheat (red line, $r^2 = 0.88$), and C_4 crops (green line, $r^2 = 0.99$). The yield response of soybeans in chambers to growth $[CO_2]$ of 900 to 999 ppm [open blue circle in (A)] was an outlier and was excluded from the curve fitting. Full details of the meta-analysis methods and results from FACE are presented in the SOM and table S2.

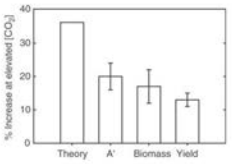

Fig. 3. Comparison of theoretical and actual changes in C_3 crop production parameters at an elevated $[CO_2]$ of 550 ppm relative to ambient $[CO_2]$. Theory, theoretical RuBisCO-limited photosynthesis at 550 ppm [(*9*) and SOM]; A', measured daily integral of carbon uptake; biomass, final above-ground biomass; yield, harvestable grain yield. Error bars indicate mean ± 90% confidence intervals. A', biomass, and yield were measured in C_3 crops exposed to elevated $[CO_2]$ in FACE experiments (table S2).

theoretically possible increase based on the well-defined properties of RuBisCO (Fig. 3). At 25°C, an increase in $[CO_2]$ to 550 ppm should increase light-saturated photosynthesis by 36%. The average increase observed for C_3 crops in FACE was 20% for the daily integral of photosynthetic CO_2 uptake, 17% for total biomass, and just 13% for yield (Fig. 3). This suggests that a series of feedbacks operate in the field to constrain realization of the potential benefits of elevated $[CO_2]$. Only with a thorough high-priority R&D effort might we overcome these feedbacks and achieve the potential gains in food supply.

The FACE experiments clearly show that much lower CO_2 fertilization factors should be used in model projections of future yields; however, the present experiments are limited in the range of growing conditions that they cover. Scientists have not investigated the interactive effects of simultaneous change in $[CO_2]$, $[O_3]$, temperature, and soil moisture. Technological advances suggest that large-scale open-air facilities to investigate these interactions over controlled gradients of variation are now possible (*26*). Although we have projected results to 2050, this may be too far in the future to spur commercial R&D, but it must not be seen as too distant to discourage R&D in the public sector, given the long lead times that may be needed to avoid global food shortage.

References and Notes

1. G. Hoogenboom *et al.*, in *Climate Change and Agriculture: Analysis of Potential International Impacts. ASA Special Publication no. 59* (American Society of Agronomy, Madison, WI, 1995), pp. 51–75.
2. M. Parry, C. Rosenzweig, M. Livermore, *Philos. Trans. R. Soc. London Ser. B* **360**, 2125 (2005).
3. R. M. Peart, J. W. Jones, R. B. Curry, K. J. Boote, L. H. Allen, in *The Potential Effects of Global Climate Change on the United States, Appendix C, Report to Congress*, J. B. Smith, D. A. Tirpak, Eds. (EPA-230-05-89-053, U.S. Environmental Protection Agency, Washington, DC, 1989), pp. 2–54.
4. C. O. Stockle, J. R. Williams, N. J. Rosenberg, C. A. Jones, *Agric. Syst.* **38**, 225 (1992).
5. H. Gitay, S. Brown, W. Easterling, B. Jallow, in *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, K. S. White, Eds. (Cambridge Univ. Press, Cambridge, 2001), pp. 237–342.
6. M. Parry, C. Rosenzweig, A. Iglesias, G. Fischer, M. Livermore, *Global Environ. Change* **9**, S51 (1999).
7. M. L. Parry, C. Rosenzweig, A. Iglesias, M. Livermore, G. Fischer, *Global Environ. Change* **14**, 53 (2004).
8. J. T. Houghton *et al.*, Eds., *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, Cambridge, 2001).
9. S. P. Long, E. A. Ainsworth, A. Rogers, D. R. Ort, *Annu. Rev. Plant Biol.* **55**, 591 (2004).
10. S. von Caemmerer, R. T. Furbank, *Photosynth. Res.* **77**, 191 (2003).
11. R. M. Adams *et al.*, *Nature* **345**, 219 (1990).
12. C. Rosenzweig, A. Iglesias, in *Understanding Options for Agricultural Production*, G. Y. Tsuji, G. Hoogenboom, P. K. Thornton, Eds. (Kluwer Academic, Dordrecht, Netherlands, 1998), pp. 267–292.
13. R. A. Brown, N. J. Rosenberg, *Clim. Change* **41**, 73 (1999).
14. R. C. Izaurralde, N. J. Rosenberg, R. A. Brown, A. M. Thomson, *Agric. For. Meteorol.* **117**, 97 (2003).
15. A. M. Thomson, R. A. Brown, N. J. Rosenberg, R. C. Izaurralde, V. Benson, *Clim. Change* **69**, 43 (2005).
16. L. H. Allen *et al.*, *Global Biogeochem. Cycles* **1**, 1 (1987).
17. J. D. Cure, B. Acock, *Agric. For. Meteorol.* **38**, 127 (1986).
18. B. A. Kimball, *Agron. J.* **75**, 779 (1983).
19. A. Anand *et al.*, *J. Exp. Bot.* **54**, 1101 (2003).
20. B. Black, *Abstr. Pap. Am. Chem.* **228**, U84 (2004).
21. E. A. Ainsworth *et al.*, *Global Change Biol.* **8**, 695 (2002).
22. D. Whitehead *et al.*, *J. Biogeogr.* **22**, 307 (1995).
23. A. R. McLeod, S. P. Long, *Adv. Ecol. Res.* **28**, 1 (1999).
24. F. Miglietta, M. Lanini, M. Bindi, V. Magliulo, *Global Change Biol.* **3**, 417 (1997).
25. F. W. Lipfert, Y. Alexander, G. R. Hendrey, K. F. Lewin, J. Nagy, *Crit. Rev. Plant Sci.* **11**, 143 (1992).
26. J. Nösberger *et al.*, Eds. *Managed Ecosystems and CO_2. Case Studies, Processes, and Perspectives, Ecological Studies*, vol. 187 (Springer, Berlin, 2006).
27. M. R. Shaw *et al.*, *Science* **298**, 1987 (2002).
28. E. A. Ainsworth, S. P. Long, *New Phytol.* **165**, 351 (2005).
29. A. D. B. Leakey, C. J. Bernacchi, F. G. Dohleman, D. R. Ort, S. P. Long, *Global Change Biol.* **10**, 951 (2004).
30. A. D. B. Leakey *et al.*, *Plant Physiol.* **140**, 779 (2006).
31. G. W. Wall *et al.*, *New Phytol.* **152**, 231 (2001).
32. M. J. Ottman *et al.*, *New Phytol.* **150**, 261 (2001).
33. M. R. Ashmore, in *Air Pollution and Plant Life*, J. N. B. Bell, M. Treshow, Eds. (Wiley, New York, 2002), pp. 89–118.
34. P. B. Morgan, T. A. Mies, G. A. Bollero, R. L. Nelson, S. P. Long, *New Phytol.* **170**, 333 (2006).
35. S. P. Long, E. A. Ainsworth, A. D. B. Leakey, P. B. Morgan, *Philos. Trans. R. Soc. London Ser. B* **360**, 2011 (2005).
36. J. S. Amthor, *Field Crops Res.* **73**, 1 (2001).
37. Materials and methods for meta-analyses are available as supporting material on *Science* Online. Full results from the meta-analyses summarized in Table 1 are presented in table S2 with references in appendix S1. C_4 crop yield responses to elevated $[CO_2]$ are presented in table S3 with references in appendix S2.

38. This work was supported by the Illinois Council for Food and Agricultural Research, Archer Daniels Midland Company, U.S. Department of Agriculture, U.S. Department of Energy (grant DE-FG02-04ER63849, and Illinois Agricultural Experiment Station.

Supporting Online Material

www.sciencemag.org/cgi/content/full/312/5782/1918/DC1
Materials and Methods
Tables S1 to S3
References
Appendices S1 and S2

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10.1126/science.1114722

Frictional Afterslip Following the 2005 Nias-Simeulue Earthquake, Sumatra

Ya-Ju Hsu,[2]* Mark Simons,[1] Jean-Philippe Avouac,[1] John Galetzka,[2] Kerry Sieh,[1] Mohamed Chlieh,[1] Danny Natawidjaja,[2] Linette Prawirodirdjo,[3] Yehuda Bock[3]

Continuously recording Global Positioning System stations near the 28 March 2005 rupture of the Sunda megathrust [moment magnitude (M_w) 8.7] show that the earthquake triggered aseismic frictional afterslip on the subduction megathrust, with a major fraction of this slip in the up-dip direction from the main rupture. Eleven months after the main shock, afterslip continues at rates several times the average interseismic rate, resulting in deformation equivalent to at least a M_w 8.2 earthquake. In general, along-strike variations in frictional behavior appear to persist over multiple earthquake cycles. Aftershocks cluster along the boundary between the region of coseismic slip and the up-dip creeping zone. We observe that the cumulative number of aftershocks increases linearly with postseismic displacements; this finding suggests that the temporal evolution of aftershocks is governed by afterslip.

Slip on faults occurs as a combination of relatively continuous aseismic creep and transient slip events. These transient events occur as earthquakes radiating seismic waves, and also as aseismic events with characteristic time scales of days to years. A better understanding of the physical factors that control the relative amounts and location of seismic and aseismic slip is a key goal in the study of fault mechanics and in particular can affect assessments of regional seismic and tsunami hazards. After a large earthquake, postseismic deformation may result from earthquake-induced slip along the plate interface, commonly referred to as afterslip, and as viscoelastic relaxation in the volume surrounding the fault rupture (*1*–*3*). Thus, well-positioned postseismic observations can probe the mechanical properties of subduction megathrusts and the media that surround them.

Geodetic and seismological investigations suggest that typical subduction megathrust earthquakes involve fault rupture at depths between ~10 km and ~50 km, and that rupture all the way up to the trench is rare (*4*). However, evidence for slip on the shallowest portions of a megathrust has been notoriously difficult to evaluate. We commonly assume that seismic slip decreases in both up-dip and down-dip directions, presumably bounded by regions where frictional behavior of the fault does not support stick-slip (i.e., seismic) rupture (*5*).

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Senator PETERS. Thank you, Mr. Chairman.

And then I also have—we have had some references by members of the panel regarding Senator Whitehouse and some comments that he had made. I would like to enter into the record as well a speech that he made that should be entered into the record as to refute some of the comments that were made by the panel.

Senator CRUZ. Without objection.

[The information referred to follows:]

TIME TO WAKE UP: THE PAUSE THAT WASN'T

Senate Floor Speech by Sen. Sheldon Whitehouse
Tuesday, September 29, 2015

Mr. President, I rise today for my 113th "Time to Wake Up" speech on climate change. They say 13 is unlucky. I don't know what 113 is, but I do know what climate change is. It is very real. We shouldn't kid ourselves. And it is an urgent challenge for our country and our world. Our leading scientific organizations say so. Our national security leaders say so. All of our National Laboratories say so. Major American businesses say so. Religious leaders of all faiths say so. Pope Francis certainly said so last week. But the Senate is jammed by persistent, meretricious climate denial. The denial comes in many guises, but, like a compass, all the denial points in the same direction: whatever helps the fossil fuel industry keep polluting. That is the true north of climate denial—whatever helps the fossil fuel industry. Look at the fossil fuel money pouring into the Republican Party and tell me this is a coincidence.

We have Senators who deny that anything is happening, who say it is a hoax. We have Senators who deny that we can solve this. We have Senators who deny their faith in the American economy to win if we innovate. We have Senators who simply shrug and say: I am not a scientist. A bunch of Senators say: Don't even worry about it; climate change has stopped. The junior Senator from Florida tells us, "Despite 17 years of dramatic increases in carbon production by humans, surface temperatures [on] the earth have stabilized." The junior Senator from Texas proclaims that "satellite data demonstrate for the last seventeen years, there's been zero warming. None whatsoever."

Let's leave aside for a moment the cherry-picked data this conclusion is based on, which leaves out the oceans, which cover a mere 70 percent of the Earth's surface. I will get back to oceans in a minute. But even this cherry-picked data needs a trick to deny the long-term trend. Using their trick, you could convince yourself climate change has stopped six times in the history of this increase from 1970. It is easy to do. You pick a spot here and you pick a spot there, and in the variability you make it a flat line and you say: There, you see a pause. The problem is that these manufactured pauses keep climbing.

When this bogus climate pause idea was trotted out in an op-ed in the Providence Journal, my home state paper, *PolitiFact* quickly determined that it uses "cherry-picked numbers and leaves out important details that would give a very different impression."

When we look at the linear trend for this whole data set, from 1970 to 2013, no one can deny that the Earth is warming. Research shows that climate change is marching on. The past decade was warmer than the one before that, which was warmer than the one before that. Seventeen of the 18 hottest years in the historical record have occurred in the last 18 years. NOAA and NASA count 2014 as the hottest year on record, and so far 2015 is on track to be even hotter than 2014. Fluctuations do not statistically alter the trend.

It is a disservice to the truth and to this Senate to suggest that this heralds the end of climate change. As noted UC Berkeley physics professor Richard Muller put it, "When walking up stairs in a tall building, it is a mistake to interpret a landing as the end of the climb."

Plus, for what reason would it have stopped? There is no basis for the pause. We know why it is happening. Global warming is caused by carbon pollution. We have known that science since Abraham Lincoln wore a top hat around this town. That is not news. And our carbon pollution sure hasn't stopped.

We just broke 400 parts per million of carbon in the atmosphere for the first time in the history of the human species.

There is no intellectual basis behind the pause theory. These claims of a climate change pause have been debunked. Just a couple of weeks ago, researchers from

Stanford University published a study: "There is no hiatus in the increase in the global mean temperature, no statistically significant difference in trends, no stalling of the global mean temperature, and no change in year-to-year temperature increases." In other words, there is no pause.

A different study prepared for the U.S. Climate Variability and Predictability Program reviewed this so-called pause data and said this: It "not only failed to establish a trend change with statistical significance, it failed by a wide margin. [A]ny argument that global warming stopped 18 or 20 years ago is just hogwash," said one of that report's authors—just hogwash. When legitimate scientists and statisticians examine the data for global mean temperature, they don't find any so-called pause.

This chart I have in the Chamber shows global average temperatures since the late 1800s, which is about the time we began burning fossil fuels in the Industrial Revolution. In yet another study out this month, researchers did a little test. They showed this chart to 25 economists, but instead of temperature they told the economists that the chart showed world agricultural output. That stripped the data of any political baggage of climate change. It made this a simple statistical question: Does this chart show that the measured phenomenon—climate change, temperature, world agricultural output—does this chart show whatever the measured phenomenon is stopped in 1998? The economists looked, and they flat out rejected that conclusion. What they agreed was that claiming the phenomenon had stopped would be misleading and ill-informed.

So why did this pause theory appear that is a mistake, that is hogwash, that is based on cherry-picked numbers all toward a conclusion that is misleading and ill-informed? Why? Because the big carbon polluters and their allies in Congress don't want us to act. So we keep getting this mischief fed to us.

The enterprise that performs that evil task of feeding mischief into this debate is perhaps the biggest and the most complex racket in American history. It is phony. They cherry-pick a handful of statistically insignificant data points and tell us the whole problem went away on its own. Then the real scientists take a look at it and say that is bunk. But in the meantime, the polluter enterprise notched a public relations victory. It bought some time to keep polluting for free, and sadly it got some of our colleagues to be party to it.

Telling the American people there is a pause in global warming may lull the gullible to sleep, but it is phony, it is inaccurate, and it is wrong. It ignores the truth. It ignores the science. Basically what it is, is cheesy fossil fuel PR dressed up in a lab coat to look like science, just enough to fool people that little bit.

Now let's turn back to the oceans—that 70 percent of the Earth's surface the other data left out. These data show the decades-long warming of the surface oceans—1960 to 2010. No pause. Remember, the deniers conveniently left all this data out when they cherry-picked their pause data—70 percent of the Earth's surface left out.

The first law of thermodynamics, conservation of energy, decrees that all of that heat in the ocean had to come from somewhere. Research shows that greenhouse gases trap excess heat in the atmosphere and that over 90 percent of that excess heat went into the oceans, was absorbed by our oceans. People who insist that the climate has not warmed in recent decades ignore this one little thing—the oceans, which cover 70 percent of the surface of the Earth. The oceans don't lie. This warming is changing the oceans and our fisheries. Water expands when it warms. That is the law of thermal expansion—unless somebody wants to come and deny that. The seas are rising across the globe. In Rhode Island, we measure it at the Newport Naval Station tide gauge. Basically it is a glorified yardstick. It is not complicated. There is no theory involved. It is a measurement. It says we are up nearly 10 inches since the 1930s. That may be funny to landlocked States, but when there are 10 more inches of sea to be thrown against your shores by a big ocean storm, coastal states take that stuff very seriously. NASA measures it around the world with satellites; it is not just the coastal stations that take these measures. NASA measures from satellites. We measure the exploding acidity of the seas. The exploding acidities of the sea are directly related to CO_2 absorption—unless people want to deny chemistry. You can put CO_2 seawater in a high school lab and you can make the pH change. That is what we are doing on a global scale, and we don't get to repeal laws of chemistry around here, no matter how powerful the special interests.

Last week, His Holiness Pope Francis called on us to work together to protect our common home. He warned us in his recent encyclical: "Those who will have to suffer the consequences of what we are trying to hide will not forget this failure of conscience and responsibility." But first we have to want to protect our common home. If what we want to protect is the fossil fuel industry, at all costs, at any cost, we need a priority adjustment.

In our rotten, post-Citizens United, billionaire special interests politics, perhaps the Pope would have had more effect if he had a super Pac, but it shouldn't take a super Pac for us to heed the Pope's warning or to heed the science or to heed our national security leaders or to heed everyone else who has lined up to try to wake us up.

Pope Francis also said "to avert the most serious effects of the environmental deterioration caused by human activity," now is the time for courageous actions and strategies.

Today's *New York Times* has this headline: "Many Conservative Republicans Believe Climate Change Is a Real Threat." Once you get away from this building and the pernicious influence of the fossil-fuel industry and its relentless money and threats, it is not a question of ideology, it is a question of special interest influence, and conservative Republicans increasingly understand that this is real. Eleven of them just broke rank in the House.

It is time to come together in good faith to tackle this real and persistent threat—the threat of climate change.

It is time for us to wake up.

I yield the floor.

Senator PETERS. Thank you very much. I yield back, Mr. Chairman.

Senator CRUZ. Thank you, Senator Peters.

I want to thank each of the witnesses for being here. Dr. Happer, you wanted to briefly——

Dr. HAPPER. I just wanted to make one response about satellite temperature measurements. They measure temperature the same way as hospitals do today. Nobody sticks a thermometer in your mouth anymore. They use a temporal scanner or they put something in your ear. And so they are measuring radiation in exactly the same way the satellites do, except medical thermotheres use infrared radiation, not microwave radiation.

Senator CRUZ. Thank you, Dr. Happer. That is helpful.

This hearing was a hearing to discuss facts and evidence and data rather than partisan dogma and ideology, and there are at least seven facts that our witnesses have laid out here to which there have been, I believe, no effective response.

Number one, that carbon dioxide, rather than being a pollutant, is good for plant life.

Number two, that the Earth right now, today, is greening.

Number three, that for significant periods in history there has been markedly more CO_2 in our atmosphere, and that was prior to the Industrial Revolution. So it could not have come from the burning of fossil fuels.

Number four, that for the last 18 years the satellite data and the weather balloon data both demonstrate no significant warming whatsoever. That fact in particular not a single Democratic Senator had an effective response to.

Number five, that the satellite data and the weather balloon data are the best evidence we have of whether warming is occurring, and that evidence, the actual data, demonstrate that it is not.

Number six, that the seas were rising more in the first half of the 20th century prior to the significant increase in carbon dioxide emissions than they are now.

And number eight, that the computer models, the apocalyptic computer models that are telling us we need to raise every hard-working American's electric bills, gas bills, cost of living, we need to make it harder for single moms, for immigrants, for African Americans, for Hispanics, for hard-working men and women, we

need to make it harder for them to make a living and make ends meet, the computer models are profoundly wrong. Not a little bit wrong, but profoundly inconsistent with the data and the evidence.

None of these eight facts tend to make it through the media gatekeepers that instead enforce, like the Inquisition, a discipline on the heretics that would dare stand in the way of their political ideology of imposing trillions of dollars of cost on people who are struggling.

Policy should be driven by facts, and as John Adams said, "Facts are stubborn things."

In addition to the number of things entered in the record, I have got a series of newspaper articles describing the persecution of so-called climate deniers that without objection are going to be entered into the record.

[The information referred to follows:]

SHOULD CLIMATE CHANGE DENIERS BE PROSECUTED?

By *Walter Olson* On 10/1/15 at 5:17PM

Around 400 demonstrators participated in a protest over climate change denialby burying their heads in the sand at Sydney's Bondi Beach November 13, 2014, ahead of a G20 summit in Brisbane. Half-truths and the selective use of data are the common currency of political debate over climate change, the author writes.

David Gray/*Reuters*

In June, I took note of Senator Sheldon Whitehouse's (D–R.I.) *op-ed* "urg[ing] the U.S. Department of Justice to consider filing a racketeering suit against the oil and coal industries for having promoted wrongful thinking on climate change, with the activities of 'conservative policy' groups an apparent target of the investigation as well."

I pointed out that this was a significant step toward criminalizing policy differences and using litigation and government enforcement to punish opponents in public debate, and meshed with an existing fishing-expedition investigation of climate-skeptic scholarship by Whitehouse and other Democrats on Capitol Hill.

Others had already gone farther than the senator himself, calling for making "climate denial" a "crime against humanity," holding public trials of fossil fuel execu-

tives for having resisted the truth and so forth. (Gawker: "*arrest climate change deniers.*")

And I noted a recurring argument-"we did it to the tobacco companies, so there's no reason we can't do it here too"-that *tended to confirm my fears* that the Federal government set a dangerous precedent back then when it "took the stance that pro-tobacco advocacy could amount to a legal offense."

Now there are further signs that a concerted campaign is under way. "Letter to President Obama: Investigate Deniers Under RICO" is the headline over a *letter from 20 scientists,* most at respected institutions, endorsing the Whitehouse idea and calling for the Federal government to launch a probe under the racketeering (RICO) law. The letter was soon being widely promoted around the Web, even at *BoingBoing,* often regarded as a pro-free-speech outlet.

It is not clear that all the scientists who signed the letter have thought carefully about the tension between what they are asking and the continuing freedom to pursue lines of inquiry in public debate that the government may find unwelcome or unreasonable. "I have no idea how it affects the First Amendment," says one Vermont scientist who backs the probe, quoted by *Bruce Parker of Vermont Watchdog.*

In a companion piece, Parker *interviewed me* about the constitutional implications of this extremely bad idea. (I should note that when I discuss RICO in the interview transcript, I'm referring to the civil-litigation side of the law, so-called civilRICO, which seems to be the part of the law the advocates hope to use.)

It is remarkable how many advocates of this scheme seem to imagine that the First Amendment protects only truthful speech and thus (they think) has no application here because climate skepticism is false.

That's not the way it works. As Cato and many others (compare *ACLU of Ohio*) argued at various stages in the case of *Susan B. Anthony List v. Driehaus,* which reached the Supreme Court on a different issue last year, controversial speech need not be true to be protected. In practice an "only truth has rights" approach chills advocacy generally and gives the state (or sometimes private litigants and complainants) a dangerous power to stifle advocacy in debates that it considers settled.

It is certainly strange to see many supporters of the Whitehouse approach suggest that the speech they dislike is actionable because they find in it half-truths, selectively marshaled data, scientific studies that spring from agendas, arguments whose ultimate sincerity is open to question, evasion of telling points made by the other side and so forth. Those are the common currency of everyday debate in Washington (and not just in Washington).

Nothing could be more common than to find both sides in an argument using these argumentative techniques. Hawks and doves do it; so do protectionists and free traders, and labor interests and business interests. The same techniques are also accepted as standard currency within the adversary process itself, in which the law takes such pride, which makes it particularly absurd to propose defining it as unlawful racketeering to (quoting one paraphrase) "use dubious information to advance a cause." The interview, again, is here.

Walter Olson is a senior fellow at the Cato Institute's Center for Constitutional Studies.

The Climate Fix

VARIOUS MUSINGS ON CLIMATE SCIENCE AND POLICY

by Roger Pielke Jr

I AM UNDER "INVESTIGATION"

FEBRUARY 25, 2015—ROGERPIELKEJR

As some of you will already know, I am one of 7 U.S. academics being investigated by U.S. Representative Raúl Grijalva (D–AZ) who is the ranking member of the House of Representatives Committee on Environment and Natural Resources. Rep. Grijalva has sent a letter to the president of my university requesting a range of information, including my correspondence, the letter is *here in PDF* (*http://democrats.naturalresources.house.gov/sites/democrats.naturalresources.house.gov/files/Roger percent20Pielke percent2C percent20Colorado.pdf*).

Before continuing, let me make one point abundantly clear: I have no funding, declared or undeclared, with any fossil fuel company or interest. I never have. Representative Grijalva knows this too, because when I have testified before the U.S.

Congress, I have disclosed my funding and possible conflicts of interest. So I know with complete certainty that this investigation is a politically-motivated "witch hunt" designed to intimidate me (and others) and to smear my name.

For instance, the Congressman and his staff, along with compliant journalists, are busy characterizing me in public as a "climate skeptic" opposed to action on climate change. This of course is a lie. I have *written a book calling for a carbon tax (http://rogerpielkejr.blogspot.com/2010/04/climate-fix.html),* I have *publicly supported President Obama's proposed EPA carbon regulations (http://rogerpielkejr.blogspot.com/2014/06/some-perspective-on-us-epa-carbon.html),* and I have just published another book strongly defending the scientific assessment of the IPCC with respect to *disasters and climate change (http://www.amazon.com/The-Rightful-Place-Science-Disasters/dp/0692297510/ref=sr_1_11?ie=UTF8&qid=1412174550&sr=8-11&keywords=pielke).* All of this is public record, so the smears against me must be an intentional effort to delegitimize my academic research.

What am I accused of that prompts being investigated? Here is my crime:

> Prof. Roger Pielke, Jr., at CU's Center for Science and Technology Policy Research has testified numerous times before the U.S. Congress on climate change and its economic impacts. His 2013 Senate testimony featured the claim, often repeated, that it is "incorrect to associate the increasing costs of disasters with the emission of greenhouse gases."

The letter goes on to note that John Holdren, President Obama's science advisor, "has highlighted what he believes were serious misstatements by Prof. Pielke." (For background on this see *here (http://www.newrepublic.com/article/116887/does-climate-change-cause-extreme-weather-i-said-no-and-was-attacked)* and *her (http://rogerpielkejr.blogspot.de/2014/03/john-holdrens-epic-fail.html)*e.) My 2013 testimony to the Senate is *here (http://sciencepolicy.colorado.edu/publications/special/senate_testimony2013.html)* and House is *here in pdf (http://sciencepolicy.colorado.edu/admin/publication_files/2013.38.pdf)* (Q&A following hearing *here (http://rogerpielkejr.blogspot.com/2014/01/questions-from-congress-part-1.html)* and *here (http://rogerpielkejr.blogspot.com/2014/01/questions-from-congress-part-2.html)*). The testimony was the basis for my *recent book on Disasters & Climate Change (http://www.amazon.com/The-Rightful-Place-Science-Disasters/dp/0692297510/).*

Congressman Grijalva doesn't have any evidence of any wrongdoing on my part, either ethical or legal, because there is none. He simply disagrees with the substance of my testimony—which is based on peer-reviewed research funded by the U.S. taxpayer, and which also happens to be the consensus of the IPCC (despite Holdren's incorrect views).

Adam Sarvana, communications director for Natural Resources Committee's Democratic delegation, reinforced *the politically-motivated nature of the investigation in an interview (http://www.al.com/news/huntsville/index.ssf/2015/02/arizona_congressman_asking_que.html):*

> "The way we chose the list of recipients is who has published widely, who has testified in Congress before, who seems to have the most impact on policy in the scientific community"

Let's see—widely published, engaged with Congress, policy impact—these are supposed to be virtues of the modern academic researcher, right? (*Here in PDF (http://sciencepolicy.colorado.edu/admin/publication_files/2013.32.pdf)* is my view on the importance of testifying before Congress when asked. I still think it is important.)

I am pleased that some colleagues with whom I have had professional disagreements with in the past have condemned the investigation via Twitter, among them Eric Steig (of Real Climate), Bob Ward (LSE) and Simon Donner (UBC). This shows some real class. In contrast, Michael E. Mann, who I *defended when a Virginia politician came after him (http://rogerpielkejr.blogspot.com/2010/07/cuccinellis-fishing-expedition.html),* used the "investigation" as a chance to lob childish insults my way via Twitter. Some things you can always count on in the climate arena!

So far, I have been contacted by only 2 reporters at relatively small media outlets. I'd say that the lack of interest in a politician coming after academics is surprising, but to be honest, pretty much nothing surprises me in the climate debate anymore. Even so, there is simply no excuse for any reporter to repeat incorrect claims made about me, given how easy I am to find and just ask.

The incessant attacks and smears are effective, no doubt, I have already shifted all of my academic work away from climate issues. I am simply not initiating any new research or papers on the topic and I have ring-fenced my slowly diminishing blogging on the subject. I am a full professor with tenure, so no one need worry about me—I'll be just fine as there are plenty of interesting, research-able policy issues to occupy my time. But I can't imagine the message being sent to younger

scientists. Actually, I can: "*when people are producing work in line with the scientific consensus there's no reason to go on a witch hunt (http://www.wired.com/2015/02/anti-gmo-activist-seeks-expose-e-mails-food-scientists/).*"

When "witch hunts" are deemed legitimate in the context of popular causes, we will have fully turned science into just another arena for the exercise of power politics. The result is a big loss for both science and politics.

Climate change deniers in Congress

[Image via Gage Skidmore, Creative Commons licensed]

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The campaign group formed to support Barack Obama's political agenda has launched an initiative to shame members of Congress who deny the science behind climate change.

In an email to supporters on Thursday, Organizing for Action said it was time to call out members of Congress who deny the existence of climate change, saying they had blocked efforts to avoid its most catastrophic consequences.

The email linked to a video mocking Republicans who reject the science on climate change. "Right now, way too many lawmakers in Washington flat-out refuse to face the facts when it comes to climate change," Jon Carson, executive director of Organizing for Action wrote in the email. "We're never going to make real progress on this issue unless members of Congress get serious."

The video mainly features Republican members of the House of Representatives who are notorious for denying the existence of climate change, or positing bizarre notions about its causes.

However, it also includes some national figures such as the Florida senator Marc Rubio and House speaker John Boehner, whose views on climate are not that broadly known. There are no Democrats in the video.

The video was the first foray into climate politics by Organizing for Action, the group which emerged out of Obama's re-election campaign to promote his second-term legislative agenda.

Until Thursday, the group had focused on gun control, immigration and the budget. Climate change did not even rate its own heading on the OFA website. But Thursday's video and an accompanying petition campaign suggest that Obama's allies have now decided that climate change is a mainline political issue.

Obama singled out climate change as one of his priorities at his inauguration and during his first state of the union address.

Since then, however, Obama has failed to offer bold policy proposals to match the sweeping speeches. Last week the New Yorker speculated that Obama may have given up on climate action entirely.

Environmental groups in Washington say that is not at all the case, but admit that other issues have taken precedence in the first months of his second term.

The appearance of the video was seen by some as a sign that Obama's allies are now ready for a broad grassroots fight on climate politics. A number of environmental organisations have tried similar grassroots efforts – most notably 350.org's campaign against the Keystone XL pipeline and Al Gore's Climate Reality Project – but the OFA move represented a new mainstreaming of climate politics.

"What is interesting to me is that it shows that climate is finally becoming a first tier political issue," said Paul Bledsoe, a political consultant who was President Clinton's climate advisor. "Every other issue in the first tier always has this kind of grassroots activism behind it, whether it's the health care bill or immigration."

But it will be an uphill battle. As the video points out, 240 Republican members of the house signed on to a measure describing climate change as a hoax.

Since Obama was first elected, opposition to climate action has become a core tenet of conservative and Republican party politics. Some Republicans deny any change in the climate, some dispute the burning of fossil fuels is warming the atmosphere. Others accept climate science but oppose broad economy-wide measures to avoid catastrophic climate change.

The video does not bother with those distinctions. However, there is broad cohesion among conservatives in their opposition to climate action – and that will make Obama's course all the more difficult.

Watchdog.org

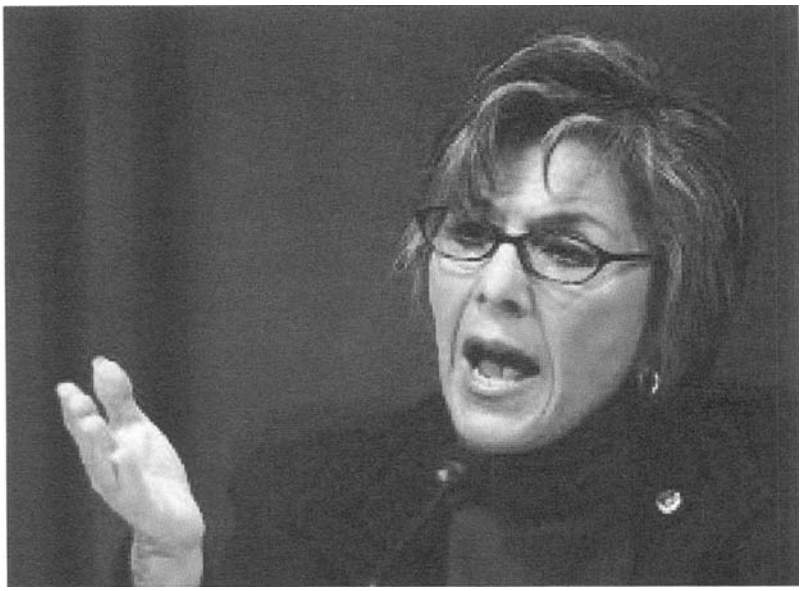
DEMOCRAT-LED WITCH HUNT INTO 'CLIMATE CHANGE DENIERS' PICKS UP FORCE

Posted By M.D. Kittle On February 27, 2015

In the left's latest assault on the First Amendment, three Democrats on the *Senate's Committee on Environment and Public Works*[1] have sent out 100 letters to free-market think tanks and energy companies asking them to turn over funding records related to any research they've conducted on climate change.

In short, U.S. Sens. *Ed Markey*[2], D-Massachusetts, *Barbara Boxer,*[3] D-California, and *Sheldon Whitehouse,*[4] D-Rhode Island, apostles in President Barack Obama's climate change war, are on another political witch hunt demanding donor information and other records that are protected under the Constitution.

First Amendment defenders rallied to the side of the targeted groups, asserting the Democrats had overreached in setting up their enemies list, another thinly veiled quest in taxpayer-funded political opposition research.



[5] GIVE IT TO ME: Skeptical of climate change? U.S. Sen. Barbara Boxer, D-California, wants to know why. She's asking free-market think tanks to turn over donor information.

"These folks have been trying to open the vaults of donor lists from all of our organizations over time. They have not been successful,and they are not going to be successful," said Kory Swanson, president of the *John Locke Foundation*[6], a North Carolina-based free-market think tank.

The organization received a *letter*[7] from the senators requesting information about "payments made . . . in support of scientific research and scientists, as well as support for other efforts related to climate change, if such payments have been made."

As members of the Senate committee, the lawmakers claim they are interested in understanding how the organizations have "undertaken such *efforts* and the degree to which these *efforts* have been publicly disclosed . . ."

Their sudden interest arises following a piece in the *New York Times* that attacks, or by some accounts, "smears," Wei-Hock "Willie" Soon, an outspoken critic of man-made climate change.

The piece, headlined *"Deeper Ties to Corporate cash for Doubtful Climate Researcher,"*[8] uses documents obtained by Greenpeace showing that Soon received more than $1 million from ExxonMobil, Southern Company and others in his work tracking the flaws in climate change research.

The story was picked up by the ”growing mega industry of climate-alarmist blogs and organizations that receive billions of dollars from government agencies, tax-exempt foundations, and major corporations,” according to the *New American.*[9]

“Following the typical smear pattern, many of the stories attempt to tar Dr. Soon with the ’denier’ label a vicious assault aimed at equating (man-made climate change) skepticism with Nazi Holocaust denial,” the publication states.

Soon did not disclose his fundi.ng in his peer-reviewed study.

The senators are going after anyone who would dare contest the science behind the climate change narrative.

They want it all, and they want it now.

In their *letter,*[7] the senators demand the past 10 years of information from the organizations, including:

> “Lists of funded research efforts (including but not limited to grants, fellowships, scholarships, consulting contracts, contracts, honoraria, and speaking events) on or related to climate, climate change, global warming, environmental issues, air quality, atmospheric or oceanic topics, greenhouse gas emissions, associated impacts of greenhouse gas in missions, carbon dioxide . . .”

For each payment made to individuals or organizations associated with the funded research efforts, the senators seek:

- Name of the recipient
- Institutional affiliation
- Payment and duration of the term of the funded research effort
- Reason for the payment

Majority members of the Senate committee reportedly were sending out letters Friday advising the target groups that they do not have to comply with the senators’ unconstitutional requests. Anonymous donations still are protected under the First Amendment.

First Amendment expert Hans von Spakovsky called the senators1 actions “outrageous.”

“This is clearly an attempt to intimidate anyone who has a different opinion on the issue than theirs,” said von Spakovsky, a former commissioner on the Federal Election Commission and senior legal fellow in *The Heritage Foundation’s*[10] Edwin Meese III Center for Legal and Judicial Studies. “This is an abuse of power. Maybe these senators don’t understand or don’t care about the fundamental First Amendment rights of Americans and their membership organizations.”

The demand for donor information von Spakovsky said, is no different than what the state of Alabama did to the NAACP in the 19sos. n this case, the result could be freezing out political speech by shutting down potential donor contributions.

“What these 100 organizations need to do is to get together and what they ought to do is send one letter signed onto by every single organization that says, ‘We’re not providing you with this information and your attempt to get it is unconscionable,’” he said. “There is strength in numbers and they ought to stand for and push forward the principle that the government is not entitled to this information because it is a violation of their First Amendment rights.”

Swanson said he is not overly concerned by the senators’ political grandstanding now that he has been informed he does not have to turn over the targeted information. The think tank president said many donors do not want their identities released because of government-led reprisals for their beliefs.

“We will proceed on with our work and not get distracted by this,” Swanson said.

Article printed from Watchdog.org: *http://watchdog.org*

URL to article: *http://watchdog.org/203041/climate-change-senate-first-amendment/*

URLs in this post:

[1] Committee on Environment and Public Works: *http://www.epw.senate.gov/public/?CFlD=130001363&CFTOKEN=17633631*

[2] Ed Markey: *http://www.markey.senate.gov/*

[3] Barbara Boxer,: *http://www.boxer.senate.gov/*

[4] Sheldon Whitehouse,: *http://www.whitehou se.senate.gov/contact/*

[5] Image: *http://watchdog.org/wp-content/blogs.dir/l/files/2015/02/Barbara Boxer.jpg*

[6] John Locke Foundation: *http://www.john locke.org/about/*

[7] letter: *http://www.markey.senate.gov/news/press-releases/markey-boxer whitehouse-query-fossil-fuel-companies-climate-denial-organizations-on-science funding*

[8] "Deeper Ties to Corporate Cash for Doubtful Climate Researcher,": *http://www.nytimes.com/2015/02/22/us/ties-to-corporate-cash-for-climate-changeresearcher-Wei-Hock-Soon.html?_r=O*
[9] New American.: *http://www.thenewamerican.com/tech/environment/item/20191-nytimes-greenpeace-smear-warming-skeptic-dr-soon*
[10] The Heritage Foundation's: *http://www.heritage.org/about/staff/v/hans-vonspakovsky*

Steyer Targets GOP 'Climate Deniers'

With polls showing that less than half of Americans believe climate change is primarily manmade, the costly attack could be a tough sell.

Tom Steyer, who spent more than $70 million through his super PAC NextGen Climate on the 2014 elections, will spend heavily in 2016 as well, the group announced Monday.

April 6, 2015, at 5:49 p.m. + More

Tom Steyer plans to put Republican presidential candidates in the "hot seat."

Declaring 2016 a "crossroads election," the billionaire megadonor's super PAC, NextGen Climate, announced an aggressive campaign Monday targeting conservative contenders who deny the existence of manmade global warming.

While many Republicans in Congress acknowledge the climate is changing, few agree it is being caused by human activity, a fact overwhelmingly supported by science across the globe but which has yet to take hold in the minds of millions of American voters.

Ted Cruz's Rollout Breaks the Rules, Scores a Quick Million

"Whoever is the next president will really represent, in our view, the last best shot to prevent a climate disaster for our children," NextGen chief strategist Chris Lehane said in a conference call with reporters Monday.

Each of the dozen or so hopefuls believed to be considering a GOP run for president has openly questioned anthropogenic global warming. One of them, Texas Sen. Ted Cruz, last month likened those who believe in manmade global warming to "flat-earthers."

That kind of rhetoric "raises basic competency questions" and also may reflect the influence of big donors over public interest, Lehane said — even as his own organization prepares to invest huge sums in the 2016 election cycle.

To that end, NextGen's effort will, in part, highlight — and in a way mirror — GOP hopefuls' ties to Charles and David Koch. The billionaire industrialists have spent hundreds of millions of dollars bankrolling libertarian super PACs such as Americans for Prosperity to defeat Democratic politicians and environmental regulation. This election cycle, the brothers plan to spend as much as $889 million, Politico reported in January.

"Spring training is over, the regular season has begun, and it's time to engage," Lehane said, going on to mix his baseball and March Madness metaphors. "Given the views that we're already seeing coming out of the mouths of these Republican presidential candidates, our climate madness is in full swing."

Steyer spent more than $70 million in the 2014 midterm elections cycle to defeat Republican candidates. Of the seven Senate and gubernatorial candidates NextGen supported, however, only three went on to win their elections.

League of Conservation Voters Spends Big in Colorado Senate Race

"It's hard to look at 2014 and say that kind of an investment campaign accomplished very much," says Barry Rabe, a professor at the Gerald R. Ford School of Public Policy at the University of Michigan. "The track record is not that you get a lot of bang for that investment."

Nonetheless, Lehane said, Steyer will "spend what it takes" in the 2016 cycle. He declined to state how

much that might be.

The goal, he continued, is to "deploy climate as a wedge issue," largely through "disruptive activities" to force candidates "to respond, react and engage" – such as by toting a polygraph machine to Kentucky Sen. Rand Paul's expected announcement launching his presidential campaign Tuesday – plus paid television ads, a "state of the art social media effort" and a so-called Hot Seat campaign to shine "a spotlight on the nexus between Koch and candidates."

That approach, Rabe says, could produce the kind of "gotcha moments and foot-in-mouth opportunities" that characterize primary campaign season – and which occasionally inflict lasting damage through the general election – but just how effective the overall advocacy campaign may prove remains an open question.

Bernie Sanders: The Billionaires May Just Win

"If the focus is on trying to influence either the outcome of the Republican nominating process or damage the potential candidate, to do that before the nomination process may not accomplish very much," Rabe says. "If you're replacing Ted Cruz with Marco Rubio on climate, have you moved the needle very much? And are we likely to see any of the top candidates really saying anything much different from one another on climate change?"

Results of recent polls also offer little incentive for 2016 candidates — and Republicans in particular — to give climate change top billing. While nearly two-thirds of Americans agree global warming is occurring, fewer than half say it is primarily a result of human activity, according to the Yale Project on Climate Change Communication. Even in left-leaning states such as California and Massachusetts, only 55 and 52 percent of voters, respectively, believe greenhouse gas emissions are mostly to blame for driving climate change.

"Climate change and environmental issues more broadly have generally not been top-level issues in presidential politics," says David Konisky, a professor of public policy at Georgetown University. "They tend to be driven by the economy, foreign affairs if we're in the midst of a war or the context of terrorism, health care. Those types of things tend to be the issues that carry most of the day."

The Daily Caller http://dailycaller.com

SCIENTISTS ASK OBAMA TO PROSECUTE GLOBAL WARMING SKEPTICS

Posted By Michael Bastasch On 4:39 PM 09/17/2015 In/*No Comments*

The science on global warming is settled, so settled that 20 climate scientists are asking President Barack Obama to prosecute people who disagree with them on the science behind manmade global warming.

Scientists from several universities and research centers even *asked Obama to use the Racketeer Influenced and Corrupt Organizations Act (RICO)* to prosecute groups that "have knowingly deceived the American people about the risks of climate change, as a means to forestall America's response to climate change."

RICO was a law designed to take down organized crime syndicates, but scientists now want it to be used against scientists, activists and organizations that voice their disagreement with the so called "consensus" on global warming. The scientists repeated claims made by environmentalists that groups, especially those with ties to fossil fuels, have engaged in a misinformation campaign to confuse the public on global warming.

"The actions of these organizations have been extensively documented in peer reviewed academic research and in recent books," the scientists wrote.

But these riled up academics aren't the first to suggest using RICO to go after global warming skeptics. The idea was *first put forward* by Rhode Island Sen. Sheldon Whitehouse, who argued using RICO was effective at taking down the tobacco industry.

"In 1999, the Justice Department filed a civil RICO lawsuit against the major tobacco companies . . . alleging that the companies 'engaged in and executed—and continue to engage in and execute—a massive 50year scheme to defraud the public, including consumers of cigarettes, in violation of RICO,'" Whitehouse *wrote* in the Washington Post in May.

"We strongly endorse Senator Whitehouse's call for a RICO investigation," the scientists wrote to Obama. "The methods of these organizations are quite similar to those used earlier by the tobacco industry. A RICO investigation (1999 to 2006) played an important role in stopping the tobacco industry from continuing to deceive the American people about the dangers of smoking."

"If corporations in the fossil fuel industry and their supporters are guilty of the misdeeds that have been documented in books and journal articles, it is imperative that these misdeeds be stopped as soon as possible so that America and the world can get on with the critically important business of finding effective ways to restabilize the Earth's climate, before even more lasting damage is done," the scientists added.

This year has been a trying one for global warming skeptics. Earlier this year, Democratic lawmakers *began an investigation* into scientists who disagreed with the White House's stance on global warming. Many of these skeptical scientists were often cited by those critical of regulations to curb greenhouse gas emissions.

Arizona Democratic Rep. Raul Grijalva went after universities employing these researchers, which *resulted in one expert* being forced to get out of the field of climate research altogether.

"I am simply not initiating any new research or papers on the topic and I have ringfenced my slowly diminishing blogging on the subject," Dr. Roger Pielke Jr. of the University of Colorado *wrote* on his blog.

"Congressman Grijalva doesn't have any evidence of any wrongdoing on my part, either ethical or legal, because there is none," Pielke wrote. "He simply disagrees with the substance of my testimony—which is based on peerreviewed research funded by the U.S. taxpayer, and which also happens to be the consensus of the IPCC (despite Holdren's incorrect views)."

Washington Examiner

EPA CHIEF SAYS CLIMATE CHANGE DENIERS NOT 'NORMAL'

By John Siciliano • 6/23/15 7:26 PM

The head of the Environmental Protection Agency appeared to hurl barbs at Congress on Tuesday, referring to an unnamed group of climate change "deniers" who aren't "normal" and who won't "carry the day" in a democracy.

EPA Administrator Gina McCarthy made the comments while addressing a climate change summit at the White House Tuesday to frame the effects of global warming on public health.

McCarthy said a report her agency released Monday makes the case for taking action against climate change by calculating the price Americans will pay for not taking action, including the thousands of lives lost due to global warming and the impact felt on the economy.

She said the EPA put out the report "not to push back against climate deniers," but to help "normal people" make a decision about the kind of world they and their children want to live in.

"I've batted my head against the wall too many times" trying to convince climate change deniers that global warming is occurring, she said. "You can have fun doing that if you want," but "if the science hasn't already changed their mind then it never will."

She said she is convinced that the climate deniers will not win in the campaign to address global warming. "In a normal democracy, it is not them that carries the day," McCarthy said. "It is normal human beings that haven't put their stake into politics above science."

"It's normal human beings that want us to do the right thing," she added. "And we will."

Her comments were being made around the same time Republican Sen. Shelley Moore Capito of West Virginia was holding a hearing on the harm the EPA's Clean Power Plan poses to energy producer states and small businesses. The EPA plan is the centerpiece of President Obama's plan to address climate change by curbing emissions from existing power plants.

"We are going to get our Clean Power Plan out. It is going to happen," McCarthy told those attending the summit, which included a broad range of public health advocates and environmentalists.

The climate summit follows another last week to announce $4 billion in private investment to develop renewable energy and other low mission technologies. Observers say the summits are being used to push the issue of climate change ahead of the Clean Power Plan being issued in August.

Yet at the same time, the House is preparing to pass legislation as soon as Wednesday that would delay implementation of the plan. The House measure would give states the ability to opt out of the rules, while allowing them to forego compliance until judicial review has concluded.

In the Senate, Capito said that companion legislation she introduced in May continues to gain strength. Capito said she is "proud to have more than 30 cosponsors," including Majority Leader Mitch McConnell, R-Ky., and Energy and Public Works Committee Chairman James Inhofe, R-Okla.

The Daily Caller http://dailycaller.com

ANOTHER GLOBAL WARMING SKEPTIC GETS SUSPENDED FROM TWITTER

Posted By *Michael Bastasch* On 2:14 PM 04/02/2015 In/*No Comments*

For the second time within two weeks, another global warming skeptic blogger has had his Twitter account suspended, this time repeating profanity used by a NASA climate scientist—and no the scientist did not get his account suspended.

On April 1st, Twitter locked the account of science blogger Tom Nelson, who runs the blog the "Hockey Schtick." Twitter told Nelson to delete a tweet that contained the word—are you ready for it?—"crap" or else his account would not be unlocked. Nelson then posted the "Delete Tweet" screen to his blog, after which Twitter promptly suspended his account. As of April 2nd, Nelson's *account* was still suspended.

Interestingly enough, Nelson was simply repeating a word used by NASA climate scientist Gavin Schmidt who *tweeted* at Nelson that [graph] is crap as I've frequently pointed out. The temperature is hand drawn. Not even you can take it seriously, surely?"

Nelson *tweeted* back on March 22nd "is this graph crap too?" About a week and a half later, Twitter locked his account and the suspended it. But Gavin Schmidt's account has not been suspended—which has raised the ire of other global warming skeptics and conservative pundits on Twitter.

"If calling a graph 'crap' is grounds for suspension, why isn't @ClimateofGavin suspended?" Nelson asked on his *blog*.

.*@ClimateOfGavin* You wouldn't happen to know why *@twitter* "suspended" another climate dissident, Tom Nelson *@tan123*? *#BigClimateEnforcers*?
—Mark Steyn (@MarkSteynOnline) *April 1, 2015*

Nelson's suspension comes *within two weeks* of Twitter suspending global warming skeptic Steven Goddard, a noted blogger who has been labelled as a "denier" by environmentalists.

Goddard, a pseudonym he blogs under, was suspended for violating Twitter's rules. goddard had been previously warned by Twitter of that other users had accused him of "nonviolent threats" and "abusive behavior." Goddard denied these accusations.

"I have never violated any Twitter rules, and Twitter has failed to respond to my requests to provide any details," Goddard said.

Both Goddard and Nelson have been highly critical of views human activity is causing the planet to warm at an alarming rate. InsideClimate News even featured Goddard on its "*Who's Who List of Climate Denialists"*—list put together by environmentalists of global warming "deniers" targeted by e-mail hackers.

But Twitter's actions against the bloggers seem to come from complaints by other Twitter users. Indeed, Nelson's account was locked about a week and a half after he used the word "crap" in a tweet. Some in the skeptic community have suggested climate scientists and environmental activists are complaining to get skeptic's account suspended.

Indeed, Penn State University climate scientist Michael Mann has *threatened* "trolls" with being reported and blocked if they interrupted an #AskDrMann session on Twitter.

But Twitter doesn't disclose such information. So any accusations of who is behind getting skeptics' account suspended is speculative at this moment.

Senator CRUZ. I am also going to enter into the record the oped that Senator Whitehouse wrote calling for RICO criminal prosecution of anyone who dares stand in the way of the political ideology that hurts working men and women.

[The information referred to follows:]

The Washington Post—Opinions

"THE FOSSIL-FUEL INDUSTRY'S CAMPAIGN TO MISLEAD THE AMERICAN PEOPLE"

By Sheldon Whitehouse May 29, 2015

Sheldon Whitehouse, a Democrat, represents Rhode Island in the Senate.

Fossil fuel companies and their allies are funding a massive and sophisticated campaign to mislead the American people about the environmental harm caused by carbon pollution.

Their activities are often compared to those of Big Tobacco denying the health dangers of smoking. Big Tobacco's denial scheme was ultimately found by a Federal judge to have amounted to a racketeering enterprise.

The Big Tobacco playbook looked something like this: (1) pay scientists to produce studies defending your product; (2) develop an intricate web of PR experts and front groups to spread doubt about the real science; (3) relentlessly attack your opponents.

Thankfully, the government had a playbook, too: the Racketeer Influenced and Corrupt Organizations Act, or RICO. In 1999, the Justice Department filed a civil RICO lawsuit against the major tobacco companies and their associated industry groups, alleging that the companies "engaged in and executed—and continue to engage in and execute—a massive 50-year scheme to defraud the public, including consumers of cigarettes, in violation of RICO."

Tobacco spent millions of dollars and years of litigation fighting the government. But finally, through the discovery process, government lawyers were able to peel back the layers of deceit and denial and see what the tobacco companies really knew all along about cigarettes.

In 2006, Judge Gladys Kessler of the U.S. District Court for the District of Columbia decided that the tobacco companies' fraudulent campaign amounted to a racketeering enterprise. According to the court: "Defendants coordinated significant aspects of their public relations, scientific, legal, and marketing activity in furtherance of a shared objective—to . . . maximize industry profits by preserving and expanding the market for cigarettes through a scheme to deceive the public."

The parallels between what the tobacco industry did and what the fossil fuel industry is doing now are striking.

In the case of fossil fuels, just as with tobacco, the industry joined together in a common enterprise and coordinated strategy. In 1998, the Clinton administration was building support for international climate action under the Kyoto Protocol. The fossil fuel industry, its trade associations and the conservative policy institutes that often do the industry's dirty work met at the Washington office of the American Petroleum Institute. A memo from that meeting that was leaked to the New York Times documented their plans for a multimillion-dollar public relations campaign to undermine climate science and to raise "questions among those (*e.g.,* Congress) who chart the future U.S. course on global climate change."

The shape of the fossil fuel industry's denial operation has been documented by, among others, Drexel University professor Robert Brulle. In a 2013 paper published in the journal Climatic Change, Brulle described a complex network of organizations and funding that appears designed to obscure the fossil fuel industry's fingerprints. To quote directly from Brulle's report, it was "a deliberate and organized effort to misdirect the public discussion and distort the public's understanding of climate." That sounds a lot like Kessler's findings in the tobacco racketeering case.

The coordinated tactics of the climate denial network, Brulle's report states, "span a wide range of activities, including political lobbying, contributions to political candidates, and a large number of communication and media efforts that aim at undermining climate science." Compare that again to the findings in the tobacco case.

The tobacco industry was proved to have conducted research that showed the direct opposite of what the industry stated publicly—namely, that tobacco use had serious health effects. Civil discovery would reveal whether and to what extent the fossil fuel industry has crossed this same line. We do know that it has funded research that—to its benefit—directly contradicts the vast majority of peer-reviewed climate science. One scientist who consistently published papers downplaying the

role of carbon emissions in climate change, Willie Soon, reportedly received more than half of his funding from oil and electric utility interests: more than $1.2 million.

To be clear: I don't know whether the fossil fuel industry and its allies engaged in the same kind of racketeering activity as the tobacco industry. We don't have enough information to make that conclusion. Perhaps it's all smoke and no fire. But there's an awful lot of smoke.

Senator CRUZ. The hearing record is going to remain open for 2 weeks. During this time, Senators are asked to submit any questions for the record, and upon receipt, the witnesses are requested to submit their written answers to the Committee as soon as possible.

I want to thank the witnesses for being here. I want to thank you for the time in preparing your testimony.

And with that, this hearing is adjourned.

[Whereupon, at 5:52 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RICHARD BLUMENTHAL TO ADMIRAL DAVID TITLEY

Issue: Climate Change and Refugees

Question 1. The globe is currently facing a refugee crisis as innocent civilians are being forced to flee war-torn areas like Syria in an attempt to find safety. There are now 4.2 million registered refugees spread across Turkey, Lebanon, Egypt, Iraq, and Jordan.

Climate scientists hold that as climate change worsens, global crises of mass population displacements can increase. As droughts become more severe or as the sea level continues to rise and puts at risk coastal communities and settlements, millions of people can end up displaced because of drinking water shortages, crop shortages, and retreating land.

Not only will there the issue of resettling millions of displaced people, but as resources grow more scarce, conflict becomes more likely.

Thirty governors have declined to accept refugees as people are now fleeing the violence of ISIS. Yet, many of the same people who argue against opening our borders to refugees refuse to take action to mitigate and reverse climate change.

Can you speak to how significant of an issue displacement may become if we do not take steps to address climate change?

Answer. Climate refugees, although not a formally recognized term, will become an increasingly urgent problem for the world to deal with. Whether people are forced from their land due to rising seas and storm surges, salt-water contamination of fresh water supplies, or are no longer able to grow food for their families and communities due to a combination of increased heat or drought, they will move. They will then be either "internally displaced" refugees within their own country or international refugees. These problems will almost certainly be worse and most severe in regions where there is already poor governance, endemic corruption, and existing ethnic strife. Syria today is a tragic example, and ominously a window to a future where this challenge is ignored.

Question 2. How serious are the Departments of Defense and Homeland Security taking this potential future risk as a result of climate change?

Answer. This administration has taken the risk of climate change seriously as part of its duties. The risks of climate change are prominently acknowledged in the highest strategy documents of these departments. In addition, in January 2016 the Department of Defense issued a "Department of Defense Directive" *http://www.dtic.mil/whs/directives/corres/pdf/471521p.pdf* that gives very specific guidance to the Under and Assistant Secretaries of Defense, the Services, Combatant Commanders and the Joint Staff as to their duties and responsibilities with respect to addressing climate risk and security. For more details, see: *https://climateandsecurity.org/2016/01/20/new-dept-of-defense-directive-on-climate-security/*

Question 3. I imagine that because of the grave responsibility of national security these two departments are charged with upholding, any official position they take has been well researched and reviewed. Can you speak to how well researched the DOD and DHS's predictions as a result of climate change are and how reliable their science is?

Answer. Both the DOD and DHS rely on the scientific enterprise's collective knowledge, judgment and wisdom. This knowledge is best summarized in the U.S. National Academy of Science's body of work on climate change (*http://nas-sites.org/americasclimatechoices/sample-page/panel-reports/),* the National Climate Assessment (http://nca2014.globalchange.gov/), and the fifth assessment report of the Intergovernmental Panel on Climate Change (*https://www.ipcc.ch/report/ar5/*). In addition, specific NASA, NOAA, Department of Energy, U.S. Geological Survey, academic, intelligence community and other technical assets are consulted as required.

Issue: Climate Change Considerations at DOD

Question 4. In addition to the rise in regional instability across the globe and the potential to exacerbate the displacement of significant populations of people, climate change has the potential to pose other national security risks like threats to military installations.

The Department of Defense has done extensive climate research and is also taking steps to increase its use of alternative fuels and further its research into alternate fuel resources to reduce its carbon foot print.

The DOD has also taken several steps to incorporate climate mitigation into its planning. In a statement from this July, the department stated that "the ability of the United States and other countries to cope with the risks and implications of climate change requires monitoring, analysis and integration of those risks into existing overall risk management measures, as appropriate for each combatant command."

What are some other national security risks that the DOD warns of if climate change isn't mitigated?

Answer. Please refer to the CNA Military Advisory Board reports of 2007 *https://www.cna.org/CNA_files/pdf/National%20Security%20and%20the%20Threat%20of%20Climate%20Change.pdf* and 2014 *https://www.cna.org/CNA_files/pdf/MAB_5-8-14.pdf.*

In summary the risks are:

- changes in the Arctic for which we are not prepared
- climate threats to DOD and critical civilian infrastructure upon which our military and economic security reside. Climate threats include:
  - rising sea levels and attendant storm surges;
  - drought and excessive heat impacting a base's operating capacity;
  - direct or indirect threat from wildfires
- increase in the "demand signal" for world-wide Humanitarian Assistance and Disaster Relief (HA/DR) missions. While the U.S. military conducts HA/DR missions in a very capable and professional manner, a significant increase in these missions has the potential to disrupt training and capacity for higher-end warfighting missions that can only be accomplished by the U.S. military.
- Increase in the geo-strategic threats, where climate is not the sole cause of instability, but, like a link in a chain, is one of the reasons a region or nation tips into chaos and extremism, with unpredictable and unknown security and stability consequences.

Question 5. What has been the extent of its efforts to reduce its carbon footprint and transition to cleaner fuels?

Answer. Please refer to Mr. John Conger's 3 March 2015 written testimony before the House Appropriations Committee, pgs 11–13 and pgs 19–23. *http://docs.house.gov/meetings/AP/AP18/20150303/103047/HHRG-114-AP18-Wstate-CongerJ-20150303.pdf*

Question 6. In your testimony, you spoke to the risk management approach to addressing climate change recommended by the CNA Military Advisory Board, a panel of former three and four star generals. How concerned is the DOD with climate change and how much is it built into future planning?

Answer. Please see my previous answer regarding the DOD's concern for climate change. In my personal opinion, the leadership has done a good job of balancing and addressing this long-term, strategic risk with the shorter-term crises that the DOD must always handle. The issuance by Deputy Secretary Work of the DOD Directive on climate change in January 2016 is a good example of their commitment to addressing this risk.

Issue: Negative Economic Impact of Climate Change as Indicated by Connecticut-originated Research

Question 7. The NOAA Northeast Fisheries Research Lab in Milford, CT has demonstrated that ocean acidification is one of the greatest risks to the healthy development of shellfish like clams and oysters. I constantly hear from my state's aquaculture and shellfish harvesting communities that they are catching smaller and more underdeveloped shellfish by the year as acidification hinders the calcification process necessary to produce a strong and robust shell.

The University of Connecticut has also been pioneering a lot of sound and reliable climate science. One study, conducted by Dr. Baumann of UConn, investigates the impact of climate change on coastal marine fishes. His most recent NSF and NOAA funded study on the Atlantic silverside, a common fish in eastern North America

and a source of food for commercially important fish species like bluefish and striped bass, showed that high levels of carbon dioxide are likely to severely impact the larvae of this species in years to come. This will likely have a cascading effect to the fish that rely on them as a food source, which in turn will have a negative impact on the commercial fishing industry.

As climate deniers continue to do the bidding of the fossil fuel industry, protecting the profits of big oil and gas interests, what will the impact be on other industries that will be harmed by climate change, like the aquaculture and commercial fishing industries?

Answer. While some select industries may temporarily benefit from delaying action on climate change, particularly those connected with extracting, transporting or burning fossil fuel assets, many industries and communities will be negatively impacted from the changes in climate. The impacts may be direct, as your constituents in the aquaculture industry have relayed to you, or indirect, in that taxpayers will ultimately shoulder the cost of combatting sea-level rise, higher food prices, and increased health risks, to name a few.

Question 8. Won't most of the economy be negatively impacted by climate change? Won't the short-sighted denial of climate change really only benefit one industry at the detriment of everyone else?

Answer. Yes sir. The number of industries that benefit directly from delaying action are small in number compared to those who are seeing adverse effects.

Issue: Sea Level Rise in the Long Island Sound

Question 9. The Long Island Sound Study (LISS), a federal, state partnership between the EPA, Connecticut, and New York that monitors water quality and changes in the climate in the Long Island Sound, has been recording changes in sea level rise in the Sound for decades—since 1932 in Kings Point, NY and since 1967 in Bridgeport, CT.

What LISS has found is that the sea level in the Sound has been steadily increasing due to warming temperatures causing the water molecules in the Sound to expand, consistent with global findings. However, what scientists monitoring the Long Island Sound have also discovered is that sea level rise is over 50 percent higher than the global average over the same timeframe. This seems to indicate that as warming continues, the regions surrounding the Sound are especially vulnerable to flooding, storm surges, and other consequences of rising ocean levels.

Additionally, research by Dr. Lisa Park Boush of UConn shows that although hurricane frequency is tied to El Nino, it is also influenced by global climate change.

Hurricane Sandy devastated the coast of Connecticut. These storms are only becoming more extreme. If we do not take action to curb climate change, what type of damage are areas like the Connecticut coast in for, where they are especially sensitive to rising sea levels?

Answer. I think your local experts are best qualified to talk about the specifics of damage to the Connecticut coastline. We do understand though, that hurricanes in the northeast U.S. are likely to become stronger, and that those storm-surges will come in on top of an ever-rising sea level. Please see the recent article published in the Proceedings of the National Academy of Science by my colleagues Andra Reed and Michael Mann and others: *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC 4611656/* for details on the increased threat to the coastline.

Question 10. Communities along the coast are still rebuilding. Small businesses are implementing resiliency plans, efforts are underway to restore historic structures damaged in the storm, and aquaculture beds are recovering. The economic impact of the storm was nothing short of devastating. What are the economic risks associated with rising sea levels?

Answer. They will of course be very significant. I often use as a point of reference how much more money the Netherlands believes they need to invest in their sea-level defenses, already seen as the best in the world, will need to invest an additional $150B by 2100. *http://www.wired.com/2008/12/ff-dutch-delta/* For scale, the length of Dutch coastline is roughly equivalent to the coasts of Massachusetts and Connecticut, combined. One way or another, we are all going to pay this carbon tax, either in preparations and fortifications of our coast—or in economic disruption and devastation if we do not.

Question 11. Some in the climate denial camp point to deviations in temperature in the atmosphere's tropospheric level—the lowest level of the atmosphere—as indication that the verdict is still out on climate change. Can you explain why measurements like sea level rise give a better indication of climate change than variations in tropospheric temperatures?

Answer. Please see my response to Sen. Markey's QFR on this same topic.

Issue: The Importance of Funding Geo and Climate Science

Question 12. As a member of the Commerce, Science, and Transportation Committee, I have had the opportunity to meet with and hear issues of importance from climate and geo-scientists from Connecticut. These scientists specialize in researching how our climate works, how the Earth responds to different climate patterns, and how our climate is currently changing.

One recurring theme that I continue to hear from scientists from around Connecticut, whether it is from climatologists at UConn or researchers at Wesleyan and Yale, is that they are worried about the threatened Federal funding for geosciences. Funding proposals that have come from the House or supported by the other side of the aisle undervalue the significance of this important science field.

Geoscience and climate science is how we understand what is happening to the Earth's climate systems, and if this field is undermined, we cannot adequately prepare for changes we might encounter.

What are some of the consequences we can expect if we do not adequately fund these science disciplines?

Answer. This letter, signed by many Universities, including Penn State, and scientific organizations, explains both the benefits to funding and consequences of not funding very well: *https://www.ametsoc.org/ams/index.cfm/about-ams/ams-formal-letters-of-support/joint-letter-supporting-nsf-geosciences/*

Question 13. Do you believe there is a multiplier effect for investing in geo and climate science? As we develop new technologies or ways to fend off the costs of climate change, don't our investments pay off in greater returns?

Answer. Yes sir.

Question 14. Given the importance of these science disciplines, what possible explanation is there for cutting funding in this area?

Answer. I do not believe that credible arguments can be made to dis-invest in this area of science. We only have one Earth on which to live and base our economy. It's in everyone's interest to have the greatest possible understanding of, and predictions about, our home planet for the benefit of all.

Issue: Climate Sensitivity to CO_2 and Time Scales

Question 15. There seems to be a broad consensus on the correlation between CO_2 in the atmosphere and the average temperature of the planet. Climate scientists at Wesleyan produced a research paper in which they studied past states of the climate and found strong correlations between low CO_2 levels and lower temperatures and higher CO_2 levels and higher temperatures.

This research was backed up by findings that researchers at Yale contributed to, which studied climate sensitivity to CO_2 and also determined that the best indicators were revealed over long time periods on the scale of centuries or millennia.

How well do we understand the correlation between CO_2 and temperature? How confident is the scientific community in idea that high levels of CO_2 in the atmosphere contribute to a warming climate? Isn't this concept very well understood and widely acknowledged?

Answer. Yes, sir, there is extremely high confidence in this relationship. The following article from the "American Institute of Physics" *https://www.aip.org/history/climate/co2.htm* describes our scientific understanding of Greenhouse Gases, beginning with Joseph Fourier's work in the 1820s. I know of no credible climate scientist who disputes this fundamental relationship.

Question 16. Can you speak to the importance of taking measurements over long periods of time when attempting to understand climatic changes? Why might shorter time periods that many climate skeptics use be misleading when compared to long-term studies?

Answer. Please see my response to Sen. Markey's QFR where I describe "internal variability", "external forcing" and "manmade forcing" on the climate system. Over short time periods, internal and external forcing can counteract the manmade increase in greenhouse gases, but over the long term the interval variability just becomes "noise" and any changes in the sun and greenhouse gasses become the "signal". NASA and many others have measured the sun's energy reaching the earth to see if it is the reason for our warming temperatures—it is not. In fact, the sun's energy has decreased slightly over the past several decades, leaving greenhouse gases (and supported by over 150 years of theory) as the reason for our warming climate.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. EDWARD MARKEY TO ADMIRAL DAVID TITLEY

Question 1. Does the natural variability of the climate system in the past, like the episodic cool periods that occurred in the northern hemisphere during the so-called "Little Ice Age" and may have impacted the Pilgrim colony at Plymouth Rock, affect in any way our understanding of how greenhouse gases, such as carbon dioxide released from the burning of fossil fuels, are affecting the climate system now? Please explain.

Answer. Climate change can be forced by multiple different external factors: reduced sunlight, either because of changes in the sun's orbit or intensity, or an increase in volcanic eruptions can cool the planet. Conversely, increases in the sun's intensity, a relative minimum in volcanic activity, or an increase in greenhouse gas (GHG) concentration can warm the planet. Through research, we understand the so-called 'Little Ice Age' reflected a decrease in the sun's energy reaching Earth and also relatively high volcanic activity. Today we also understand with extremely high confidence why our climate is warming: the overwhelming driver for sustained warming is the increase in GHG concentration in the atmosphere. Scientists began to understand this effect as early as the middle of the 19th Century, and by the 1950s the theory was well established and well accepted. With the advent of Keeling's CO_2 measurements atop Mauna Loa in Hawaii, we have a continual record of the increase in GHG that correlates with the increase in global surface temperatures. {See Fig. 3, page 8, in my written testimony submitted for this hearing). While correlation per se does not equate to causation, the theory is well understood and science has systematically ruled out other reasons (primarily an increase in incoming energy from the sun) that would cause the Earth to warm so rapidly in such a short period of time.

Question 2. In the attached peer-review article by Richard Muller and his Berkeley Earth group's independent assessment of temperatures found temperature to have increased 2.7 °F in the last 250 years, with 1.6 °F of that rise occurring in the last 50 years. They find that the temperature changes can be explained by human greenhouse gas emissions and volcanoes, but not solar forcing. They also disclose their funding sources, one of which is the Charles G. Koch Charitable Foundation. Are the findings of this paper comparable to the scientific consensus that global temperatures are rising and that human are causing it?

Answer. Yes, the paper by Muller et. al. is broadly consistent with the scientific consensus that human-induced GHG increases are responsible for the overwhelming increase in 20th Century surface temperature increase. Although partially funded by the Charles G. Koch Charitable Foundation, Muller et. al. appear to have processed the data correctly, and have obtained basically the same answer as NASA, NOAA, the UK Met Office, the Japanese Meteorological Agency, and other reputable organizations who have studied this issue. Interestingly, Exxon-Mobil (then Esso) also reached this same conclusion back in the late 1970s and early 1980s. See Fig. 4, page 9 of my written testimony submitted for this hearing.

Question 3. During the hearing Dr. Curry claimed that the IPCC and the scientific consensus have no explanation for the increase of ice in the Antarctic. Can you comment on the scientific community's current understanding of changes in Antarctic land and sea ice and how they relate to anthropogenic climate change?

Answer. While the expansion of Antarctic Sea ice is still a topic of active research, it would be incorrect to that that science has "no explanation" for this phenomenon. A good summary of our state of knowledge can be found at: *https://www.skepticalscience.com/increasing-Antarctic-Southern-sea-ice-intermediate.htm*

> "If the Southern Ocean is warming, why is sea ice increasing? There are several contributing factors. One is the drop in ozone levels over Antarctica. The hole in the ozone layer above the South Pole has caused cooling in the stratosphere (Gillet 2003). A side-effect is a strengthening of the cyclonic winds that circle the Antarctic continent (Thompson 2002). The wind pushes sea ice around, creating areas of open water known as polynyas. More polynyas leads to increased sea ice production (Turner 2009).
>
> Another contributor is changes in ocean circulation. The Southern Ocean consists of a layer of cold water near the surface and a layer of warmer water below. Water from the warmer layer rises up to the surface, melting sea ice. However, as air temperatures warm, the amount of rain and snowfall also increases. This freshens the surface waters, leading to a surface layer less dense than the saltier, warmer water below. The layers become more stratified and mix less. Less heat is transported upwards from the deeper, warmer layer. Hence less sea ice is melted (Zhang 2007).

Antarctic sea ice is complex and counter-intuitive. Despite warming waters, complicated factors unique to the Antarctic region have combined to increase sea ice production. The simplistic interpretation that it's caused by cooling is false."

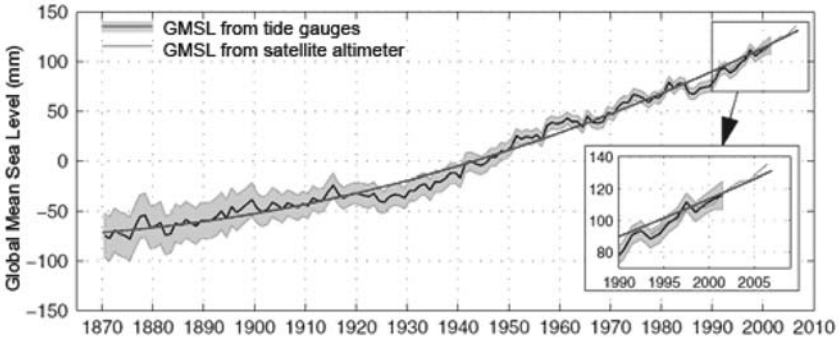
Question 4. During the hearing Dr. Curry claimed that the IPCC report has no explanation for the fact that the rate of sea level rise from 1920 to 1950 was large. Please describe the trends in sea level rise from 1920 to today and what is known about how they relate to anthropogenic climate change.

Answer. Dr. Curry's question ignores the broader implications of an ever-rising sea level. Although this reference *http://www.skepticalscience.com/Sea-level-rise-the-broader-picture.html* is nearly six years old, it provides a good overview and shows that sea level rise in the period from 1920–1950 was not anomalous.

"Sea level rises as ice on land melts and as warming ocean waters expand. Sea level rise mutually corroborates other evidence of global warming as well as being a threat to coastal habitation and environments.

The blue line in the graph below clearly shows sea level as rising, while the upward curve suggests sea level is rising faster as time goes on. The upward curve agrees with global temperature trends and with the accelerating melting of ice in Greenland and other places.

Because the behavior of sea level is such an important diagnostic aid for tracking climate change, skeptics seize on the sea level record in an effort to cast doubt on this evidence. Sea level bounces up and down slightly from year to year so it's possible to cherry-pick data falsely suggesting the overall trend is flat, falling or linear. You can try this yourself. Starting with two closely spaced data points on the graph below, lay a straight-edge between them and notice how for a short period of time you may create almost any slope you prefer, simply by being selective about what data points you use. Now choose data points farther apart. Notice that as your selected data points cover more time, the more your mini-graph reflects the big picture. The lesson? Always look at all the data, don't be fooled by selective presentations.



(graph from Church 2008)

Other skeptic arguments about sea level concern the validity of observations, obtained via tide gauges and more recently satellite altimeter observations.

Tide gauges must take into account changes in the height of land itself caused by local geologic processes, a favorite distraction for skeptics to highlight. Not surprisingly, scientists measuring sea level with tide gauges are aware of and compensate for these factors. Confounding influences are accounted for in measurements and while they leave some noise in the record they cannot account for the observed upward trend.

Various technical criticisms are mounted against satellite altimeter measurements by skeptics. Indeed, deriving millimeter-level accuracy from orbit is a stunning technical feat so it's not hard to understand why some people find such an accomplishment unbelievable. In point of fact, researchers demonstrate this height measurement technique's accuracy to be within 1mm/year. Most importantly there is no form of residual error that could falsely produce the upward trend in observations.

As can be seen in an inset of the graph above, tide gauge and satellite altimeter measurements track each other with remarkable similarity. These two inde-

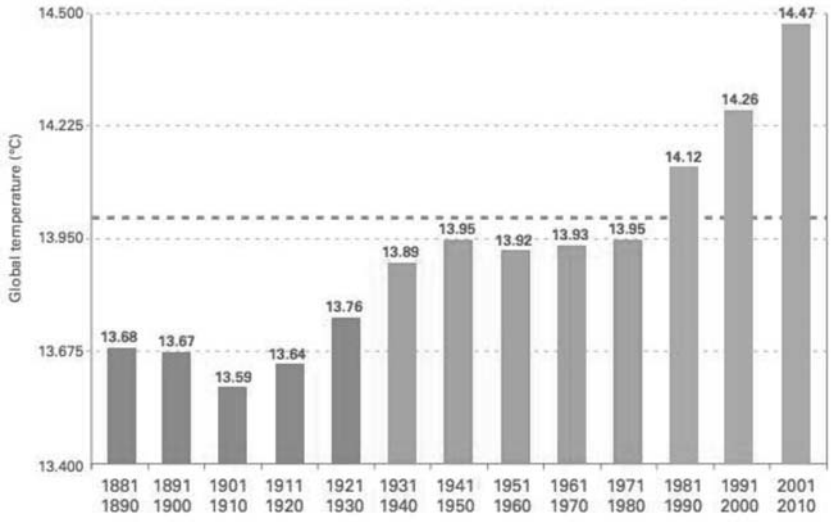
pendent systems mutually support the observed trend in sea level. If an argument depends on skipping certain observations or emphasizes uncertainty while ignoring an obvious trend, that's a clue you're being steered as opposed to informed. Don't be mislead by only a carefully-selected portion of the available evidence being disclosed.

Current sea level rise is after all not exaggerated, in fact the opposite case is more plausible. Observational data and changing conditions in such places as Greenland suggest if there's a real problem here it's underestimation of future sea level rise. The IPCC synthesis reports offer conservative projections of sea level increase based on assumptions about future behavior of ice sheets and glaciers, leading to estimates of sea level roughly following a linear upward trend mimicking that of recent decades. In point of fact, observed sea level rise is already above IPCC projections and strongly hints at acceleration while at the same time it appears the mass balance of continental ice envisioned by the IPCC is overly optimistic (*Rahmstorf 2010*)."

More to the point, the rate of sea level rise is accelerating, as shown in recent papers summarized by Climate Central *http://www.climatecentral.org/news/study-reveals-acceleration-of-sea-level-rise-20055* and researchers at Penn State *http://news.psu.edu/story/400758/2016/03/30/research/sea-level-rise-antarctic-ice-sheet-could-double?utm__source=newswire&utm__medium=e-mail&utm__term=401922__HTML&utm__content=04-04-2016-16-55&utm__campaign=daily%20newswire* These are the real risks to our society—not dissecting the noise in the sea level record from over half a century in the past.

Question 5. Climate change deniers have often pointed to a hiatus or pause in warming since 2000. However, the attached peer-reviewed study by Thomas Karl et. al. shows that newly corrected and updated global surface temperatures from NOAA's NCEI do not support a global warming "hiatus" and that there is no discernable decrease in the rate of warming between the second half of the 20th century and the first 15 years of the 21st century. From your review of the latest scientific evidence, do you agree that the global temperatures have continued to rise over the past 15 years? Also, please address the scientific problem with making conclusions about climate change based on short-term trends.

Observed climate change is the net result of 'internal variability' (analogous to changes in water level that's sloshing about in a shallow pan; no water is added or lost, but the height of the water (or temperature in case of the earth) bounces up and down—but the average does not change over time), external forcing (*e.g.,* changes in the sun's energy reaching the earth, changes in the number and intensity of volcanic eruptions), and man-made forcing (primarily addition of greenhouse gasses but also by the addition of very small particles (aerosols) that tend to have a net cooling on the planet). Sometimes these forces all act in the same direction at the same time—at other times they can oppose one another. Michael Mann and colleagues have published convincing peer-reviewed research (summarized here: *http://www.realclimate.org/index.php/archives/2015/02/climate-oscillations-and-the-global-warming-faux-pause/*) that shows the 'internal variability' of the climate system has been counter-acting much but not all of the continuing warming caused by the man-made addition of GHG to the atmosphere. Despite such temporary cooling factors, overall temperatures have continued to rise. You can see this in Figure 3 (page 8) of my written testimony submitted for this hearing. In addition the World Meteorological Organization (WMO) has a chart of temperatures averaged over every decade starting from 1890 (here's the source: *http://library.wmo.int/pmb__ged/wmo__1119__en.pdf*)



RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. GARY PETERS TO ADMIRAL DAVID TITLEY

Question. Dr. Titley, there were a number of claims made in the hearing that run counter to scientific findings and conclusions. Some examples include claims about carbon dioxide and its effect on plant life and agriculture, the historical abundance of CO_2 in the atmosphere, the so called warming "hiatus" and the relative value of satellite and balloon data versus direct measurements, sea level rise, and inconsistency of model predictions and measured observations.

Could you please briefly address any false or misleading claim not already covered in your testimony, and also please provide references to quality, peer-reviewed scientific publications that dispute these false or misleading claims?

Answer. Senator, I addressed the recent temperature record and sea-level rise issues in my QFR's in response to Senator Markey. The single most comprehensive source to the issues you raise is in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). *http://www.ipcc.ch/* This report summarizes and synthesizes the body of peer-reviewed research and addresses what we do—and do not know—about our changing climate, and the degree of confidence to which we understand specific aspects of climate change. If there is a fault of the IPCC process, it's a consensus body of the world's nations, so its conclusions are that of a 'least common denominator' agreed to by all. If the IPCC reports are wrong, it's because the climate is changing faster than the consensus body of literature would indicate, and that the 'fat tail' risks are underestimated.

For a detailed accounting of how drastically over-simplified and false the argument that "more CO_2 is better for plants" is, please see *https://www.skepticalscience.com/co2-plant-food-advanced.htm* The article contains multiple references to respected, peer-reviewed articles.

An advanced and technical description of the challenges of re-creating surface temperature record proxies from satellite-derived measurements can be found here: *https://www.skepticalscience.com/satellite-measurements-warming-troposphere-advanced.htm,* again with embedded peer-reviewed references.

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