A RATIONAL DISCUSSION OF CLIMATE CHANGE: THE SCIENCE, THE EVIDENCE, THE RESPONSE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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A RATIONAL DISCUSSION OF CLIMATE CHANGE: THE SCIENCE, THE EVIDENCE, THE RESPONSE

WEDNESDAY, NOVEMBER 17, 2010

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY
Washington, DC.

The Subcommittee met, pursuant to call, at 10:38 a.m. In Room 2325, Rayburn House Office Building, Hon. Brian Baird [Chairman of the Subcommittee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

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COMMITTEE ON SCIENCE AND TECHNOLOGY

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Subcommittee on Energy and Environment Hearing

A Rational Discussion of Climate Change: The Science, the Evidence, the Response

Wednesday, November 17, 2010
2325 Rayburn House Office Building

Panel I

Dr. Ralph J. Cicerone
President, National Academy of Sciences

Dr. Richard Lindzen
Alfred P. Sloan Professor of Meteorology, Department of Earth, Atmospheric and Planetary Scientists
Massachusetts Institute of Technology

Dr. Gerald A. Meehl
Senior Scientist, Climate and Global Dynamics Division, National Center for Atmospheric Research

Dr. Heidi M. Cullen
Chief Executive Officer and Director of Communications, Climate Central

Panel II

Dr. Patrick J. Michaels
Senior Fellow in Environmental Studies, Cato Institute

Dr. Benjamin D. Santer
Atmospheric Scientist, Program for Climate Model Diagnosis and Intercomparison
Lawrence Livermore National Laboratory

Dr. Richard B. Alley
Evan Pugh Professor, Department of Geosciences and Earth and Environmental Systems Institute
The Pennsylvania State University

Dr. Richard A. Feely
Senior Scientist, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration

Panel III

Rear Admiral David W. Titley
Oceanographer and Navigator of the U.S. Navy

Mr. James Lopez
Senior Adviser to the Deputy Secretary, U.S. Department of Housing and Urban Development

Mr. William Geer
Director of the Center for Western Lands, Theodore Roosevelt Conservation Partnership

Dr. Judith A. Curry
Chair of the School of Earth and Atmospheric Sciences, Georgia Institute of Technology

HEARING CHARTER

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES

A Rational Discussion of Climate Change: the Science, the Evidence, the Response

WEDNESDAY, NOVEMBER 17TH, 2010
10:30 AM
2325 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Wednesday, November 17, 2010 the Subcommittee on Energy and Environment of the House Committee on Science and Technology will hold a hearing entitled: "A Rational Discussion of Climate Change: the Science, the Evidence, the Response". The Subcommittee will receive testimony on the basic science underlying how climate change happens; the evidence and the current impacts of climate change; and the actions that diverse sectors are taking today to respond to and prepare for a changing climate.

Witnesses

Panel 1

- **Dr. Ralph Cicerone** is the President of the National Academy of Sciences. Dr. Cicerone will explain the basic science, including the fundamental physics, underlying how climate change happens. He will also discuss the role of the National Academy of Sciences in advancing climate science and informing the public on the issue.
- **Dr. Heidi Cullen** is the CEO and Director of Communications at Climate Central. Dr. Cullen will discuss the basic science of climate change, including the fundamental chemistry, the causes of production of greenhouse gases; and the expected impacts on the climate.
- **Dr. Gerald A. Meehl** is a Senior Scientist in the Climate and Global Dynamics Division at the National Center for Atmospheric Research. Dr. Meehl will discuss the basic physics underlying how climate change happens and how the physics is incorporated into the development of the climate models.
- **Dr. Richard Lindzen** is the Alfred P. Sloan Professor of Meteorology in the Department of Earth, Atmospheric, and Planetary Sciences at Massachusetts Institute of Technology. Dr. Lindzen will discuss how greenhouse gas emissions resulting from human activities will only minimally contribute to warming. He will also discuss the limitations in the global climate models and the problems with the positive feedbacks built into the models.

Panel 2

- **Dr. Benjamin Santer** is an Atmospheric Scientist in the Program for Climate Model Diagnosis and Intercomparison at the Lawrence Livermore National Laboratory. Dr. Santer will discuss the evidence of climate change; how well the science validates that climate change is happening; and the computational climate models, including how the various climate data sets are utilized and analyzed.
- **Dr. Richard Alley** is the Evan Pugh Professor in the Department of Geosciences and an Associate of the Earth and Environmental Systems Institute at Pennsylvania State University. Dr. Alley will describe the effects of climate change on ice dynamics and explain how changes in levels of carbon dioxide in the atmosphere have led to a rise in global temperatures.
- **Dr. Richard Feely** is a Senior Scientist at the Pacific Marine Environment Laboratory of the National Oceanic and Atmospheric Administration (NOAA). Dr. Feely will discuss the current science and understanding of ocean acidifi-

cation, the factors that contribute to the acidification process, and the resulting impacts.

- **Dr. Patrick Michaels** is a Senior Fellow in Environmental Studies at the Cato Institute. Dr. Michaels will discuss the rate of greenhouse-related warming; the Endangerment Finding by the Environmental Protection Agency; and scientific integrity.

Panel 3

- **Rear Admiral David Titley** is an Oceanographer and Navigator for the United States Department of the Navy, Department of Defense. RADM Titley will discuss the impacts of climate change on U.S. Navy missions and operations, the national security implications of climate change, and the role of the U.S. Navy's Task Force Climate Change.
- **Mr. James Lopez** is the Senior Advisor to the Deputy Secretary at the Department of Housing and Urban Development. Mr. Lopez will discuss the impacts of climate change on vulnerable populations and communities; HUD's proposed Sustainable Communities Initiative; and how the Department is working to improve the coordination of transportation and housing investments to ensure more regional and local sustainable development patterns, more transit-accessible housing choices, and reduced greenhouse gas emissions.
- **Mr. William Geer** is the Director of the Center for Western Lands for the Theodore Roosevelt Conservation Partnership. Mr. Geer will discuss the threat of climate change to hunting and fishing; its impacts on fish and wildlife; and how the Theodore Roosevelt Conservation Partnership is responding to the impacts of climate change.
- **Dr. Judith Curry** is the Chair of the School of Earth and Atmospheric Sciences at Georgia Institute of Technology. Dr. Curry will discuss how uncertainty in data and conclusions is evaluated and communicated. She will also discuss how this uncertainty should be incorporated into decision-making efforts.

Background

Human society is shaped by the climate in fundamental ways, and so for many decades researchers around the world have been working to understand how humans are affecting the climate, the impacts of these changes, and how society can mitigate and prepare for these effects. Since human settlement began, climate has influenced what we wear, the food that we eat, where we live, and how we build our houses. And despite our greatest technological advances, climate still affects how and where we live our lives today, as well as our economy and national security. Various sectors, from agriculture to transportation, rely on climate certainty. Climate change has increased uncertainty in many sectors; therefore, many decisions with significant economic impacts will have to be made with greater levels of associated risk. Advancements in climate science may reduce uncertainty in climate dependent sectors, thus better informing decisions that impact the quality of our lives.

Climate and Weather

Climate can be defined as the product of several meteorological elements [1] in a given region over a period of time. In addition, spatial elements such as latitude, terrain, altitude, proximity to water and ocean currents affect the climate. We experience climate on a daily basis through the weather. The difference between weather and climate is a measure of time—weather consists of the short-term (minutes to months) changes in the atmosphere. Weather is often thought of in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure. Weather is what conditions of the atmosphere are over a short period of time, and climate is how the atmosphere "behaves" over relatively long periods of time. In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. Climate, however, is the average of weather over a period of years to decades. Generally, climate is what you expect, like a very

[1] Meteorological elements such as temperature, humidity, atmospheric pressure, wind, rainfall, and atmospheric particle count.

hot summer in the American Southwest, and weather is what you get, like a hot day with pop-up thunderstorms.[2]

The Science

Climate can be influenced by a variety of factors, including: changes in solar activity, long-period changes in the Earth's orbit, natural internal processes of the climate system, and anthropogenic (i.e. human-induced) increases in atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs).[3] As described above, "climate" is the long-term average of a region's weather patterns, and "climate change" is the term used to describe changes in those patterns. Climate change will not have a uniform effect on all regions and these differing effects may include changes to average temperatures (up or down), changes in season length (e.g. shorter winters), changes in rain and snowfall patterns, and changes in the frequency of intense storms. The scientific community has made tremendous advances in understanding the basic physical processes as well as the primary causes of climate change. And researchers are developing a strong understanding of the current and potential future impacts on people and industries.

Throughout Earth's history, the climate has changed in dramatic ways. What makes this point in time different from the past is the human influence on this change and the rate at which this change is occurring. Volumes of peer-reviewed scientific data show that CO_2 concentrations in the atmosphere have increased substantially since industrialization began. Fossil fuel use has become an increasingly important part of our lives, and as a result, CO_2 concentrations have increased approximately 30% since pre-industrial times.[4] And the current level of CO_2 in the atmosphere is the highest in the past 650,000 years.[5] According to the National Academies, there is strong scientific consensus that these increases in CO_2 concentrations intensify the greenhouse effect, and this effect plays a critical role in warming our planet.[6]

Greenhouse Effect

Greenhouses work by trapping heat from the sun. The glass panels of the greenhouse let in light but keep heat from escaping. This causes the greenhouse to heat up, much like the inside of a car parked in sunlight. Greenhouse gases in the atmosphere behave much like the glass panes in a greenhouse. Sunlight enters the Earth's atmosphere, passing through the blanket of greenhouse gases. As it reaches the surface, the Earth's land, water, and biosphere absorb the sun's energy. Once absorbed, this energy is eventually transmitted back into the atmosphere through physical processes such as heat conduction, convection, and evaporation. Some of the energy passes back into space, but much of it remains trapped in the atmosphere by the greenhouse gases, causing the Earth to heat up.

As a basis for discussion about GHGs and their influence on the climate, it should be noted that there is a natural, non-anthropogenic greenhouse effect, which Joseph Fourier discovered more than 150 years ago. Fourier argued that "the atmosphere acts like the glass of a hothouse because it lets through the light rays of the sun but retains the dark rays from the ground".[7] This is a major simplification in describing the greenhouse effect, but it does provide insight into why the Earth's surface is considerably warmer than it would be without an atmosphere.

Several scientists built on Fourier's greenhouse theory by recognizing the importance of the selective absorption of some of the minor constituents of the atmosphere, such as CO_2 and water vapor. Swedish chemist Svante Arrhenius conducted

[2] *See <http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html>.*

[3] In addition to long-term climate change, there are shorter term climate variations. This so-called climate variability can be represented by periodic or intermittent changes related to El Niño, La Niña, volcanic eruptions, or other changes in the Earth system.

[4] *See <http://www.wpro.who.int/NR/rdonlyres/33FA546E-7813-4E51-BA89-48759FF45360/0/climate_factsheet.pdf>.*

[5] Michael Hopkin, *Greenhouse-Gas Levels Highest for 650,000 Years: Climate Record Highlights Extent of Man-Made Change*, NATURE NEWS. Published Online. (24 Nov 2005). doi:10.1038/news051121-14.

[6] National Research Council, AMERICA'S CLIMATE CHOICES: ADVANCING THE SCIENCE OF CLIMATE CHANGE (2010).

[7] Joseph Fourier, *Remarques Générales Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires*, 27 ANNALES DE CHIMIE ET DE PHYSIQUE p.136–67 (1824). *and* Joseph Fourier, *Mémoire Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires*, 7 MÉMOIRES DE L'ACADÉMIE ROYALE DES SCIENCES p.569–604 (1827).

an extensive analysis of the greenhouse effect.[8] Arrhenius calculated the temperature increase caused by the greenhouse effect as a function of the atmospheric concentration of "carbonic acid"[9], latitude, and season. The values Arrhenius obtained for the warming of the atmosphere are very much in agreement with what are now being obtained using complex climate models. Further research in the 1930s showed that, due to the more extensive use of fossil fuels, the atmospheric concentration of carbon dioxide was increasing, and the first projection of the atmospheric CO_2 concentration was made in the late 1950s.[10] As these scientific findings were coming to light, operational data collection programs were initiated for measuring atmospheric CO_2 in Scandinavia, Mauna Loa, Hawaii and at the South Pole.

Carbon dioxide (CO_2) is a greenhouse gas (GHG) that traps the sun's radiation within the troposphere, i.e. the lower atmosphere. It has accumulated along with other man-made greenhouse gases, such as methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). GHGs are an important part of our atmosphere because they keep Earth from having an inhospitably cold surface temperature.[11] That said, if the greenhouse effect becomes stronger, through increased concentrations of GHGs and water vapor, it could make the Earth warmer than human civilization and its surrounding ecosystem has currently adapted to. Even a small additional warming is predicted to cause significant issues for humans, plants, and animals.

The Scientific Process: Uncertainty, Consensus, and Peer Review

Climate science, like all science, is an iterative process of collective learning: data are collected; hypotheses are formulated, tested, and refined; theories are constructed and models are built in order to synthesize understanding and to generate predictions; and experiments are conducted to test these hypotheses, theories, and models. New observations and refined theories are incorporated throughout this process, and predictions and theories will be further supported or refuted. Confidence in a theory grows if it is able to survive this rigorous testing process, if multiple lines of evidence converge in agreement, and if competing explanations can be ruled out.

The scientific community uses a highly formalized version of peer review to validate research results and improve our understanding of the relevance of these results. Through this process, only those concepts that have been described through well-documented research and subjected to the scrutiny of other experts in the field become published papers in science journals and accepted as current scientific knowledge. Although peer review does not guarantee that any particular published result is valid, it does provide a high assurance that the work has been carefully vetted for accuracy by informed experts prior to publication. The overwhelming majority of peer-reviewed papers about global climate change acknowledge that human activities are substantial contributing factors.

Science is based on observations and therefore uncertainty is inherent to the scientific process. Uncertainties about climate change will never be completely eliminated by scientific research, but science can enable decision makers to make informed choices in the face of risks.[12]

The Evidence

There are numerous effects that can result from climate change. Some effects are already being felt today, and some are projected by scientists to occur in the future. Scientifically documented evidence of climate change includes:

Sea Level Rise. The global sea level rose about 17 centimeters (6.7 inches) in the last century. The rate in the last decade, however, is nearly double that of the last century.[13]

Global Temperature Rise. The major comprehensive global surface temperature reconstructions, which use a wide variety of data sources from satellites to weather

[8] Svante Arrhenius, *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground* 41 PHILOSOPHICAL MAGAZINE p.237–276 (1896). *and* Elisabeth T. Crawford, ARRHENIUS: FROM IONIC THEORY TO THE GREENHOUSE EFFECT (Science History Publications) (1996).

[9] Carbonic acid is a byproduct of carbon dioxide when dissolved in water.

[10] Roger Revelle and Hans E. Suess, *Carbon Dioxide Exchange Between Atmospheric and Ocean and the Question of an Increase of Atmospheric CO_2 during the Past Decades*, 9 TELLUS p.18–27 (1957).

[11] *See <http://www.epa.gov/climatechange/glossary.html>*.

[12] National Research Council, AMERICA'S CLIMATE CHOICES: ADVANCING THE SCIENCE OF CLIMATE CHANGE p.15 (2010).

[13] J.A. Church and N.J. White, *A 20th Century Acceleration in Global Sea Level Rise*, 33 GEOPHYSICAL RESEARCH LETTERS (2006).

stations, show that Earth has warmed since 1880.[14] Most recorded warming has occurred since the 1970s, with the twenty warmest years having occurred since 1981 and with all ten of the warmest years occurring in the past twelve years.[15] Even though the 2000s witnessed a solar output decline resulting in an unusually deep solar minimum in 2007–2009, surface temperatures continue to increase.[16]

Warming Oceans. The oceans have absorbed much of the increased heat, with the top 700 meters (about 2,300 feet) of ocean showing warming of 0.302 degrees Fahrenheit since 1969.[17]

Shrinking Ice Sheets. The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 cubic kilometers (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometers (36 cubic miles) of ice between 2002 and 2005.[18]

Declining Arctic Sea Ice. Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.[19]

Glacial Retreat. Glaciers are retreating almost everywhere around the world—including in the Alps, Himalayas, Andes, Rockies, Alaska, and Africa.[20]

Extreme Weather Events. The number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing, since 1950. The U.S. has also witnessed increasing numbers of intense rainfall events.[21]

Ocean Acidification. The carbon dioxide content of the Earth's oceans has been increasing since 1750, and is now increasing at a rate of approximately 2 billion tons per year. This has increased ocean acidity by about 30 percent.[22]

The Response

Scientific research is also invested in developing ways to respond and adapt to climate change, in addition to developing technologies and policies that can be used to limit the magnitude of future changes to the climate. The issues of mitigating, adapting, and responding to the impacts of climate change are currently being explored through global collaborative input from a wide range of experts, including physical scientists, engineers, social scientists, public health officials, business leaders, economists, and governmental officials. Demand for information to support climate-related decisions has grown as people, organizations, and governments have moved ahead with plans and actions to reduce greenhouse gas emissions and to adapt to the impacts of climate change. Today, however, the nation lacks comprehensive, robust, and credible information systems to inform climate choices and evaluate their effectiveness.

Scientific research plays a role in guiding the nation's response to climate change by:

- projecting the beneficial and adverse effects of climate changes;
- identifying and evaluating the likely or possible consequences, including unintended consequences, of different policy options to address climate change;
- improving the effectiveness of existing options and expanding the portfolio of options available for responding to climate change; and
- developing improved decision-making processes.

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[14] *See <http://www.ncdc.noaa.gov/cmb-faq/anomalies.html>.*

[15] T.C. Peterson et. al., *State of the Climate in 2008*, 90 Special Supplement to the Bulletin of the American Meteorological Society p.S17–S18 (2009).

[16] I. Allison et. al., The Copenhagen Diagnosis: Updating the World on the Latest Climate Science, (UNSW Climate Change Research Center, Sydney, Australia) (2009).

[17] Levitus et. al., *Global Ocean Heat Content 1955–2008 In Light of Recently Revealed Instrumentation Problems*, 36 Geophysical Research Letters (2009).

[18] *See <http://climate.nasa.gov/evidence/>, <http://www.giss.nasa.gov/research/news/20100121/> and <http://science.nasa.gov/headlines/y2009/01apr_deepsolarminimum.htm>.*

[19] L. Polyak et. al., History of Sea Ice in the Arctic *In* Past Climate Variability and Change in the Arctic and at High Latitudes, U.S. Geological Survey, Climate Change Science Program Synthesis and Assessment Product 1.2. chapter 7 (2009). *and* R. Kwok and D.A. Rothrock, *Decline in Arctic sea ice thickness from submarine and ICESAT records: 1958–2008*, 36 Geophysical Research Letters (2009).

[20] *See <http://nsidc.org/sotc/glacier_balance.html> and <http://www.geo.unizh.ch/wgms/mbb/sum08.html>.*

[21] *See <http://lwf.ncdc.noaa.gov/extremes/cei.html>.*

[22] C.L. Sabine et. al., *The Oceanic Sink for Anthropogenic CO_2*, 305 Science p.367–371 (2004),; Copenhagen. *Also see <http://www.pmel.noaa.gov/co2/OA/>.*

Chairman BAIRD. The hearing will now come to order. Our hearing today is titled: “A Rational Discussion of Climate Change: The Science, the Evidence, the Response.” The purpose of today’s hearing is to conduct an objective review of the science behind the greenhouse effect, climate change, and acidification.

My impression has been for some time that many members of the public and perhaps some in Congress have never had the opportunity to consider the basic science and, for that matter, the long history of investigation and data that underlies scientific understanding of the greenhouse effect, and more recently, of ocean acidification.

Therefore, today we have three panels of experts with us. The first will begin today’s hearing by setting the foundation of basic science. They will explain to us the fundamental physics and chemistry underlying the role of CO_2 and other atmospheric gases in regulating or altering our planet’s temperature and the acidity of the oceans. A bit of a scientific history lesson will be included as we learn that the science behind this issue goes back more than 100 years. The panel will also address questions about how much CO_2 has been entering the atmosphere, from what sources, and with what predicted effects.

From basic scientific findings and methodologies described by the first panel, we will then consider whether or not the predicted impacts of CO_2 on temperature and ocean acidity are, in fact, occurring. In other words, we will ask the question if basic science makes certain predictions about what should happen if CO_2 levels increase in the air and oceans, what is actually happening in the real world? How do we know if it is happening or not, and what can we predict for the future?

The third and final panel will then discuss the impacts that are being observed and that can be anticipated from climate change and ocean acidification. Our witnesses will discuss how we are already responding today and actions we need to take to prepare for the future. The analysis includes such matters as national security, social impacts, economic effects, and health concerns, among others.

I have had the opportunity in preparation for this hearing to read all of the written testimony. I want to thank the witnesses for taking time from their busy schedules to prepare this material and submit it beforehand for the Committee’s analysis. We are also going to post that on the Science Committee website for those of you who are interested. And I hope you will be. It is wonderful testimony and very illuminating.

Before we hear from the witnesses, I want to make just a few key points. Having taught scientific methodology and basic statistics and having published, myself, in peer-reviewed journals, I personally place a paramount importance on scientific integrity. That is why in the America COMPETES Act, I authored the provision that insists that institutions seeking to receive NSF funding have specific course training in scientific ethics. My understanding is that from academia and from NSF that this is having a salutary impact, and I am proud of that impact.

I mention it today because, after all, this is the Science and Technology Committee. We must, if we are to have any credibility at all, insist that our witnesses adhere to the highest standards of integrity, and simultaneously we, Members of Congress, must hold ourselves and this Committee as an institution to that standard in our study of the issues and in our conduct today and in the future.

In the context of climate change and ocean acidification, I also believe that because our Nation is the biggest historical producer and second largest current producer of greenhouse gases, we have a profound moral responsibility to be sure we get this right. Scripture teaches us to love thy neighbor as thyself. If our disproportionate impacts on the rest of the world are harming billions of other people and countless other species, we are not living up to that scriptural guidance.

Finally, even if one completely rejects the evidence that will be presented today in reports from the National Academies of Science and countless other respected bodies, I believe it still makes good sense to strive for our Nation to be a leader in clean-energy technology for economic self-interest alone.

Is not the reality of sending hundreds of billions of dollars abroad, often to countries with values antithetical to our own, at least a bit troubling for all of us? Is not the national security risk this creates disconcerting? Are the known impacts of events such as Exxon Valdez, the Gulf oil spill, and numerous other events not of sufficient concern to argue for change, and are not the facts of red-alert days in our Nation's cities, in which it is unsafe for our children to breathe, sufficient cause for some degree of consternation and change?

I personally believe the evidence of climate change and ocean acidification is compelling and troubling. But even without that conclusion, I am convinced we must change our energy policies for reasons of economics, national security, and environmental and human health. Our Nation has long been a leader in renewable-energy technology and I believe we must remain a leader.

This Committee, under the leadership of Chairman Gordon, and before him Chairman Boehlert, have taken positive steps to ensure that continues. So too we have been at the forefront of climate research and should remain a leader there as well. We must continue this endeavor if we intend to leave our children and our grandchildren a strong economy and truly an independent and secure Nation and an environment in which to live, work, and play.

Finally, as the parent of 5–1/2-year-old twin boys, the whole effort of my service in Congress and on this committee has been to ensure that they have a brighter and better future. If we don't address this issue well and responsibly, I fear we will fail in that mission and leave them a much less pleasant future than we have been able to enjoy.

I am excited about today's hearing and these three panels of witnesses. I thank them for their time. They will help us better understand the concepts and impacts of climate change. And I personally thank each of you for being here. And I thank our outstanding Committee staff for their work in bringing such superb witnesses.

[The prepared statement of Chairman Baird follows:]

PREPARED STATEMENT OF CHAIRMAN BRIAN BAIRD

Good morning and welcome to today's hearing—*A Rational Discussion of Climate Change: the Science, the Evidence, the Response*. Several months ago I suggested to our Science Committee staff that it was time this Committee held a comprehensive and in depth hearing to really discuss the science behind climate change and ocean acidification.

I wanted the hearing to fully present the information as objectively and clearly as possible so that we could all have a sense of the basic science behind the greenhouse effect and ocean acidification, and the likely impacts. I also believed it would be important for our understanding to ensure that scientists with differing views be invited to testify.

Therefore, today we have three panels of experts with us. The first panel will begin today's hearing by setting the foundation of basic science. They will explain to us the basic physics and chemistry underlying the role of CO_2 and other atmospheric gases in regulating or altering our planet's temperature and the acidity of the oceans. A bit of scientific history lesson will be included as we learn that the fundamental science behind this issue goes back more than one hundred years. This panel will also address questions about how much CO_2 has been entering the atmosphere, from what sources, and with what predicted effects.

From the basic scientific findings and methodologies described by the first panel, we will then consider whether or not the predicted impacts of CO_2 on temperature and ocean acidity are, in fact, occurring. In other words, we will ask the question, "If basic science makes certain predictions about what should happen if CO_2 levels increase in the air and the oceans, what is actually happening in the 'real world,' how do we know if it is happening or not, and what can we predict for the future?"

The third and final panel will then discuss the impacts that are being observed and that can be anticipated from climate change and ocean acidification. Our witnesses will discuss how we are already responding today and actions we need to take to prepare for the future. This analysis includes such matters as national security, social impacts, economic effects, and health concerns, among others.

I have had the opportunity in preparation for this hearing to read all of the written testimony. I want to thank the witnesses for taking time from their busy schedules to prepare this material and submit it beforehand for the Committee analysis. I hope and trust many of my colleagues have taken the time as I have to read the testimony from all the witnesses.

In addition to the written testimony provided by our panelists, I should note that I have personally gone well beyond to review published articles by many of those will testify before us today. I have also had the privilege to participate in various scientific forums domestically and globally that have examined this issue. Further, I have followed the matter very closely in the pages of *Science* magazine, which I subscribe to personally as a long time member of the American Association for the Advancement of Science.

Before we hear from the witnesses, I want to make just a few key points. First, as someone who has taught scientific methodology and basic statistics, and having published in peer review journals myself, I place a great importance, *paramount* importance, on scientific integrity. That is why I authored the language in the America COMPETES Act which makes it mandatory for those institutions seeking National Science Foundation funding to include explicit training in scientific ethics as a required part of their curriculum. I am proud to say that initial reports from NSF and the academic community indicate that this policy is having a substantial and positive effect, as institutions that formally provided no such explicit training have indeed incorporated it into their training regimes.

I mention this here because this is, after all, the Science and Technology Committee. We simply must, if we are to have any credibility at all, insist that our witnesses adhere to the highest standards of scientific integrity. Simultaneously, we must hold ourselves and this Committee as an institution to that standard in our study of the issues and in our conduct today and in the future.

Recently, some of our colleagues and friends in Congress have suggested that we needn't worry about this issue of climate change because God has promised not to let anything happen to us. Speaking personally, I would be the last to presume that I know God's intentions. I would, however, suggest that we were given brains for a reason and the role of this Committee on Science and Technology is to use those brains to evaluate the information before us as thoroughly and objectively as possible and take responsible action on that basis. Perhaps, just perhaps, that is what God might want us to do and that is how we are supposed to prevent cataclysmic events from occurring.

For those who are convinced, in spite of the evidence, that the threat of climate change and ocean acidification is not real, we must ask if the United States, as the biggest historical producer and second largest current producer of greenhouse gases, does not bear a great and indeed a moral responsibility to the rest of the world to be sure we get this right and do not impose adverse consequences on others as the result of disproportionate impacts from our own actions. Referring to scripture myself, the Golden Rule, "love thy neighbor as thyself," and other pearls of wisdom seem especially relevant here.

Moreover, even if one completely rejects the evidence that will be presented today and in reports from the National Academies of Science and countless other respected bodies, does it not make sense to strive for our nation to be a leader in clean energy technology for economic self-interest alone? Is not the reality of sending hundreds of billions of dollars abroad, often to countries with values antithetical to our own, at least a bit troubling? Is not the national security risk this creates disconcerting? Are the known impacts, such as Exxon Valdez, the recent Gulf Oil spill, and numerous other events not of sufficient concern to argue for change? Are not the facts of "red alert" days in our nation's cities, days in which it is "unsafe to breathe" for our children, cause for some degree of consternation?

The United States has been a leader in renewable energy technology and I believe we must remain a leader. Likewise, we have been at the forefront of climate research and should remain a leader there as well. Many of the satellite monitoring capabilities, ground observations, and other tools that enable us to know our local weather and climate patterns, the health of our ecosystems and oceans, and the quality of the air we breathe, and that track the many changes occurring on Earth are available only because of our investments in science programs at our many federal agencies and academic institutions. We must continue our investments if we intend to leave our children and grandchildren an environment in which they too can live, work, and play.

I am excited about this hearing and these three panels of star witnesses that will help us to better understand these concepts of climate change and ocean acidification. I want to personally and sincerely thank you for being here today and I look forward to each of your testimonies.

Chairman BAIRD. And with that, I recognize my friend and colleague, Mr. Inglis, for opening remarks. Sorry. Mr. Hall has to leave. Are you ready, Mr. Hall? I am told you have to leave at some point.

Mr. HALL. I am not ready, but I will go.

Chairman BAIRD. All right. Then, we will recognize you out of respect for the likely-soon-to-be Chairman of this committee and a dear friend and a respected member. I recognize Mr. Hall for as much time as——

Mr. HALL. Thank you, Mr. Chairman. Mr. Chairman, I do thank you for holding this hearing and I welcome all of the witnesses testifying on today's three panels. I think we have one witness for each panel, which is kind of an improvement. Usually we have one witness for each hearing. But one out of three is about a fair match, I think. It depends on the quality. But we are going to have a lot of different approaches to this and disagreements on it. And I appreciate everybody being here.

Today our country finds itself at a crossroads and we face a staggering national debt of more than 13 trillion. Almost one in ten people are out of work, and a bloated Federal Government. These are serious problems that require solutions that are defined by restraint and discipline. No longer should the economy be strained by writing checks we can't afford and a burdensome regulatory regime brought about by policies that serve to hamper industry and productivity across our country.

Despite this economic reality, the Administration is proceeding with regulations to reduce greenhouse gas emissions, a policy to supplant the cap and trade proposal that failed to win Congressional approval. The Secretary of Energy testified before this Committee that such a policy would raise energy prices for every American. The Energy Information Administration conducted an analysis of the cap and trade bill that passed the House in June. It was projected that this legislation would increase energy prices for consumers anywhere between 20 percent and 77 percent.

The Administration claims that we must cut our emissions of carbon dioxide despite the cost, so that we stave off global climate disruption. They had been calling it global climate warming. First of all, this new terminology pronounced by the White House Office of Science and Technology Policy is just another example of this Administration attempting to rebrand events to suit their policy objectives. There is no more war. We don't have war now according to them. Now we have what they say is overseas contingency operations. There are no more terrorist acts, despite that guy that murdered those people at Fort Hood. There is no more terrorist acts. We now have man-caused disasters, according to the Administration. Let me tell you something. Changing the name doesn't change what it is. It is high time the Administration learns how to call a bluebird blue.

Secondly, this Administration argues—if cutting greenhouse gas emissions is the policy direction that is justified by the science, I think this hearing today will demonstrate and could demonstrate that reasonable people have serious questions about our knowledge of the state of the science, the evidence, and what constitutes a proportional response. Furthermore, there has been an escalating sense of public betrayal by those who would claim the science justifies these policy choices.

The e-mails posted last November from the Climate Research Unit at the University of East Anglia in England expose a dishonest undercurrent within the scientific ethics community. This incident ignited a renewed public interest in the level of uncertainty of the scientific pronouncements and an increased concern that the policy of cap and trade may not achieve its objective of reducing the impacts of climate change.

While there are only a few scientists involved in this unethical behavior, it only takes a few bad apples to spoil the whole bunch. It has created a general atmosphere of doubt with regards to all scientific endeavors involving the government. We need only look at how the Administration responded to the Deepwater Horizon oil spill and see how scientific information was distorted to promote a specific policy agenda or to change people's perception of the government's competence.

To add insult to injury, this Administration has neglected to follow through on promises to issue basic guidelines for scientific integrity, a failure that has only served to further erode the public trust.

Given these persistent problems, Mr. Chairman, the public has even more questions and concerns about how Federal officials use science to inform policy debates. Sorting scientific fact from rhetoric is essential and we have a long way to go on this topic. We must insist on information derived from objective and transparent scientific practices and we must hold this Administration accountable for meeting a level of scientific integrity that the public expects from their government. Above all, we cannot afford to enact policies that destroy jobs, hinder economic growth and whittle away our competitiveness.

I look forward to hearing from our witnesses today and I yield back my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Mr. Chairman, thank you for holding this hearing and I welcome all of the witnesses testifying on today's three panels.

Today, our country finds itself at a crossroads. We face a staggering national debt of more than $13.7 trillion, almost one in ten people are out of work, and a bloated federal government. These are serious problems that require solutions that are defined by restraint and discipline. No longer should the economy be strained by writing checks we cannot afford and a burdensome regulatory regime brought about by policies that serve to hamper industry and productivity across America.

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Furthermore, there has been an escalating sense of public betrayal by those who would claim the science justifies these policy choices. The emails posted last November from the Climate Research Unit at the University of East Anglia in England exposed a dishonest undercurrent within the scientific community. This incident ignited a renewed public interest in the level of uncertainty of the scientific pronouncements and an increased concern that the policy of "cap and trade" may not achieve its objective of reducing the impacts of climate change.

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Above all, we cannot afford to enact policies that destroy jobs, hinder economic growth and whittle away our competitiveness. I look forward to hearing from our witnesses today, and I yield back the remainder of my time.

Chairman BAIRD. I thank the gentleman. And I am pleased to recognize my friend and colleague, the Ranking Member of the Subcommittee, Mr. Inglis.

Mr. INGLIS. Thank you, Mr. Chairman. And this is the last time that you will be chairing a subcommittee, so I want to thank you for your service. And I hope everybody will join me in recognizing Mr. Baird for his excellent service here on this Committee.

Chairman BAIRD. If I may, I am going to interrupt my friend because this is the last time he will be in the Ranking chair, and he has been an outstanding partner to work with and a real model of a distinguished Member of Congress. Please join me in—yeah.

Mr. INGLIS. There is a cautionary tale there about what happens when you get friendly with a Democrat. But actually he is a dear friend and a great guy. Anyhow, I am very excited to be here, Mr. Chairman, because this is on the record. And, you know, it is a wonderful thing about Congressional hearings, they are on the record.

Kim Beazley, who is Australia's Ambassador to the United States, tells me that when he runs into climate skeptics, he says to them to make sure to say that very publicly, because I want our grandchildren to read what you said and what I said. And so we are on the record and our grandchildren or great-grandchildren are going to read it.

And so some are here suggesting to those children that here is the deal. Your child is sick—this is what Tom Friedman gave me as a great analogy yesterday. Your child is sick. Ninety-eight doctors say treat him this way. Two say no, this other is the way to go. I will go with the two. You are taking a big risk with those kids. Ninety-eight of the doctors say do this thing. Two say do the other.

So on the record, we are here with important decisions to be made. And I would also suggest to my free-enterprise colleagues, especially conservatives here, whether you think it is all a bunch of hooey that we have talked about in this Committee, the Chinese don't. And they plan on eating our lunch in this next century. They plan on innovating around these problems and selling to us and the rest of the world the technologies to lead the 21st century. So we may just press the pause button here for several years, but China is pressing the fast forward button. And as a result, if we wake up in several years and we say, gee, this didn't work very well for us, the two doctors turned out not to be so right. Ninety-eight might have been the ones to listen to. Then what we will find, is we are way behind those Chinese folks. Because, you know, if you have got a certain number of geniuses in the population, if you are one in a million in China, there are 1,300 of you. And you know what? They plan on leading the future. So whether you—if you are a free-enterprise conservative here, just think, if it is a bunch of hooey, this science is a bunch of hooey, if you miss the commercial opportunity, you have really missed something.

And so I think it is great to be here on the record. I think it is great to see the opportunity that we have got ahead of us. And since this is sort of a swan song for me and Mr. Baird, I would encourage scientists that are listening out there to get ready for the hearings that are coming up in the next Congress. Those are going to be difficult hearings for climate scientists, but I would encourage you to welcome those as fabulous opportunities to teach. Don't come here defensively. Don't come to this committee defensively.

Say I am glad you called me here today, I am glad you are going to give me an opportunity to explain the science of climate change. Because I am here to show you what you spent, say $340 million a year on the U.S. polar programs. So you spent the money.

Now I am here to tell you what you got out of it. I am happy to educate you on what the data is. And hopefully we will have experts like some who are here today, but also—you know, on a trip from this committee to Antarctica to visit with the money, the $340 million a year we spent on the polar programs—that Donald Manahan, who is a professor at USC—the other one. We claim the real one is in Columbia, South Carolina. But the other one, you know, the one out on the west coast. That one. Dr. Manahan is a master teacher. I hope he is one of the witnesses here, because he is the kind of guy that would welcome the inquiry and would lead a tutorial for folks that are skeptics so they could see the science.

Meanwhile, we have got people that make a living and a lot of money on talk radio and talk TV pronouncing all kinds of things. They slept at Holiday Inn Express last night and they are now experts on climate. And those folks substitute their judgment for the people who have Ph.D.s and who are working tirelessly to discover the data.

So we have some real choices ahead of us. But I hope in the future, as we have these hearings, that we realize it is all on the record and our grandchildren and great grandchildren are going to get to see. And it could turn out the science is all wrong. You know, we have had that before. We used to blood-let people, and I think John Quincy Adams, the Speaker, made the very helpful suggestion that we move him to the window, and the poor guy froze to death. Right? He had the stroke over there in the Lindy Boggs room. So sometimes science turns out to be wrong.

But other times it turns out to be very right and the key to scientific endeavor is what we are here to discuss today, is openness, access to the data, and full challenging of the data. That is how we advance science.

And I look forward to the hearing, Mr. Chairman. Thank you for the opportunity.

Chairman BAIRD. Thank you, Mr. Inglis, for your opening remarks and for your many years of service in the Congress and on this committee.

[The prepared statement of Mr. Inglis follows:]

PREPARED STATEMENT OF REPRESENTATIVE BOB INGLIS

Good morning, and thank you, Dr. Baird for this hearing and for your great leadership as Chairman of this Subcommittee.

I'm not a scientist; I just play one in Committee. That's why I'm so excited about this hearing. After years of intense conversations about climate policy, energy markets, and technology innovation, we're closing with a frank discussion about the science of climate change. This is our chance to ask lingering questions about whether the climate is changing, what the causes are, and what impacts we can expect to see. It's a great opportunity to get answers from some of the people that know best, and to engage people on all sides of the debate in an endeavor to understand the science.

Right now, I think the most important questions about climate change are what impacts we can expect to see, and where. Changing rainfall, temperature patterns, and ocean acidity will have huge impacts on agriculture, energy infrastructure, ecosystems, and the marine-based economy. These changes will be very different in the upstate of South Carolina and in southwest Washington. Those differences mean big things for farmers, insurance agents, energy companies, government planners, and anyone else making long term investments on the ground. I hope to hear from our witnesses how scientists are working to fill the gaps in our knowledge and give us the tools we need to cope with a changing climate.

I also hope that the panelists will touch on the *Climategate* scandal. While the hacked and leaked emails did not shake the foundations of scientific agreement on climate change, they exposed a breach of the public trust. We count on our scientists to live up to the highest standards of scientific integrity, collaborative science, and peer review. I'd like to hear about the status of scientific discourse in the climate community and what improvements need to be made.

Finally, climate science is so important on capitol hill because of how climate policy will impact our energy markets. There is an irrefutable connection between the ways we use energy and the quantity of greenhouse gases that we emit. There is also an irrefutable connection between the ways that we use energy and the amount of risk we expose ourselves to in terms of our public health and our national security. It's difficult to get Congress to come to agreement on climate science, but I hope we'll bridge that gap to build a more prosperous, secure, innovation-driven economy.

I look forward to hearing from our distinguished panelists about all these issues.

Thank you again, Mr. Chairman, it has been a pleasure serving with you on this Subcommittee. I would yield to Mr. Hall for his opening remarks.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good Morning. Thank you, Mr. Chairman, for holding today's hearing to receive testimony and engage in a discussion of the science, evidence, and actions different sectors are using to respond to climate change.

This Committee has met several times in the 111th Congress to discuss the implications of the changing climate and what solutions are available to mitigate these impacts. I agree that we must have complete information from both sides of the debate about how and why our climate is changing based on science and what steps we can take to address these changes now and in the future.

First, the majority of scientists now agree the planet is warming, based on dramatic increases in ocean acidification, rising temperatures and rainfall, the retreating of glaciers, and the shrinking of ice sheets. Based on this scientific evidence, these changes will impact our society and will require responses from public health officials, economists, scientists, and government officials worldwide. Along with our international partners, we are taking a variety of approaches to reduce emissions and improve energy efficiency, but to date no global response to climate change has been adopted. I would like to hear from our witnesses how the United States in collaboration with our international partners can respond to impacts of climate change.

I welcome our panels of witnesses, and I look forward to their testimony. Thank you again, Mr. Chairman.

Panel I

Chairman BAIRD. With that, it is my pleasure to introduce our distinguished first panel of witnesses. And I think Mr. Inglis' desire to have people who are thoughtful and critical analysts of the data will be realized with this outstanding panel. The panel includes Dr. Ralph Cicerone, the President of the National Academy of Sciences; Dr. Richard Lindzen, the Alfred P. Sloan professor of meteorology for the Department of Earth, Atmospheric and Planetary Science, at Massachusetts Institute of Technology; Dr. Gerald Meehl, Senior Scientist for the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR); and Dr. Heidi M. Cullen, the Chief Executive Officer and Director of Communications for Climate Central.

Now, those introductions took me about five seconds to read each. If you read the distinguished biographies of these extraordinary individuals, it would take you almost five years, almost, to read. So forgive me for not going into such detail, but I hope you will check them out on their website. You will see this is indeed a very competent and capable group of individuals.

As our witnesses know, we are asking you to summarize an entire career of research in five brief minutes, after which we will ask a series of questions. And this is the first panel. We have two other panels after this. And we will do our level best to make sure that each panel gets a proportionate amount of time at our hearing today.

And with that, Dr. Cicerone, please begin.

STATEMENT OF RALPH J. CICERONE, PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Dr. CICERONE. Thank you, Chairman Baird and Members of the Subcommittee, for the opportunity to participate in your hearing today. With your permission, I will present only a summary of my written testimony.

Scientists have records from geological history of many past climate changes. For example, there is physical evidence of past ice ages with warmer intervals in between and of a 100,000-year cycle of ice ages in the past. Volcanoes have also caused climate changes. For example, a worldwide cooling followed the June 1991 explosive eruption of Mount Pinatubo in the Philippines. Our ability to calculate the amount of that cooling is very high if the volcanic cloud material amounts and types are measured well. Natural climate changes are likely to occur in the future.

However, the main reason that we are here today in this hearing is that humans are also capable of causing Earth's climate to change. The underlying mechanism is the greenhouse effect, wherein certain gases and clouds in the atmosphere surrounding the planet can absorb outgoing planetary infrared radiation. Each greenhouse gas selectively absorbs infrared radiation at specific wavelengths, and this signature can be seen by Earth-orbiting satellites, and was indeed seen as long ago as 1972.

The natural greenhouse effect has been enhanced by the increased amounts of greenhouse gases in the air due to human activity. These increases have occurred in a period of only a few decades, a very rapid change. The climatic impact of these greenhouse gases in the atmosphere is influenced also by changes in atmospheric water vapor and clouds that are initiated in turn by the warming. As water warms, it evaporates faster—in fact, disproportionately faster—than the warming. The evaporation injects water vapor into the air.

While some scientists propose that water vapor increases due to greenhouse warming might not amplify the original warming, they are fighting against a fundamental fact of physics, the steep dependence of vapor pressure of water, which is the Clausius-Clapeyron equation. The human-caused greenhouse effect exerts additional leverage on Earth's surface energy budget. The changes that have been observed in the last three decades, greenhouse gas concentration increases, temperature rises on the surface of the Earth, and decreased ice amounts, can all be seen from space. In fact, that is how many of the data have been obtained, by looking at the Earth from space.

The specific molecular properties of greenhouse gases have been measured through laboratory experiments so that the calculations of the enhanced greenhouse effect due to these increases in concentrations are very quantitative today. The equations are the same that we use in designing nuclear weapons and neutron transport. The impacts of materials which are less uniformly distributed of various kinds is more difficult to estimate.

A change in the amount of sunlight reaching the Earth would also be very important for the planetary energy balance, and scientists have proposed that changes from the sun are causing contemporary climate change. But recent evidence from monitoring the sun itself shows that the amount of solar energy reaching the Earth has not increased during the last 30 years, this time of clearly observed climate changes.

Increased concentrations of greenhouse gases have been observed worldwide for carbon dioxide. The data are of extremely high quality. Measurements are taken frequently from many locations on the surface from aircraft satellites and from dated ice cores that extend back hundreds and thousands of years; carbon dioxide amounts have increased from approximately 280 parts per million in the late 19th century to around 390 parts per million now, and that the increases are due to human activities is clear from several lines of evidence.

Fossil fuel burning is causing approximately 85 percent of the rise, while the release of carbon dioxide from deforestation, perhaps 15 percent of the total. Methane has also risen rapidly in the last century, as evidenced from surface measurements of all kinds and from dated ice cores. Methane sources for the atmosphere include rice agriculture, emissions from cattle, the use and transmission of natural gas, the decay of organic matter placed in landfills, and many human activities.

Nitrous oxide and other greenhouse gas also has an array of processes that injects it into the air, mostly traceable to the increased human usage of synthetic nitrogen fertilizer for agriculture.

Several classes of chemicals containing fluorine are also contributing to the enhanced greenhouse effect. And these increases observed in the concentration in all of these gases are clearly attributed to human activities.

Now, some observed changes: Surface temperatures, both of air and of water, show a warming of the Earth in all regions. The globally averaged warming since 1980 is approximately 1 degree Fahrenheit. Stronger warmings have been measured in the Arctic region, along with differences season by season and locality by locality.

Just as one example, the calendar year 2009 was significantly warmer than the long-term average in the Northern Hemisphere, but it was cooler than several of the previous years, while the temperatures in the Southern Hemisphere in 2009 were at a 130-year record high. Further temperature rises are usually larger over land areas than over oceans.

Chairman BAIRD. Dr. Cicerone, I am sorry. I will ask you to summarize briefly if you can. It is always hard to keep it in the five minutes.

Dr. CICERONE. The heat content of the oceans have increased roughly in accord with the calculated greenhouse effect and sea level rise has been increasing more rapidly since the early nineties than had been observed earlier. And now we are in a position for measured ice losses over Greenland and Antarctica, to sum up what is causing the sea level rise. And we got an answer which is in accord with the measured sea level rise.

This is enormous progress over the last few years. A lot of continued research is underway. It is needed, for example, for quantitative calculations and where we go in the future.

I will just close by saying that the National Academy of Sciences has been active in our national efforts to understand these issues for over 30 years, and that in all of our reports we have always said that there is a lot more to learn about future climate change, but the potential for future changes, including sudden, abrupt, and large changes is large. Thank you, Mr. Chairman.

Chairman BAIRD. Thank you very much.

[The prepared statement of Dr. Cicerone follows:]

PREPARED STATEMENT OF RALPH J. CICERONE

Chairman Baird and members of the Subcommittee on Energy and Environment, thank you for the opportunity to participate in your hearing today. I will address the basic science and physics of climate change and how climate change happens. In addition, I will describe the role of the National Academy of Sciences in advancing the science and informing the public on this topic.

Climate Change in the Past

Earth's climate shapes the conditions for life and it has done so over geological history as it does now. The kinds of plant and animal species that can survive are determined or are strongly influenced by climate as are the locations and kinds of human installations and settlements such as agricultural areas and routes of transportation on rivers and oceans.

We have records of many past climate changes from sea-level changes, from deposits of soils and rocks, and from fossils and other debris from plant and animal life, big and small, and from chemical traces such as abundances of elements and their isotopes. There is such evidence of periodic Ice Ages when glaciers extended over the northern half of North America, for example, and of intervening warm periods. The mapping of many of these historical climate changes is imprecise, that is, we do not know exactly how big were the geographical regions that experience the changes. Yet, some patterns are clear. For example, there is a 100,000-year cycle of Ice Ages in the past. These repeated events were probably triggered by changes in the non-circularity (eccentricity) of the earth's orbit around the sun. Earth's orbit is not circular but more like an elipse and just how non-circular the orbit is, changes slowly. Also, Earth's tilt angle of the access of its rotation changes periodically and its access of rotation wobbles a bit over tens of thousands of years. These astronomical changes lead to small changes in the amount of sunlight received by earth and to the geographical distribution of sunlight. While no one has yet been able to predict exactly how Ice Ages are brought on or how earth exits them, and how quickly, the principles of our understanding are sound. Volcanoes of certain types have also caused climate changes in the past. Regions of the earth or even the entire earth can experience cooling due to volcano injection of reflective matter that floats in the upper atmosphere (stratosphere). For a year or a few years, such coolings have been observed, for example, following the June 1991 explosive eruption of Mt. Pinatubo (in the Philippines). Our ability to calculate the amount of cooling is very high if the volcanic cloud material amounts and types are measured well.

Earth's Energy Balance and Climate Change Today

These kinds of natural climate changes are likely to occur in the future although their timing and sizes are not predictable. The main reason that we are here in this hearing today is that humans are capable of causing earth's climate change. The underlying mechanism is the greenhouse effect and the leverage that it exerts is worth understanding. In fact, many people are not yet aware of how large this leverage is, or how it arises.

The key scientific principles can be seen by considering the energy balance of the Earth. The Earth receives energy from the sun and it sends energy back to space. Every physical body that is warmer than its surroundings loses energy to its surroundings. Because of the temperature of the sun, the form of energy that escapes it is mostly visible light while the temperature of the Earth causes most of the energy sent away from the Earth to be in the form of infrared wavelengths. For example, if you have ever done any infrared photography such as looking at an inhabited house from outside on a cold winter night, you can see where the hot spots are. Also, some infrared detector devices for military purposes also operate in infrared wavelengths. The Earth's energy balance is such that we receive approximately 237 watts per square meter from the sun as visible light, averaged over day and night, over the entire surface of the Earth. A watt is a rate of energy flow of one Joule per second. Approximately, the same amount of energy leaves the Earth, 237 watts per square meter, but as infrared waves. One of the earliest scientific instruments ever orbited around Earth saw the wavelength matter and distribution of Earth's planetary radiation to space (IRIS instrument), thus demonstrating the greenhouse effect. Many more recent instruments and measurements have led to the numbers that I just quoted.

The greenhouse effect is a natural phenomenon that has been active over the history of the Earth. This fact can be demonstrated by calculating the temperatures of various planets using the energy-balance framework and the principles that I just outlined. When we calculate the temperature of Mars from the amount of sunlight that reaches it and its reflectivity, we obtain very close to the right answer as compared to actual measurements. When we calculate the temperatures of Earth or of Venus using the same framework with appropriate numbers, we arrive at too low a temperature. We calculate that the average temperature of Earth is approximately 15 degrees below zero centigrade which is perhaps 30 degrees centigrade too low and we calculate a temperature of Venus which is far below what is actually measured. These errors indicate that something is missing from the calculation and it is easily demonstrated that inclusion of the natural greenhouse effect enables one to get much closer to the actual observed temperature in a revised calculation.

Greenhouse Gases

The key ingredients in the greenhouse effect are greenhouse gases and clouds which when in the atmosphere surrounding the planet can absorb outgoing planetary infrared radiation. Mars has a very thin atmosphere with not much gas at all. Venus has a very thick high-pressure carbon dioxide atmosphere with many clouds and Earth has the atmosphere which we have measured and experienced with significance amounts of natural greenhouse gases, carbon dioxide, water vapor, methane, and several others. The signature of a greenhouse gas is the selectivity in how it absorbs infrared radiation at different wavelengths. This signature is measured in laboratory experiments using each gas and the signature of individual greenhouse gases can be seen by Earth-orbiting instruments or even from some other vantage point in space.

The natural greenhouse effect on Earth has been enhanced or amplified by the increased amounts of greenhouse gases in the air due to human activities. The human-enhanced greenhouse effect due to such increased atmospheric concentrations is now calculated to be 2.7 watts per square meter, or more than one percent of the incoming solar energy. And this increase has occurred in a period of a few decades, a very rapid change. The components of this increase listed in order starting with the largest is carbon dioxide, methane, nitrous oxide, a number of fluorine-containing chemicals, and ozone in the lower atmosphere, etc. When one attempts to calculate the impact on the climate of the earth, the way that wind motions are forced, and how temperatures and precipitation amounts change, one must include the additional forcing due to water-vapor changes caused by the original greenhouse-gas forcings. The climatic impact of these atmospheric greenhouse-gas increases is influenced by changes in atmospheric water vapor and clouds which are initiated by warming. As water warms, it evaporates faster, disproportionately faster than the amount of warming. Thus, water vapor is injected into the air. While some scientists continue to propose that water-vapor changes due to greenhouse forcing might not amplify the original warming, they are fighting against this fundamental fact of physics, the dependence of vapor pressure on temperature (Clausius-Clapeyron Effect).

As I said earlier, it is important to realize that this enhanced greenhouse effect represents leverage over Earth's energy balance and Earth's climate. If we look only at humans *direct* influence on Earth's energy budget, we find a smaller influence.

In particular if we take all energy, all human energy usage today, all nuclear power, the burning of all fossil fuels, coal, petroleum, gasoline, natural gas, the burning of wood, the use of hydroelectric power, of geothermal power, tidal and solar and wind power, and we average it over the surface of the Earth, we find a number of 0.025 watts per square meter or barely 1/100th of the enhanced greenhouse effect. Thus, we see that the greenhouse effect is exerting leverage of more than a factor of 100 over the impact on Earth's energy budget due only to human energy usage. This notion and these numbers are very important to understand. From the viewpoint of atmospheric chemistry, this leverage is not very surprising considering that chemical catalysis causes minute amounts of chemicals to be far more important than their small numbers might suggest. The chemical impact of catalysts can be enhanced by 100,000 to a million times through the mechanism of catalysis.

Less technically, one can appreciate this leverage by realizing that these changes on Earth that have been observed in the last three decades—the greenhouse-gas concentrations, the temperature rises on the surface of the Earth, the ice amounts on Earth—can all be seen from space looking back at Earth. In fact, that is how many of the data have been obtained, by looking at the Earth from space. So these changes are not small. One of the easiest tasks in foreseeing how climate change due to human activities will happen, is indeed evaluating the enhanced greenhouse effect. We know the properties of greenhouse gases that make them either more or less effective. For example, because the outgoing planetary radiation occurs mostly in a well-defined range of wavelengths, an ideal greenhouse gas is one that absorbs radiation in that same range and does so effectively. An ideal greenhouse gas is also one which can survive in the atmosphere without being broken apart and which can be distributed more or less uniformly on a global scale without being removed. Those properties are largely chemical and they can be measured through laboratory experiments, and they have been so measured, so that the calculations of the enhanced greenhouse effect due to a measured increase in the gas's concentration are very quantitative and reasonably precise today.

The concept of radiative forcing was first created and employed by scientists who created the first fluid dynamical models of the atmosphere. Bob Dickinson and I used the concept to permit a comparison of the effectiveness of greenhouse gases and their amounts in 1986. In the early and mid-1980s scientists had become aware that not only are the increased carbon dioxide amounts capable of influencing Earth's climate but a number of other chemicals also have this capability although in lesser amounts. Radiative forcing is a measure of how strongly substances in the atmosphere affect Earth's energy budget. The concept has been extended to materials which are less uniformly distributed such as aerosol particles from biomass burning, from sulfur pollution, from fossil-fuel burning, smoke particles, and the like. The impact of those less uniformly distributed substances is more difficult to estimate because the substance's geographical distributions are not as well known, so the estimates of such substances on Earth's energy budget are not as well defined.

Now, obviously, if our concern is over changes to the net energy balance of the Earth, then a change in the amount of *sunlight* reaching the earth is also very important. In fact, any number of scientists have tried to focus on whether changes from the sun are causing contemporary climate change. But it is only in the last few years that we have had enough evidence to be able to say that the changes in climate that have been observed over the last several decades, are not due to changes in the output of the sun. It has been known in principle for a long time that the sun, like other stars, can change its luminosity over geological timescales but there is no evidence from other stars or any theory of stellar evolution that suggests that the sun's output could change by as much of the enhanced greenhouse effect has changed, that is, over one percent in say 50 years. A more solid kind of evidence has come from monitoring the sun itself. By stringing together the records of a series of satellites that have orbited the earth while observing the incoming sunlight, several scientists have shown that the amount of sunlight energy reaching the Earth has oscillated with an approximate 11-year cycle over the last 30 years, that is, the amount of solar energy reaching the Earth has not increased during the time of the observed climate changes. So we are left with the realization that the enhanced greenhouse effect is 15 or 20 times larger than the difference between solar maximum and solar minimum in the output of the sun. Moreover, the enhanced greenhouse effect is not oscillating, it is simply continuing to rise, so the evidence today rules out any significant role for solar changes in causing the observed climate changes of the last several decades.

I have alluded to increased concentrations of greenhouse gases that have been observed worldwide that demonstrate human impact. In the case of carbon dioxide, our data are of extremely high quality; measurements are taken frequently from many locations on the surface of the Earth, from aircraft, satellites, and from dated ice cores extending back over hundreds and thousands of years. The evidence that the increase in carbon dioxide worldwide amounts from approximately 280 parts per million in the late 19th century to approximately 390 parts per million this year is very strong and that the increases due to human activities is also clear. The lines of evidence that one uses in attributing the carbon dioxide increase to human activities includes the rate of the concentration increase compared to the rate of release of carbon dioxide from fossil-fuel usage, the isotopic content of the carbon dioxide, the carbon dioxide patterns geographically compared to the places where carbon dioxide is being released by human activity, by oceanic amounts, and by known patterns of movement of atmospheric chemicals. There is a contribution to this increase from human-caused deforestation. This contribution is approximately 15 percent of the total while fossil-fuel usage is approximately 85 percent of the total. The release of carbon dioxide from deforestation is due both to the direct burning of wood and the decay of exposed soil organic matter.

Methane as a greenhouse gas has also risen rapidly since the late 19th century as evidenced by surface measurements made at many sites around the world, by satellite measurements and by the amounts of methane extracted from dated ice cores. The list and sizes of methane sources for the atmosphere is complicated and it includes rice agriculture, the domestication of cattle, the use and transmission of natural gas, the decay of organic matter placed in landfills, and many other sources. Nitrous oxide, another greenhouse gas, also has an array of processes that injected it into the atmosphere, mostly traceable to the increased human usage of synthetic nitrogen fertilizer for agriculture. Several classes of chemical gases containing fluorine also contribute to the enhanced greenhouse effect. The chlorofluorocarbons whose usage was regulated and banned due to the Montreal Protocol and later amendments to it, still reside in the atmosphere. Several kinds of replacement chemicals for the chlorofluorocarbons, namely, hydrochlorofluorocarbons and hydrofluorocarbons are observed to be increasing in concentration worldwide along with measured increases of perfluorinated chemicals such as carbon tetrafluoride and perfluoroethane along with sulfur hexafluoride. The increases observed in the concentrations of all of these gases are clearly attributed to human activities. While the enhanced greenhouse effect due to all of these greenhouse gases has been an inadvertent consequence of human activities, this force, led by carbon dioxide emissions, continues to grow with larger consequences for future climate.

Observed Climate Changes

A number of meaningful changes to Earth's climate have been measured since 1980 or the late 1970s. These include globally averaged surface temperatures, both of air and of water. Large data sets covering almost all of the world are available from at least three climate centers around the world, one from NASA, one from NOAA, and one from the University of East Anglia. These data sets are generally similar although they consist of somewhat different entries with more or less weighting from individual continents and the Arctic and they employ somewhat different methods to adjust for potential biases such as the encroachment of urban areas and the urban heat-island effect on thermometer stations which were at one time far from urban areas. As an example, the data sets use slightly different time periods of comparison but they all show a warming of the earth in all regions. The globally averaged warming since 1980 is approximately one degree F. Stronger warmings have been measured in the Arctic region with, of course, differences season-by-season and locality-by-locality. Just as one example, the calendar year 2009 was significantly warmer than the long-term average of the Northern Hemisphere but it was cooler than several of the previous years while the temperatures in the Southern Hemisphere in 2009 were at an all-time record high. Further, temperature rises are higher over land areas than over oceans.

The data on the temperatures and heat content of the upper layers of the ocean are very important as a measure of global climate change yet these data are more difficult to obtain with the density of stations that we would desire because the oceans are not as well monitored as the atmosphere. Nonetheless, in the last several years, new data sets have materialized which show an upward trend with time over the last 40 or 50 years with the amount of heat stored in the upper layers of the ocean rising, roughly in accord with calculations of the enhanced greenhouse effect.

A climate variable of great importance especially in the longer term is sea level. Since 1992, sea level has been measured by Earth-orbiting instruments on satellites which are capable of measuring sea level nearly worldwide and frequently so that the trend of rising sea levels has now been measured more accurately and more precisely in more places than had been possible before 1992. There is now evidence of a rate of sea-level rise since 1992 which is approximately twice as fast as the sea-level rise observed from the late 19th century to 1992 with far more primitive and fewer instruments in coastal environments.

The amounts of ice residing on land formations in Greenland and Antarctica are now being measured by independent instruments, vertical ranging devices on Earth-orbiting satellites, as well as instruments which measure the deviations of the Earth's gravitational field from that of a perfect sphere and the rate at which those deviations are changing. In other words, the data from this instrument can be used to infer the rate of change of ice mass over those continents. Both kinds of data now show that over the last perhaps seven or eight years, that is the entire record of the measurements, that the masses of ice lodged on Greenland and Antarctica are both decreasing with time with a possibly accelerating rate. When combined with the inferred amount of ice lost from continental glaciers and the rate at which sea level is rising due to thermal expansion, due to the increased temperatures, one can now calculate how fast sea level is rising and find agreement with the sea-level rise that is actually measured independently. So this kind of evidence is new and rather compelling.

Many other important measures of climate change are being gathered, measures of variables which are directly important to human, animal and plant life, but which are inherently more variable spatially, that is, geographically and with time such as the rate of flows of various streams and rivers, the amounts and kinds of cloudiness, the frequency and duration of droughts and of storms in many locations, and the length of growing season and the frequency of new high-temperature settings and of new low-temperature settings. Continued research on these variables and many others is essential for us to gauge and predict climate changes that are underway and how effective human responses might be.

Efforts to predict more detailed evolution of future climate change begin with mathematical expressions of the laws that govern the motion of fluids and their temperatures and of ice amounts. These equations are of the type which cannot be solved with paper and pencil and with neat mathematical expressions. Instead, they can only be solved by numerical computations, computations that are becoming more rigorous and more understood. Other witnesses will describe more of the actuality and the details of these efforts, but I do want to emphasize several kinds of inputs to these mathematical models which require continued scientific effort. One is the specification of the role of aerosol particles and of clouds in the atmosphere and another is the need to specify the rate at which fossil-fuel burning will be used discharging carbon dioxide into the atmosphere, which rate depends on growing human population, human activities and energy technology.

The National Academy of Sciences has been active in our national efforts to detect, understand and predict climatic change. Most of our analyses are conducted through our operating arm, the National Research Council, which is co-administered by the National Academy of Sciences and the National Academy of Engineering. And we often obtain help from our own Institute of Medicine. There are, of course, many other nations that are active in climate research and are attempting to mitigate climate change and/or to adapt to it. And some of these nations not only conduct research but perform their own nationally based assessments. In addition, there are international bodies performing analyses of climate change such as the Intergovernmental Panel on Climate Change which is a creature of the World Meteorological Organization and of the United Nations Environmental Program.

Our NAS/NRC reports have been issued more frequently and they have grown in size over the last 30 years with one of the first major reports being released in the last 1970s followed by another in 1983, another series in 1991–92, and then a large number in the early part of this decade. In the past year, we have written and released a series of reports entitled, *America's Climate Choices*, in response to a Congressional request from the House Subcommittee on Commerce, Justice, Science and Related Agencies under Chairman Mollohan. This series of reports examined the state of climate science, what we know, and what we believe we still must learn along with the state of strategies for climate mitigation and climate adaptation as well as an analysis of how to communicate with decision makers and the general public. Another recent report on climate from the National Research Council is on how to estimate the emissions of greenhouse gases with regard to any international agreement that might be adopted and on how well we could determine compliance with any international agreement. On a completely separate topic, the National Research Council issued a report recently on what impacts could be expected by stabilizing the atmosphere at various target levels of greenhouse gas concentrations. We have also been asked in the last several years, both by Congress and by Federal agencies, to examine the effectiveness of the United States Climate Change Science Program under President Bush, both its plans and its achievements. All of our reports have been clear that there is much to learn about future climate change and that the potential of future disruptions is large.

The Congressional Charter under President Lincoln that created the National Academy of Sciences in 1863, charges us to be responsive to requests from the Federal Government for analyses of topics involving science. Our analyses are conducted by leading American experts occasionally augmented by talent from other countries. Each of our reports is peer reviewed by participants who did not engage in the study itself but whose evaluations and analyses are used so as to suggest revisions or corrections to the early draft versions of our reports. This method and the high standards which we attempt to employ assure that our reports will be of value as our government, our businesses, and our citizens continue to gauge how to respond to the challenges which we face today and in the future concerning human-caused climate change.

BIOGRAPHY FOR RALPH J. CICERONE

Ralph J. Cicerone is President of the National Academy of Sciences and Chair of the National Research Council. His research in atmospheric chemistry, climate change and energy has involved him in shaping science and environmental policy at the highest levels nationally and internationally.

Dr. Cicerone's research has focused on atmospheric chemistry, the radiative forcing of climate change due to trace gases, and the sources of atmospheric methane, nitrous oxide and methyl halide gases. He has received a number of honorary degrees and awards for his scientific work. Among the latter, the Franklin Institute recognized his fundamental contributions to the understanding of greenhouse gases and ozone depletion with its 1999 Bower Award and Prize for Achievement in Science. One of the most prestigious American awards in science, the Bower Award also recognized his public policy leadership in protecting the global environment. In 2001, he led a National Academy of Sciences study of the current state of climate change and its impact on the environment and human health, requested by President Bush. The American Geophysical Union awarded Dr. Cicerone its James B. Macelwane Award in 1979 for outstanding contributions to geophysics by a young scientist and its 2002 Roger Revelle Medal for outstanding research contributions to the understanding of Earth's atmospheric processes, biogeochemical cycles, and other key elements of the climate system. In 2004, the World Cultural Council honored him with the Albert Einstein World Award in Science. Dr. Cicerone is a member of the National Academy of Sciences, the American Academy of Arts and Sciences, the American Philosophical Society, the *Accademia Nazionale dei Lincei*, the Russian Academy of Sciences, the Korean Academy of Science and Technology, and Academia Sinica. He has served as president of the American Geophysical Union, the world's largest society of earth scientists.

Dr. Cicerone was educated at the Massachusetts Institute of Technology and the University of Illinois at Urbana-Champaign. In his early career, he was a research scientist and held faculty positions in electrical and computer engineering at the University of Michigan. The Ralph J. Cicerone Distinguished University Professorship of Atmospheric Science was established there in 2007. In 1978 he joined the Scripps Institution of Oceanography at the University of California, San Diego as a research chemist. From 1980 to 1989, he was a senior scientist and director of the Atmospheric Chemistry Division at the National Center for Atmospheric Research in Boulder, Colorado. In 1989 he joined the University of California, Irvine, where he was founding chair of the Department of Earth System Science and the Daniel G. Aldrich Professor of Earth System Science. As Dean of the School of Physical Sciences from 1994 to 1998, he recruited outstanding faculty and strengthened the school's curriculum and outreach programs. Immediately prior to his election as Academy president, Dr. Cicerone served as Chancellor of UC Irvine from 1998 to 2005, a period marked by a rapid rise in the academic capabilities of the campus.

Chairman BAIRD. Dr. Lindzen.

Dr. LINDZEN. Thank you, Mr. Baird.

Chairman BAIRD. Make sure the mic is on.

STATEMENT OF RICHARD S. LINDZEN, ALFRED P. SLOAN PROFESSOR OF METEOROLOGY, DEPARTMENT OF EARTH ATMOSPHERIC AND PLANETARY SCIENCE, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. LINDZEN. Yes. Thank you, Mr. Baird. Thank you, Committee, for the opportunity to speak here.

As a student, I was told something rather important; that the primary thing in solving the problem is to have the right question. And here I am, a little bit concerned about the guidelines for this meeting.

I think if we are to properly consider our concern over greenhouse gases, we must separate the basic science upon which there is great agreement from the specific bases for our concern. For instance, there is general agreement that climate is always changing. There is agreement that over the last two centuries there has been on the order of 3/4 of a degree Centigrade increase in something called globally averaged temperature anomaly.

There is no such thing as average temperature for the Earth. There is a greenhouse effect. Nobody is arguing that. That CO_2 is a greenhouse gas is not argued by anyone I know. And that CO_2 is increasing due to man's activities is also widely accepted. To be sure, general agreement hardly guarantees truth, but I am not questioning it at this stage. But what is commonly forgotten—and that is crucial to this hearing—is that these facts do not lead to major climate concern per se. So, for example, if doubling carbon dioxide alone leads to only about a degree of warming and if all the increase in globally averaged temperature anomaly were due to the added greenhouse gases that Dr. Cicerone described, it would suggest a sensitivity that is even lower than that.

The only—the case for alarm rests on three rather doubtful propositions. One is that climate sensitivity to increasing greenhouse gases is much greater than the above, due to the alleged dominance of positive feedbacks. The second is the association of phenomena, such as sea level rise, arctic sea ice and so on, which depend on many, many factors, of which globally averaged temperature anomaly is not even the most important factor. And to use these changes as evidence for dangerous warming is illogical. This is especially true with arctic sea ice. The oversimplification—this is the third item—of climate to a single number globally averaged temperature anomaly and a single forcing number—let us say a radiative forcing from CO_2—is a gross distortion of what is really going on.

Now, with respect to climate sensitivity, greenhouse physics tells us that temperature changes at the surface should reduce certain change in outward flux of heat, which at the top of the atmosphere is in the form of radiation. It will in the absence of feedbacks correspond to a sensitivity of about 1 degree for a doubling of CO_2. Now, if you have positive feedbacks and you go to space and measure the outgoing flux associated with the temperature perturbation, you should see less than you would expect without feedbacks. And if you have negative feedbacks, you should see more.

Now, it turns out that the models, when you ask what they calculate, calculate what is consistent with positive feedbacks. If you go to the data, you find the opposite. Most recently, there has been an attempt to measure these fluxes from the surface. Now, you have to understand, the flux might be reasonably constant through the atmosphere, but its process is different. So at the top of the atmosphere it is radiation. At the surface it is mostly evaporation.

And there is a problem that has been noted for some years. Models predict very little change in evaporation as you warm, compared to observations. And this can be directly translated into sensitivity. The model's behavior is consistent with 1–1/2 to 4–1/2 degrees for a doubling of CO_2. The data suggests it is closer to half the lowest limit. So there too, I mean, one has the problem that the observations, when specifically turned to feedbacks rather than specific mechanisms, show the opposite. And this isn't surprising.

One speaks of clouds as a kind of peripheral uncertainty. But they are capable—they involve changes in the radiative balance that are, you know, more than a factor of 20, larger than what you get from a doubling of CO_2.

Now, parenthetically, we might wonder why models that have such high sensitivity can simulate past behavior if the past behavior is consistent with low sensitivity. And the answer is I think, as Jerry would point out, is aerosols. Now, you might say there are really aerosols, so they cancel some of the greenhouse. But if you check, each model uses a different value. And the aero—because they want to adjust their model to look right, so it is an adjustable parameter.

And the aerosol community, Schwartz, Roda, Charlson and so on have published a paper in the last year pointing out the uncertainties, meaning that if you include arbitrary aerosols you can get any sensitivity you want. That is hardly reassuring.

Chairman BAIRD. Dr. Lindzen, I will ask, if I may——

Dr. LINDZEN. Okay.

Chairman BAIRD. We are about a minute and a half over. I know it is hard to summarize. But if you can——

Dr. LINDZEN. Okay. Let me just put it—let me just point out that in my full testimony there are examples, further examples of each of these things. The climate is certainly worth understanding better, but the basis for grave worries is poor; certainly poorer than the changes of suggested policies, though perhaps not so poor as the prospects for suggested policies to significantly impact climate or even CO_2 levels. Thank you.

Chairman BAIRD. Thank you, Dr. Lindzen.

[The prepared statement of Dr. Lindzen follows:]

PREPARED STATEMENT OF RICHARD S. LINDZEN

Global Warming:
How to approach the science.

(Climate Models and the Evidence?)

Richard S. Lindzen
Program in Atmospheres, Oceans, and Climate
Massachusetts Institute of Technology

Testimony: House Subcommittee on Science and Technology hearing on *A Rational Discussion of Climate Change: the Science, the Evidence, the Response*

November 17, 2010

A pdf of these slides is available on request to rlindzen@mit.edu 1

I wish to thank the House Committee on Science and Technology for the opportunity to present my views on the issue of climate change – or as it was once referred to: global warming. The written testimony is, of course, far more detailed than my oral summary will be. In the summary, I will simply try to clarify what the debate over climate change is really about. It most certainly is not about whether climate is changing: it always is. It is not about whether CO_2 is increasing: it clearly is. It is not about whether the increase in CO_2, by itself, will lead to some warming: it should. The debate is simply over the matter of how much warming the increase in CO_2 can lead to, and the connection of such warming to the innumerable claimed catastrophes. The evidence is that the increase in CO_2 will lead to very little warming, and that the connection of this minimal warming (or even significant warming) to the purported catastrophes is also minimal. The arguments on which the catastrophic claims are made are extremely weak – and commonly acknowledged as such.

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In my long experience with the issue of global warming, I've come to realize that the vast majority of laymen -- including policymakers – do not actually know what the scientific debate is about. In this testimony, I will try to clarify this. Some of you may, for example, be surprised to hear that the debate is not about whether it is warming or not or even about whether man is contributing some portion of whatever is happening. I'll explain this in this testimony. Unfortunately, some part of the confusion is explicitly due to members of the scientific community whose role as partisans has dominated any other role they may be playing.

3

Here are two statements that are completely agreed on by the IPCC. It is crucial to be aware of their implications.

1. A doubling of CO_2, by itself, contributes only about 1C to greenhouse warming. All models project more warming, because, within models, there are positive feedbacks from water vapor and clouds, and these feedbacks are considered by the IPCC to be uncertain.

2. If one assumes all warming over the past century is due to anthropogenic greenhouse forcing, then the derived sensitivity of the climate to a doubling of CO_2 is less than 1C. The higher sensitivity of existing models is made consistent with observed warming by invoking unknown additional negative forcings from aerosols and solar variability as arbitrary adjustments.

Given the above, the notion that ***alarming*** warming is 'settled science' should be offensive to any sentient individual, though to be sure, the above is hardly emphasized by the IPCC. 4

The usual rationale for alarm comes from models. The notion that models are our only tool, even, if it were true, depends on models being objective and not arbitrarily adjusted (unfortunately unwarranted assumptions).

However, models are hardly our only tool, though they are sometimes useful. Models can show why they get the results they get. The reasons involve physical processes that can be independently assessed by both observations and basic theory. This has, in fact, been done, and the results suggest that all models are exaggerating warming.

The details of some such studies will be shown later in this testimony.

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Quite apart from the science itself, there are numerous reasons why an intelligent observer should be suspicious of the presentation of alarm.

1. The claim of 'incontrovertibility.'

2. Arguing from 'authority' in lieu of scientific reasoning and data or even elementary logic.

3. Use of term 'global warming' without either definition or quantification.

4. Identification of complex phenomena with multiple causes with global warming and even as 'proof' of global warming.

5. Conflation of existence of climate change with anthropogenic climate change.

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Some Salient Points:

1. Virtually by definition, nothing in science is 'incontrovertible' – especially in a primitive and complex field as climate. 'Incontrovertibility' belongs to religion where it is referred to as dogma.

2. As noted, the value of 'authority' in a primitive and politicized field like climate is of dubious value – it is essential to deal with the science itself. This may present less challenge to the layman than is commonly supposed. Consider the following example:

This letter appeared last Spring in *Science*. It was signed by 250 members of the National Academy of Science. Most signers had no background whatever in climate sciences. Many were the 'usual suspects.' (ie, Paul Ehrlich, the late Steve Schneider, George Woodwell, Don Kennedy, John Schellnhuber, ...) but a few were indeed active contributors.


LETTERS | BOOKS | POLICY FORUM | EDUCATION FORUM | PERSPECTIVES

LETTERS

Climate Change and the Integrity of Science

Here are two of their assertions:

(iii) Natural causes always play a role in changing Earth's climate, but are now being overwhelmed by human-induced changes.

(iv) Warming the planet will cause many other climatic patterns to change at speeds unprecedented in modern times, including increasing rates of sea-level rise and alterations in the hydrologic cycle.

Now, one of the signers was Carl Wunsch. Here is what he says in a recent paper in *Journal of Climate* (Wunsch et al, 2007) (and repeated a couple of weeks ago in a departmental lecture):

It remains possible that the data base is insufficient to compute mean sea level trends with the accuracy necessary to discuss the impact of global warming–as disappointing as this conclusion may be.

In brief, when we actually go to the scientific literature we see that the 'authoritative' assertions are no more credible than the pathetic picture of the polar bear that accompanied the letter.

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3. 'Global Warming' refers to an obscure statistical quantity, globally averaged temperature anomaly, the small residue of far larger and mostly uncorrelated local anomalies. This quantity is highly uncertain, but may be on the order of 0.7C over the past 150 years. This quantity is always varying at this level and there have been periods of both warming and cooling on virtually all time scales. On the time scale of from 1 year to 100 years, there is no need for any externally specified forcing. The climate system is never in equilibrium because, among other things, the ocean transports heat between the surface and the depths. To be sure, however, there are other sources of internal variability as well.

Because the quantity we are speaking of is so small, and the error bars are so large, the quantity is easy to abuse in a variety of ways.

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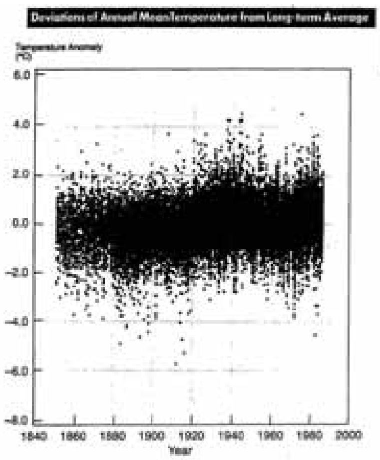
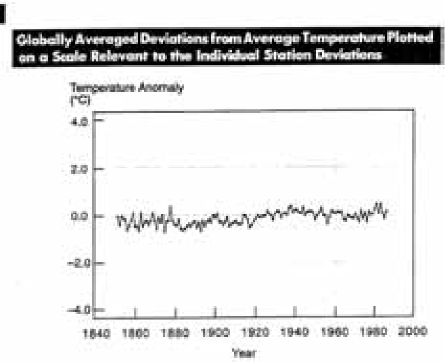


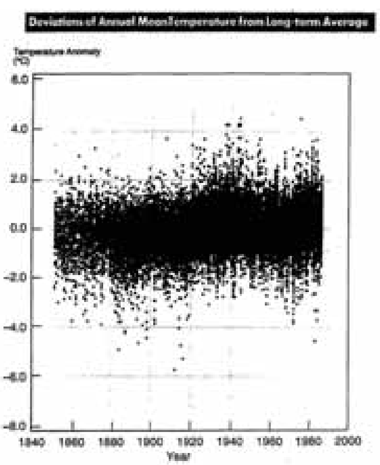
1. Data points averaged to obtain time record of global mean temperature. Note points range from less than -2C to more than +2C.

Source: S. L. Grotch, Lawrence Livermore Laboratory, Livermore California



2. Average of points in previous figure.

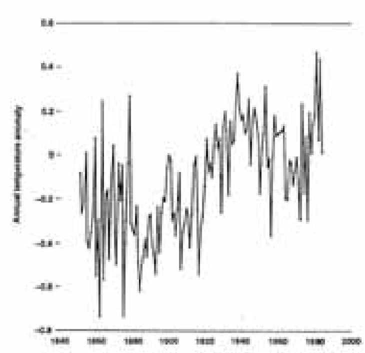
Notice the vertical scale in the above diagrams. Relative to the variability in the data, the changes in the globally averaged temperature anomaly look negligible.



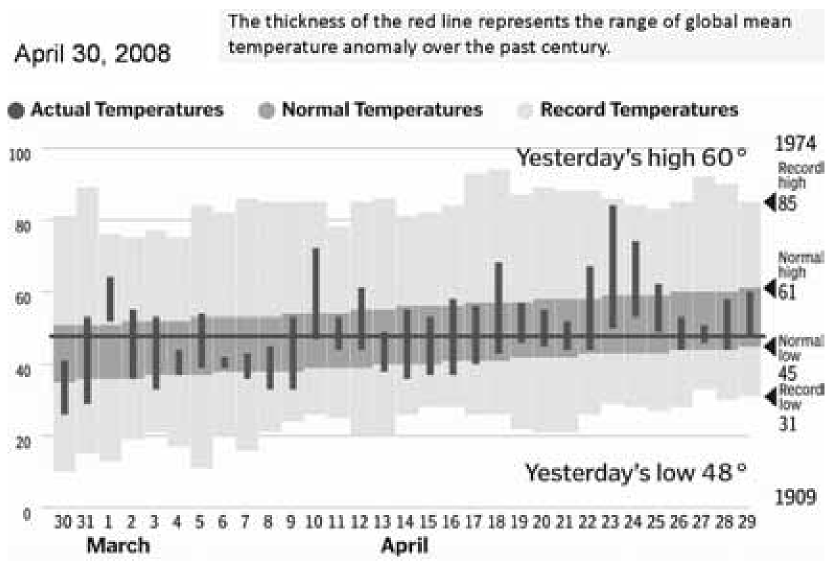
1. Data points averaged to obtain time record of global mean temperature. Note points range from less than -2C to more than +2C.

Source: S. L. Grotch, Lawrence Livermore Laboratory, Livermore California

CRU NH Average Annual Anomalies (1851-1984)



3. Curve in previous figure stretched to fill graph. Note that range is now from about -0.6C to +0.3C.



One month's record of high and low temperatures for Boston. 13

4. The claims that the earth has been warming, that there is a greenhouse effect, and that man's activities have contributed to warming, are trivially true and essentially meaningless in terms of alarm.

Nonetheless, they are frequently trotted out as evidence for alarm. For example, here is the response of the American Physical Society to Hal Lewis' resignation letter:

On the matter of global climate change, APS notes that virtually all reputable scientists agree with the following observations:
Carbon dioxide is increasing in the atmosphere due to human activity;
Carbon dioxide is an excellent infrared absorber, and therefore, its increasing presence in the atmosphere contributes to global warming; and
The dwell time of carbon dioxide in the atmosphere is hundreds of years.
On these matters, APS judges the science to be quite clear.

The last item is actually quite misleading on its own terms. The APS also denies financial involvement despite the fact that POPA's chair is Bob Socolow who is chair of the Carbon Mitigation Initiative, and on the advisory board of Deutsche Bank.

14

Two separate but frequently conflated issues are essential for alarm:

1) The magnitude of warming, and

2) The relation of warming of any magnitude to the projected catastrophe.

15

When it comes to unusual climate (which always occurs some place), most claims of evidence for global warming are guilty of the 'prosecutor's fallacy.' For example this confuses the near certainty of the fact that if A shoots B, there will be evidence of gunpowder on A's hand with the assertion that if C has evidence of gunpowder on his hands then C shot B.

However, with global warming the line of argument is even sillier. It generally amounts to something like if A kicked up some dirt, leaving an indentation in the ground into which a rock fell and B tripped on this rock and bumped into C who was carrying a carton of eggs which fell and broke, then if some broken eggs were found it showed that A had kicked up some dirt. These days we go even further, and decide that the best way to prevent broken eggs is to ban dirt kicking.

16

Some current problems with science

1. **Questionable data**. (Climategate and involvement of all three centers tracking global average temperature anomaly.) This is a complicated ethical issue for several reasons. Small temperature changes are not abnormal and even claimed changes are consistent with low climate sensitivity. However, the public has been mislead to believe that whether it is warming or cooling – no matter how little – is of vital importance. Tilting the record slightly is thus of little consequence to the science but of great importance to the public perception.

2. More sophisticated data is being analyzed with the aim of supporting rather than testing models (validation rather than testing). That certainly has been my experience during service with both the IPCC and the National Climate Assessment Program. It is also evident in the recent scandal concerning Himalayan glaciers.

(Note that in both cases, we are not dealing with simple measurements, but rather with huge collections of sometimes dubious measurements that are subject to often subjective analysis – sometimes referred to as 'massaging.')

17

In point of fact, we know that some of the recent temperature data must be wrong!

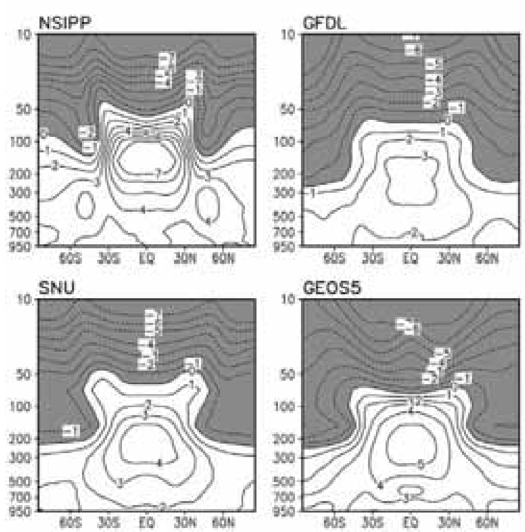


FIG. 14. Zonal-mean distributions of temperature change (2 × CO_2 − Control). Units are kelvin.

Here we see the meridional distribution of the temperature response to a doubling of CO_2 from four typical models. The response is characterized by the so-called hot spot (ie, the response in the tropical upper troposphere is from 2-3 times larger than the surface response). We know that the models are correct in this respect since the hot spot is simply a consequence of the fact that tropical temperatures approximately follow what is known as the moist adiabat. This is simply a consequence of the dominant role of moist convection in the tropics.

18

However, the temperature trends obtained from observations fail to show the hot spot.

Taking Greenhouse Warming Seriously 943

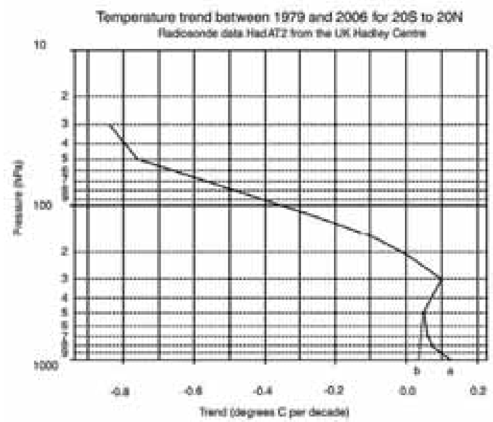


Figure 5: Temperature trend as a function of pressure level for period 1979–2006 in the tropics (20S-20N) based on balloon data analyzed by the Hadley Centre.

The resolution of the discrepancy demands that either the upper troposphere measurements are wrong, the surface measurements are wrong or both. If it is the surface measurements, then the surface trend must be reduced from 'a' to 'b'.

Given how small the trends are, and how large the uncertainties in the analysis, such errors are hardly out of the question.

19

3. Sensitivity is a crucial issue. This refers to how much warming one expects from a given change in CO_2 (usually a doubling). It cannot be determined by assuming that one knows the cause of change. If the cause is not what one assumes, it yields infinite sensitivity. This problem infects most attempts to infer climate sensitivity from paleoclimate data.

4. Models cannot be tested by comparing models with models. Attribution cannot be based on the ability or lack thereof of faulty models to simulate a small portion of the record. Models are simply not basic physics.

All the above and more are, nonetheless, central to the IPCC reports that supposedly are 'authoritative' and have been endorsed by National Academies and numerous professional societies.

20

Here is a recent letter signed by the presidents of both the Royal Society and the National Academy of Science.

It tells us a great deal about the current state of science, and the exploitation of authority.

FT.com FINANCIAL TIMES COMMENT **Letters**

What's happening to the climate is unprecedented

Published: April 9 2010 03:00 | Last updated: April 9 2010 03:00

From Prof Martin Rees and Dr Ralph J. Cicerone.

Sir, We were stimulated by your editorial "Cooler on warming" (April 5). There has undoubtedly been a shift in public and media perceptions of climate change – a consequence of, at least in part, leaked e-mails from some climate scientists and the publication of errors in the fourth Intergovernmental Panel on Climate Change report.

However, as your editorial acknowledges, neither recent controversies, nor the recent cold weather, negate the consensus among scientists: something unprecedented is now happening. The concentration of carbon dioxide in the atmosphere is rising and climate change is occurring, both due to human actions. If we continue to depend heavily on fossil fuels, by mid-century CO 2 concentrations will reach double pre-industrial levels. Straightforward physics tells us that this rise is warming the planet. Calculations demonstrate that this effect is very likely responsible for the gradual warming observed over the past 30 years and that global temperatures will continue to rise – superimposing a warming on all the other effects that make climate fluctuate. Uncertainties in the future rate of this rise, stemming largely from the "feedback" effects on water vapour and clouds, are topics of current research.

It is the responsibility of scientific organisations like ours to present the public and politicians with a balanced assessment of the evidence – and, importantly, to indicate the level of confidence and the range of uncertainties attached to them.

Our two science academies have long contributed critical, objective and open reports on climate change. We intend to draw upon the efforts of leading scientists everywhere to make our future reports more accessible and valuable and, by fostering scientific research, we hope to do a better job of reducing inherent uncertainties. We must also promote best scientific practice, especially with regard to the sharing of data. But policymakers and the public must realise that, even if scientific uncertainties could be reduced to zero, formulating effective political responses would still be controversial and challenging. Our academies will provide the scientific backdrop for the political and business leaders who must create effective policies to steer the world toward a low-carbon economy.

Martin Rees,
President of the Royal Society

Ralph J Cicerone,
President of the US National Academy of Sciences

21

Let us focus on three sentences in this letter.

1. *However, as your editorial acknowledges, neither recent controversies, nor the recent cold weather, negate the consensus among scientists: something unprecedented is now happening. The concentration of carbon dioxide in the atmosphere is rising and climate change is occurring, both due to human actions.*

Note that this statement seems to go well beyond the IPCC statement that claimed that only more than half the temperature change over the preceding 50 years could be attributed to man's emissions – with aerosols included in order to cancel much of the excess warming the models produce.

Moreover, the assumptions underlying this claim have been shown to be false (namely that all other possible causes had been adequately accounted for).

Of course, one could carefully parse the sentence. Perhaps they meant that there was increasing CO_2 due to man, and that there was warming due to this though it might only be a small part of the already small observed warming. If this is what they meant, then the statement is trivial and suggests no basis for alarm. However, there is no doubt that this is not what they intended the reader to infer.

22

2. Uncertainties in the future rate of this rise, stemming largely from the "feedback" effects on water vapour and clouds, are topics of current research.

Who would guess from this throw away comment, that feedbacks are the critical issue? Without strong positive feedbacks there would be no cause for alarm, and no need for action. What Rees and Cicerone are actually saying is that we don't know if there is a problem.

3. Our academies will provide the scientific backdrop for the political and business leaders who must create effective policies to steer the world toward a low-carbon economy.

Rees and Cicerone are saying that regardless of the evidence the answer is predetermined. If the government wants carbon control, that is the answer that the Academies will provide. Nothing could better epitomize the notion of science in the service of politics – something that, unfortunately, has characterized so-called climate science.

23

Where do we go from here?

Given that this has become a quasi-religious issue, it is hard to tell. However, my personal hope is that we will return to normative science, and try to understand how the climate actually behaves. Our present approach of dealing with climate as completely specified by a single number, globally averaged surface temperature anomaly, that is forced by another single number, atmospheric CO_2 levels, for example, clearly limits real understanding; so does the replacement of theory by model simulation. In point of fact, there has been progress along these lines and none of it demonstrates a prominent role for CO_2. It has been possible to account for the cycle of ice ages simply with orbital variations (as was thought to be the case before global warming mania); tests of sensitivity independent of the assumption that warming is due to CO_2 (a circular assumption) show sensitivities lower than models show; the resolution of the early faint sun paradox which could not be resolved by greenhouse gases, is readily resolved by clouds acting as negative feedbacks.

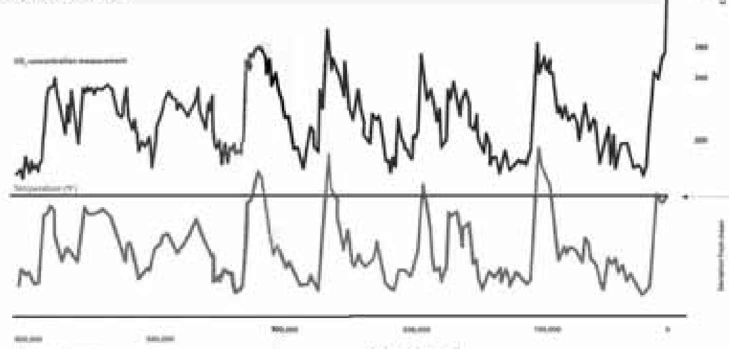
So far we have approached the science in a somewhat peripheral way. In the remainder of this testimony, we will deal with the science more directly.

24

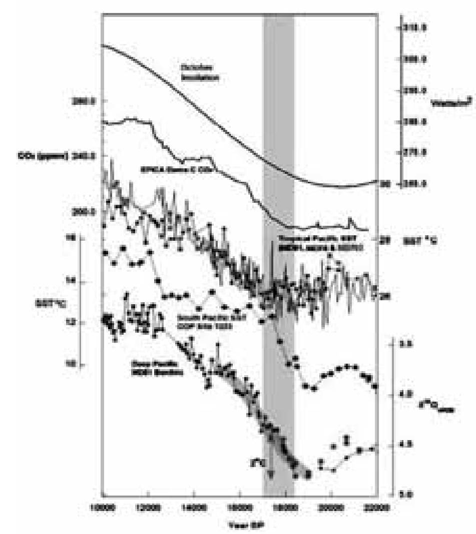
Here is a graphic made famous by Al Gore. There are lots of problems with this picture. For starters, it confuses correlation with causality. Moreover, it clearly shows that temperature preceded CO_2 by hundreds of years at the last glaciation. It also shows that previous interglacials were warmer than the present.

about South America and Africa—he would ask, "Did they ever fit together?"

However, the biggest problem may be that the use of a single number to characterize climate, completely obscures what is really happening. We see this in the next slide.



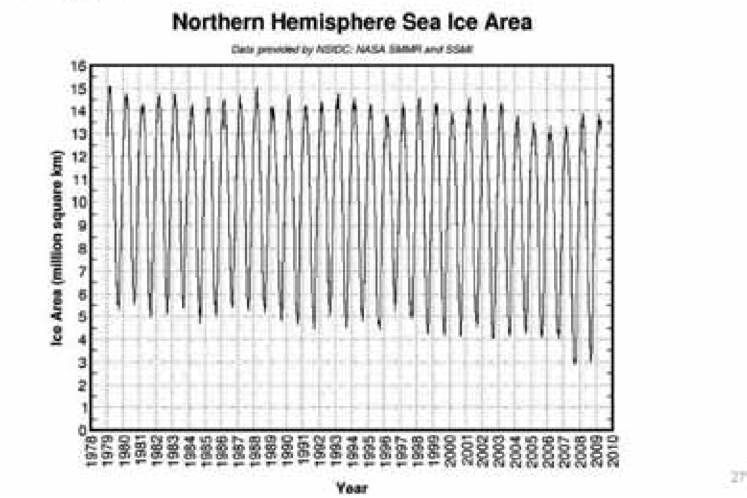
Here is we see why it is often useless to consider merely global mean temperature anomaly and CO_2.



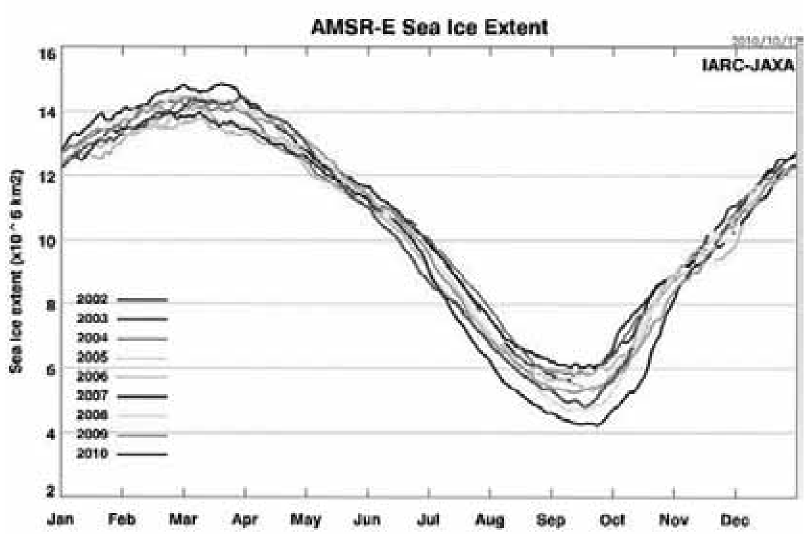
According to Stott et al, warming first occurred in the South Pacific in the region of formation of Upper Circumpolar Deep Water between 19,000BP and 17,000 BP. It was not until about 17,000 BP that the tropical surface water began to warm and the CO_2 concentration also began to rise at this time. It was not until 15,000BP that the Greenland region began to warm. With such a sequence it is apparent that the interglacial warming was initiated in the waters of the Southern Ocean and took nearly 4,000 years to be reflected in Greenland changes; also, the CO_2 variations would seem to be tied to tropical ocean temperature changes.

Here is a simple example of how current approaches inhibit progress.

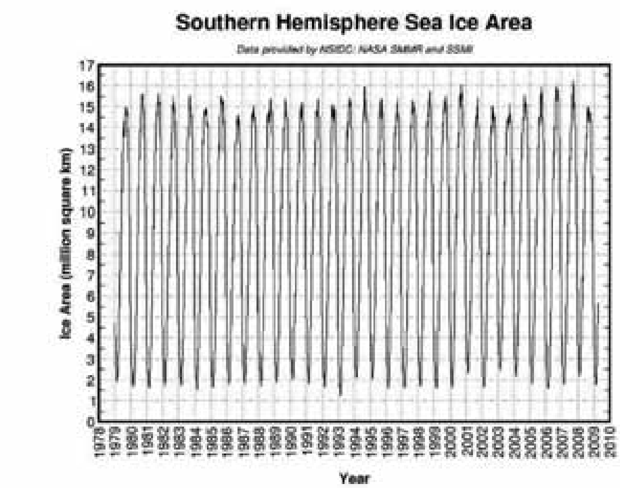
You have all heard about the arctic sea ice disappearing. Here is what is being spoken of.



The latest value : 6,599,688 km^2 (October 11, 2010)



As you may have heard, nothing of the sort has been happening to Antarctic sea ice, although claims of record extent of Antarctic sea ice are also overly dramatic.

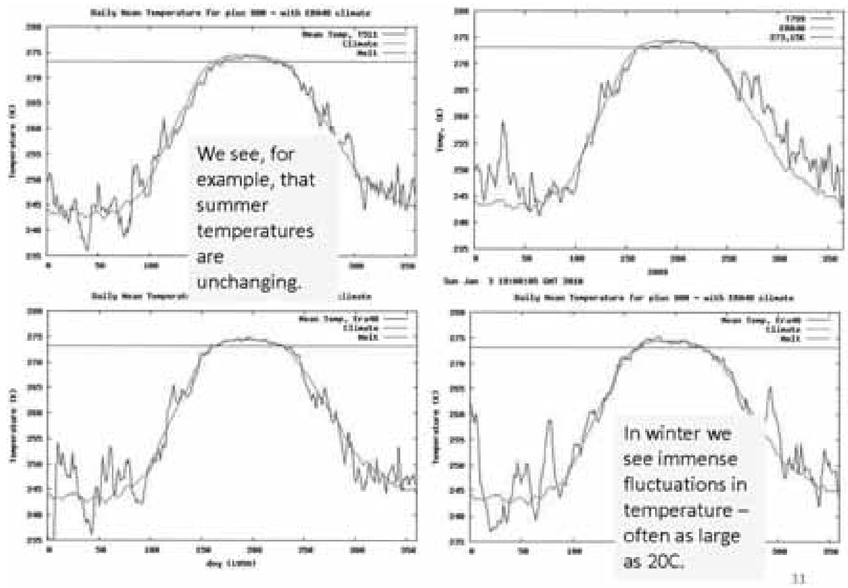


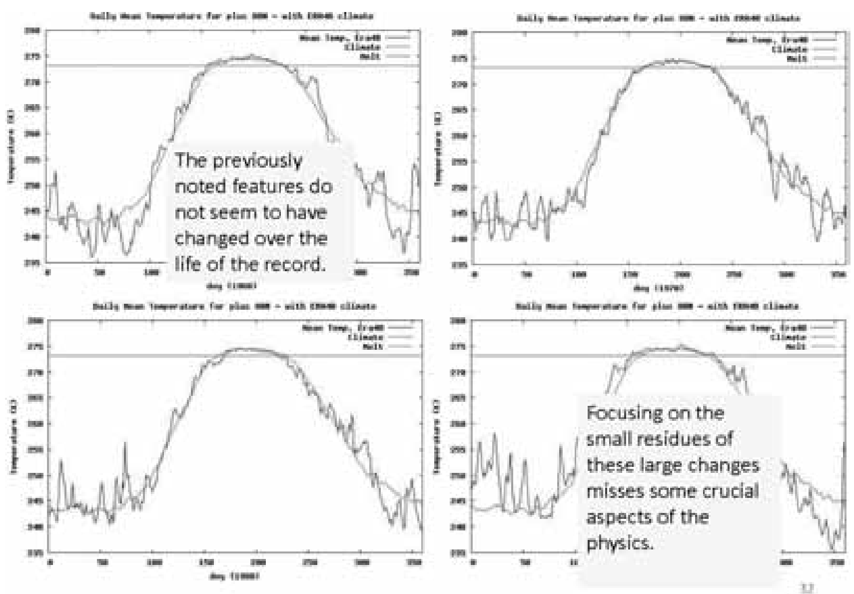
29

Let us now look at the temperature of polar regions in some detail. The following figures show daily arctic temperatures for each day available from reanalyses since 1958. They also show the average temperatures for each day.

If one focuses on variations in annually averaged temperatures, one misses some crucial information, and that information tells us quite a lot.

30


We see, for example, that summer temperatures are unchanging.
In winter we see immense fluctuations in temperature – often as large as 20C.
11


The previously noted features do not seem to have changed over the life of the record.
Focusing on the small residues of these large changes misses some crucial aspects of the physics.
12

What the previous slides illustrate is that during summers, when there is sunlight, temperatures are largely determined by local radiative balance and this does not seem to be changing. However, during the winter night, temperatures would be even colder than they are but for the transport of heat from lower latitudes. This transport is by the turbulent eddies or storms. Understanding arctic temperatures must involve understanding why these storms erratically penetrate to the arctic. Judging from the behavior of summer temperatures, CO_2 is not obviously a major player.

Just for the record, summer ice depends mostly on how much is blown out of the arctic basin – something that used to be textbook information.

33

While there really doesn't appear to be that much going on, anecdotal information can be more dramatic.

"THE ARCTIC OCEAN IS WARMING UP, ICEBERGS ARE GROWING SCARCER AND IN SOME PLACES THE SEALS ARE FINDING THE WATER TOO HOT. REPORTS ALL POINT TO A RADICAL CHANGE IN CLIMATE CONDITIONS AND HITHERTO UNHEARD-OF TEMPERATURES IN THE ARCTIC ZONE. EXPEDITIONS REPORT THAT SCARCELY ANY ICE HAS BEEN MET WITH AS FAR NORTH AS 81 DEGREES 29 MINUTES. GREAT MASSES OF ICE HAVE BEEN REPLACED BY MORAINES OF EARTH AND STONES, WHILE AT MANY POINTS WELL KNOWN GLACIERS HAVE ENTIRELY DISAPPEARED."

—US WEATHER BUREAU, 1922

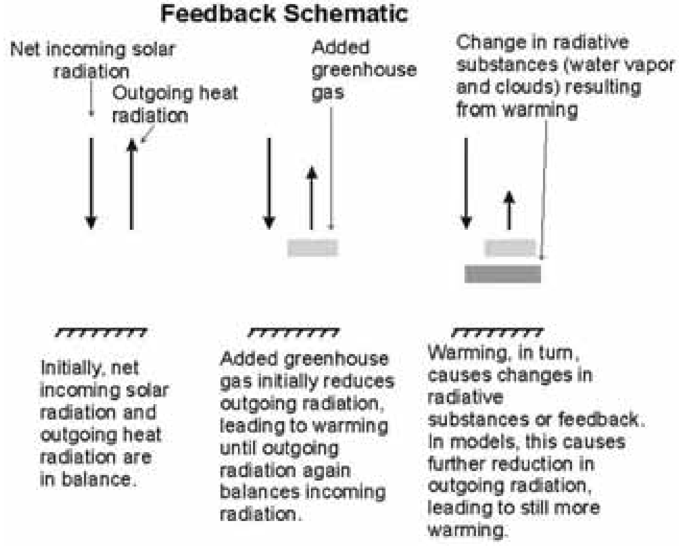
In fact, the arctic is notoriously variable; similar statements are available for 1957, and the Skate surfaced at the N. Pole in 1959. So much for 'unprecedented.'

34

As already mentioned, it is essential to know climate sensitivity. Model predictions depend on positive feedbacks and not just the modest effect of CO_2. There follows a schematic of what we mean by feedbacks.

35

Feedback Schematic



36

One is able to use satellite data from ERBE and CERES (that measures net outgoing radiation in both the visible and infrared portions of the spectrum) to test the preceding situation, and to quantitatively evaluate climate feedback factors. These are related to climate sensitivity by the following equation:

$$\Delta T = \frac{\Delta T_0}{1-f},$$

ΔT_0 is the zero feedback response to a doubling of CO_2. It is about 1C.

37

The basis of the approach is to see if the satellite measured outgoing radiation associated with short term fluctuations in Sea Surface Temperature (SST) is larger or smaller than what one gets for zero feedback. Remember that a positive feedback will lead to less outgoing radiation (increased blanket) while a negative feedback will lead to more.

It turns out that the model intercomparison program has the models used by the IPCC, forced by actual SST, calculate outgoing radiation. So one can use the same approach with models, while being sure that the models are subject to the same surface temperature fluctuations that applied to the observations.

38

Feedbacks as measured by ERBE and CERES
(after corrections described by Trenberth et al, 2009)

Mean+/-standard error of the variables.

	Variables	Value	Comments for likely lag
a	Slope, LW	5.2±1.3	Lag = 1
b	Slope, SW	2.2±3.0	Lag = 3
c	Slope, Total	7.1±2.2	= a+b for the same SST interval
d	f_{LW}	**–0.3±0.2**	Calculated from a
e	f_{SW}	**–0.3±0.4**	Calculated from b
f	f_{Total}	**–0.6±0.3**	Calculated from c

Note that feedbacks are negative.

Lags are used to distinguish fluctuations caused by SST (ie feedbacks) from radiation changes that are not feedbacks (due to volcanic eruptions for example).

For all models, the feedbacks are positive.

		LW				SW				LW+SW			
	N	Slope	R	SE	f_{LW}	Slope	R	SE	f_{SW}	Slope	R	SE	f
CCSM3	19	1.5	0.4	1.8	0.3	-3.1	-0.5	2.2	0.5	-1.6	-0.3	2.7	**0.7**
ECHAM5/MPI-OM	18	2.8	0.6	1.7	0.1	-1.1	-0.2	3.1	0.2	1.7	0.3	3	**0.2**
FGOALS-g1.0	18	-0.2	-0.1	1.6	0.5	-2.8	-0.7	1.3	0.4	-3	-0.7	1.6	**1**
GFDL-CM2.1	18	1.5	0.6	1	0.3	-0.4	-0.1	2.8	0.1	1.1	0.2	2.5	**0.3**
GISS-ER	22	2.9	0.6	1.4	0.1	-3.3	-0.5	2.3	0.5	-0.5	-0.1	1.8	**0.6**
INM-CM3.0	24	2.9	0.6	1.5	0.1	-3.1	-0.6	1.7	0.5	-0.3	-0.1	1.9	**0.5**
IPSL-CM4	22	-0.4	-0.1	2.1	0.6	-2.6	-0.5	2	0.4	-3	-0.5	2.1	**0.9**
MRI-CGCM2.3.2	22	-1.1	-0.2	2.2	0.7	-3.9	-0.4	3.1	0.6	-5	-0.6	2.6	**1.2**
MIROC3.2(hires)	22	0.7	0.1	2.2	0.4	-2.1	-0.5	1.6	0.3	-1.4	-0.3	2.5	**0.7**
MIROC3.2(medres)	22	4.4	0.7	1.8	-0.2	-5.3	-0.7	2.3	0.8	-0.9	-0.2	1.9	**0.6**
UKMO-HadGEM1	19	5.2	0.7	2.2	-0.3	-5.9	-0.7	2.1	0.9	-0.8	-0.1	2.2	**0.6**

Note that much of the 'error' in the regressions arises because radiatively important factors like clouds and aerosols vary due to many factors apart from SST. For observations there is also instrumental error, though relative errors over short time scales are likely to small.

We see that all the models are characterized by positive feedback factors (associated with amplifying the effect of changes in CO_2), while the satellite data implies that the feedback should be negative. Similar results are being obtained by Roy Spencer.

This is not simply a technical matter. Without positive feedbacks, doubling CO_2 only produces 1C warming. Only with positive feedbacks from water vapor and clouds does one get the large warmings that are associated with alarm. What the satellite data seems to show is that these positive feedbacks are model artifacts.

This becomes clearer when we relate feedbacks to climate sensitivity (ie the warming associated with a doubling of CO_2).

41

Models

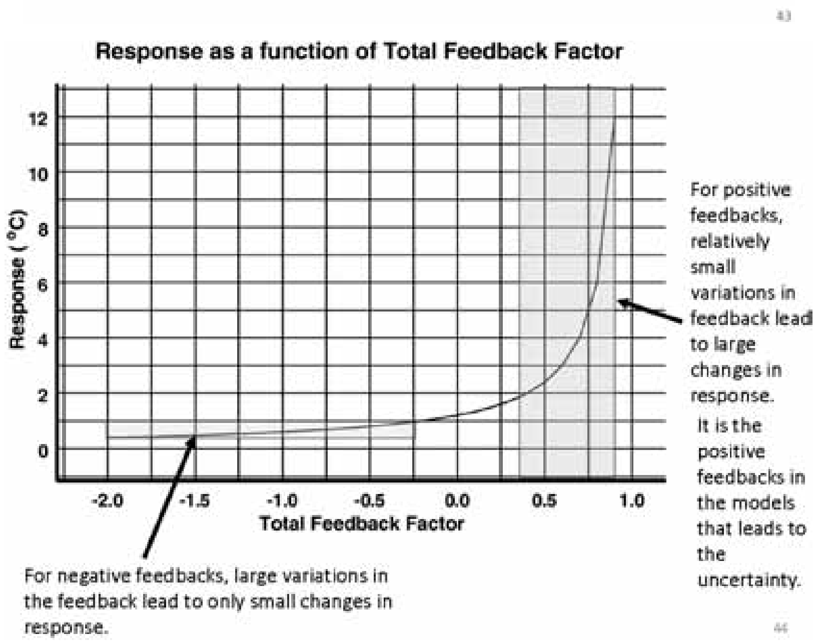
Models	AR4 sensitivity	Sensitivity, mean	Sensitivity, 90%	Sensitivity, 95%
CCSM3	2.7	4.2	1.2 – Infinity	1.0 – Infinity
ECHAM5/MPI-OM	3.4	1.4	0.7 – 28.9	0.7 – Infinity
FGOALS-g1.0	2.3	22.4	2.4 – Infinity	2.1 – Infinity
GFDL-CM2.1	3.4	1.6	0.9 – 15.4	0.8 – Infinity
GISS-ER	2.7	2.5	1.2 – Infinity	1.1 – Infinity
INM-CM3.0	2.1	2.4	1.2 – Infinity	1.1 – Infinity
IPSL-CM4	4.4	19.5	1.9 – Infinity	1.6 – Infinity
MRI-CGCM2.3.2	3.2	Infinity	2.8 – Infinity	2.2 – Infinity
MIROC3.2(hires)	4.3	3.8	1.2 – Infinity	1.1 – Infinity
MIROC3.2(medres)	4	3.0	1.3 – Infinity	1.2 – Infinity
UKMO-HadGEM1	4.4	2.8	1.2 – Infinity	1.1 – Infinity

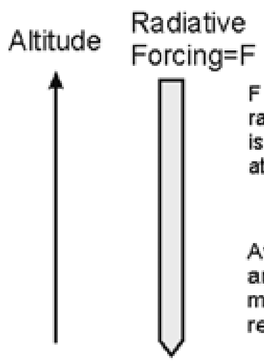
Observations

Sensitivity, mean	0.7	Calculated from f
Sensitivity, 90%	0.5-1.1	Twice standard error
Sensitivity, 95%	0.5-1.2	3 times standard error

42

$$\Delta T = \frac{\Delta T_0}{1 - f},$$





F is roughly non-divergent, but while F is radiative at the top of the atmosphere, it is mostly due to latent heat flux (ie evaporation) at the surface.

Averaged over the globe Evaporation=Precipitation and both Precipitation and Evaporation can now be measured from space. This permits one to test one's results for consistency.

From the above, we see that an alternative to observing outgoing radiation from space is to measure evaporation from the surface. This has, in fact, been done. Wentz, F.J. et al (How much more rain will global warming bring. *ScienceExpress*, 31 May 2007) used the above and space based observations to measure how evaporation changed with temperature and compared their results with GCM results.

In GCMs, E (evaporation) increased from 1-3% for each degree increase in temperature. Observationally, E increased 5.7%. Now a 1% change in E corresponds to about 0.8 watts m^{-2}. Climate sensitivity is essentially $\Delta T/\Delta F$.

45

EC=ΔEvaporation/ΔT (in units of percent change per degree)

CF=Radiative Forcing due to doubling of CO_2=3.6 Watts m^{-2}

FL=Heat Flux associated with EC=0.8 Watts m^{-2} x EC

Climate sensitivity=CF/FL

Source	EC (percent change in E per degree)	Climate Sensitivity (degrees Centigrade)
Model Range	1	4.5
	3	1.5
Observed	5.7	0.8

We may reasonably consider the observed sensitivity to be an overestimate since Wentz et al explicitly rejected observations that were 'too' far from models. The results are, however, very similar to those based on measurements of outgoing radiation.

46

Discussion of other progress in science can also be discussed if there is any interest. Our recent work on the early faint sun may prove particularly important. 2.5 billion years ago, when the sun was 20% less bright (compared to the 2% change in the radiative budget associated with doubling CO_2), evidence suggests that the oceans were unfrozen and the temperature was not very different from today's. No greenhouse gas solution has worked, but a negative cloud feedback does.

You now have some idea of why I think that there won't be much warming due to CO_2, and without significant global warming, it is impossible to tie catastrophes to such warming. Even with significant warming it would have been extremely difficult to make this connection.

47

Perhaps we should stop accepting the term, 'skeptic.' Skepticism implies doubts about a plausible proposition. Current global warming alarm hardly represents a plausible proposition. Twenty years of repetition and escalation of claims does not make it more plausible. Quite the contrary, the failure to improve the case over 20 years makes the case even less plausible as does the evidence from climategate and other instances of overt cheating.

In the meantime, while I avoid making forecasts for tenths of a degree change in globally averaged temperature anomaly, I am quite willing to state that unprecedented climate catastrophes are not on the horizon though in several thousand years we may return to an ice age.

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BIOGRAPHY FOR RICHARD S. LINDZEN

Professor Lindzen is a dynamical meteorologist with interests in the broad topics of climate, planetary waves, monsoon meteorology, planetary atmospheres, and hydrodynamic instability. His research involves studies of the role of the tropics in mid-latitude weather and global heat transport, the moisture budget and its role in global change, the origins of ice ages, seasonal effects in atmospheric transport, stratospheric waves, and the observational determination of climate sensitivity. He has made major contributions to the development of the current theory for the Hadley Circulation, which dominates the atmospheric transport of heat and momentum from the tropics to higher latitudes, and has advanced the understanding of the role of small scale gravity waves in producing the reversal of global temperature gradients at the mesopause, and provided accepted explanations for atmospheric tides and the quasi-biennial oscillation of the tropical stratosphere. He pioneered the study of how ozone photochemistry, radiative transfer and dynamics interact with each other. He is currently studying what determines the pole to equator temperature difference, the nonlinear equilibration of baroclinic instability and the contribution of such instabilities to global heat transport. He has also been developing a new approach to air-sea interaction in the tropics, and is actively involved in parameterizing the role of cumulus convection in heating and drying the atmosphere and in generating upper level cirrus clouds. He has developed models for the Earth's climate with specific concern for the stability of the ice caps, the sensitivity to increases in CO_2, the origin of the 100,000 year cycle in glaciation, and the maintenance of regional variations in climate. Prof Lindzen is a recipient of the AMS's Meisinger, and Charney Awards, the AGU's Macelwane Medal, and the Leo Huss Walin Prize. He is a member of the National Academy of Sciences, and the Norwegian Academy of Sciences and Letters, and a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Sciences, the American Geophysical Union and the American Meteorological Society. He is a corresponding member of the NAS Committee on Human Rights, and has been a member of the NRC Board on Atmospheric Sciences and Climate and the Council of the AMS. He has also been a consultant to the Global Modeling and Simulation Group at NASA's Goddard Space Flight Center, and a Distinguished Visiting Scientist at California Institute of Technology's Jet Propulsion Laboratory. (Ph.D., '64, S.M., '61, A.B., '60, Harvard University)

Chairman BAIRD. Dr. Meehl.

STATEMENT OF GERALD A. MEEHL, SENIOR SCIENTIST, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. MEEHL. Thank you, Chairman Baird, Members of the Committee, for the opportunity to communicate information regarding processes involved with climate change, climate models, extreme weather, and climate events. But first I want to begin with a personal perspective that I think is worth stressing. I think that one of the most interesting, exciting, and challenging science problems—I emphasize the word "science" problems—facing the research community today is the following: If you add greenhouse gases to the atmosphere, what is the response of the climate system? It is because of this compelling science problem that I find research in this area fascinating and a tremendous intellectual challenge, and it is why I am here today.

So anyway, the idea that additional CO_2 and other greenhouse gases would cause a warming of the climate is not a new one. The so-called greenhouse effect has been studied since the late 1800s, and a number of simple calculations performed over the early 20th century indicated that the doubling of CO_2 in the atmosphere would likely warm the planet by at least several degrees.

However, a major development in this field of study was the emergence of numerical models that could be run on computers. Equations from fluid dynamics, physics, and thermodynamics can be used to simulate weather, and this had already been addressed early in the 20th century in a series of arduous calculations, performed at that time by hand. It was not until electronic computers came into use in the 1950s that the equations could be solved in a rapid enough manner to be used for actual weather forecasts. This new science of numerical weather prediction became feasible for operational forecasts in the 1960s and is still in use today.

Using the same principles and many of the same equations, early climate models in the 1960s were devised that could be mathematically integrated forward in time, much like numerical weather forecasts but for much longer into the future. It was well known that after about a week, due to the chaotic nature of the atmosphere, the time evolution of individual storms could not be resolved by climate models. Instead, the climate simulations attempted to capture the statistics of weather over months, seasons, years and decades.

Since the climate models look to weather and climate in this new way, other factors that could change slowly and thus affect the statistics of weather had to be included. Therefore, unlike weather predictions where there was only an atmospheric numerical model, climate models had an atmosphere as well as confluence of oceans, land surface, sea ice and equations that accounted for heating and greenhouse gases or cooling from visible air pollution.

All of these components were linked together in one large computer program, run on the fastest supercomputers available, so that as much detail as possible could be included in the equations. These models account for physical processes and feedbacks such as those alluded to by Dr. Lindzen. And these feedbacks involve water vapor, changes in snow and sea ice and clouds. And, of course, all of these affect how the climate system responds to changes in greenhouse gases.

Some of the uncertainty to the range of model responses seen in increasing CO_2 arises from uncertainties in these feedbacks, particularly clouds. However, climate models with a cooling contribution from negative cloud feedback still warms significantly on average over the 20th and 21st century due to the contributions to increased temperatures, not only from increasing greenhouse gases but also from warming feedbacks involving increased water vapor, decreased snow, and sea ice.

Since the end of the 19th century, global average temperatures have warmed nearly 3–1/2 degrees Fahrenheit. Many wonder why we should worry about such seemingly small increases of temperature. However, even small changes in average temperature produces very large and more noticeable changes in weather and climate extremes. It stands to reason that in a warmer climate, there will be more very hot days and fewer very cold days.

For precipitation, there is also a temperature-related connection. As more moisture evaporates from the warming oceans, the warmer atmosphere can hold that increased moisture. And when that moisture gets caught up in a storm, there is a greater moisture source for precipitation. Therefore, we typically see a greater intensity of precipitation in a warmer climate. That is, we see greater daily rainfall totals, or when it rains it pours. Exactly these kind of changes have been documented in the observations; namely, more heat extremes and pure cold extremes and increases in precipitation and intensity.

Additionally, the shift to warmer temperatures has also produced an increase in daily record-high temperatures compared to daily record-low temperatures over the United States, with this ratio currently being about 2-to-1.

For example, since January 1, 2000, there have been over 300,000 daily record-high maximum temperatures set and only about 150,000 daily record-low minimum temperatures set, a ratio of about 2-to-1. Just this year since January 1, 2010, there have been over 17,000 daily record highs and about 6,000 daily record lows, a ratio of more than 2-to-1. Thus, as the average temperatures warm, the probabilities have shifted towards more unprecedented heat and less unprecedented cold.

To a first order, climate models are able to reproduce these changes of temperature and precipitation extremes, thus building credibility for their future projections. Those projections of future climate change show ever-increasing heat extremes and reductions in cold extremes, ongoing increases of precipitation intensity, and a growing ratio of record-setting heat compared to record-setting cold.

For example, in one model for one future climate change scenario, the current ratio of about 2-to-1 record highs to record lows increases to about 20-to-1 by mid-century and about 50-to-1 by late century. However, even in the late 21st century, when warming average over the United States was about 4 degrees C, or roughly 70 degrees Farenheit in that model, there are still record-setting daily low temperatures occurring. Thus, even in a climate that has warmed significantly in the model, winter still occurs and it does occasionally get extremely cold in some locations, cold enough to set a few daily record-low temperatures every year in that model. However, those few daily record lows occur in the context of many more daily record-high maximum temperatures. And this is yet another aspect of a future warmer climate. Thank you.

Chairman BAIRD. Thank you, Dr. Meehl.

[The prepared statement of Dr. Meehl follows:]

PREPARED STATEMENT OF GERALD A. MEEHL

Introduction

I thank the Chairman and other Members of the Committee for the opportunity to communicate to you today information regarding processes involved with climate change, climate models, and extreme weather and climate events. My name is Gerald Meehl, Senior Scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. My research interests include tropical climate involving the monsoons and El Nino Southern Oscillation, climate variability and climate change. I have authored or co-authored more than 185 peer-reviewed scientific journal articles and book chapters. I was a lead author on the U.S. Climate Change Science Program (CCSP) Report 1.1 on temperature trends in the atmosphere, and was co-coordinator of the CCSP Report 3.3 on weather and climate extremes in a changing climate. I have been involved with the Intergovernmental Panel on Climate Change (IPCC) assessments since the first one that was published in 1990. I was a Contributing Author on that first assessment and its update in 1992, a Lead Author for the 1995 Assessment, a Coordinating Lead Author for the 2001 and the 2007 assessments, and I am currently a lead author for the recently initiated IPCC Fifth Assessment Report (AR5) due to be completed in 2013. I am chair of the National Academy of Sciences/National Research Council Climate Research Committee (CRC). I have been involved with committees of the World Climate Research Program (WCRP) on Climate Variability and Predictability (CLIVAR), and am currently co-chair of the WCRP/CLIVAR Working Group on Coupled Models (WGCM). This committee organized and coordinated the international modeling groups in performing climate model experiments for assessment in the AR4, and in the collection and analysis of data from those model experiments that was made openly available to the international climate research community. Our committee is currently involved in performing similar coordination activities for climate change experiments now being run by about 20 international climate modeling groups to increase our understanding of climate model performance and to provide insight into the climate system response to future climate change mitigation scenarios. As before, these experiments will be made openly available for analysis by the international climate science community, and will also be assessed as part of the IPCC AR5.

The greenhouse effect and how increasing greenhouse gases warm the climate

Since roughly the beginning of the Industrial Revolution in the second part of the 19th century, human societies have come to rely on fossil fuels for an energy source. These fossil fuels—coal, oil, and natural gas—produce greenhouse gases when they are burned. Thus, as humans have excavated fossil fuels from beneath the surface of the earth where they have been sequestered for millions of years, those fuels have been burned for energy and have released forms of carbon into the air—greenhouse gases such as CO2 and methane. These greenhouse gases in trace amounts occur naturally in the atmosphere and effectively trap some heat in the climate system that would otherwise escape to space. This occurs because molecules with more than two atoms (e.g. CO2, CH4, H2O) have the well-known property of being able to absorb and re-emit infrared or heat energy.

Most molecules are transparent to incoming sunlight, and almost all sunlight that is not reflected by clouds reaches the earth's surface. That sunlight heats the surface. and heat (infrared radiation) is emitted upwards. If greenhouse gases were not in the atmosphere, most of this heat energy would make it out of the system to space, leaving the earth a much colder and inhospitable place. However, greenhouse gases intercept some of this heat or infrared energy, absorb it, and re-radiate some of it upwards where it continues on out to space, and some of it is re-radiated downwards, thus staying in the system to warm the planet. Thus, this heat-trapping effect of greenhouse gases makes the planet habitable for human, plant and animal life.

Greenhouse gases have been present in our atmosphere for millennia. It has been shown, from air bubbles trapped in ice sheets, that greenhouse gases such as CO2 have fluctuated naturally over at least the past 800,000 years with the ice ages. Of course humans were not present to cause these fluctuations, but, due to well-understood orbital variations that change the intensity of solar input, the planet cools and warms naturally over thousands of years producing the ice ages and inter-glacial periods. We also know that warmer oceans tend to emit more CO2 to the atmosphere, while cooler oceans absorb CO2. Thus, as the orbital variations produce differences in the intensity of solar input to the climate system that contribute to the ice ages, the oceans warm and cool as the ice ages come and go naturally, and there is an amplifying effect from CO2 to enhance the warmth between ice ages (i.e. the warmer oceans emit more CO2 that warms the climate more), while the opposite occurs during ice ages to contribute to even colder conditions.

The concept that CO2 and other greenhouse gases, released when fossil fuels are burned, would cause a warming of the climate is not a new idea. In 1895 Svante Arrhenius postulated that increasing levels of greenhouse gases in the air would warm the climate such that a doubling of CO2 would warm the planet on average by about 5 to 6C (he later revised this number downward to 1.6C). These numbers, calculated very simply from early radiative theory, are not that far off from modem estimates of 2C to 4.5C derived from global climate models and inferred from observational data. In the late 1930s Guy Callendar suggested that the burning of fossil fuels should increase greenhouse gases in the atmosphere, and that these increases should warm the climate. It wasn't until the late-1950s, when Charles Keeling started to directly measure the time evolution of CO2 in the atmosphere to show that there was, indeed, an increasing trend, that the earlier theoretical estimates of CO2 increase from the burning of fossil fuels had a basis in a definitive time series measurement.

The concept that equations from fluid dynamics, physics and thermodynamics could be used to simulate weather was addressed early in the 20th century when L.F. Richardson attempted to use a set of those equations to calculate, by hand, a simple weather forecast for a single location. However, due to the complexity of the equations and considerable numerical calculations required, it was not until electronic computers came into use in the 1950s that the equations could be solved to produce simulations of the weather in a rapid enough manner to be used for actual weather forecasts. This new science of numerical weather prediction became feasible for operational forecasts in the 1960s. and is still in use today to produce weather forecasts.

Using the same principles, and even many of the same equations, early climate models were devised that could be integrated forward in time, much like numerical weather forecasts, but for much longer into the future. It was well-known that after about a week, due to the chaotic nature of the atmosphere, the time evolution of individual storms cannot be resolved by climate models. Instead, the climate simulations attempted to capture the statistics of weather over months, seasons, years and decades. Since climate models looked at weather and climate in this new way, other factors that could change slowly and thus affect the statistics of weather had to be included. Therefore, equations that took into account the effects of greenhouse gases were refined. The varying output of the sun could also be included, as well as the effects of volcanic eruptions in equations that accounted for how visible air pollution could cause cooling of the climate. Perhaps most importantly for longer term variations of the statistics of weather and climate, the slowly varying parts of the climate system had to be included, namely the oceans and sea ice, as well as land surface processes. Unlike weather prediction where there was only an atmospheric numerical model, climate models had an atmosphere (similar to a numerical weather prediction model), as well as components of ocean, land surface, sea ice, and sophisticated equations that accounted for the heating of greenhouse gases or the cooling of visible air pollution. All of these components were linked together in one large computer program that had be run on the fastest supercomputers available so that as much detail in the equations could be included as possible, balanced by the need to run the models for tens and even hundreds of years (as opposed to only about a week for numerical weather prediction models). Thus, most of the physics, processes, and feedbacks known to be operating in the climate system were included in even the earliest global climate models that began to be used in the 1960s.

The warming produced by increases of greenhouse gases, along with the first order feedbacks, were shown to occur in these very early climate models. This led to the "Charney Report" published by the National Academy of Sciences in 1979, over 20 years ago. That report noted that the measured increases in CO2 in the atmosphere, when included in the basic climate models of that time, produced significant warming on average over the planet, and that, with further increases in CO2, the climate would continue to warm. Interestingly, this report was published after over 30 years of the observed climate not warming (there was warming until the 1940s, and then little warming until the late 1970s). Thus, based on the physics of climate already known in the 19th century, and the basic understanding of that time of the processes that could be captured in equations and included in climate models to study the statistics of climate, future warming was predicted as a result of ongoing increases of greenhouse gases, even though the observed climate had not been warming for decades. Since the time the Charney Report was published in the late 1970s, there has been an overall average warming trend. It was not until over 20 years later, at the beginning of the 21st century, that a generation of improved climate models, along with better observed datasets, was able to show how the combinations of natural and human factors that influence climate produced the time evolution of observed temperature change over the 20th century.

Results from those studies showed that the warming in the early part of the 20th century was mainly due to natural causes; a hiatus of warming from the 1940s to the 1970s was mostly due to a balance between the warming that would have occurred due to the increases of greenhouse gases, and the cooling from the visible air pollution in part produced by the burning of fossil fuels; and finally in the 1970s after air quality was improved, thereby reducing cooling from visible air pollution, the ongoing increases of greenhouse gases produced a multi-decadal warming trend over the past 35 years or so. This warming trend is not uniform in time (i.e. each year is not warmer than the year before) due to internally generated natural variability of the climate system. Depending on the start and end points used to calculate ten year trends, there are some decades when the warming trend is nearly flat (e.g.1986–1995; 1998–2007) and times when the warming trend for a given decade is greater than the longer term trend (e.g. 1975–1984; 1988–1997)

Measurements from the ice cores of air bubbles trapped over the last 800,000 years indicate the CO2 amount in the atmosphere only ever got about as high as 280 ppm. In just the last 100 years, that CO2 amount has increased to an unprecedented (over the last 800,000 years) amount of about 380 ppm currently. Since we know CO2 traps heat in the atmosphere, the increase in CO2 alone would warm the climate somewhat. But, just as CO2 acts as an amplifier to past ice ages and inter-glacials, it also produces other amplifying effects in the atmosphere called "feedbacks". The main ones are water vapor feedback and ice albedo feedback.

As the oceans warm from the effects of increasing human-produced greenhouse gases, more moisture evaporates and goes into the atmosphere as water vapor. Water vapor itself is a greenhouse gas, and also contributes to trapping heat in the atmosphere, thus amplifying the effects from increasing CO2 and other greenhouse gases. Ice-albedo feedback involves ice that covers high latitude oceans ("sea ice") as well as snow cover over land. As the climate warms, there is less snow and sea ice during winter. Because snow and sea ice are highly reflective ("high albedo"), when there are decreases in snow and sea ice there are more areas with lower reflectivity. The land and ocean surfaces with lower reflectivity absorb more energy from sunlight in the non-winter months. That increase in surface heat content then inhibits snow and ice from forming in the following winter, thus leaving even more open ocean and snow-free land to absorb even more heat the next summer, and so on.

Another feedback that is less certain is cloud feedback. That is, if clouds increase in a warming climate, there would be more sunlight reflected and that would be a check on warming (a “negative feedback”). However if clouds decrease in a warming climate, the cloud feedback would be positive and would contribute to even more warming. To first understand how cloud feedback works, and then incorporate those processes in climate models, there have to be high quality observations of the three dimensional structure of clouds. However, this three dimensional structure has traditionally been very difficult to observe, though a new generation of recent satellites is, for the first time, providing observations of just that three dimensional structure. It is hoped that these new data, coupled with improved representations of clouds in climate models, will be better able to pin down the sign and magnitude of cloud feedback. However, even in models that have a negative cloud feedback, the climates of those models still warm significantly over the 20th and 21st centuries due to contributions to warming from increasing greenhouse gases and the other feedbacks, such as those involved with water vapor, snow and sea ice. Those have been observed to operate on various timescales that can be measured, such as the seasonal cycle, and then validated in climate models.

Many climate change impacts will be experienced through changes in weather and climate extremes

Droughts, floods, hurricanes, record heat and cold extremes affect human societies, economies and ecosystems in significant ways, from effects on human health and mortality, to disruptions of agriculture and economic activity, to impacts on outdoor activities and tourism. Though there are many types and categories of extremes, I will focus here on changes in daily temperature and precipitation extremes.

Weather and climate extremes are a naturally occurring part of our climate system, and thus have always had a disruptive effect on humans and the natural system. As such there has been a certain degree of adaptation to such extreme events. These adjustments range from such mundane things as air conditioning, to insurance programs that cover losses from extreme events. However, if the naturally occurring aspects of weather and climate extremes change significantly, so will the impacts, and thus weather and climate extremes in a changing climate become of interest for a variety of applications.

A small change in average climate produces a disproportionately large change in extremes

Since the end of the 19th century, globally averaged temperatures have warmed about 0.8C or about 1.4F. Projections for the end of the 21st century made with climate models using a variety of scenarios of future climate change show temperature increases that range from a couple of degrees Centigrade (about 3.5F) for a low emissions scenario to over 8C (about 14F) for a high emission scenario by the end of this century. However, these are seemingly small increases when the day-night temperature differences at certain locations are often tens of degrees. Many wonder why we should worry about such seemingly small increases in temperature.

Of course these small changes in globally averaged temperature do not reflect the geographic pattern of change where some regions so far have seen very little warming (e.g. the southeastern part of the U.S.) to other areas that have already experienced substantial warming of nearly 10C in some high latitude areas of the Arctic. And these average changes are reflected by a host of impacts that happen over the long term that have already affected human societies.

However, even such small changes in average temperature produce disproportionately large changes in extremes. A good example is temperature. A weather station with a record long enough to capture most of the eventualities of weather at that location usually has a probability of a certain temperature occurring at that location in the form of the familiar “bell-shaped curve”. There is the highest probability of a temperature occurring that is near the long term average (near the center of the curve), with a much smaller probability of an extremely hot or cold temperature occurring (out near the right and left “tails” of the curve, respectively). Thus, if there is even a small warming in the average temperature, all else being equal, the curve shifts to the right a bit. But this small shift is reflected in a much higher probability of an extremely hot temperature occurring, and a much lower probability of an extremely cold temperature happening. Therefore, seemingly small warming can produce very large and more noticeable changes in extremes.

The physical processes involved in changes in daily temperature and precipitation extremes are relatively straightforward to understand in the observed system, and can be captured by climate models

There are a couple of relatively simple physical principles that govern daily extremes of temperature and precipitation. For temperature, as noted above, a small average warming produces a disproportionately large increase in hot extremes and a greater decrease in cold extremes. It stands to reason that in a warmer climate, there will be more very hot days, and fewer very cold days. For precipitation, there is a temperature-related connection in that warmer air can hold more moisture. Thus, as the climate warms, more moisture evaporates from the warming oceans, the warmer atmosphere can hold that increased moisture, and when that more moist air gets caught up in a storm, there is a greater moisture source for precipitation. Therefore, we typically see a greater intensity of precipitation in a warmer climate (i.e. greater daily rainfall totals, or "when it rains it pours").

Have we already seen a change in daily temperature and precipitation extremes over the U.S.?

Since there are thousands of weather stations over the U.S. (and internationally) that routinely collect daily temperature and rainfall data, there have been a number of studies that have catalogued an increase in extreme heat over the past 50 years, a decrease in extreme cold, and an increase in precipitation intensity. During this time period, average temperatures have warmed, and, from the physical principles noted above, we would expect to see just these kinds of changes in extremes in a warming climate. Such changes have been documented not only in numerous publications in the peer-reviewed scientific literature, but also summarized in various assessments of that literature (e.g. the IPCC AR4, CCSP3.3, and the recent National Academy of Sciences America's Climate Choices Science Panel Report).

For example, there has been a documented observed trend of decreases of "frost days" (i.e. when the nighttime temperatures go below freezing), with greater decreases of frost days in the western U.S. compared to the eastern U.S., also reflecting average warming patterns over the second half of the 20th century when there has been a good coverage of stations reporting daily temperature data. The reduction of extreme cold has had numerous impacts, one being an increase of pine bark beetles in the western U.S. Extreme cold is needed to kill the dormant insects during the winter. Due to the average warming, there has been less extreme cold, and more live to become active in summer, and they kill even more pine trees. Increases in extreme warm days have also been documented in observations over the U.S.

The shift to warmer temperatures has also produced an increase in daily record high temperatures compared to daily record low temperatures over the U.S., with this ratio currently being about two to one. For example, Since January 1, 2000, there have been 311,734 record daily high maximum temperatures set, and only 152,329 daily record low minimum temperatures, a ratio of about two to one. Since January 1, 2010, this year, there have been 17,148 daily record highs, and 6,315 daily record lows, more than a ratio of two to one. Thus, as the average temperature has warmed, the probabilities have shifted towards more unprecedented heat, and less unprecedented cold.

For precipitation, the intensity of daily precipitation has also been observed to increase since the second half of the 20th century, again when we have a good geographic coverage of daily temperature data.

Climate models are able to reproduce these observed changes of temperature and precipitation extremes, and thus build credibility that we can believe what they tell us about the future. Projections of future climate change in the models with scenarios of future greenhouse gas emissions show ever-increasing heat extremes and reductions in cold extremes, ongoing increases of precipitation intensity, and a growing ratio of record-setting heat compared to record-setting cold, with, in one model for one scenario, the current ratio of about two to one increasing to twenty to one by mid-century, and about fifty to one by late century. However, even in the late 21st century when warming averaged over the U.S. is about 4C (or roughly 7F) in the model, there are still record-setting daily low temperatures occurring. Thus, even in a climate that has warmed significantly in the model, winter still occurs, and it does occasionally get extremely cold in some locations, cold enough to set a few daily record low temperatures every year. However, those few record daily lows occur in the context of many more daily record high maximum temperatures that would occur every year.

Summary

The concept that greenhouse gases in the atmosphere make the planet warm enough to be habitable, and that increasing those greenhouse gases by the burning of fossil fuels could make the planet even warmer, is not a new idea and has been studied for over a century. Early attempts at numerical weather prediction, solving the relevant equations that describe the physics and thermodynamics of the atmosphere by hand for a single location in the early 1900s, presaged modem numerical weather predictions performed routinely by atmospheric models run on supercomputers. Those atmospheric models attempt to resolve the time evolution of individual storm systems over the next few days. Subsequently developed global climate models include atmospheric components similar to those used in numerical weather prediction, but add components of the slowly varying parts of the climate system (ocean, sea ice, and land surface processes). The dynamical coupling of those components in the models, as in the real world, is relevant to the statistics of weather over climate timescales of months to years to decades to centuries. Climate models also have equations that capture the effects of greenhouse gases and relevant feedbacks in the climate system that can influence climate. These climate models can reproduce, to first order, the observed changes in temperature and precipitation extremes observed over the past 50 years or so. These have included more heat extremes, fewer cold extremes, greater increases in daily record high temperatures compared to daily record low temperatures, and increased precipitation intensity. This lends credibility to the climate models such that there is likely to be useful information in their climate projections about future changes of extremes. With continued increases of greenhouse gases and consequent warming, these model projections depict a world with ongoing increases in heat extremes and record heat, reductions in cold extremes and record cold, and greater precipitation intensity.

BIOGRAPHY FOR GERALD A. MEEHL

Gerald A. Meehl is a Senior Scientist at the National Center for Atmospheric Research. His research interests include studying the interactions between El Niño/Southern Oscillation (ENSO) and the monsoons of Asia; identifying possible effects on global climate of changing anthropogenic forcings, such as carbon dioxide, as well as natural forcings, such as solar variability; and quantifying possible future changes of weather and climate extremes in a warmer climate. He was contributing author (1990), lead author (1995), and coordinating lead author (2001, 2007) for the first four Intergovernmental Panel on Climate Change (IPCC) climate change assessment reports, and is currently a lead author on the near-term climate change chapter for the IPCC AR5. He received his Ph.D. in climate dynamics from the University of Colorado, and was a recipient of the Jule G. Charney Award of the American Meteorological Society in 2009. Dr. Meehl is an Associate Editor for the Journal of Climate, a Fellow of the American Meteorological Society, and a Visiting Senior Fellow at the University of Hawaii Joint Institute for Marine and Atmospheric Research. He serves as chair of the National Academy of Sciences/National Research Council Climate Research Committee, and co-chair of the Community Climate System Model Climate Change Working Group. Additionally, he is co-chair of the World Climate Research Programme (WCRP) Working Group on Coupled Models (WGCM), the group that coordinates international global climate model experiments addressing anthropogenic climate change.

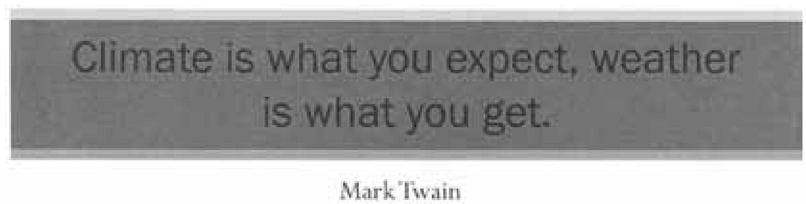
Chairman BAIRD. Dr. Cullen.

STATEMENT OF HEIDI M. CULLEN, CEO AND DIRECTOR OF COMMUNICATIONS, CLIMATE CENTRAL

Dr. CULLEN. Thank you, Chairman Baird and Members of the Subcommittee, for this opportunity to have a rational discussion on the science of climate change. I have got a PowerPoint, which we are going to bring up. And it will reinforce several of the points that have already been made on the panel this morning. And I will say that my background is a little bit different than some of my panel members in the sense that I spent several years at The Weather Channel as their on-camera climate expert, and it was a great experience. And it was really interesting to me because when I got there, most people just assumed I was a meteorologist. So I got a lot of questions about what the five-day forecast would be. And while I love the five-day forecast, it was a really important opportunity to just help people understand the difference between climate and weather, the difference between climatologists and meteorologists, and the difference between weather forecasts and climate forecasts.

You see the great quote by Mark Twain up there.

[The information follows:]

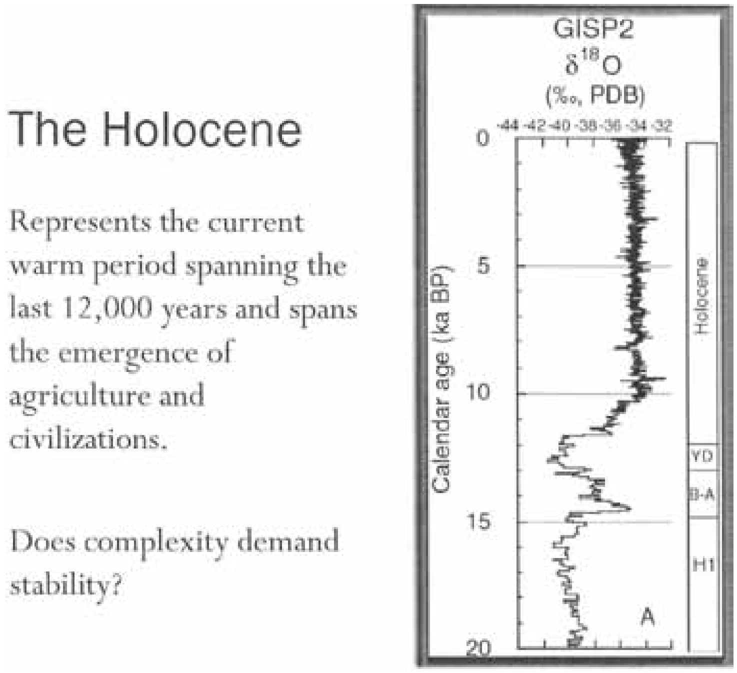


He basically said it all, which is, "Climate is what we expect, weather is what we get." And I will say basically it is a lot easier to see the weather. It is a lot easier to see what we get. Climate is a statistical construct and it is tough to see it. So our job today is to help you see it and to help you understand why the forecasts that we make for the end of this century are something that we can trust.

To start out with, Mother Nature's strongest fingerprint on our climate system is the seasonal cycle. So here is a climate forecast for you. Here in DC. It is going to be colder in January, but then it is going to warm up in July. The climate forecast. My grandmother could give it to you. It doesn't take a genius. But it shows you that we have an understanding of our climate system that allows us to look further into the future.

The other thing that I really hope that our discussion this morning can help you understand is why our long-term forecast for the future is something that so many of us on this panel are deeply concerned about. I made it here by training.

[The information follows:]



I worked on Wall Street for a little while and then decided I was really fascinated by climate. It is a lot like Wall Street. In many respects it looks kind of like stock market, ups and downs on various time scales. And I will say that the tremendous variability of the climate system is fascinating to me. And this gets to ice core records that you see.

Focus on the last 10,000 years. The top part, which is pretty flat, that is the last 10,000 years of our climate. And what is really fascinating is it is relatively stable. So what drew me into climate science was this question of, to what extent does climate stability link with human civilization? These complex human civilizations started at about 10,000 years ago, right about the same time where our climate began to become more stable.

So if any of you have read the book "Collapse" by Jared Diamond, you will note that civilizations have failed over time due to the inability to look out on long enough time scales and to be adaptive to our environment.

Now, my next slide is more or less to just highlight the fact that, gosh, we have been studying this problem for an incredibly long time.

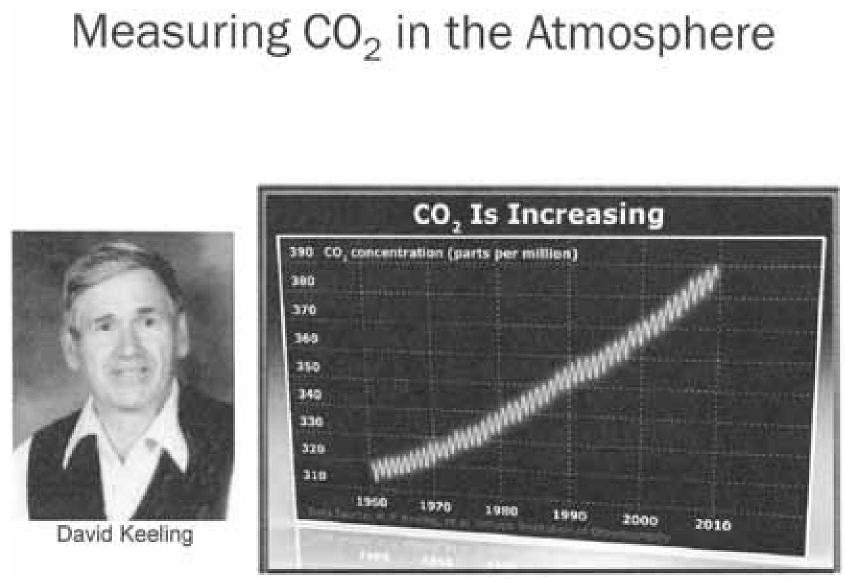
[The information follows:]

Standing on the Shoulders of Giants...

The gentleman in the oil painting is Svante Arrhenius. He got the Nobel prize in chemistry in 1903 for doing the back-of-the-envelope calculation that Dr. Meehl spoke about, which is that if we doubled CO_2 in our atmosphere, our planet would warm roughly eight degrees Farenheit. Where Arrhenius made his mistake was that he was around at the turn of the century in the 1800s, and he basically assumed that we would continue to emit fossil fuels at the 1895 rate, so it would take 3,000 years to double. And he was wrong there.

But that is where Bert Bolin came in. Bert Bolin actually calls for the creation of the IPCC. And he did his own back-of-the-envelope calculation which suggested that CO_2 would increase by about 30 percent by the year 2000. That turned out to be very true.

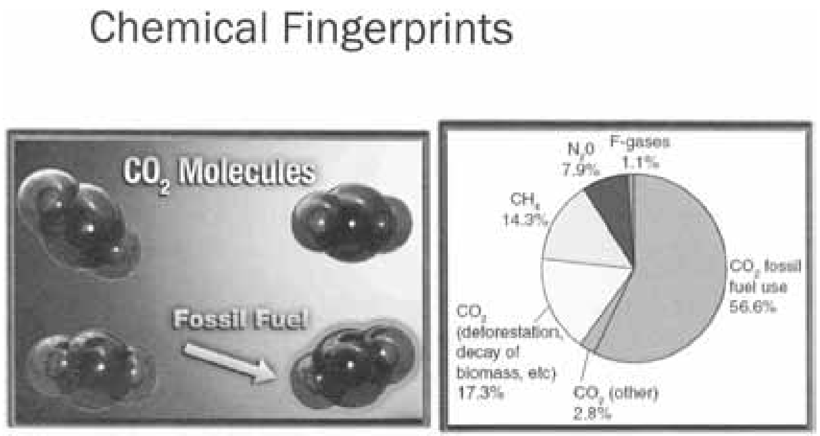
[The information follows:]



Charles David Keeling, another giant in the field of climate science, basically figured out how to measure this invisible greenhouse gas we call carbon dioxide. We wouldn't need to have this panel if we could see carbon dioxide, because it is everywhere. By burning fossil fuels and through deforestation we emit it. But he figured out a way to create and build a machine that was like an atmospheric Breathalyzer that could measure CO_2 in the atmosphere. And he showed, just as Bert Bolin calculated, that we have increased our CO_2 in the atmosphere by about 36 percent now. We are at 390 parts per million. I know that that does not sound like a lot. But because of the special chemical structure of carbon dioxide, unlike nitrogen and oxygen, which there is so much more of in our atmosphere—they have just two atoms—CO_2 has three. And that allows it to absorb tremendous amounts of long-wave radiation and be a great absorber of heat. And that is why our planet is essentially warming up.

The other thing that Keeling was able to do was to chemically fingerprint the CO_2 so that we knew that it was coming from us. Carbon comes in three different flavors. You call them isotopes.

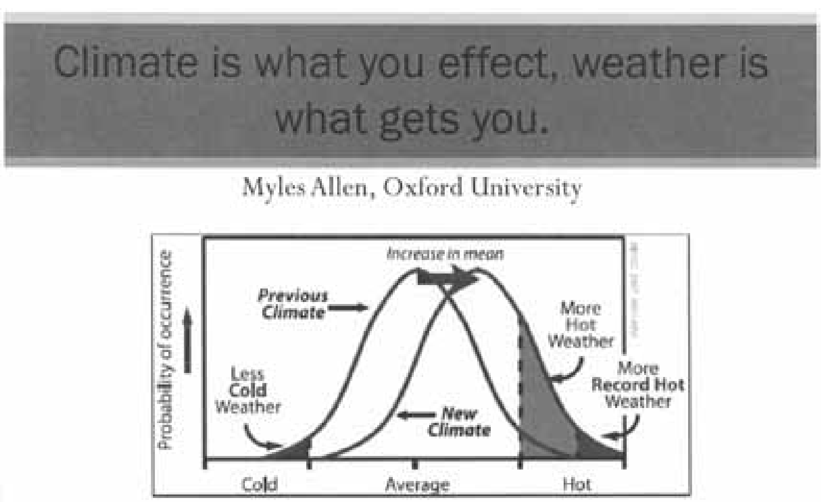
[The information follows:]



Fossil fuels, when they give off CO_2 from burning, they have essentially no C14 because they are ancient. So what Keeling was able to do is just say that roughly one out of every four carbon dioxide molecules in our atmosphere today was put there by us. It is our human fingerprint on the climate system.

As Jerry said, we are increasing the overall temperature of our climate about 1.4 degrees Farenheit over the past century. How does that make its way into our weather? My experience at The Weather Channel made it very clear that we can see our weather, we experience our weather, we know what that means. But how is climate change impacting our weather?

[The information follows:]



Essentially, Mark Twain's quote can now be rewritten, which is to say that climate is what we expect and weather is what it gets us. So we can expect to see more extreme events. And if you talk to, you know, Warren Buffet or anyone who deals with insurance, they will tell you that if we don't take climate change into account, we are making very, very costly mistakes.

We insure very, very high amounts of weather-related disasters each year. This is a picture from the national flood of 2010. It was considered a 1 in 1,000 year event. That probability is expected to increase more so with each passing year if we continue to emit greenhouse gases. Business as usual.

And just to summarize. I am a scientist by training and I have to say my time at The Weather Channel really—it just awed me the way our country could rally around a weather forecast. Whether it was sand-bagging in advance of the Red River floods or evacuating in advance of Hurricane Gustav, we know what to do with the weather forecast. I mean, it is really impressive. And the thing is how do we figure out how to respond similarly to a climate forecast. Weather forecast is all defense. I mean, we get the information, we have got to figure out what to do. With the climate forecast, the one difference is that we have the opportunity to change it because it is just one potential future. So essentially when we think about the future, we are talking about an increase of 10 degrees Farenheit by the end of the century, three feet of sea level rise, a radically different climate.

And the question is, if climate change is this ultimate procrastination problem, we are in a race essentially to understand our climate forecasts and just get to the point where we can act on them. And I would just say that as a scientist, if we don't do that, that would just simply be irrational.

Chairman BAIRD. Thank you, Dr. Cullen.

[The prepared statement of Dr. Cullen follows:]

PREPARED STATEMENT OF HEIDI M. CULLEN

Chairman Baird and Members of the Subcommittee, thank you for this opportunity to engage in a rational discussion of the science of climate change. My testimony will focus on the basic science and physics of climate change, the causes and production of anthropogenic greenhouse gases and the expected impacts on the climate.

Introduction

I am a climate scientist by training, but I have spent the last several years as a climate science educator—producing reports for outlets like PBS NewsHour and The Weather Channel. When I first started at The Weather Channel in 2003 people assumed that if I worked at a 24/7 weather network, I must be a meteorologist. The question I was asked most often was "What's the forecast?" I was always happy to provide the local weather forecast. But these experiences made me realize that many people do not truly understand the difference between climate and weather, between climatologists and meteorologists. Here's a rough answer: climatologists pick up where meteorologists leave off. We focus on timescales beyond the memory of the atmosphere, which is only about one week. Climatologists look at patterns that range from months to hundreds, thousands, and even millions of years. The single most important and obvious example of climate is the seasonal cycle, otherwise known as the four seasons. Summer, the result of the Earth being tilted closer to the sun, is warmer. And winter, the result of the Earth being tilted away from the sun, is colder. The forecast follows the physics. Which is why, if in January, I issued a forecast that said it would be significantly warmer in six months, you might not think I was a genius, but you'd believe it.

There are countless others patterns on our planet that influence the weather. Take El Niño, for example. El Niño can bring drought to northern Australia, Indonesia, the Philippines, southeastern Africa and northern Brazil. Heavier rainfall is often seen along coastal Ecuador, northwestern Peru, southern Brazil, central Argentina, and equatorial eastern Africa. There are many ways in which climate can work itself into the weather.

Meteorologists focus on the atmosphere, whereas climatologists focus on everything that *influences* the atmosphere. The atmosphere may be where the weather lives, but it speaks to the ocean, the land, and sea ice on a regular basis. The hope is that if scientists can untangle all the messy relationships at work within our climate system, we should be better able to keep people out of harm's way. The further we can extend our forecasts, the longer out in time a society can see, the better prepared we'll be for what's in the pipeline.

And this is where global warming enters the equation. If the four seasons are *Mother Nature's* most powerful signature within the climate system, then global warming, the term that refers to Earth's increasing temperature due to a build-up of greenhouse gases in the atmosphere, is *humanity's* most powerful signature.

The Basic Science and Physics of Climate Change

We tend to think of man-made global warming as a purely modern concept, something that has come into vogue in the last 20 or so years, but in reality this idea is more than 100 years old. The notion that the global climate could be affected by human activities was first put forth by Svante Arrhenius in 1895, who based his proposal on his prediction that emissions of carbon dioxide from the burning of fossil fuels (i.e., coal, petroleum, and natural gas) and other combustion processes would alter atmospheric composition in ways that would lead to global warming. Arrhenius calculated the temperature increase to be expected from a doubling of CO_2 in the atmosphere—a rise of about 8°F.

More than a century later, the estimates from state-of-the-art climate models doing the same calculations to determine the increase in temperature due to a doubling of the CO_2 concentration show that the calculation by Arrhenius was in the right ballpark. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) synthesized the results from 18 different climate models used by groups around the world to estimate the climate sensitivity and its uncertainty. They estimated that a CO_2 doubling would lead to an increase in global average temperature of about 5.4°F with an uncertainty spanning the range from about 3.6°F to 8.1°F. It's pretty amazing that Arrhenius, doing his calculations by hand and with very little data, came so close to the much more detailed calculations that can be done today.

In the following section, I aim to provide a brief history of climate change that will explain the basic physics and chemistry of global warming and important climate discoveries that serve as the groundwork of our current scientific understanding of this life-threatening issue.

- *The discovery of the greenhouse effect*

The French mathematician and physicist Joseph Fourier in 1824 helped discover the greenhouse effect. Specifically, Fourier was looking to use the principles of physics to understand what sets the average temperature of Earth. Fourier was interested in understanding some basic principles about the flow of heat around the planet. It made perfect sense that the sun's rays warmed the surface of the Earth, but this left a nagging question: when light from the sun reaches the surface of the Earth and heats it up, why doesn't the Earth keep warming up until it's as hot as the sun? Why is the Earth's temperature set at roughly 59°F—the average temperature at the Earth's surface?

Fourier reasoned that there must be some type of balance between what the sun sends in and what the Earth sends back out, so he coined the term *planetary energy balance*, which is simply a fancy way of saying that there is a balance between energy coming in from the sun and going back out to outer space. If the Earth continually receives heat from the sun yet always hovers around an average temperature of 59°F, then the Earth must be sending an equal amount of heat back to space. Fourier suggested that the Earth's surface must emit invisible infrared radiation that carries the extra heat back into space. Infrared radiation (IR), like sunlight, is a form of light. But it's a wavelength that our eyes can't see.

It was a great idea, but when he actually tried to calculate the planet's temperature using this effect, he got a temperature well below freezing. So, he knew he must be missing something. To arrive at 59°F, the Earth's average temperature, Fourier realized that he needed the atmosphere to pick up the slack. And in the process, he discovered a phenomenon he called the *greenhouse effect*. The greenhouse effect is a process whereby the gases in the Earth's atmosphere trap certain wavelengths of sunlight, not allowing them to escape back out to space. Like the glass in a greenhouse, these *greenhouse gases* let sunlight through on their way in from space, but intercept infrared light on their way back out.

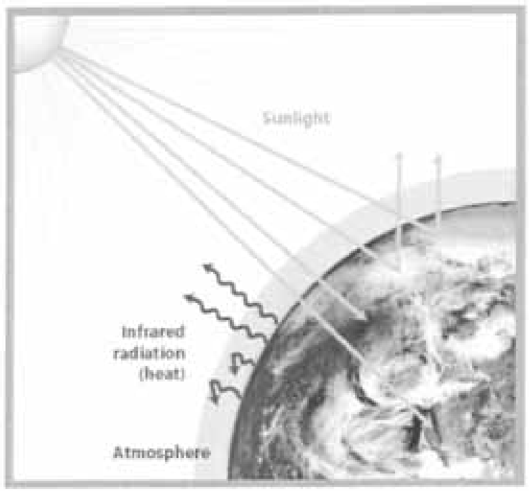


Figure 1: The Greenhouse Effect

In 1849, an Irish scientist named John Tyndall was able to build on this idea after he became obsessed with the glaciers he was climbing while visiting the Alps on vacation. Like so many other scientists at the time, Tyndall wanted to understand how these massive sheets of ice formed and grew. He brought his personal observations of glaciers into the laboratory with him in 1859, when at the age of 39, he began a series of groundbreaking experiments.

Tyndall was intrigued by the concept of a *thermostat*. We know them today as devices that regulate the temperature of a room by heating or cooling it. So Tyndall devised an experiment that tested whether the Earth's atmosphere might act like a thermostat, helping to control the planet's temperature. Tyndall reasoned that it might help explain how ice ages had blanketed parts of the Earth in the past.

For his experiment, Tyndall built a device, called a spectrophotometer, which he used to measure the amount of radiated heat (like the heat radiated from a stove) that gases like water vapor, carbon dioxide, or ozone could absorb. His experiment showed that different gases in the atmosphere had different abilities to absorb and transmit heat. While some of the gases in the atmosphere—oxygen, nitrogen and hydrogen—were essentially transparent to both sunlight and IR, other gases were in fact opaque, in that they actually absorbed the IR, as if they were bricks in an oven. Those gases include CO_2, but also methane, nitrous oxide and even water vapor. These "greenhouse gases" are very good at absorbing infrared light. They spread heat back to the land and the oceans. They let sunlight through on its way in from space, but intercept infrared light on its way back out. Tyndall knew he was on to something. The fact that certain gases in the atmosphere could absorb infrared radiation had the makings of a very clever natural thermostat, just as he suspected. His top three thermostat picks were water vapor, without which he said the Earth's surface would be "held fast in the iron grip of frost", methane, ozone, and of course, carbon dioxide. Bingo, a natural thermostat right inside our atmosphere.

Tyndall's experiments proved that Fourier's greenhouse effect was indeed real. His experiment proved that nitrogen (78%) and oxygen (21%), the two main gases in the atmosphere, are not greenhouse gases because these molecules only have two atoms, so they cannot absorb or radiate energy at infrared wavelengths. However, water vapor, methane and carbon dioxide, which each have three or more atoms, are excellent at trapping infrared radiation. They absorb 95% of the long-wave or infrared radiation emitted from the surface. So, even though there are only trace amounts of CO_2 in the atmosphere, a little goes a long way to making it really tough for all the heat to escape back into space. In other words, greenhouse gases in the atmosphere act as a secondary source of heat in addition to the sun. And it's the greenhouse gases that provide the additional warming that Fourier needed to explain that average temperature of 59°F.

Thanks to Tyndall it is now accepted that visible light from the sun passes through the Earth's atmosphere without being blocked by CO_2. Only about 50% of incoming solar energy reaches the Earth's surface, with about 30% being reflected by clouds and the Earth's surface (especially in icy regions), and about 15% absorbed by water vapor. The sunlight that makes it to the Earth's surface is absorbed and re-emitted at a longer wavelength known as infrared radiation that we cannot see, like heat from an oven. Carbon dioxide (and other heat-trapping gases such as methane and water vapor) absorbs the infrared radiation and warms the air, which also warms the land and water below it. More carbon dioxide translates to more warming. And this is where the concept of a natural thermostat becomes very powerful—mess with the amount of CO_2 in the atmosphere and you're resetting the thermostat of the planet.

- *The discovery of global warming*

Svante Arrhenius (1859–1927), a Swedish physicist and chemist, began his research on global warming by trying to understand the cause of ice ages. He took Tyndall's thermostat mechanism and explored whether the amount of CO_2 in the atmosphere could raise or lower the Earth's temperature.

We refer to events or processes that result in changes to the climate as *forcings*. A volcano eruption is an example of a natural forcing. A forcing can often result in an amplification (positive) or a reduction (negative) in the amount of change and often comes hand in hand with something known as a *feedback*—a situation where some effect causes more of itself. A negative feedback tends to reduce or stabilize a process, while a positive feedback tends to grow or magnify it.

Arrhenius believed some type of positive feedback mechanism was responsible for plunging the planet into an ice age. For example, a drop in carbon dioxide would lead to a drop in temperature creating more snow and ice. When snow and ice cover a region, such as the Arctic or Antarctica, their white, light-reflecting surface tends to bounce sunlight back out to space, helping to further reduce temperature. If snow and ice covered regions expanded over more of North America and Europe, the climate would further cool while also leading to growing ice sheets.

Arrhenius thought his theory was pretty solid, but he wanted to prove it mathematically. So he set about doing a series of grueling calculations that attempted to estimate the temperature response of changing levels of carbon dioxide in the atmosphere. It was a classic 'back of the envelope' calculation, but he was confident enough that he published the work in 1896 for his colleagues to read. The end result of all that work was one simple number: 8°F. That number represented roughly how much Arrhenius thought the Earth's average temperature would drop if the amount of CO_2 in the atmosphere fell by half.

But back in the time of Arrhenius, global warming impacts were mainly left to future investigation—at the time, the majority of scientists still needed to be convinced that the concentration of CO_2 in the atmosphere could vary, even over very long timescales, and that this could affect the climate. Scientists at the time were focused more on trying to understand the gradual shifts that took place over periods a thousand times longer than Arrhenius' estimate, those that accounted for alternating ice ages and warm periods, and in distant times (more than 65 million years ago), the presence of dinosaurs. They couldn't even begin to wrap their minds around climate change on a human time scale, like decades or centuries. Nobody thought there was any reason to worry about Arrhenius's hypothetical future warming that he suggested would be caused by humans and their fossil fuel burning. It was an idea that most experts at the time universally dismissed. Simply put, most scientists of the era believed that humanity was too small and insignificant to influence the climate.

- *the chemical fingerprint of human activity*

Fast-forward to the mid-1950's and enter Charles David Keeling, a brilliant and passionate scientist who was just beginning his research career at Cal Tech. Keeling had become obsessed with carbon dioxide and wanted to understand what processes affected fluctuations in the amount of CO_2 in the atmosphere. Answering a question like that literally required an instrument that didn't exist, the equivalent of an ultra-accurate 'atmospheric breathalyzer'. So Keeling built his own instrument and then spent months tinkering with it until it was as close to perfect as he could get at measuring the concentration in canisters with a range of values of known concentration. Keeling tried his instrument out by measuring CO_2 concentrations in various locations around California and then comparing these samples in the lab against calibration gases. He began to notice that the samples he took in very pristine locations (i.e., spots where air came in off the Pacific Ocean) all yielded the same number. He suspected that he had identified the baseline concentration of CO_2 in the atmosphere; a clear signal that wasn't being contaminated by emissions from factories or farms or uptake by forests and crops. With this instrument, formally called a *gas chromatograph*, Keeling headed to the Scripps Institution of Oceanography to begin what is perhaps the single most important scientific contribution to the discovery of global warming. Keeling was on a mission to find out, once and for all, if CO_2 levels in the atmosphere were increasing. He would spend the next 50 years carefully tracking CO_2 and building, data point by data point, the finest instrumental record of the CO_2 concentration in the atmosphere, generating a time history that is now known to scientists simply as *the Keeling Curve*.

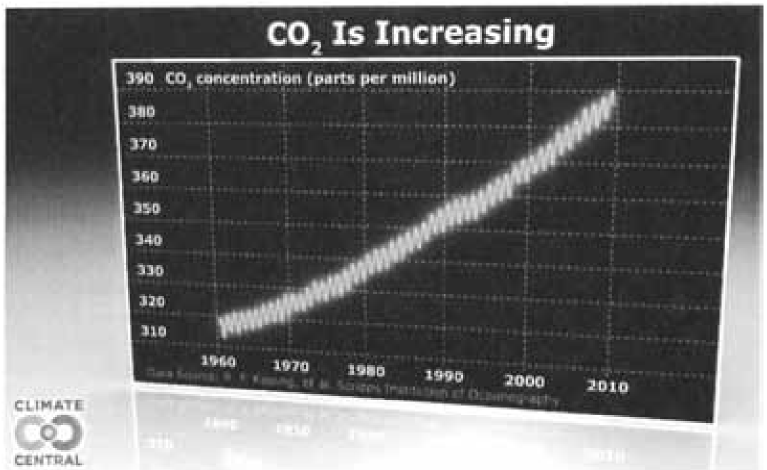


Figure 2: The Keeling Curve

The Keeling Curve refers to a monthly record of atmospheric carbon dioxide levels that begins in 1958 and continues to today. The instrument Keeling built, the gas chromatograph, works by passing infrared light through a sample of air and measuring the amount of infrared light absorbed by the air. Because carbon dioxide is a greenhouse gas, Keeling knew that the more infrared light absorbed by the air, the higher the concentration of CO_2 in the air. Because CO_2 is found in very small concentrations, the gas chromatograph doesn't measure in terms of per cent, which means out of a hundred, but in terms of parts per million (ppm). What he found was both disturbing and fascinating. Keeling, using his Mauna Loa measurements, could see that with each passing year CO_2 levels were steadily moving upward. In 2010, more than fifty years after Keeling began his observations, the concentration at Mauna Loa is 390 ppm. Keeling's measurements thus provided solid evidence that the atmospheric CO_2 concentration was increasing. If anything proved Arrhenius was on to something, it was these data. Keeling's record was the icing on the cake and he rightly stands with Fourier, Tyndall, and Arrhenius as one of the giants of climate science. He helped prove the importance of the greenhouse effect and the reality of global warming. He provided the data upon which the groundbreaking theories of Tyndall and Arrhenius firmly rest. As is the case in research science, Keeling's painstaking measurements have been verified and supplemented by many others. Measurements at about 100 other sites have confirmed the long-term trend shown by the Keeling Curve.

Keeling established that carbon dioxide was rising in the atmosphere. The next step was to find the smoking gun, and see what or who was causing the increase. In order to put Arrhenius's theory to rest once and for all, scientists were looking to identify the source of all that additional carbon dioxide. And they came up with some very clever ways to identify this smoking gun.

Just as we come into this world with our own unique set of fingerprints, so too does carbon. Carbon enters the atmosphere from a lot of different places, places that stamp each molecule of carbon dioxide and send it off into the atmosphere with a unique fingerprint. Volcanoes emit CO_2 into the atmosphere when they erupt, the soil and oceans release CO_2 into the atmosphere, and plants and trees give off carbon dioxide when they are cut or burned. Burning coal, oil and natural gas are all sources that release carbon into the atmosphere to forms carbon dioxide. The average person, in fact, breathes out about two pounds of carbon dioxide every day. When you have the right tools, distinguishing where an individual molecule of CO_2 comes from is not that hard. As with many other important advances in the fields of climate and weather, this fingerprint device was an outgrowth of military activity.

Carbon, like virtually all of the chemical elements, come in different varieties known as isotopes, distinguished by the number of neutrons in their atomic cores. Carbon dioxide can be made from all of the isotopes of carbon—but not all sources of CO_2 have the same types of carbon atoms in them. In addition to carbon–14, there is carbon–12, which is the most common form of carbon, as well as carbon–13, which makes up only about 1 in every 100 carbon atoms. Carbon–14, the radioactive one, is even more rare, with only one carbon–14 isotope for every trillion carbon atoms in the atmosphere. Scientists can use these isotopes to fingerprint the origin of the carbon. You can literally trace where the CO_2 in the atmosphere originated by measuring the amount of different carbon isotopes. It's like a tracing a bullet back to the gun from which it was shot.

All living organisms are built out of carbon atoms. Coal, oil and natural gas are ancient. In fact, they are called 'fossil fuels' because coal, oil and natural gas come from plants and marine organisms that lived roughly 200–300 million years ago. Fossil fuels such as coal, oil and natural gas, for example, have no carbon–14, and neither does the CO_2 that comes from burning them. A small fraction of the CO_2 molecules that enter the atmosphere through natural means such as the decay of plants, on the other hand, does contain carbon–14. Because they have extra neutrons, atoms of carbon–14 are more massive than atoms of carbon–12, and so are the CO_2 molecules they are made of. Instruments called mass spectrometers measure that difference. Based on how much of the heavier CO_2 they measure in samples of atmosphere, scientists calculate that about a quarter of the CO_2 present today must come from fossil fuels. From the perspective of a molecule of carbon dioxide, that means roughly one out of every four CO_2 molecules in the atmosphere today, was put there by us. That conclusion is confirmed by the fact that this fraction amounts to most of the growth in CO_2 over the last 250 years, when fossil-fuel burning has really taken off. It is this increase in CO_2 concentrations that is primarily responsible for the increase in global average temperatures over the past century, and especially in recent decades. So while it's true that most of the carbon dioxide in the atmosphere today comes from natural sources, most of the *additional* CO_2 that's been placed in the atmosphere over the last 250 years comes from us.

- the causes and production of anthropogenic greenhouse gases

From 1000 A.D. to about 1750 AD, carbon dioxide levels in the atmosphere hovered between 275 and 285 parts per million (ppm), and then began to increase. Initially, the increase was largely due to the burning of coal, which was the primary energy source for the Industrial Revolution, and whose exhaust products when burned include CO_2. Since then, the other major fossil fuels, oil and natural gas, have also become sources of growth in CO_2 levels. The latest IPCC report presents statistics over the years since 1970, which are indicative of the historical proportion that fossil fuel burning occupies in the sources of CO_2. The percentage of emissions from solid, liquid and gas fuels represents about a 70% fraction of CO_2 emissions and has seen its share increasing during this period.

But other factors contribute as well. For example, the widespread cutting down of forests can add CO_2 to the atmosphere if the trees are burned; like fossil fuels, they release this greenhouse gas as well. If the trees are left to rot, that too releases CO_2, albeit more slowly. And because living trees absorb CO_2 in the process of photosynthesis, the cutting of forests eliminates a source of CO_2 removal, so the gas builds up more quickly than it otherwise might. The same estimates from the IPCC quantify deforestation and land-use change emissions as about 22% of CO_2 emissions.

Some manufacturing processes add CO_2 to the atmosphere as well. The manufacture of cement is one; it does not just require energy, which often comes from fossil-fuels, but the chemical reactions involved in its manufacture release large amounts of the gas as well. All in all cement production has occupied a 3% share of CO_2 emissions. All this said, fossil fuel burning remains the predominant source of the historical increase in atmospheric CO_2 concentrations that added about 100 ppm (36%) over the last 250 years to the CO_2 levels of the pre-industrial era.

- the expected impacts on the climate

Data collected over the past 50 years point to the fact that our weather is getting more extreme. But trying to isolate the fingerprint of global warming within the weather is much harder than isolating the fingerprint of global warming within the climate system. That doesn't mean it's not there; it just means seeing climate change in the weather is a much noisier, more chaotic and more complicated process. Statistical analyses can help us see the story buried beneath the noise. And climate scientists have come up with some very clever variations on using a slow motion instant replay of the weather to help them see how the statistics of extreme events are changing.

It turns out that you can use climate models as an "instant replay" to recreate a specific weather event. Think of it like doing an autopsy, except it's being performed on a specific extreme weather event. The European heat wave of 2003, an extreme weather event that killed over 35,000 people, offers the best example of how climate models can help us see the global warming embedded within our weather.

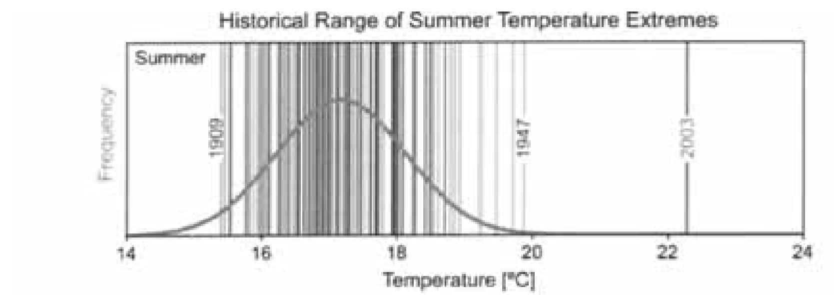


Figure 3: Each vertical line represents the mean summer temperature for a single year from the average of four stations in Switzerland over the period 1864 through 2003. Extreme values from the years 1909, 1947, and 2003 identified. Source: From Schär *et al.*, 2004.

When you step back and compare the summer of 2003 with summers past, it becomes even more obvious. As you can see in Figure 3, there are a series of vertical lines that almost look like a bar code. Each vertical line represents the mean summer temperature for a single year from the average of four stations in Switzerland over the period 1864 through 2003. Until the summer of 2003, the years 1909 and 1947 stood out at the edges as the most extreme temperatures in terms of hot and cold summers. Climate scientists estimate the summer of 2003 was probably the hottest in Europe since at least AD 1500.

If climate is what you expect and weather is what you get, then the summer of 2003 in Europe was way outside the envelope of what anyone would have expected. Statistically speaking, in a natural climate system with no man-made CO_2 emissions, the chance of getting a summer as hot as 2003 would have been around once every thousand years or one in a thousand.

The point of this weather autopsy isn't so much whether the 2003 heat wave was caused solely by global warming. Indeed, almost any weather event can occur on its own by chance in an unmodified climate. But using climate models, it is possible to work out how much human activities may have increased the risk of the occurrence of such a heat wave. It's like smoking and lung cancer. People who don't smoke can still get the disease, but smoking one pack of cigarettes a day for 20 years increases your chances of developing lung cancer 20-fold. Thanks to some sophisticated climate models and well-honed statistical techniques, scientists can identify the push that global warming is giving the weather.

This weather autopsy showed that human influences had at least doubled the very rare chance of summers as hot as the one Europe experienced in 2003. More specifically, climate models showed that greenhouse gas emissions had contributed to an increase in 2003-style summers—moving from a one in a thousand years to at least once in every 500 years and possibly as high as once in every 250 years. What is perhaps the most shocking is what happens when you run the models in forecast mode instead of autopsy mode. If the summer of 2003 had been a freak event of nature, we could just chalk it up to the luck of the draw. But according to the model predictions, by the 2040's, the 2003-type summers will be happening every other year. And by the end of this century, people will look back wistfully upon the summer of 2003 as a time when summers were much colder.

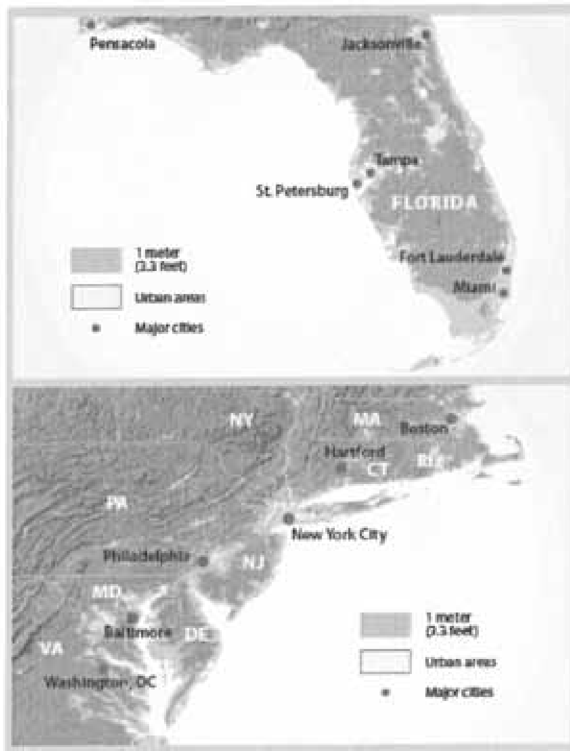


Figure 4: Land Vulnerability to Rising Sea Level.

Scientists now believe that the Earth could warm up by more 7°F, on average, by the end of the century, if emissions of greenhouse gases continue to grow at current rates. That's significant enough to trigger all sorts of big changes in the environment. To start with, scientists expect sea level to rise by three feet or more—partly because water expands as it warms, partly due to melting ice in Greenland and other places. Low-lying areas—including significant parts of states like Florida, and entire countries like Bangladesh and the Maldive Islands will be much more prone to erosion and to catastrophic flooding from storm surges. The warming could also make the most powerful of tropical storms even more powerful. And rainstorms in general are likely to become more intense, with more of them causing damaging floods.

As mountain glaciers melt, they'll cause even more flooding—at first. But if they shrink enough, the fresh water they provide will become scarce. Billions of people in India and China, for example, depend on water that comes off glaciers in the Himalayas and the Tibetan Plateau. In the U.S., warmer winters and spring will induce earlier snowmelt in the Rocky and Sierra Nevada mountains. That means less meltwater for a thirsty California, especially during the summer when water is really needed.

In already arid regions (Australia and the American West are just two examples) droughts are likely to come more often and be more severe, and they could last longer. That's likely to lead to more wildfires. Heat waves will be more frequent too, not just in deserts but in temperate zones, including most of the continental U.S.

All of these changes will have an impact on people, our physical safety and our ability to grow food and get water. But climate change could have an even greater impact on the survival of some species. Plants and animals thrive in certain specific climate conditions. They cannot easily adapt to the changes that have already begun. The trees that produce Vermont maple syrup, for example, may have trouble surviving in Vermont as the New England climate changes, and Georgia may lose its population of Brown Thrashers—the state bird. Not all of the changes will happen on land. The warming of the oceans has already contributed to a worldwide die-off in coral reefs, which is expected to accelerate as temperatures continue to rise. Corals are home to a wide variety of sea-dwelling creatures, so when they go, many other species could be in big trouble.

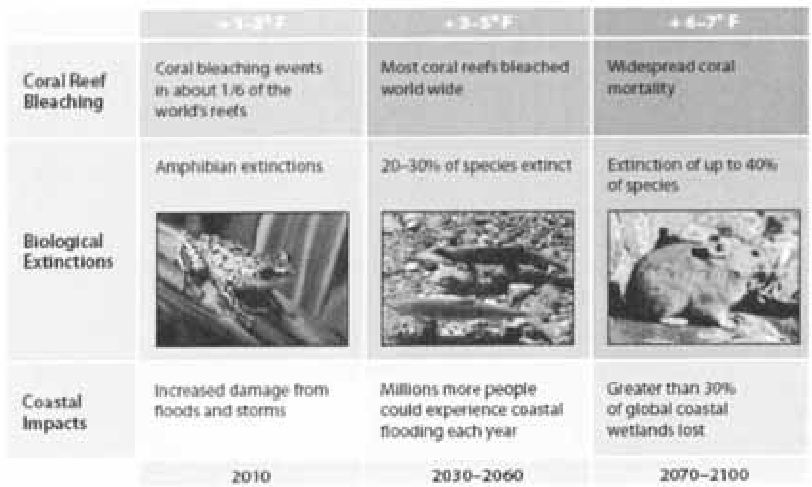


Figure 5: As temperatures increase, so will the damage.

Conclusion

When I worked at The Weather Channel, I was constantly awestruck by the extent to which people rallied around a weather forecast. Whether it was sandbagging in advance of the Red River flood, or evacuating in advance of Hurricane Gustav. There's something so inspiring about the way communities can pull together under these extremely challenging circumstances. We're clearly pretty good at processing the risks associated with extreme weather, which is why it's so important for people to understand that their weather is their climate. As such climate and global warming need to be built into our daily weather forecasts because by connecting climate and weather we can begin to work on our long-term memory and relate it to what's outside our window today. If climate is cold statistics, weather is personal experience. We need to reconnect them.

The weather forecast is so engrained in our existence that we know very well how to make it actionable. If we hear on the radio in the morning that it's going to rain, we bring an umbrella. If we hear that the temperature is going to be unseasonably cool, then we pack a sweater. By definition, weather is a timescale we can't stop. With a weather forecast, we're strictly working on our defense. However, with the climate forecast, the necessary actions are not as straightforward, and this highlights some of the basic philosophical differences between weather and climate. I've come to view long-range climate projections as an "anti-forecast" in the sense that it's a forecast you want to prevent from happening. Until now, we've been able to view extreme weather like flooding as an act of God. But the science tells us that due to climate change these floods will happen more often and we need to be prepared for them. I say that a climate forecast is an "anti-forecast" because it is in our power to prevent it from happening. It represents only a *possible* future, if we continue to burn fossil fuels *business as usual*. The future is ultimately in our hands. And the urgency is that the longer we wait, the further down the pipeline climate travels and works its way into weather, and once it's in the weather, it's there for good.

We are currently in a race against our own ability to intuitively trust what the science is telling us, assess the risks of global warming, and predict future impacts. So when we look at a climate forecast out to 2100 and see significantly warmer temperatures (both average and extreme) and sea level three feet higher, we need to assess the risk as well as the different solutions necessary to prevent it from happening. The challenge is to reduce greenhouse gas emissions, replace our energy infrastructure and adapt to the warming already in the pipeline.

Thank you for affording me this opportunity to share with you this brief history of climate change. I would be pleased to address any questions you might wish to raise.

BIOGRAPHY FOR HEIDI M. CULLEN

In addition to her responsibilities as interim CEO and Director of Communications, Dr. Heidi Cullen serves as a research scientist and correspondent for Climate Central—a non-profit science journalism organization headquartered in Princeton, NJ. Before joining Climate Central, where she reports on climate and energy issues for programs like *PBS NewsHour*, Dr. Cullen served as *The Weather Channel*'s first on-air climate expert and helped create *Forecast Earth*, a weekly television series focused on issues related to climate change and the environment. Prior to that Dr. Cullen worked as a research scientist at the National Center for Atmospheric Research (NCAR) in Boulder, CO. She received the NOAA Climate & Global Change Fellowship and spent two years at Columbia University's International Research Institute for Climate and Society working to apply long-range climate forecasts to the water resources sector in Brazil and Paraguay. She is a member of the American Geophysical Union, the American Meteorological Society and is an Associate Editor of the journal *Weather, Climate, Society*. Dr. Cullen also serves as a member of the NOAA Science Advisory Board. She received a Bachelor of Science degree in Industrial Engineering from Columbia University and went on to receive a Ph.D. in climatology and ocean-atmosphere dynamics at the Lamont-Doherty Earth Observatory of Columbia University. Dr. Cullen is the author of *The Weather of the Future* published in August of 2010 by Harper Collins.

DISCUSSION

Chairman BAIRD. Thanks to all of our witnesses.

At this point, I will recognize myself for five minutes, and we will follow in alternating order as Members wish to have questions.

THE IMPACTS OF CO_2 INCREASES ON TEMPERATURES

Just to start with a premise that I don't think people often appreciate, and I don't think there is any disagreement on this panel—though I think I have heard disagreement by some of my colleagues occasionally—that CO_2 is essential to maintain the current temperature of the Earth. If it were not for CO_2 and/or some other greenhouse gas—Dr. Lindzen?

Dr. LINDZEN. Certainly understand if you double CO_2——

Chairman BAIRD. No, that is not what I am saying. Let me finish my question.

Dr. LINDZEN. The current climate is mostly water vapor and clouds.

Chairman BAIRD. Okay. But let me finish the question. It is established science that the presence of CO_2 in the atmosphere has an important role in maintaining the current surface temperature of the Earth in the atmosphere. If you did not have CO_2, would the Earth be a cooler place or a warmer place?

Dr. LINDZEN. It would be approximately 2–1/2 degrees cooler.

Chairman BAIRD. Any others wish to comment on that?

Dr. CICERONE. I think it would be a much bigger effect than that.

Chairman BAIRD. Hit the mic.

Dr. CICERONE. In the mid-1980s, Bob Dickinson and I did some of the earliest calculations of the radiative forcings. And Bob is one of the few geniuses in this field. And when he tried to do the experiment that you just referred to, to figure out what impact the current amount of CO_2 is having, the calculations broke apart because the disruptions in the atmosphere were so large that he had to go back and start over. I think it would be far more than 2–1/2 degrees.

Chairman BAIRD. Let me ask a second question. Is there any doubt that CO_2 absorbs more heat than oxygen?

Dr. CICERONE. No.

HUMANS HAVE CAUSED INCREASES IN ATMOSPHERIC CO_2

Chairman BAIRD. No doubt about that. Is there any doubt that human activity has increased the amount of CO_2 in the air? No doubt of that. That is a given.

Dr. LINDZEN. How shall I put it? I would advise you to stop with the no doubt. But, you know, that is the prevailing view.

Chairman BAIRD. Okay. Fair enough. Okay. I am a Ph.D. scientist. I understand that science is never 100 percent, Doctor. But I would say the prevailing view and abundant evidence suggests that humans have caused a substantial increase of CO_2. Is that fair?

Dr. LINDZEN. Yeah.

THE GREATER PROPORTION OF RECORD HIGH TEMPERATURES

Chairman BAIRD. Okay. Now, here is the question. Is there disagreement with Dr. Meehl's analysis and Dr. Cullen's analysis and Dr. Cicerone's of greater proportion of record highs in recent years relative to record lows? Each person will need to use their mic when they speak.

Dr. LINDZEN. Yeah. I don't think they are meaningful statements. I mean, during this whole period that he is referring to, if you look at it, it still looks like a random process, one. And two, the instrumentation has changed dramatically during that period so that the response time of modern thermometers is almost infinitesimal compared to the ones used in the earlier part of the record.

Chairman BAIRD. Actually, I will rephrase my question because I think it was pretty clear, but your answer didn't address it. My question is: Is there a doubt that in the recent years—and I will state it as clearly as I can—there is a greater preponderance of record highs than record lows? Unless you are suggesting in the past that the measurement devices were erroneous in one direction and not another.

Dr. LINDZEN. Absolutely, because you have high response time. You will pick up perturbations——

Chairman BAIRD. I am not talking perturbations. Simply are we suggesting Dr. Meehl, Dr. Cullen—if you are suggesting that the thermometers today are more sensitive to increases than to cooling——

Dr. LINDZEN. Yeah. Oh, yeah.

Chairman BAIRD. That is right. That is your——

Dr. LINDZEN. I think that is pretty much true. But there is another issue here which is a bit weird; namely, why do we have record highs and record cold on any given day?

Chairman BAIRD. I don't want to ask the why first. I just want to get the facts.

Dr. Meehl, Dr. Cullen, Dr. Cicerone, is it generally accepted scientific fact that there are more record highs today than record lows? Dr. Meehl.

Dr. MEEHL. Yes.

Chairman BAIRD. Dr. Cullen?

Dr. CULLEN. Yes.

Chairman BAIRD. Dr. Cicerone?

Dr. CICERONE. Yes.

Chairman BAIRD. Dr. Lindzen may disagree with that. It seems to me that that is a fairly objective piece of evidence that we could look at, that there are more general record—you may disagree, but part of what is happening here is that we have a preponderance of folks. If I look at a temperature, a thermometer, and I say this is pretty hot, other people could say it is pretty cold. But if we have got a measurement device we have been using for a very long time and it is showing a hotter temperature than what it showed a year ago, either the measurement device has changed or the temperature has changed. Maybe the measurement device has changed, but we are talking thousands of measurement devices changing and only in one direction.

Dr. Meehl.

Dr. MEEHL. May I just add a little bit to that? This analysis we did, we were looking at basically temperature records in the second half of the 20th century from weather stations that had good daily records. And this is actually, I think, a bigger problem than the thermometer problem. You have to have stations recording their daily high temperature and daily low temperature every day so you can have a lot of daily records.

And this ratio, which is now 2-to-1, which we thought was kind of odd, we thought initially—in fact, this came from a guy at The Weather Channel, because he was noticing this. He was keeping track of records on his own. He is a meteorologist. And Heidi invited me down there. And he said, what is with this 2-to-1 ratio? I said, I don't know. He said, Well, is that some kind of unique thing about climate change? I said, I have no idea. I said, Let's look at it.

So we started looking at it and it turns out this ratio—we just happen to be at about 2-to-1 right now. A decade ago it was a little less than 2-to-1, and a decade before that it was a little less than that. If you had a climate that wasn't changing, you would expect that ratio to be about 1-to-1, because you would have an equal chance of getting record highs and record lows.

So I think what was interesting about that study is it showed—and I think this is a thing that we have trouble communicating to the public, but climate change is a shift in statistics, it is a shift in the odds of certain things happening. So as you warm the average temperature, you just have a greater chance of extreme warm temperatures and less chance of extreme cold temperatures.

Chairman BAIRD. Thank you.

Dr. CULLEN. And if I could just build on that very quickly. What Jerry did was he carried that thought experiment forward, which is part of the exercise that we all need to go through. And what they found was if we continue to make greenhouse gas business as usual, by the middle of the century that would then become 20-to-1. So it gets worse as you move forward in time.

Chairman BAIRD. Because of the shifting and the probability.

Mr. Inglis.

QUANTIFYING CLIMATE SENSITIVITY AND WATER VAPOR

Mr. INGLIS. Thank you, Mr. Chairman. I notice the discrepancy in some numbers here. Dr. Lindzen said that a doubling of CO_2 would cause a one degree C increase in temperature. Doubling of CO_2 would cause a one degree increase in——

Dr. LINDZEN. I said by itself. In other words, absence of feedbacks—and this the IPCC says also—you expect about one degree from changing CO_2 from 280 to 560. You again get the same thing for a doubling from 560 to 10,120. It is nonlinear. It is logarithmic. So every molecule of CO_2 does a little less than its predecessor. But one degree is what you expect from a doubling. Anything more is due to the positive feedbacks, from water vapor and clouds primarily. In the models.

Mr. INGLIS. I am going to ask the others to say whether they agree with that. Dr. Cullen, I think I heard you say it is an eight degree Farenheit rise, right? So it is——

Dr. CULLEN. No. The basic climate sensitivity doubling of CO_2 experiments suggests an eight degree Farenheit rise. That was the Svante Arrhenius calculation. IPCC estimates give a range, including all the feedbacks.

Mr. ROHRABACHER. I didn't hear the answer. What did she say?

Mr. INGLIS. Somebody help me explain that. Maybe Dr. Cicerone wants to try that.

Dr. CICERONE. Yes. What Dr. Lindzen is saying is if we could isolate the impacts one by one, the CO_2 effect itself and the way it interacts with the planetary radiation would cause about a one degree warming under these circumstances Centigrade. It's the additional forcing, which I mentioned in my testimony briefly, of adding more water that causes part of the increased effect.

Part of it would be due to the way clouds are being treated in the calculations, also. But if I focus on the water, that's when I mentioned the disproportionate amount of evaporation increase as we warm a body of water. This is just a fact of physics. So that people who propose that this enhancing effect, which Dr. Lindzen denies, people who propose to deny that enhancing effect are fighting against a very fundamental part of physics.

Dr. LINDZEN. May I respond?

Dr. CICERONE. The fact that the rate at which a liquid evaporates is a grossly disproportionate function of the temperature.

Dr. LINDZEN. May I respond?

Mr. INGLIS. Please.

Dr. LINDZEN. What Dr. Cicerone is referring to is the Clausius-Clapeyron relation. That is a relation that tells you what the saturation vapor pressure is for water as a function of temperature. The atmosphere, first of all, is almost never saturated. So the basic physics that Cicerone is referring to is stating if you have a big bottle and somebody has this cup, no matter what I have done to pour water into each, this will always have more. That doesn't make much sense.

But the other thing is the data are——

Mr. INGLIS. Let me stop you right there. What does that mean? Dr. Cicerone, what is your response to that?

Dr. CICERONE. I didn't follow him. I know the Clausius-Clapeyron equation.

Chairman BAIRD. You need to turn your mic on.

Dr. CICERONE. I know the relationship he is speaking of. I know the relationship with the entropy and thermodynamic quantities, and I don't understand what he is saying.

Dr. LINDZEN. I am saying it's the saturation vapor pressure, right?

Dr. CICERONE. Yeah, sure.

Dr. LINDZEN. Okay. Is the atmosphere saturated?

Dr. CICERONE. No, we have a more or less relative humidity, on average, of 70 percent.

Dr. LINDZEN. Yeah, fluctuating all over the place.

Dr. CICERONE. Yeah.

Dr. LINDZEN. Clausius-Clapeyron tells you nothing about that.

Dr. CICERONE. It gives you an approximation to the slope.

Chairman BAIRD. I will ask both gentlemen to use your mics.

Dr. LINDZEN. Okay.

Dr. CICERONE. We can get an approximation to the slope. That is the way——

Chairman BAIRD. You need to turn your mic on. Go ahead and leave it on.

Dr. CICERONE. All right.

The way the evaporation takes place can be also approximated by the thermodynamic quantities that give the slope of the relationship. And it's just a rapid increase. It's very hard to hold back the vapor pressure of a liquid against this relationship, whether it's evaporating into gas above it that's saturated or not.

Mr. INGLIS. Yes, Dr. Meehl.

Dr. MEEHL. Yeah, I was just going to add that this quantity we are talking about, which is an equilibrium response of the climate system to a doubling of CO_2, actually has a history to it that goes back to the early days of climate modeling, which that's about all you could do, would be to double the CO_2 and see what happens. So it has ended up being this kind of equilibrium climate sensitivity. And that actually goes back even earlier than that. We will never actually see the equilibrium value because it takes so long for the oceans to catch up. So this is a kind of metric we use to gauge, give us a rough calibration of how the climate system may respond. So these are kind of relative numbers.

But I think maybe the point is that there is a range of what we think this number may be. The current range we think is anywhere between two degrees Centigrade and 4–1/2 degrees Centigrade. This number was derived a lot of times from models, but now we have multiple lines of evidence. People have actually looked at observations, they have looked at the response of the climate system to big volcanic eruptions, they have looked at paleoclimate data. So now we have multiple lines of evidence that seem to suggest that that's probably about the right range and that the most likely value is actually around three. And I think Dr. Alley is going to say a lot more about this in Panel II.

Mr. INGLIS. Thank you.

Thank you, Mr. Chairman. I am out of time.

Chairman BAIRD. Dr. Bartlett.

THE COMMON CAUSE FOR CLEAN ENERGY DEVELOPMENT

Mr. BARTLETT. Thank you very much.

This hearing today I think is one of the more important things that the Science Committee needs to do. There should be no dispute as to what the facts are relative to climate change, and there is a lot of dispute as to what the facts are. There can be a great deal of dispute as to how you interpret those facts. But before you can have an honest discussion, you need to agree on the facts, and we don't now agree on the facts. So I really appreciate the Chairman holding this hearing and thank the witnesses for their contribution to this.

The Chairman's question, if there was no CO_2, would the Earth be colder? Not if there was just a little bit more water vapor. Because water vapor is a hugely more important greenhouse gas than CO_2. I know the Chairman meant that if all other things remained equal would the Earth be colder if there was no CO_2? And, of course, it would. But CO_2 is a pretty small greenhouse gas compared to water vapor. That doesn't mean that it's not important, because it can be the tipping point.

There are three groups that have common cause in wanting to reduce the consumption of fossil fuels; and, regretfully, they are at each other's throat rather than joining hands and marching forward.

One group is a group that is represented today, those who are concerned about climate change and the effect that the CO_2 produced from burning fossil fuels would have on that.

A second group is a group that is really concerned that the United States has only two percent of the known reserves of oil in the world, and we use 25 percent of the world's oil, and we import just about two-thirds of what we use. And the solution to that, obviously, is to stop burning so much fossil fuel and use alternatives, which is exactly the same solution that we have today in looking at the effect of CO_2 on climate. We would like to produce less of it by moving to alternatives which do not produce CO_2 if you have a short cycle rather than a million-year cycle like we have in fossil fuels.

And the third group that has common cause in this—and I just happen to have a paper this morning that just came out, the World's Energy Outlook for 2010 now out. And I will try to have this thrown on the screen later today, because it is really a startling picture. It shows that we have now peaked in conventional oil production at about 65 million barrels a day. The total world production is about 84. The rest of that is made up of natural gas liquids and unconventional oil. This chart has that plummeting to about 15—only about 15 million barrels a day by 2035. That's just 25 years from now. And it has the difference made up—because they have plateaued essentially with production of oil. And the difference is made up, and it's I think about 42 million barrels per day, they say that we are going to get from fields yet to be developed or found. You know, that's the impossible dream. That's not going to happen.

Now, the solution to this problem, the fact that the fossil fuels just aren't going to be there to burn, is to move to alternatives. And so whether or not you are right that the increase in CO_2 is producing climate change, there are two other very good reasons for doing exactly what you want to do, and that is to move away from fossil fuel use to alternatives.

Why aren't these three groups locking arms and marching together? Because they have exactly the same solution to very different problems. What keeps you from doing that?

Dr. CULLEN. I think the three groups have locked arms and have moved together. But I think there is a lot of opposition. I think it's a very difficult thing to change one's invested infrastructure. And I think much of the discussion about climate change and alternative energy is making that leap and moving forward and embracing new technologies. So, you know, can we do a better job? Absolutely. But I do think that our three communities have aligned and, you know, it's clear that there are multiple reasons to shift away from fossil fuel.

Mr. BARTLETT. You know, even if your premise is not correct, that is, that human production of CO_2 is not changing the climate, what you want to do about it is exactly the right thing to do for two other very good reasons.

Again, I ask why do not these three groups, instead of sniping at each other's premise and ridiculing each other, why don't you just lock arms and march forward? Because the solution to these three very different problems is exactly the same solution: less fossil fuels and more alternatives.

Thank you, Mr. Chairman, for holding this hearing.

Dr. LINDZEN. Would you like an answer?

Mr. BARTLETT. Yes, sir.

Dr. LINDZEN. It's profoundly dishonest. And I think integrity is important. I think Mr. Baird emphasized that. If somebody is asking you how climate changed and you influence your answer because you have some ideas on energy policy, you are short-changing your interlocutor. And I don't think that's appropriate. If somebody has an energy policy they wish to propose, it should be defended on its own grounds and sold on its own grounds.

The notion that a climate scientist who disagrees that CO_2 is important there should join the bandwagon—or even if they did agree, to say to push my view of greenhouse gases I will also support your view of energy, it's confusing the issue for the public. It's not helping it for everyone to march in lockstep.

Mr. BARTLETT. Sir, in a former life I was a scientist. I have a Ph.D. I have about a hundred papers in the literature. I understand science. And I am a rare Republican. I tell audiences that I am a conservative Republican, but on these kind of issues I am not an idiot.

Dr. LINDZEN. I am not accusing you of that. But I am saying that when you ask a scientist to lock arms with a politician because they both have aims that have the same policy, that's probably dangerous.

Mr. BARTLETT. If the goal you want to accomplish is a national security goal—and, ultimately, it is—then I don't see a compromise of science because you happen to have a common goal with a political or a military person.

Chairman BAIRD. Dr. Bartlett, if I may, as well as I know Dr. Bartlett, I would never expect Dr. Bartlett to suggest that a scientist should modify his or her findings to fit a political agenda. This, by the way, goes to both sides. But I do believe what he is suggesting, and he suggested it many times—and not only does he suggest it in hearings, he embodies it in his life—that there are national interests that are meritorious beyond single aims. I mean, the debate today is about the scientific findings. I think what he is saying and what he has literally embodied in his own life—he is more off the grid than anybody I know, and I mean that as a compliment. He is off the electricity grid because he is so on the grid of the data. He is saying, I think, that this is not a matter of distorting the scientific findings, but let's make our policy consistent with the common interests.

Mr. BARTLETT. Yes, sir. We have three common interests, and there is no reason that we should be limiting our ability to reach those common goals because we simply disagree with each other's premise. That's all I am saying.

Chairman BAIRD. Dr. Cicerone, I know you want to comment, but I am going to invite Mr. Rohrabacher, who has rejoined us. If we have time, I will get back to you on this matter because I know it's important. Mr. Rohrabacher.

CLIMATE SKEPTICISM

Mr. ROHRABACHER. Thank you very much, Mr. Chairman.

And, again, we will miss Chairman Baird. I appreciated his leadership, although we have strongly disagreed on several issues, this being one of them. And I actually would thank him very much for including one witness out of four to present the other point of view.

The fact is, in the past, as Ranking Member Hall mentioned, we have had one witness in a whole hearing, as compared to any type of balanced presentation. This has been—this tactic of not permitting the other side to be heard or trying to muzzle people in academe and elsewhere from expressing opposition views to the manmade global warming theory is a travesty, and it's about time that people in the scientific world admit that that's what's been going on. Because what we have had is, yeah, one witness out of four; in the past, we had one witness out of 16.

And how many of us have heard over and over again "case closed", where there are presentations with nobody on the other side being able to express their opinion. They have made a mockery out of science. And I am very happy that at least today we have one witness out of four in the panels who are going to present the other side.

Because there is a fundamental disagreement on whether or not the climate cycle that we are in today is basically being caused by mankind or whether or not this is a natural cycle. And if it is created by some sort of human activity, is it something that we should be concerned about because it is not a major factor but a minor factor in what's going on?

Mr. Chairman, I noted that you used your case to say why CO_2 should be of more concern in terms of—because it adjusts the oxygen in the atmosphere because CO_2 does absorb more heat. Well, let us just note that oxygen is, I believe, 21 percent of the atmosphere. CO_2 is 390 parts per million. That's one-half of one-tenth—less than one-half of one-tenth of one percent of the atmosphere as compared to 21 percent. Of this, 58 parts per million are manmade as compared to what's in there naturally.

So this idea that CO_2—most people who are discussing this issue, the presentation to the public has been so skewed and the debate has been so hampered by not presenting the other side that most people believe that CO_2 represents ten percent or 20 percent of the atmosphere. Ask the people around you, and you will find even Members of Congress giving you that answer.

Well, today, we are trying to get to the bottom of this; and I appreciate the fact that, again, we are having a debate where at least one out of four witnesses is going to be able to address some issues.

Let me ask Dr. Lindzen some of the points that you have made. I would like to specifically ask you whether or not you believe that there will be dire consequences due to our lifestyle on the climate of this planet.

Dr. LINDZEN. No, I don't think so. I think—we are talking about finite issues. The elevation of finite issues to catastrophism probably would leave behind a large portion of the scientific community.

I think there has been a problem that the agreement is on the trivial. The controversy is on really obscure things that depend on many factors. I mean, one of the things that bothers me in this in the discussion of extremes and storms and so on, a basic feature of meteorology is the cause of storms in mid-latitudes is the temperature difference between the Equator and pole. Under a warmer climate, that should be reduced, and that should lead to fewer storms. It is the storms that bring in record highs and lows by carrying air from distant places. Why suddenly in this complex thing a particular observation that is actually contrary to the basic physics assumes importance, I don't know.

Mr. ROHRABACHER. We have had many cycles of warming and cooling throughout the history of this planet, many, many cycles. And a minuscule change in the amount of CO_2 in the atmosphere, as compared to other time periods when there were other cycles going on, when CO_2, by the way, was dramatically higher than what it is today, we have seen that the relationship between CO_2——

This is what it comes down to. People are trying to tell us—in the scientific community, there are people trying to tell us that we have got to accept Draconian changes in our way of life mandated by law because the CO_2 that we are emitting is going to cause drastic consequences to the planet's climate. That does not seem to hold up.

Dr. LINDZEN. It's also that even if the U.S. shut down period, retired from the world, its impact on the CO_2 levels would be rather undramatic.

Mr. ROHRABACHER. And the CO_2 levels in the atmosphere are rather undramatic.

Dr. LINDZEN. Yeah.

Mr. ROHRABACHER. The fact is CO_2 is a minor, minuscule part of the atmosphere. Its increase during the time period where mankind has increased the standard of living of the people of the human race has been used as a scare tactic to frighten people into accepting controls over their lives that they otherwise would not accept. That's what this debate is all about. And, frankly, I have seen in the past—I am a former journalist. I have seen example after example where people in the political world will try to frighten the public on an issue in order to achieve a political end, and this is one of the worst examples of that that I have seen.

Thank you very much, Mr. Chairman.

Chairman BAIRD. Mr. Rohrabacher, whereas you began your statements by emphasizing the importance of hearing from all sides and during the most recent questioning you heard from one side, I am going to invite the witnesses if they—other witnesses if they wish to respond to some of the points that you made to do so, because I am sure you would want to hear their responses.

Dr. MEEHL. There was a number of different points made there. I don't know quite where to start. Maybe I will just take a couple of them.

This is one of the things that I personally find difficult, that a lot of times the science gets kind of blurred together with the political side of this issue. What we are here to talk about is the science of this issue. When you talk about dire consequences, those are value judgments made by human societies that aren't science issues.

You know, there has been an effort in the European community to come up with a number of two degrees sea warming above preindustrial as a threshold for dangerous climate change, and people argue about that a lot. And that number is out there, but I think you would find a lot of disagreement even among the scientific community about what constitutes dangerous climate change.

Certainly with climate change things will shift around. You will have dry areas probably getting dryer; wet areas will get wetter. You will see changes to extremes. You see things that would have impacts on human societies.

But the fact that these greenhouse gases, which we call trace gases—because, as you point out, rightfully so, they constitute a really small fraction of the composition of the Earth's atmosphere—the fact that they have this interesting and unique property that they have more than two atoms per molecule. Oxygen and nitrogen, which are the biggest constituents, as you say, have only two atoms per molecule, when you have more than two atoms per molecule that makes that molecule really active and really important, and it can absorb and reemit heat and trap it. So I think that——

Mr. ROHRABACHER. But if it's so minuscule, how does that then have a greater impact?

Dr. MEEHL. See, that's the interesting thing about it. Because even at these really small quantities they can be really important to the climate system and really make a difference in how the climate of the Earth is behaving. So I think in terms of the science, these are the things that we grapple with, too. You know, we try to incorporate these things in the models the best we can, and we try to use the tools the best we can, and these are the indications that we get.

In terms of evidence, science is a great thing because, you know, Dick Lindzen has his theories about low climate sensitivity. Other people have tried to use other evidence to contradict what he said, and this is how science works. We have this ongoing discussion, and at the end of the day try to come up with some idea of what we think is really going on out there in the world. So I think that's why all of us probably got into science in the first place, because we are really interested in how the world works.

But, you know, focusing on the science makes it a very interesting problem that has all these interesting things that go on in terms of physical processes that we can try to use tools like climate models to understand. And I think that's where the interest is for us. I think that's what makes this a very interesting problem.

Now, as far as what you decide to do as policymakers about this problem is something we can try to give you information on. I think Mr. Inglis' example of the advice you get from doctors that maybe 98 give you A, and two say B, and you say, well, okay, what do you want to do? It's still a call that you have to make as policymakers as to what you do with this information. But I think we have to do the best we can to give you the best possible information from our community.

Chairman BAIRD. So help us understand.

First of all, I very much appreciate what you said, Dr. Meehl, because on this committee and elsewhere in the public and the media there is an assertion that climate science is a hoax, meaning something intentionally perpetrated. Piltdown Man is a hoax, but I don't see this as a hoax. People may disagree on the findings and implications and the models, et cetera, but the idea that it's a conspiracy to force Draconian changes or that it's a hoax flies in the face of what I know about the individuals on all sides before us today. And so, if nothing else, let us put to rest this assertion that in some way you are motivated by some bizarre intent to change our way of life.

Help us understand, though, the fundamental question that Mr. Rohrabacher asked about how a relatively small trace element impacts raising temperatures. That's really——

Mr. ROHRABACHER. As compared to the natural cycles.

Chairman BAIRD. That's a fair question. That's a fair question. Help us understand that. Dr. Cicerone. I am going to call on—we will work our way down.

Dr. LINDZEN. I will be happy to answer that.

There is no simple relation between the amount of a constituent and its ability to absorb radiation. If you have a very strong absorbing molecule, then you need less of it to do something.

CO_2 is a significant absorber. I differ with my colleagues about the reason why. It's the permanent dipole moment that's important. You know, OH, NO, all have two atoms and they absorb well in the infrared. So, I don't know, that makes me wonder about the testimony.

But, still, it is possible for a trace gas to be important. It isn't strictly the amount, even though the amount is minuscule. For instance, a very thin visibly invisible cloud will absorb more infrared than all the other infrared absorbers in the atmosphere when it's present.

Chairman BAIRD. Dr. Cicerone.

Dr. CICERONE. The framework is the energy balance of the planet. And so in deciding whether an entry is small or diminutive or whatever, it's when we look at those balancing, as you said, Mr. Rohrabacher, compared to the natural balances. And these polyatomic molecules that have vibrational and rotational modes that they can interact with the infrared radiation, as Dr. Lindzen just said, sometimes the tiniest presence can intercept parts of the spectrum which are otherwise transparent.

Generally speaking, the Earth's atmosphere is transparent in some of these infrared wavelength regions where the planet's emitting. So it's not too much of a mystery. We have to go through the numbers.

If I may, Mr. Chairman, could I make a comment on Mr. Bartlett's very interesting puzzle about energy policy?

Chairman BAIRD. Please. And then I will give one more opportunity to others, and then we will finish. We have two more panels to get through.

Dr. CICERONE. I have heard a very graphic presentation of the same three conundrums in testimony to the House from a former CIA director, Jim Woolsey, where he gets back to your three overlapping groups and interests by having a fictional conversation between John Muir, Mahatma Gandhi, and General George Patton. And he shows that they can agree on the kinds of things that you just said. He testified in the House a year or two ago, and I have heard him give this presentation. It's fascinating.

Getting down to basics, energy efficiency is a solution that should appeal to all three of your groups; and yet if all of this free money is lying on the floor to be saved with energy efficiency, why aren't more people taking advantage of it? We now have some analysis from business groups of why various companies and individuals are not doing more to capture this free energy through efficiency, and I am optimistic that people will get their acts together who are concerned about those three different sides of the issue.

Chairman BAIRD. Any final comments by Dr. Meehl or Dr. Cullen? And then we will release this excellent panel for the next one.

Dr. CULLEN. I think one remark I would like to simply make is that with this notion that extreme weather events will increase over time, I think it's important to just remember that in our daily lives as we move forward there are numerous things we all need to worry about. And if you look at the tragic events that happened during the national floods, yes, we dealt with extreme weather events in the past, but from an infrastructure standpoint, from doing things in the short term to reduce to our overall vulnerability, I think rather than think about catastrophes it's thinking about the fact that we have information that can reduce our overall vulnerability, make our communities stronger.

And, you know, I just come back to the fact that, just as meteorologists on the short term are trying to keep people out of harm's way, this is information that is ultimately meant to make our communities stronger and safer. And it's sort of as simple as that as we move forward over the next decade or two.

Chairman BAIRD. Dr. Meehl, any final comment?

I want to thank this outstanding panel for their expertise, for their years of work, and for modeling a productive and constructive discussion. Thank you very much.

We will recess for about four or five minutes until the next panel can be seated. I am sure my colleagues join me in thanking this panel of witnesses, and I will ask them to retire at this moment and invite our others to join us.

[Recess.]

Panel II

Chairman BAIRD. I appreciate everyone joining us again. We now will begin our second panel.

As before, it's my pleasure to introduce our second panel of witnesses: Dr. Patrick Michaels is a Senior Fellow in Environmental Studies for the Cato Institute. Dr. Benjamin D. Santer is an Atmospheric Scientist for the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory. Dr. Richard B. Alley is the Evan Pugh Professor for the Department of Geosciences and Earth and the Environmental Systems Institute at Pennsylvania State University. And Dr. Richard Feely, from my home State of Washington, is a Senior Scientist for the Pacific Marine Environmental Laboratory with the National Oceanic and Atmospheric Administration.

As our witnesses observed before, we do our level best to try to stick to five minutes. Sometimes if you go a little bit over I will be as patient as I can. But please do your best to keep it at five minutes. And following the presentations, we will have a series of questions. Again, I thank our witnesses.

Dr. Michaels, you are welcome to begin. Thank you.

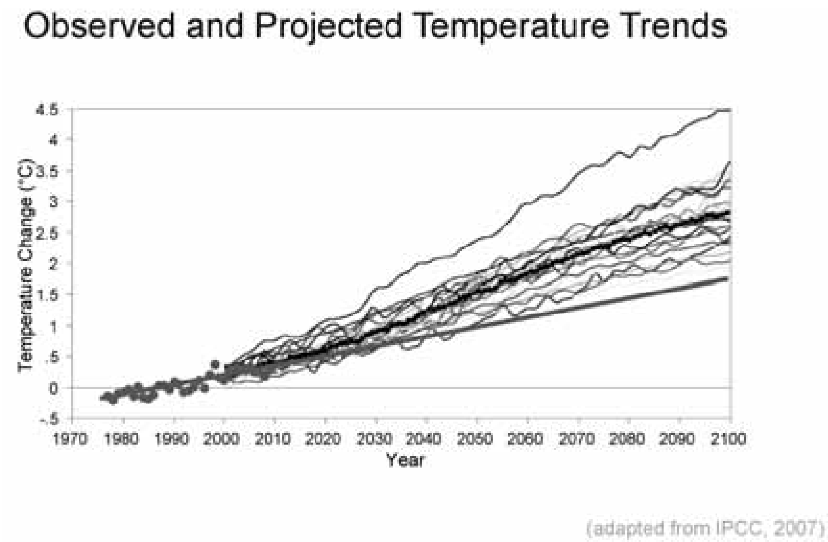
STATEMENT OF PATRICK J. MICHAELS, SENIOR FELLOW IN ENVIRONMENTAL STUDIES, CATO INSTITUTE

Dr. MICHAELS. Thank you, Congressman Baird. It's very nice to be here. It's an honor to be here.

I think the first panel set what I think what is an interesting scientific discussion. What we are really looking at here is to whether the sensitivity of temperature to carbon dioxide is as large as some people think or whether there are other factors that are responsible for the temperature changes that we have seen.

I would like to show the first slide, if I could.

[The information follows:]



The important thing about climate change to remember is that it doesn't matter whether people change the climate. One of the rhetorical devices that is inaccurate on this is to say all scientists agree that human beings have an influence on climate. So what? What matters is how much we influence the climate. And we are getting some guidance from Mother Nature on this, despite our best efforts, if you will.

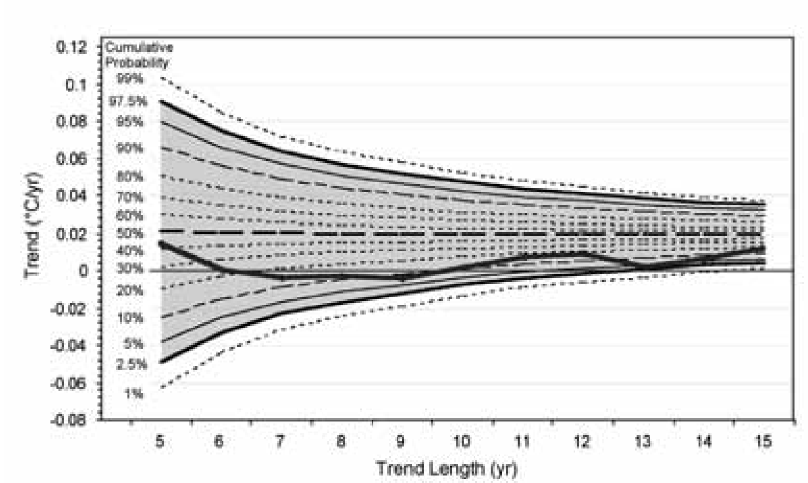
This slide shows—each piece of colored spaghetti on this slide is a computer model. There are 21 different models from the United Nations IPCC scenario for concentrations in the atmosphere that pretty much resemble what's been going on in the atmosphere. One of the things you see is each one of those pieces of colored spaghetti is pretty much a straight line, and the reason for that is because we put carbon dioxide in the atmosphere exponentially, but the response is logarithmic, and it tends to do that.

Now, ask yourself the question: Since the planet started its warming of the late 20th century, has the warming been a straight line? And the answer is yes. So how do you discriminate between these straight lines? The same thing you tell students in weather forecasting, which I have taught. When different models say different things, look out the window. And when you look out the window, what you see here is at the low end of this line.

Now, I hope it went to the next image. Very good.

[The information follows:]

Observed and Projected Temperature Trends



Another way to look at this issue is to look at the frequency distribution of temperatures produced by all these temperature trends produced by all these models for periods say of five on out to 15 years. And the blue line are the observed trends from the Climate Research Center—Climate Research Unit at East Anglia. And what you can see, which corresponds to what we saw on the last slide, is in fact the warming is clearly below the average predicted by these models. Yes, we have a greenhouse gas fingerprint, and we are going to hear about that in this talk. But I submit to you that it's a pinkie. It's not one of the dreaded other fingers.

And, furthermore, if we take a look at the attempts like this, they are very sensitive to the years that are chosen.

[The information follows:]

ARTICLE

A search for human influences on the thermal structure of the atmosphere

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‡ National Center for Atmospheric Research, Boulder, Colorado 80307-3000, USA
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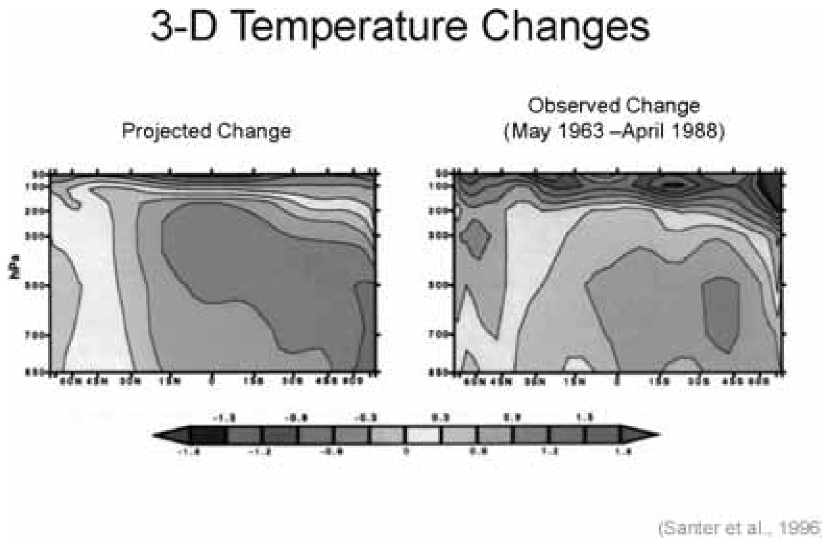
The observed spatial patterns of temperature change in the free atmosphere from 1963 to 1987 are similar to those predicted by state-of-the-art climate models incorporating various combinations of changes in carbon dioxide, anthropogenic sulphate aerosol and stratospheric ozone concentrations. The degree of pattern similarity between models and observations increases through this period. It is likely that this trend is partially due to human activities, although many uncertainties remain, particularly relating to estimates of natural variability.

This particular paper right here is probably the most famous paper ever published on attribution of climate change. It appeared in 1996, and it shows that the temperature between 1963 of the free atmosphere and 1987 corresponded remarkably to what was modeled. It was fantastic. It was a wonderful result.

And here is the left-hand side, is the computer.

[The information follows:]



You can see in the Southern Hemisphere, which is on the right-hand side of the left-hand image, a massive warming, and you see from 1963 through 1987 in the Southern Hemisphere a massive warming. What a wonderful finding. But the weather data actually begins in 1957, the weather balloon record for this, and it ends in 1995 for the purposes of a paper published in 1996.

I offer you the observation by the way, this paper appeared four days before probably the most important conference on climate change ever held by the United Nations Policy Committee; and it was highly, highly influential.

At any rate, when you add in all the data from 1957 through 1995, the relationship vanishes. So these studies are very, very sensitive to what goes on with the temperature—what period we study, rather.

So the search goes on. Sulfates, aerosols, the sensitivity or the effect of them is estimated between zero and minus two watts per meter squared. You can pick pretty much any value you want, which makes it very easy to fit curves.

Then there is the problem of volcanoes. After this appeared, another research effort was made to look at the effect of volcanoes on the temperature. You see, scientists actually are involved mainly in trying to find out why it has warmed so little compared to the greenhouse-gas-only models. And so a paper came out by pretty much the same group that said, well, if we go back to Krakatoa in 1883 and we factor in the volcanoes, my God, 2/3 of the warming that would have occurred has been suppressed. Wow.

That's another remarkable finding that turns out to be incredibly time-dependent. Because, you see, there were volcanoes before 1883. Mount Tambora went off in 1815, created the year without a summer, 1816. We have these records.

And, very recently, Jonathan Gregory just got a paper accepted, and it will be published very soon, which uses the entire volcanic record.

[The information follows:]

Jonathan Gregory, GRL, 2010

[Climate models] generally suggest a long persistence of historical volcanic cooling. Assuming that the behaviour of other models is qualitatively similar to that of [the model we used in this paper], we suggest that this is an artefact of experimental design, caused by the [models] not having been "spun up" to a steady state with episodic volcanic forcing before the historical simulations began. Consequently the volcanic forcing, with its long-term negative average, superimposes a cooling tendency on the ocean throughout the historical simulation. This artefact could be misleading in comparisons and attribution of observed and simulated changes in ocean heat content.

(from Gregory, *GRL*, 2010)

And I offer you this is an artifact of experimental design caused by the models having been spun up to a steady state with episodic volcanic forcing before the historical simulations began. This artifact could be misleading in comparison and attributions observed and simulated changes in climate.

So I will tell you what my conclusion is.

First of all, scientists works by tentative hypotheses, and you look at data to see whether you can maintain your tentative hypothesis or whether you have to modify it. My tentative hypothesis would be that the sensitivity has been overestimated, in agreement with Lindzen and Spencer and a whole host of other scientists; and that is the prospect that we need to test.

Now, I realize some people might not agree with me on this, because some people say there is no such thing as climate change, and some people say, well, yes, climate change is the end of the world. If you disagree, you can join this Facebook site that appeared and you can take care of me.

Thank you very much.

[The prepared statement of Dr. Michaels follows:]

PREPARED STATEMENT OF PATRICK J. MICHAELS

Thank you for inviting my testimony. I am a Senior Fellow in Environmental Studies at the Cato Institute and Distinguished Senior Fellow in the School of Public Policy at George Mason University. This testimony represents no official point of view from either of these institutions and is tendered with the traditional protections of academic freedom.

My testimony has four objectives

1) Demonstration that the rate greenhouse-related warming is clearly below the mean of climate forecasts from the United Nations Intergovernmental Panel on Climate Change (IPCC) that are based upon changes in atmospheric carbon dioxide concentrations that are closest to what is actually being observed,
2) demonstration that the Finding of Endangerment from greenhouse gases by the Environmental Protection Agency is based upon a very dubious and critical assumption,
3) demonstration that the definition of science as a public good induces certain biases that substantially devalue efforts to synthesize science, such as those undertaken by the IPCC and the U.S. Climate Change Science Program (CCSP), and
4) demonstration that there is substantial discontent with governmental and intergovernmental syntheses of climate change and with policies passed by this House of Representatives.

"Climate change" is nothing new, even climate change induced by human activity. What matters is not whether or not something so obvious exists, but to what magnitude it exists and how people adapt to such change.

For decades, scientists have attempted to model the behavior of our atmosphere as carbon dioxide and other greenhouse gases are added above the base levels established before human prehistory. The results are interesting but are highly dependent upon the amount of carbon dioxide that resides in the atmosphere, something that is very difficult to predict long into the future with any confidence. It is safe to say that no one—no matter whether he or she works for the government, for industry, or in education—can tell what our technology will be 100 years from now. We can only say that if history is to be any guide, it will be radically different from what we use today and that therefore projecting greenhouse gas emissions so far into the future is, to choose a word carefully, *useless*.

One thing we are certain of, though, is that the development of future technologies depends upon capital investment, and that it would be foolish to continue to spend such resources in expensive programs that will in fact do nothing significant to global temperature.

Fortunately, despite the doomsaying of several, we indeed have the opportunity to not waste resources now, but instead to invest them much further in the future. That is because the atmosphere is clearly declaring that the response to changes in carbon dioxide is much more modest that what appears to be the consensus of scientific models.

Testimony Objective #1: Greenhouse-related warming is clearly below the mean of relevant climate forecasts from the IPCC

Figure 1 shows the community of computer model projections from the IPCC's "midrange" scenario. Observed changes in atmospheric carbon dioxide concentrations correspond closer to this one than to others. You will note one common characteristic of these models: they predict warmings of a relatively constant rate. This is because, in large part, the response of temperature to changes in atmospheric carbon dioxide is logarithmic (meaning that equal incremental increases produce proportionally less warming as concentration increases), while the increase in carbon dioxide itself is a low-order exponent rather than a straight line. This combination tends to produce constant rates of warming.

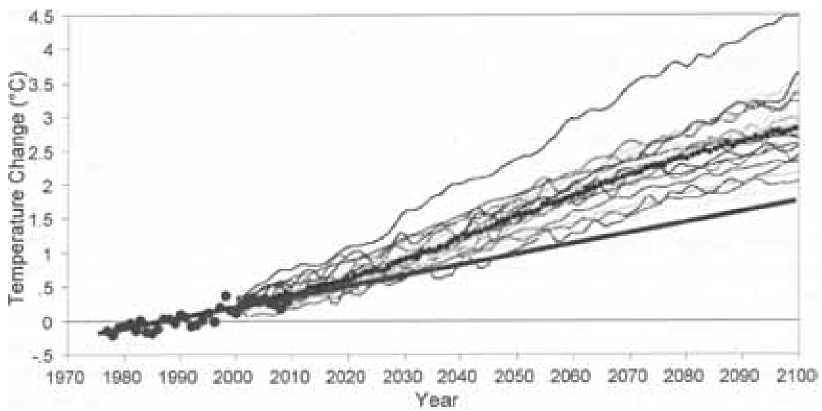


Figure 1. Projected temperature rise over the course of the 21st century from climate models used in the IPCC's *Fourth Assessment Report* (colored lines) running a 'midrange" emissions scenario, with observed temperatures superimposed (red circles).

The various models just produce different quasi-constant rates. Divining future warming then becomes rather easy. Do we have a constant rate of warming? And if so, then we know the future rate, *unless the functional form of all of these models is wrong*. And if this is wrong, scientists are so ignorant of this problem, that you are wasting your time in soliciting our expertise.

How does the observed rate of global temperature increase compare to what is being projected? For that, we can examine the behavior of literally hundreds of iterations of these models. For time periods of various lengths, some of these models will actually produce no significant warming trend (as has been observed since 1996), or even a short-term interval of cooling.

Figure 2 gives us the mean and 95% confidence limits of the midrange family of IPCC models as well as temperatures observed by the Climate Research Unit at the University of East Anglia. (More will be said on this history below). It is quite apparent that the observed rates of change are below the mean value forecast by the IPCC.

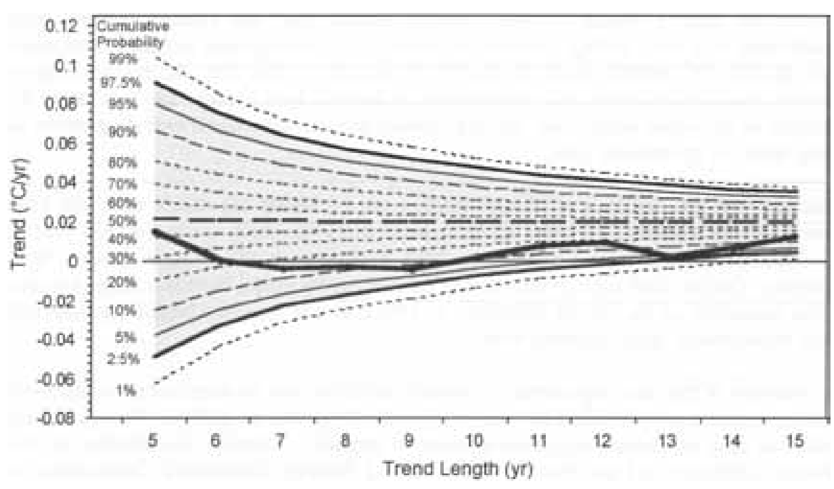


Figure 2. Range of climate model probabilities of surface temperature trends (gray shading) overlaid with the observed surface temperature trend from the Climate Research Unit (blue line) (data through September 2010).

An additional and important discrepancy between the models and reality extends into the lower atmosphere as well. In the lower atmosphere, climate models expectations are that the degree of warming with increasing greenhouse gas concentrations should be greater than that experienced at the surface, with the lower atmosphere warming about 1.4 times faster than the average surface temperature. Despite claims that observations and models are in agreement (Santer et al., 2008), new analyses incorporating a large number of both observational datasets as well as climate model projections, clearly and strongly demonstrate that the surface warming (which itself is below the model mean) is significantly outpacing the warming in the lower atmosphere—contrary to climate model expectations. Instead of exhibiting 40% more warming than the surface, the lower atmosphere is warming 25% less—a statistically significant difference (Christy et al., 2010).

And further, the climate models are faring little better with oceanic temperature changes. There again, they project far more warming than has been observed. In a much-publicized paper published in *Nature* magazine in 2006 (by authors Gleckler, Wigley, Santer, Gregory, AchutaRao, Taylor, 2006), it was claimed that by including the cooling influence of a string of large volcanic eruptions starting in 1880, that climate models produced a much closer match to observed trends in ocean warming than when the models did not include the volcanic impacts. Further, it was claimed that volcanic eruptions as far back as Krakatoa in 1883 were still significantly offsetting warming from human greenhouse gas emissions. However, a soon-to-be-published paper by one of the *Nature* paper's original authors, Jonathan Gregory, shows that the influence of volcanoes was greatly exaggerated as the original climate models assumed that no major volcanic eruptions had occurred prior to Krakatoa. In fact, episodic major eruptions are an integral part of the earth's natural climate. Gregory shows that had climate models been equilibrated with more realistic natural conditions, that the long-term impact of volcanoes since the late 19th century would be greatly minimized. In that case, the apparent match between model simulations and observations of oceanic heat content that was noted by Gleckler et al. would deteriorate, leaving climate models once again over-responsive to rising levels of greenhouse gases.

I caution you that analyses of climate models can be highly dependent upon the time period chosen. There was a major El Nino event in 1998, which is the warmest year in the instrumental histories. Thus any analysis beginning in this year will show little warming. On the other hand, if one studies the last twenty years, there is a major volcano at the beginning of the record (Pinatubo in 1991), so any analysis beginning then will show anomalously large warming trends.

An example of the time dependency of model validation can be seen in one of the most famous papers ever published on this subject, by Santer et al. (1996). It was clearly rushed to print by *Nature* magazine in order to provide a scientific justification for the Second Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Geneva a mere few days after its publication. The findings were reported in virtually every major newspaper on the planet in this politically sensitive timeframe.

The analysis shows a remarkable fit between the observed three-dimensional changes in the atmosphere and what was projected by models between 1963 and 1987. But, indeed, this three-dimensional history actually begins in 1957, and, for the purposes of this paper, clearly ends in 1995, not 1987.

The major match for this record results from the substantial warming of the southern hemisphere compared to the northern (Figure 3). Indeed the time evolution of southern hot spot is striking from 1963 through 1987. But, when all of the data are used, the warming trend completely disappears.[1]

[1] The attitude displayed in the famous "climategate" emails has a long provenance. This finding was shown in an invited presentation to the American Meteorological Society annual meeting in 1997. A scientist whom I had held in high esteem, Tim Barnett of Scripps Institute of Oceanography, in the discussion after its presentation, threatened to asphyxiate me with the microphone cord "if I ever gave it again".

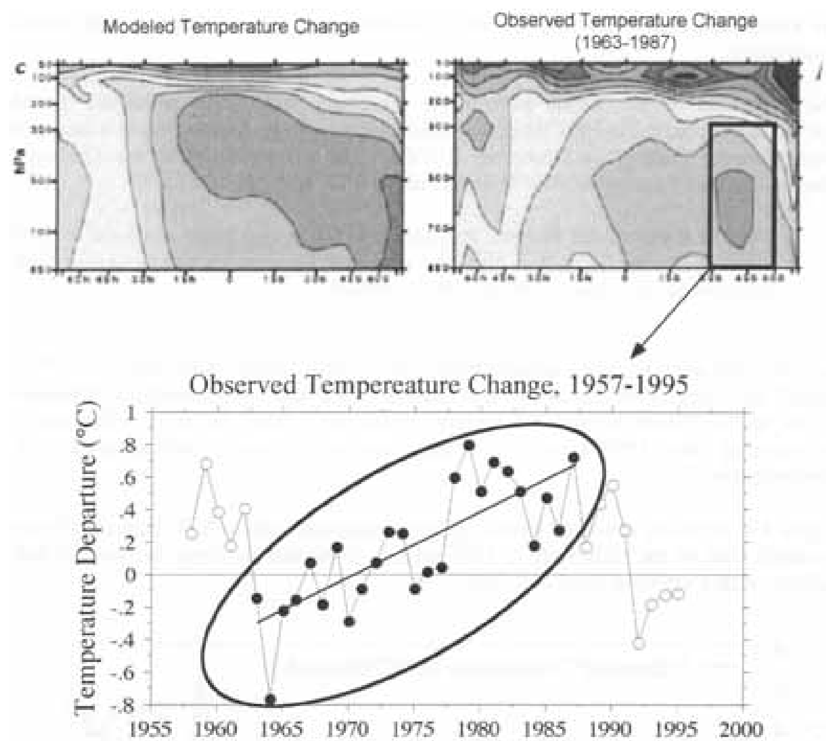


Figure 3. Modeled (upper left) and observed (upper right) temperatures changes throughout the atmosphere. Time series of temperatures in the region of the highlighted box in the upper right panel, 1957–1995. Filled circles: 1963–1987; Open circles, 1957–62 and 1988–95. Use of all the available data clearly changes the result.

Nonetheless, the Geneva conference marked the turning point in international climate change policy. It was agreed there that at the next conference, in Kyoto, that the nations of the world would adopt a binding protocol to reduce carbon dioxide emissions. The resultant Kyoto protocol demonstrably did nothing about climate change and was an historic, expensive failure that led to the ultimate failure in subsequent policy that took place in Copenhagen last December.

Testimony Objective #2: The Finding of Endangerment from greenhouse gases by the Environmental Protection Agency is based upon a very dubious and critical assumption

The reluctance of the Senate to mandate significant reductions in carbon dioxide emissions has resulted in EPA taking the lead in this activity. Consequently it issued an “endangerment finding” on December 7, 2009. The key statement in this Finding is adapted from the Fourth Assessment Report of the IPCC and from the CCSP:

> *Most* of the observed increase in global average temperatures *since the mid-20th century* is very *likely* due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations. [italics added]

Here the EPA gives us a very testable hypothesis. “Most” means more than 50%. “Very likely”, according to the IPCC and CCSP, means with a subjective probability of between 90 and 95 %. “Since the mid-20th century” means after 1950. So, is more than half of the warming since 1950 a result of “the observed increase in anthropogenic GHG concentrations?”

Figure 4 is a plot of observed global surface temperature since 1950 from the Climate Research Unit of the University of East Anglia. Note that its linear behavior is quite striking, with a warming trend of 0.70°C.

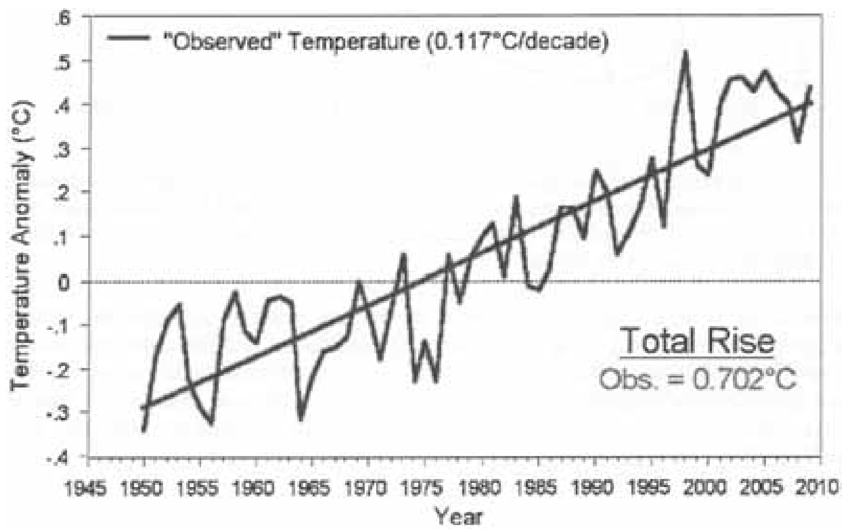


Figure 4. Annual global average temperature history from 1950 to 2009 (source: U.K. Hadley Center).

Thompson et al., writing in *Nature* in 2008, noted that sea-surface temperatures were measured too cold between the mid-1940s and mid-1960s. Accounting for this lowers the surface warming trend from 0.70 to 0.55°C; see Figure 5.

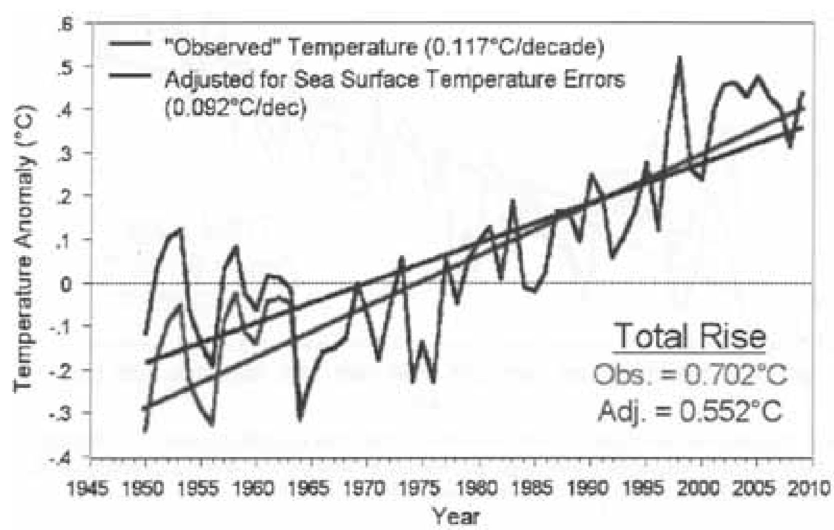


Figure 5. Annual global average temperature history from 1950 to 2009 (source: U.K. Hadley Center) and adjusted annual global average temperature to remove SST errors (Thompson et al., 2008).

Late in 2007, Ross McKitrick and I published an analysis of "non climatic" trends in surface temperature data. While the global effect was not as large as some erroneous reports have stated, we found that approximately .08°C of the warming trend was a result of these factors. We were looking at effects that could only occur over land, and Thompson et al. was concerned with the ocean, so these two adjustments are obviously independent, additive, and not from GHG changes. The remaining warming is now 0.47°C (Figure 6).

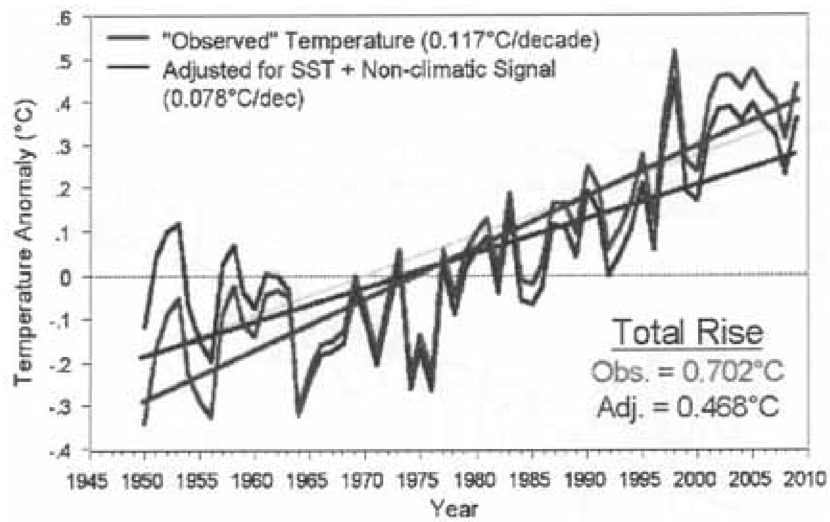


Figure 6. Annual global average temperature history from 1950 to 2009 (source: U.K. Hadley Center) and adjusted annual global average temperature to remove SST errors (Thompson et al., 2008) and non-climatic influences (McKitrick and Michaels, 2007).

In January, 2010, in an attempt to explain the lack of significant warming that has been observed since 1996, Susan Solomon published a new simulation in *Science* that took into effect the radiative consequences of changing water vapor in the stratosphere. No one really knows why this is happening, but it is not an obvious consequence of changing GHG concentrations. This additional factor drops the warming to 0.41°C; see Figure 7.

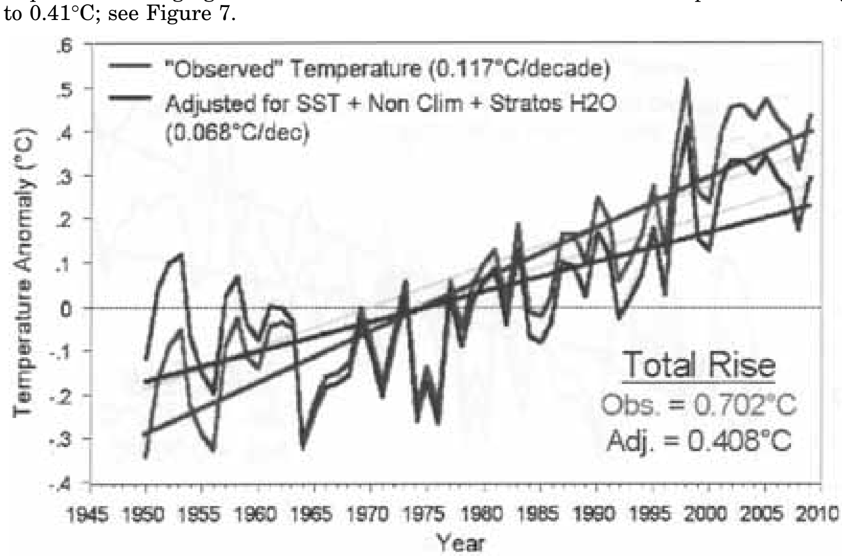


Figure 7. Annual global average temperature history from 1950 to 2009 (source: U.K. Hadley Center) and adjusted annual global average temperature to remove SST errors (Thompson et al., 2008), non-climatic influences (McKitrick and Michaels, 2007) and the influence of stratospheric water vapor increases (Solomon et al., 2010).

In 2009, Ramanathan and Carmichael reviewed the effects of black carbon—which is not a GHG—on temperature and concluded it was responsible for approximately 25% of observed warming. This now drops the residual warming to a ceiling of 0.31°C, or 44% of the original 0.70° (Figure 8). Note that this catena of results does not invoke solar variability, as estimates of its impact on recent climate vary widely (Scafetta, 2009).

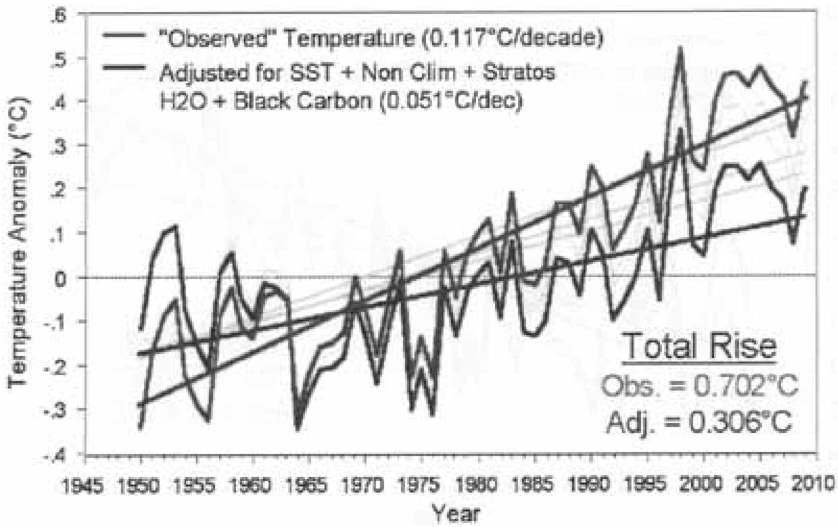


Figure 8. Annual global average temperature history from 1950 to 2009 (source: U.K. Hadley Center) and adjusted annual global average temperature to remove SST errors (Thompson et al., 2008), non-climatic influences (McKitrick and Michaels, 2007), the influence of stratospheric water vapor increases (Solomon et al., 2010) and the influence of black carbon aerosols (Ramanathan and Carmichael, 2009).

Consequently EPA's core statement (as well as that of the IPCC and the CCSP), "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations", is not supported.

Testimony Objective #3: The definition of science as a public good induces certain biases that substantially devalue efforts to synthesize science, such as those undertaken by the IPCC and the U.S. Climate Change Science Program (CCSP).

Visitors to the website of *Scientific American* have been invited to participate in an ongoing survey on global warming. This survey finds—despite the general environmentalist bent of its readership—that only a tiny minority (16%) agree that the IPCC is "an effective group of government representatives, scientists, and other experts". 84% agree, however, that it is "a corrupt organization, prone to groupthink, with a political agenda" (Figure 9). The concordance between the IPCC and the bizarre one-sidedness of the CCSP Synthesis would compel the respondents to say the same about it, if asked.

4. The IPCC, or Intergovernmental Panel on Climate Change is:

	Response Percent	Response Count
an effective group of government representatives, scientists and other experts.	15.8%	1,065
a corrupt organization, prone to groupthink, with a political agenda.	83.6%	5,652
something to do with Internet protocols.	0.6%	42
answered question		6,759
skipped question		2

Figure 9. Only a tiny minority of respondents (16%) agree that the IPCC is “an effective group of government representatives, scientists, and other experts”. 84% agree, however, that it is “a corrupt organization, prone to groupthink, with a political agenda” (Questions 4 from a *Scientific American* on-line poll, downloaded November 12, 2010).

This stems from the very nature of modern science, which is treated largely as a public good, to be funded by taxpayer dollars. But, like other tax-supported entities, science also competes within itself for attention to its disciplines and problems. In the environment of Washington, the most emergent or apparently urgent subjects receive proportional public largesse. With regard to incentives, no scientific community ever came into this House of Representatives and claimed that its area of interest was overemphasized and that funding should be directed elsewhere. This is normal behavior.

However, an implication of this behavior is that the peer-review process is also populated by a community of incentivized individuals. The test of this hypothesis would be in fact if that literature were demonstrably biased.

Rather than use the inflammatory subject of climate change as an example, I draw your attention to the everyday weather forecast. In the US, we recast our global forecasting models twice a day, based upon three dimensional measurements of atmospheric state variables that simultaneously updated.

If the initial forecast model is unbiased, each new pieced of information has an equal probability of either raising or lowering the high temperature forecast three days from now. And, indeed, that turns out to be the case.

The same should apply to climate science if there is no incentivized bias. In fact, the “mainstream” community of climate scientists claims this is true. In their *Amicus* brief in *Massachusetts v EPA*, the supreme court case that required the EPA to determine whether or not carbon dioxide caused “endangerment”, Battisti et al., writing as “The Climate Scientists” state:

> Outcomes may turn out better than our best current prediction, but it is just as possible that environmental and health damages will be more than severe than the best predictions.

As with the EPA’s use of “most” and “mid-20th century”, “just as possible” is a quantitatively testable hypothesis. In this case, “The Climate Scientists” are stating that there is an equal probability that a new scientific finding in global warming, in amount or consequence makes future prospects either worse than previously thought or not as bad.

I examined 13 consecutive months of *Nature* and *Science* to test the hypothesis of unbias. Over a hundred articles were examined. Of those that demonstrably had a “worse than” or “not as bad as” component, over 80 were in the “worse” category and 11 were “not as bad”.

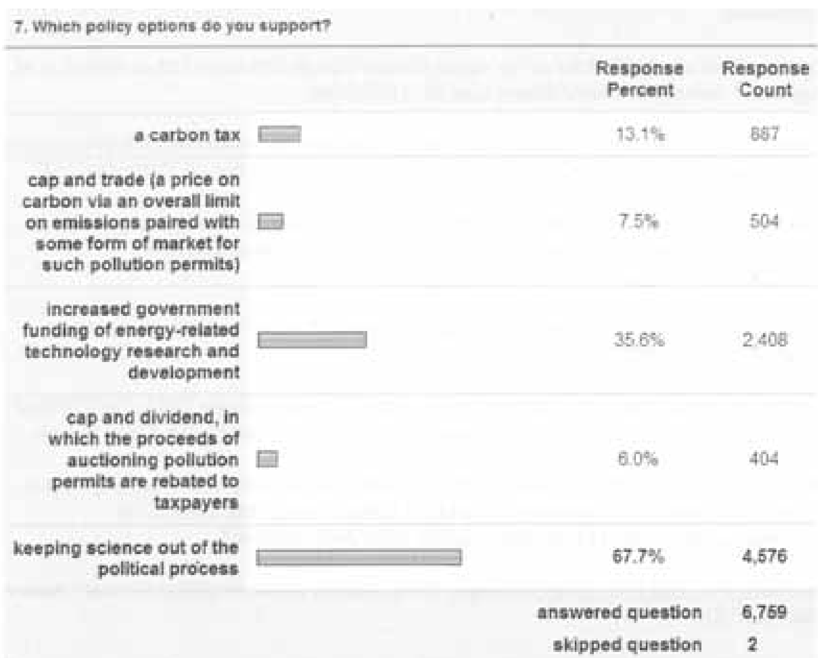
The possibility that this did not reflect bias can be determined with a binomial probability. It is similar to the likelihood that a coin could be tossed 93 times with only 11 “heads” or “tails”. That probability is less than 1 in 100,000,000,000,000,000.

In fact, climate science holds itself apart from other quantitative fields. Both economics and biomedical science acknowledge this problem, known as “publication bias" when doing meta-analyses. It a concept is completely foreign to the dominant mainstream in my profession, in the IPCC and in the CCSP.

Testimony Objective #4: There is substantial discontent with governmental and intergovernmental syntheses of climate change and with policies passed by this House of Representatives.

In response to a perceived political need for mandated reductions to demonstrate our national resolve at Copenhagen, this House passed a cap-and-trade bill on June 26, 2009. The Senate never considered such legislation and it will rest when this Congress adjourns.

The survey by *Scientific American* shows the unpopularity of this approach. Figure 10 shows that only 7.5% of nearly 7,000 respondents say cap and trade was the course that should have been taken.



7. Which policy options do you support?

	Response Percent	Response Count
a carbon tax	13.1%	887
cap and trade (a price on carbon via an overall limit on emissions paired with some form of market for such pollution permits)	7.5%	504
increased government funding of energy-related technology research and development	35.6%	2,408
cap and dividend, in which the proceeds of auctioning pollution permits are rebated to taxpayers	6.0%	404
keeping science out of the political process	67.7%	4,576
	answered question	6,759
	skipped question	2

Figure 10. Only 7.5% of nearly 7,000 respondents said cap and trade was the course that should have been taken (Questions 7 from a *Scientific American* on-line poll, downloaded November 12, 2010).

Conclusion

I hope to have demonstrated in this testimony that observed warming rates are certainly below the mean of the most likely suite of climate models, and that the finding of endangerment by the EPA is based upon an important assumption that may not be true.

Further, science and scientists are demonstrably incentivized, as publicly funded goods, in ways that make any synthesis of the scientific literature highly susceptible to bias. Finally, an ongoing survey by *Scientific American* reveals profound distrust of scientific institutions such as the IPCC, and by extension, the CCSP, probably caused by the incentives noted above.

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BIOGRAPHY FOR PATRICK J. MICHAELS

Patrick J. Michaels is Senior Fellow in Environmental Studies at the Cato Institute Distinguished Senior Fellow in the School of Public Policy at George Mason University. He is a past president of the American Association of State Climatologists and was program chair for the Committee on Applied Climatology of the American Meteorological Society. Michaels was also a research professor of Environmental Sciences at University of Virginia for thirty years. Michaels was a contributing author and is a reviewer of the United Nations Intergovernmental Panel on Climate Change, which was awarded the Nobel Peace Prize in 2007. His writing has been published in the major scientific journals, including *Climate Research*, *Climatic Change*, *Geophysical Research Letters*, *Journal of Climate*, *Nature*, and *Science*, as well as in popular serials worldwide. He was an author of the climate "paper of the year" awarded by the Association of American Geographers in 2004. He has appeared on most of the worldwide major media. Michaels holds A.B. and S.M. degrees in biological sciences and plant ecology from the University of Chicago, and he received a Ph.D. in ecological climatology from the University of Wisconsin at Madison in 1979.

Michaels is the author of five books on climate change, the latest of which is *Climate of Extremes: Global Warming Science They Don't Want You to Know* (Cato Books, 2009).

Chairman BAIRD. Dr. Santer.

STATEMENT OF BENJAMIN D. SANTER, ATMOSPHERIC SCIENTIST, PROGRAM FOR CLIMATE MODEL DIAGNOSIS AND INTERCOMPARISON, LAWRENCE LIVERMORE NATIONAL LABORATORY

Dr. SANTER. Thank you very much, Chairman Baird, for the opportunity to talk to you here today about climate change and have a rational discussion.

I am not going to address some of the issues that Professor Michaels raised. I hope that I may be able to do so in the question and answer session.

Today is November the 17th, and my dad was born 91 years ago on November the 17th, 1919.

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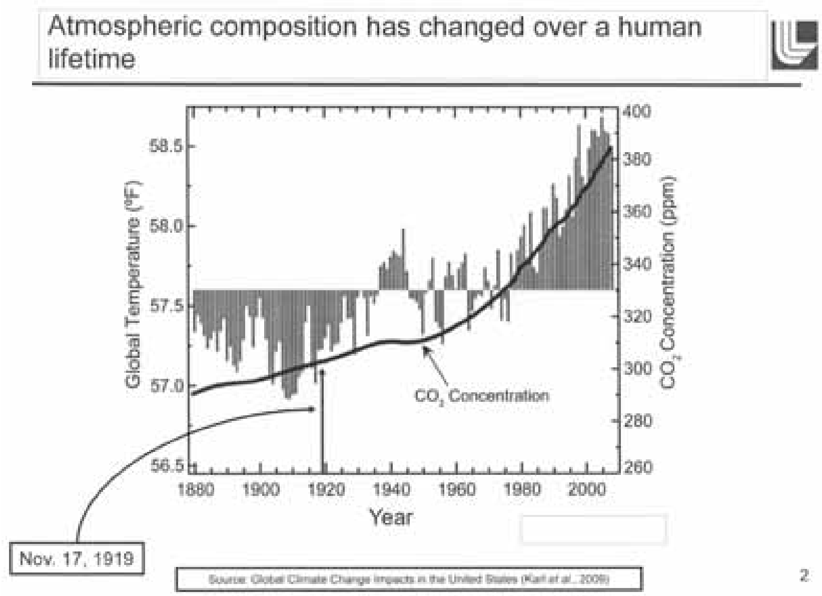

This figure is from the report which was published last year by the U.S. Global Change Program, *Global Climate Change Impacts in the United States*; and what you see on the right-hand side is a scale that shows you the change in atmospheric CO_2 levels, as Dr. Cicerone mentioned earlier, measured worldwide. On the left-hand side, the temperature change, this difficult estimate of the average temperature of the planet.

And the point I want to illustrate with this is over a human lifetime there has been a change from roughly 300 parts per million per volume CO_2 in the atmosphere to 390. That's not a belief system. People often ask me, Dr. Santer, do you believe in global warming? I believe in facts and evidence. This is a fact. I think we can all agree on this.

So the question is, what did this change in atmospheric composition do, if anything? Well, that's a difficult question to answer. Climate change is not an either/or proposition. It's not either all human influences or all natural influences. Clearly, many things are happening simultaneously: massive volcanic eruptions, changes in the Sun's energy output, human changes in greenhouse gases, and aerosol particles. The difficulty is separating the natural factors from the nonnatural factors.

In the real world, of course, we can't do that. We have no undisturbed Earth without any human intervention. But with computer models of the climate system we can look purely at the natural factors, and that's what you see here, and how they may have changed over the 20th century, changes in the Sun's energy output and volcanic aerosols.

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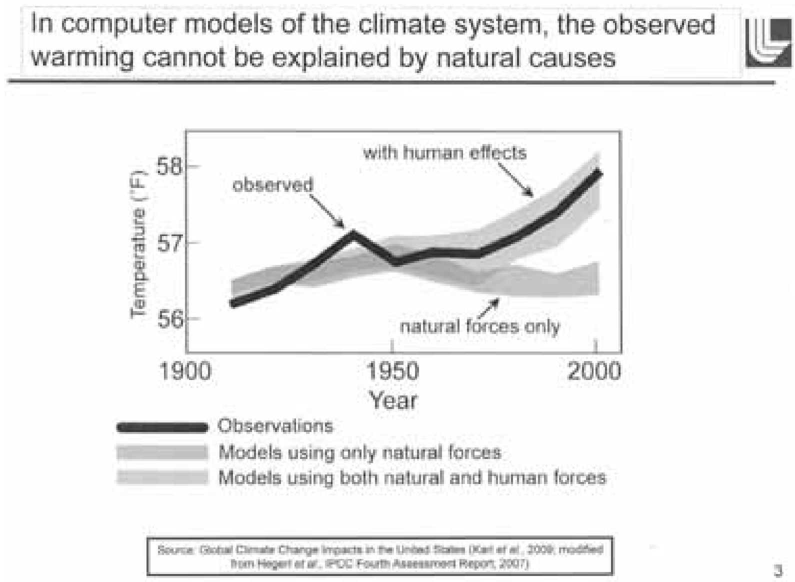
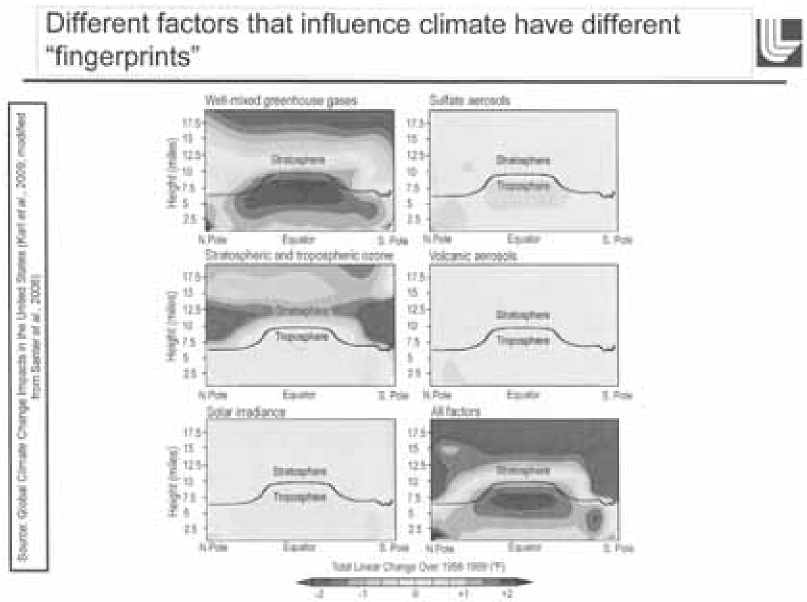


You use a computer model, many computer models in this case, and what you can see is that just with natural factors you can't explain the warming we have observed over the second half of the 20th century. When you have put in combined human and natural factors, you can.

Now, this isn't convincing evidence. I agree with Dr. Lindzen on that point. He said, you know, if you just look at global temperature alone it's difficult to make reliable influences about causation.

And that's why, as scientists since 1979, since the first paper on fingerprinting, we have looked beyond the global mean. We have looked at complex patterns of climate change. And what you see here, again from last year's Global Climate Change Impacts in the United States report, is a model-based estimate of the fingerprints of different factors which affect climate.

[The information follows:]



And there are five different fingerprints up there. There are changes in well-mixed greenhouse gases. There are changes in sulfate aerosol particles. Both of those are human. Sulfate aerosols are produced by the burning of fossil fuels. Then there are changes in stratospheric and tropospheric ozone, changes in volcanic aerosols, solar irradiance, and then the final pattern is all factors considered together.

Now, I don't want to go into the details. The key point here is that they are all different. And what we are doing here is we are looking at slices of the atmosphere from the Earth's surface right up to 20 miles, and from the North Pole to the South Pole; and these are model-based estimates of changes in temperature over the last 50 years of the 20th century. They are different, and we exploit those differences in fingerprinting to try and understand cause and effect relationships.

As you have heard, some people still posit even today that the Sun explains everything. That is a testable hypothesis. We routinely look at that hypothesis. Our best understanding is, if the Sun's energy output had slightly increased over the last 50 years, there would be more solar energy arriving at the top of the atmosphere; we would see heating throughout the full vertical extent of the atmosphere. We don't see that.

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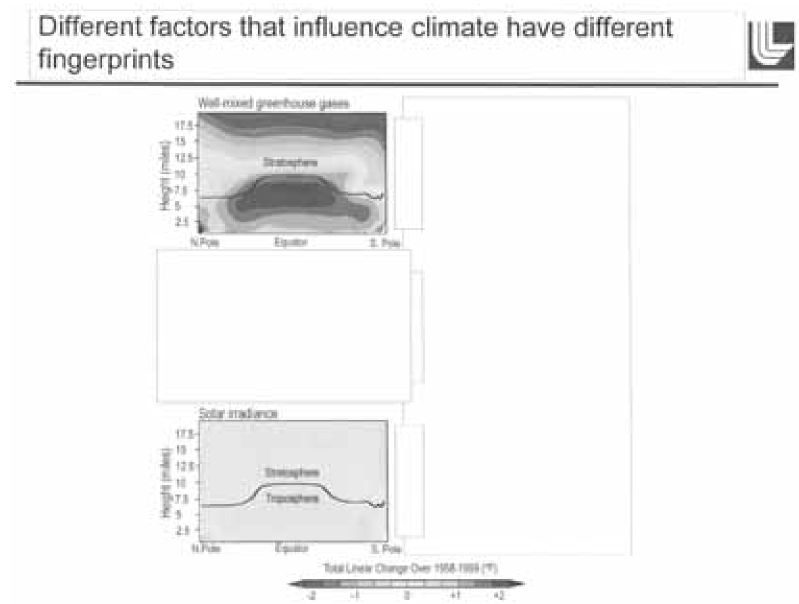

The reality is that the observations look much more similar to the top fingerprint, the signature of well-mixed greenhouse gases. They don't look anything like the Sun explains everything.

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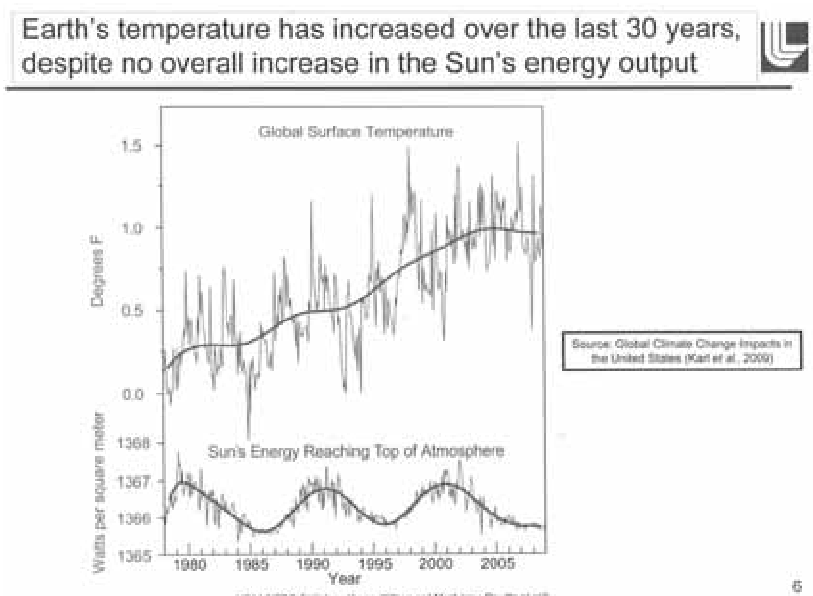

Also, as Dr. Cicerone mentioned earlier, for the last 30 years we have measured with a number of different satellite instruments the Sun's energy output in space, and we know that there are these 11-

year cycles, but there is no overall increase in temperature in solar irradiance over the last 30 years. There is, however, an increase in temperature over the last 30 years. So the Sun explains everything does not convincingly explain observed climate change. It doesn't fit the bill.

Now, back at the time when this fingerprinting work first came to the fore, Professor Michaels mentioned that in the mid-1990s it was criticized. Quite rightly, I believe. People said if there really is a human-caused fingerprint in observations, go look in many different locations, not just at the at the surface of the Earth, not just in atmospheric temperatures. But look in rainfall, look in moisture, look in pressure patterns. And that's exactly what the community has done. The community has looked in many different aspects of the climate system, used these statistical rigorous comparisons to look at patterns of change, not global mean numbers, and has been able to show that the changes in all of these things are not consistent with natural causation alone. Now, you may not like that result, but that's our best understanding that we have. The climate system is telling us an internally and physically consistent story.

[The prepared statement of Dr. Santer follows:]

BIOGRAPHY AND PREPARED STATEMENT OF BENJAMIN D. SANTER

1. Biographical information

My name is Benjamin Santer. I am a climate scientist. I work at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Laboratory (LLNL) in California. I am testifying today as a member of Lawrence Livermore National Laboratory and of PCMDI.

I have been employed at PCMDI since 1992. PCMDI was established in 1989 by the U.S. Department of Energy, and has been at LLNL since then. PCMDI's mission is to quantify how well computer models simulate important aspects of present-day and historical climate, and to reduce uncertainties in model projections of future climate change.

PCMDI is not engaged in developing its own computer model of the climate system ("climate model "). Instead, we study the performance of all the world's major climate models. We also coordinate international climate modeling simulations, and help the entire climate science community to analyze and evaluate climate models.

I have a Ph.D. in Climatology from the Climatic Research Unit of the University of East Anglia in the United Kingdom. I went to the Climatic Research Unit in 1983 because it was (and still is) one of the world's premier institutions for studying past, present, and future climate. During the course of my Ph.D., I was privileged to work together with exceptional scientists—with people like Tom Wigley, Phil Jones, Keith Briffa, and Sarah Raper.

My thesis explored the use of so-called "Monte Carlo" methods in assessing the quality of different climate models. After completing my Ph.D. in 1987, I spent five years at the MaxPlanck Institute for Meteorology in Hamburg, Germany. During my time in Hamburg, I worked with Professor Klaus Hasselmann on the development and application of "fingerprint" methods, which are valuable tools for improving our understanding of the nature and causes of climate change.

Much of the following testimony is adapted from a chapter Tom Wigley and I recently published in a book edited by the late Professor Stephen Schneider (1), and from previous testimony I gave to the House Select Committee on Energy Independence and Global Warming (2).

2. Introduction

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Programme. The goals of this panel were threefold: to assess available scientific information on climate change, to evaluate the environmental and societal impacts of climate change, and to formulate response strategies. The IPCC's first major scientific assessment, published in 1990, concluded that "unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more" (3).

In 1996, the IPCC's second scientific assessment made a more definitive statement regarding human impacts on climate, and concluded that "the balance of evidence suggests a discernible human influence on global climate" (4). This cautious sentence marked a paradigm shift in our scientific understanding of the causes of recent climate change. The shift arose for a variety of reasons. Chief amongst these was the realization that the cooling effects of sulfate aerosol particles (which are produced by burning fossil fuels that contain sulfates) had partially masked the warming signal arising from increasing atmospheric concentrations of greenhouse gases (5).

A further major area of progress was the increasing use of "fingerprint" studies (6, 7, 8). The strategy in this type of research is to search for a "fingerprint" (the climate change pattern predicted by a computer model) in observed climate records. The underlying assumption in fingerprinting is that each "forcing" of climate—such as changes in the Sun's energy output, volcanic dust, sulfate aerosols, or greenhouse gas concentrations—has a unique pattern of climate response (see Figure 1). Fingerprint studies apply signal processing techniques very similar to those used in electrical engineering (6). They allow researchers to make rigorous tests of competing hypotheses regarding the causes of recent climate change.

The third IPCC assessment was published in 2001, and went one step further than its predecessor. The third assessment reported on the magnitude of the human effect on climate. It found that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (9). This conclusion was based on improved estimates of natural climate variability, better reconstructions of temperature fluctuations over the last millennium, continued warming of the climate system, refinements in fingerprint methods, and the use of results from more (and improved) climate models, driven by more accurate and complete estimates of the human and natural "forcings" of climate.

This gradual strengthening of scientific confidence in the reality of human influences on global climate continued in the IPCC AR4 report, which stated that "warming of the climate system is unequivocal", and that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (10) (where "very likely" signified >90% probability that the statement is correct). The AR4 report justified this increase in scientific confidence on the basis of ". . . longer and improved records, an expanded range of observations and improvements in the simulation of many aspects of climate and its variability" (10). In its contribution to the AR4, IPCC Working Group II concluded that anthropogenic warming has had a discernible influence not only on the physical climate system, but also on a wide range of biological systems which respond to climate (11).

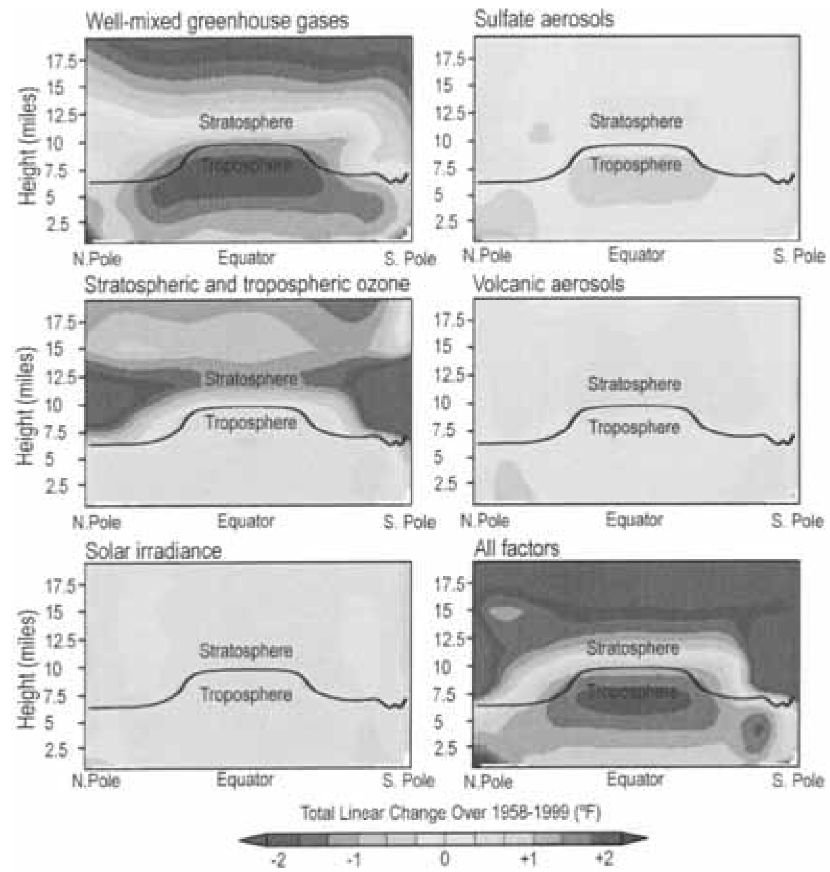

Figure 1: Climate simulations of the vertical profile of temperature change due to five different factors, and the effect due to all factors taken together. The panels above represent a cross-section of the atmosphere from the North Pole to the South Pole, and from the surface up into the stratosphere. The black lines show the approximate location of the tropopause, the boundary between the lower atmosphere (the troposphere) and the stratosphere. This Figure is reproduced from Karl *et al.* (12).

Extraordinary claims require extraordinary proof (13). The IPCC's extraordinary claim that human activities significantly altered both the chemical composition of Earth's atmosphere and the climate system *has* received extraordinary scrutiny. This claim has been independently corroborated by the U.S. National Academy of Sciences (14), the Science Academies of eleven nations (15), and the Synthesis and Assessment Products of the U.S. Climate Change Science Plan (16). Many of our professional scientific organizations have also affirmed the reality of a human influence on global climate (17).

Despite the overwhelming evidence of pronounced anthropogenic effects on climate, important uncertainties remain in our ability to quantify the human influence. The experiment that we are performing with the Earth's atmosphere lacks a suitable control: we do not have a convenient "undisturbed Earth", which would provide a reference against which we could measure the anthropogenic contribution to climate change. We must therefore rely on numerical models and paleoclimate evidence (18, 19, 20) to estimate how the Earth's climate might have evolved in the absence of any human intervention. Such sources of information will always have significant uncertainties.

In the following testimony, I provide a personal perspective on recent developments in the field of detection and attribution ("D&A") research. Such research is directed towards detecting significant climate change, and then attributing some portion of the detected change to a specific cause or causes (21, 22, 23, 24). I also make some brief remarks about openness and data sharing in the climate modeling community, and accommodation of "alternative" views in the IPCC.

3. Recent Progress in Detection and Attribution Research

Fingerprinting

The IPCC and National Academy findings that human activities are affecting global-scale climate are based on multiple lines of evidence:

1. Our continually-improving physical understanding of the climate system, and of the human and natural factors that cause climate to change;
2. Evidence from paleoclimate reconstructions, which enables us to place the warming of the 20th century in a longer-term context (25, 26);
3. The qualitative consistency between observed changes in different aspects of the climate system and model predictions of the changes that should be occurring in response to human influences (10, 27);
4. Evidence from rigorous quantitative fingerprint studies, which compare observed patterns of climate change with results from computer model simulations.

Most of my testimony will focus on the fingerprint evidence, since this is within my own area of scientific expertise.

As noted above, fingerprint studies search for some pattern of climate change (the "fingerprint") in observational data. The fingerprint can be estimated in different ways, but is typically obtained from a computer model experiment in which one or more human factors are varied according to the best-available estimates of their historical changes. Different statistical techniques are then applied to quantify the level of agreement between the fingerprint and observations and between the fingerprint and estimates of the natural internal variability of climate. This enables researchers to make rigorous tests of competing hypotheses (28) regarding the possible causes of recent climate change (21, 22, 23, 24).

While early fingerprint work dealt almost exclusively with changes in near-surface or atmospheric temperature, more recent studies have applied fingerprint methods to a range of different variables, such as changes in ocean heat content (29, 30), Atlantic salinity (31), sea-level pressure (32), tropopause height (33), rainfall patterns (34, 35), surface humidity (36), atmospheric moisture (37, 38), continental river runoff (39), and Arctic sea ice extent (40). The general conclusion is that for each of these variables, natural causes alone cannot explain the observed climate changes over the second half of the 20th century. The best statistical explanation of the observed climate changes invariably involves a large human contribution.

These fingerprint results are robust to the processing choices made by different groups, and show a high level of physical consistency across different climate variables. For example, observed atmospheric water vapor increases (41) are physically consistent with increases in ocean heat content (42, 43) and near-surface temperature (44, 45).

There are a number of popular misconceptions about fingerprint evidence. One misconception is that fingerprint studies consider global-mean temperatures only, and thus provide a very poor constraint on the relative contributions of human and natural factors to observed changes (46). In fact, fingerprint studies rely on information about the detailed spatial structure (and often the combined space and time structure) of observed and simulated climate changes. Complex patterns provide much stronger constraints on the possible contributions of different factors to observed climate changes (47, 48, 49).

Another misconception is that computer model estimates of natural internal climate variability ("climate noise") are accepted uncritically in fingerprint studies, and are never tested against observations (50). This is demonstrably untrue. Many fingerprint studies test whether model estimates of climate noise are realistic. Such tests are routinely performed on year-to-year and decade-to-decade timescales, where observational data are of sufficient length to obtain reliable estimates of observed climate variability (51, 52, 53, 54).

Because regional-scale climate changes will determine societal impacts, fingerprint studies are increasingly shifting their focus from global to regional scales (55). Such regional studies face a number of challenges. One problem is that the noise of natural internal climate variability typically becomes larger when averaged over increasingly finer scales (56), so that identifying regional and local climate signals becomes more difficult.

Another problem relates to the climate "forcings" used in computer model simulations of historical climate change. As scientific attention shifts to ever smaller spatial scales, it becomes more important to obtain reliable information about these forcings. Some forcings are both uncertain and highly variable in space and time (57, 58). Examples include human-induced changes in land surface properties (59) or in the concentrations of carbon-containing aerosols (60,61). Neglect or inaccurate specification of these factors complicates D&A studies.

Despite these problems, numerous researchers have now shown that the climate signals of greenhouse gases and sulfate aerosols are identifiable at continental and sub-continental scales in many different regions around the globe (62, 63, 64, 65). Related work (66, 67) suggests that a human-caused climate signal has already emerged from the background noise at spatial scales at or below 500 km (68), and may be contributing to regional changes in the distributions of plant and animal species (69).

In summarizing this section of my testimony, I note that the focus of fingerprint research has evolved over time. Its initial emphasis was on global-scale changes in Earth's surface temperature. Subsequent research demonstrated that human fingerprints were identifiable in many different aspects of the climate system—not in surface temperature only. We are now on the verge of detecting human effects on climate at much finer regional scales of direct relevance to policymakers, and in variables tightly linked to climate change impacts (70, 71, 72, 73, 74).

Assessing Risks of Changes in Extreme Events

We are now capable of making informed scientific statements regarding the influence of human activities on the likelihood of extreme events (75, 76, 77).

As noted previously, computer models can be used to perform the control experiment (no human effects on climate) that we cannot perform in the real world. Using the "unforced" climate variability from a multi-century control run, it is possible to determine how many times an extreme event of a given magnitude should have been observed in the absence of human interference. The probability of obtaining the same extreme event is then calculated in a perturbed climate—for example, in a model experiment with historical or future increases in greenhouse gases, or under some specified change in mean climate (78). Comparison of the frequencies of extremes in the control and perturbed experiments allows climate scientists to make probabilistic statements about how human-induced climate change may have altered the likelihood of the extreme event (53, 78, 79). This is sometimes referred to as an assessment of "fractional attributable risk" (78).

Recently, a "fractional attributable risk" study of the 2003 European summer heat wave concluded that "*there is a greater than 90% chance that over half the risk of European summer temperatures exceeding a threshold of 1.6 K is attributable to human influence on climate*" (78).

This study (and related work) illustrates that the "D&A" community has moved beyond analysis of changes in the mean state of the climate. We now apply rigorous statistical methods to the problem of estimating how human activities may alter the probability of occurrence extreme events. The demonstration of human culpability in changing these risks is likely to have significant implications for the debate on policy responses to climate change.

4. Summary of Detection and Attribution Evidence

In evaluating how well a novel has been crafted, it is important to look at the internal consistency of the plot. Critical readers examine whether the individual storylines are neatly woven together, and whether the internal logic makes sense.

We can ask similar questions about the "story" contained in observational records of climate change. The evidence from numerous sources (paleoclimate data, rigorous fingerprint studies, and qualitative comparisons of modeled and observed climate changes) shows that the climate system is telling us an internally consistent story about the causes of recent climate change.

Over the last century, we have observed large and coherent changes in many different aspects of Earth's climate. The oceans and land surface have warmed (29, 30, 42, 43, 44, 45, 80, 81). Atmospheric moisture has increased (36, 37, 38, 41). Rainfall patterns have changed (34, 35). Glaciers have retreated over most of the globe (82, 83, 84). The Greenland Ice Sheet has lost some of its mass (85). Sea level has risen (86). Snow and sea-ice extent have decreased in the Northern Hemisphere (40, 87, 88, 89). The stratosphere has cooled (90), and there are now reliable indications that the troposphere has warmed (16, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100). The height of the tropopause has increased (33). Individually, all of these changes are consistent with our scientific understanding of how the climate system should be responding to anthropogenic forcing. Collectively, this behavior is inconsistent with the changes that we would expect to occur due to natural variability alone.

There is now compelling scientific evidence that human activity has had a discernible influence on global climate. However, there are still significant uncertainties in our estimates of the size and geographical distribution of the climate changes projected to occur over the 21st century (10). These uncertainties make it difficult for us to assess the magnitude of the mitigation and adaptation problem that faces us and our descendants. The dilemma that confronts us, as citizens and stewards of this planet, is how to act in the face of both hard scientific evidence that our actions are altering global climate and continuing uncertainty in the magnitude of the planetary warming that faces us.

5. Openness and Data Sharing in the Climate Modeling Community

Recently, concerns have been expressed about ease of access to the information produced by computer models of the climate system. "Climate modeling" is sometimes portrayed as a secretive endeavor. This is not the case.

In the 1970s and 1980s, the evaluation and intercomparison of climate models was largely a qualitative endeavor, mostly performed by modelers themselves. It often involved purely visual examination of maps from a single model and observations (or from several different models). There were no standard benchmark experiments, and there was little or no community involvement in model diagnosis. It was difficult to track changes in model performance over time (101).

This situation changed dramatically with the start of the Atmospheric Model Intercomparison Project (AMIP) in the early 1990s. AMIP involved running different Atmospheric General Circulation Models (AGCMs) with observed sea-surface temperatures and sea-ice changes over 1979 to 1988. Approximately 30 modeling groups from 10 different countries participated in the design and diagnosis of the AGCM simulations. Subsequent "revisits" of AMIP enabled the climate community to track changes in model performance over time (102).

The next major Model Intercomparison Project ("MIP") began in the mid-1990s. In phase 1 of the Coupled Model Intercomparison Project (CMIP–1), over a dozen fully-coupled Atmosphere/Ocean General Circulation Models (A/OGCMs) were used to study the response of the climate system to an idealized climate-change scenario—a 1% per year (compound interest) increase in levels of atmospheric CO_2 (103). The key aspect here was that each modeling group performed the same benchmark simulation, allowing scientists to focus their attention on the task of quantifying (and understanding) uncertainties in computer model projections of future climate change.

AMIP and CMIP have spawned literally dozens of other international *M*odel *I*ntercomparison *P*rojects. "MIPs" are now a *de facto* standard in the climate science community. They have allowed climate scientists to:

- Identify systematic errors common to many different models;
- Track changes in model performance over time (in individual models and collectively);
- Make informed statements about the relative quality of different models;
- Quantify uncertainties in model projections of future climate change.

Full community involvement in "MIPs" has led to more thorough model diagnosis, and to improved climate models.

Perhaps the best-known model intercomparison is phase 3 of CMIP. The CMIP–3 project was a valuable resource for the Fourth Assessment Report (FAR) of the IPCC (10). In the course of CMIP–3, simulation output was collected from 25 different A/OGCMs. The models used in these simulations were from 17 modeling centers and 13 countries. Twelve different types of simulation were performed with each model. The simulations included so-called "climate of the 20th century" experiments (with estimated historical changes in greenhouse gases, various aerosol particles, volcanic dust, solar irradiance, *etc.*), pre-industrial control runs (with no changes in human or natural climate forcings), and scenarios of future changes in greenhouse gases. All of the simulation output was stored at LLNL's PCMDI.

At present, 35 Terabytes of CMIP–3 data are archived at PCMDI, and nearly 1 Petabyte of model output (1 Petabyte = 10^{15} bytes) has been distributed to over 4,300 users in several dozen countries. The CMIP–3 multi-model archive has transformed the world of climate science. As of November 2010, over 560 peer-reviewed publications used CMIP–3 data. These publications formed the scientific backbone of the IPCC FAR. The CMIP–3 archive provided the basis for roughly 75% of the figures in Chapters 8–11 of the Fourth Assessment Report, and for 4 of the 7 figures in the IPCC "Summary for Policymakers" (10).

The CMIP–3 database can be used by anyone, free of charge. It is one of the most successful data-sharing models in any scientific community—not just the climate science community.

6. Accommodation of "alternative" views in the IPCC

Some parties critical of the IPCC have claimed that it does not accommodate the full range of scientific views on the subject of the nature and causes of climate change. In my opinion, such claims are specious. I would contend that all four previous IPCC Assessments (3, 4, 9, 10) have dealt with "alternative viewpoints" in a thorough and comprehensive way. The IPCC reports have devoted extraordinary scientific attention to a number of highly-publicized (and incorrect) claims.

Examples include the claim that the tropical lower troposphere cooled over the satellite era; that the water vapor feedback is zero or negative; that variations in the Sun's energy output explain all observed climate change. The climate science community has not dismissed these claims out of hand. Scientists have done the research necessary to determine whether these "alternative viewpoints" are scientifically credible, and have shown that they are not.

7. Concluding Thoughts

My job is to evaluate climate models and improve our scientific understanding of the nature and causes of climate change. I chose this profession because of a deep and abiding curiosity about the world in which we live. The same intellectual curiosity motivates virtually all climate scientists I know.

As my testimony indicates, the scientific evidence is compelling. We know, beyond a shadow of a doubt, that human activities have changed the composition of Earth's atmosphere. And we know that these human-caused changes in the levels of greenhouse gases make it easier for the atmosphere to trap heat. This is simple, basic physics. While there is legitimate debate in the scientific community about the *size* of the human effect on climate, there is really no serious scientific debate about the scientific finding that our planet warmed over the last century, and that human activities are implicated in this warming.

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Chairman BAIRD. Thank you Dr. Santer.

Dr. Alley.

STATEMENT OF RICHARD B. ALLEY, EVAN PUGH PROFESSOR, DEPARTMENT OF GEOSCIENCES AND EARTH AND ENVIRONMENTAL SYSTEMS INSTITUTE, THE PENNSYLVANIA STATE UNIVERSITY

Dr. ALLEY. Yes. Thank you for the honor, Chairman Baird, Mr. Rohrabacher. It's a pleasure to be here.

Your body has, in its wisdom, established mechanisms to gain an assessment of the science. Because, as you know, the lead scientists sometimes can argue about things. In fact, you pay us to argue about things. We love arguing about things. And so you have set up things such as the National Academy to give you assessments that are outside of the argument and say, what does the science say?

And if you look at the assessments, the science is now very clear for my interests, or especially with ice as well as climate history. And the science says that the ice is melting almost everywhere, almost all of it consistent with warming.

[The information follows:]

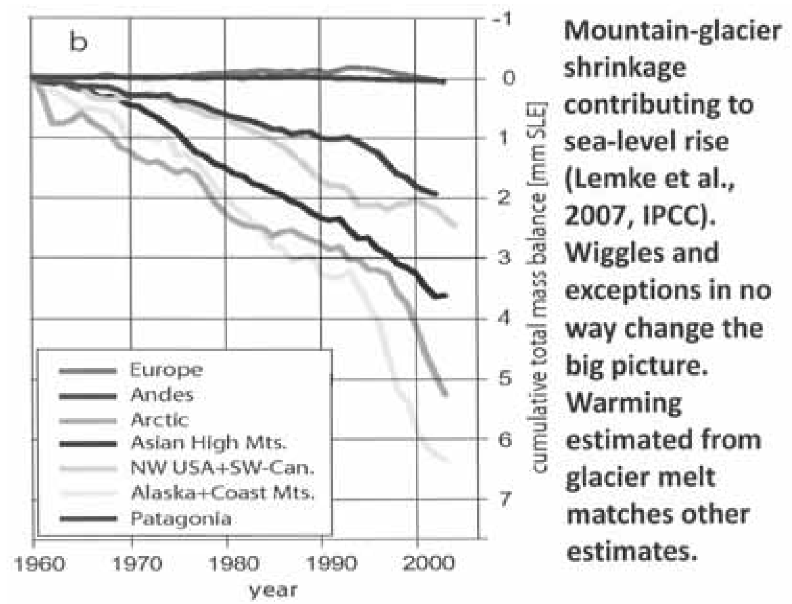
Recent behavior of ice

- Widespread loss, consistent with expectations for warming (reductions in snow, river & lake ice, permafrost, seasonally frozen ground, Arctic sea ice, glaciers, and great ice sheets of Greenland & Antarctica; Lemke et al., IPCC, 2007);
- Growth in a few cold cases (Antarctic sea ice, central Greenland ice sheet) as effects of rising precipitation have exceeded effects of rising temperature; consistent with expectations and projected to reverse with more warming (see Manabe et al., 1992; Liu and Curry, 2010; also see Turner et al., 2009).

There are a few really cold places, the top of Greenland and the frozen ocean water around Antarctica, that increasing precipitation has still been controlling. And that is also consistent with our understanding of the effects of warming, and that is expected to switch to shrinkage in the fairly near future.

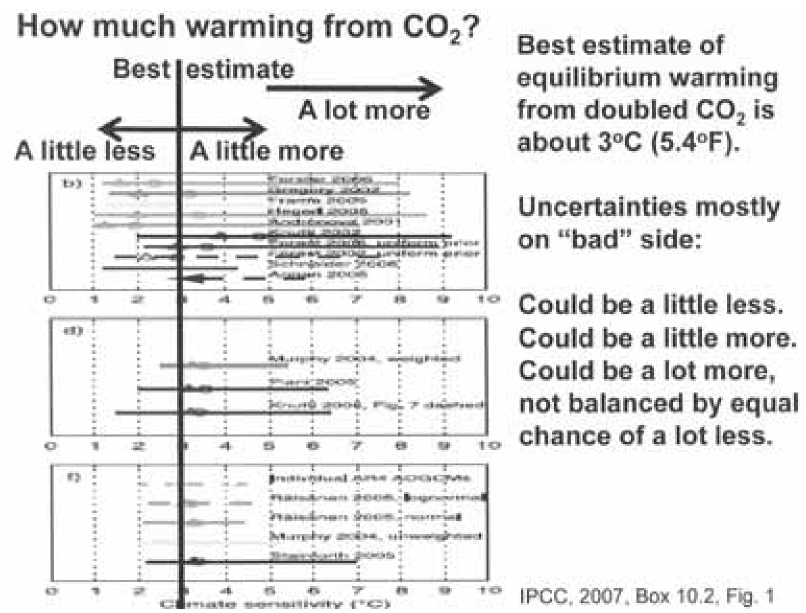
So when we look at the world, what we see is ice shrinking because it's getting warmer. And in fact you can estimate the warming from looking at how much the ice shrinks. And that agrees with the thermometers.

[The information follows:]



This is the plot of melting of mountain glaciers contributing to the global sea level rise. You will find people that put the plummeting one there and say catastrophe, and you will find people that look at that blue one on top that's Norway that grew a little bit before it started shrinking, or they look at one wiggle in that black one, which is the Himalayas, and they say, oh, nothing's happening. If you look at those curves, the mountain glaciers assessed taken together are shrinking, and they are contributing to sea level rise. And there is really no serious question about that.

[The information follows:]

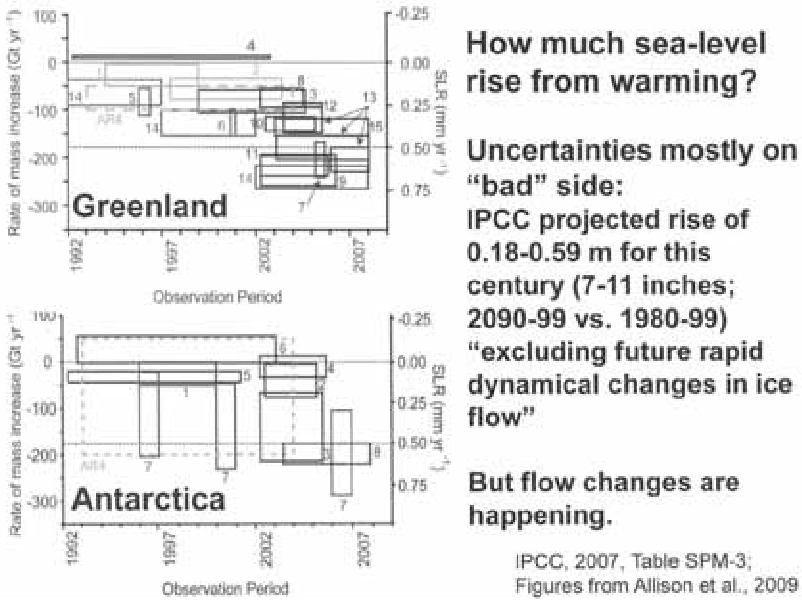


Now, if we want to know what happens in the future, this is a very complicated plot, and I hope that you don't look in any great detail at it. This is how much warming we expect from rising CO_2. And this particular one is if you just doubled CO_2 and then let the climate come into equilibrium how much warming. We may go way past doubled CO_2. But the blue number up there, which is a little over five degrees Fahrenheit, is sort of the most likely. If you could bet on one horse, you would bet on that horse.

You have heard Dr. Michaels and earlier you heard Dr. Lindzen arguing, well, couldn't it be lower than that, down the green arrow? And it certainly could be. That's within the realm of scientific possibility. But the orange arrow shows that it could be higher than that, and the red arrow shows it could be a lot higher than that.

You have now sort of had a discussion or a debate here between people who are giving you the blue one and people giving you the green one. This is certainly not both sides. If you want both sides of it, we would have to have somebody in here who is screaming hairy panic conniption fit on the red end. But you are hearing just one, very optimistic side—we wish that Dr. Michaels and Dr. Lindzen were correct—against the assessed central value.

[The information follows:]



Now, when we look at the impacts of warming we get the same sort of story. The IPCC looked at sea level rise, and they said, well, this century it's probably not going to be huge. But that excludes anything weird that the ice sheets do. And we are very nervous because the ice sheets have started doing something weird, and they started doing it a hundred years before we expected them to from the previous assessment. So when you look at sea level rise, what you find is that it's going to rise. There is virtually no way to avoid that. But there is a big unknown.

And so if you look at what people have been planning for, it's something. It might be a little better, a little worse, or a lot worse. But we don't find any evidence for a lot better. The ice sheets are already shrinking, and they are shrinking way before we expected them to.

[The information follows:]

Sea-level rise from ice sheets

- Possibility of ice-flow "tipping points" causing loss faster than anticipated;
- Complete ice-sheet loss still believed to require at least centuries or longer; but
- Within decades may warm enough to lose an ice sheet;
- Geologic history clearly shows much higher sea level during much warmer times;
- Greenland Ice Sheet more than 7 m of sea level by itself; Antarctic Ice Sheet much bigger;
- Roughly 10% of world population within 10 m of sea level (McGranahan et al., 2007).

Now, we do not believe in any way that you could melt a whole ice sheet in mere decades. But we are very nervous that within decades we could get warm enough to melt a whole ice sheet. Now, Greenland would be seven meters plus of sea level. Antarctica is very much bigger than Greenland. The last estimate I saw, ten percent of the world population lives within 10 meters of sea level. So the amount of ice which is in play is huge for people and where they live and what they do.

We don't have really reliable projections, but we do see sea level rising and the possibility that this century we get to a point where we are committed to very, very large rises. So what the planning people have been doing on this is our best estimate. It could be a little better, a little worse, or a lot worse, where worse I mean larger impacts on people.

So, just to summarize then, it's getting warmer. That's melting ice. This is all consistent with what we understand about what should happen. Everything is in there. We keep hoping that we have overestimated the impacts, it will be better than that. But if you plot all of the unknowns, it could be a little better, a little worse, or a lot worse.

Thank you.

[The prepared statement of Dr. Alley follows:]

PREPARED STATEMENT OF RICHARD B. ALLEY

Introduction. My name is Richard Alley. I am Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute at the Pennsylvania State University. I have authored over 200 refereed scientific papers, which are "highly cited" according to a prominent indexing service, and I have made many hundreds of public presentations concerning my areas of expertise. My research is especially focused on the great ice sheets of Greenland and Antarctica, their potential for causing major changes in sea level, the climate records they contain, and their other interactions with the environment; I also study mountain glaciers, and ice sheets of the past. I have served with distinguished national and international teams on major scientific assessment bodies, including chairing the National Research Council's Panel on Abrupt Climate Change (report published in

2002), and serving the Intergovernmental Panel on Climate Change (IPCC) in various ways, and the U.S. Climate Change Science Program. I had the honor of testifying to the Subcommittee on Investigations and Oversight of the House Committee on Science and Technology in 2007; my testimony today updates and extends the material I presented then.

Background on Climate Change and Global Warming. Scientific assessments such as those of the National Academy of Sciences of the United States (e.g., National Research Council, 1975; 1979; 2001; 2006; 2008; 2010a; 2010b), the U.S. Climate Change Science Program, and the Intergovernmental Panel on Climate Change have for decades consistently found with increasingly high scientific confidence that human activities are raising the concentration of CO_2 and other greenhouse gases in the atmosphere, that this has a warming effect on the climate, that the climate is warming as expected, and that the changes so far are small compared to those projected if humans burn much of the fossil fuel on the planet.

The basis for expecting and understanding warming from CO_2 is the fundamental physics of how energy interacts with gases in the atmosphere. This knowledge has been available for over a century, was greatly refined by military research after World War II, and is directly confirmed by satellite measurements and other data (e.g., American Institute of Physics, 2008; Harries et al., 2001; Griggs and Harries, 2007).

Although a great range of ideas can be found in scientific papers and in statements by individual scientists, the scientific assessments by bodies such as the National Academy of Sciences consider the full range of available information. The major results brought forward are based on multiple lines of evidence provided by different research groups with different funding sources, and have repeatedly been tested and confirmed. Removing the work of any scientist or small group of scientists would still leave a strong scientific basis for the main conclusions.

Ice Changes. There exists increasingly strong evidence for widespread, ongoing reductions in the Earth's ice, including snow, river and lake ice, Arctic sea ice, permafrost and seasonally frozen ground, mountain glaciers, and the great ice sheets of Greenland and Antarctica. The trends from warming are modified by effects of changing precipitation and of natural variability, as I will discuss soon, so not all ice everywhere is always shrinking. Nonetheless, warming is important in the overall loss of ice, although changes in oceanic and atmospheric circulation in response to natural or human causes also have contributed and will continue to contribute to changes. The most recent assessment by the IPCC remains relevant (Lemke et al., 2007). Also see the assessment of the long climatic history of the Arctic by the U.S. Climate Change Science Program (CCSP, 2009), showing that in the past warming has led to shrinkage of Arctic ice including sea ice and the Greenland ice sheet, and that sufficiently large warming has removed them entirely.

The large snowfalls that closed much of Washington, D.C. last winter are successfully explained by the accidental "weather" of El Nino and the North Atlantic Oscillation (Seager et al., 2010), and do not undermine our understanding of the long-term effects of warming on snow and ice. The existence of such variability virtually guarantees that any climate record will be "bumpy", but scientific techniques successfully identify the long-term trends in such bumpy records.

For sea ice (frozen ocean water), the trends in Arctic sea-ice area and volume have been strongly downward. The reports of the National Snow and Ice Data Center (a research institute at the University of Colorado with funding from NSF, NASA, and NOAA) provide up-to-date data; also see Kwok and Rothrock (2009) among many other studies. Note that the observed shrinkage of Arctic sea ice with warming is consistent with (although somewhat faster than) expectations from a great range of climate models. The models generally project shrinkage of Antarctic sea ice once warming becomes notably larger, but for the warming to date some models have projected growth of Antarctic sea ice in response to changing winds and ocean conditions in the very cold Antarctic winter including freshening of the surface waters from increasing precipitation and shrinkage of the land ice, consistent with observations (e.g., Manabe et al., 1992; Turner et al., 2009; Liu and Curry, 2010).

Glaciers and ice caps occur primarily in mountainous areas, and near but distinct from the Greenland and Antarctic ice sheets. On average, the world's glaciers were not changing much around 1960 but have lost mass since, generally with faster mass loss more recently. Glacier melting contributed almost an inch to sea-level rise during 1961–2003 (about 0.50 mm/year, and a faster rate of 0.88 mm/year during 1993–2003). Glaciers experience numerous intriguing ice-flow processes (surges, kinematic waves, tidewater instabilities), allowing a single glacier over a short time to behave in ways that are not controlled by climate. Care is thus required when interpreting the behavior of a particular iconic glacier (and especially the coldest tropical glaciers, which interact with the atmosphere somewhat differently from the great majority of glaciers). But, ice-flow processes and regional effects average out if enough glaciers are studied for a long enough time, allowing glaciers to be quite good indicators of climate change. Furthermore, for a typical mountain glacier, a small warming will increase the mass loss by melting roughly 5 times more than the increase in precipitation from the ability of the warmer air to hold more moisture. Thus, glaciers respond primarily to temperature changes during the summer melt season. Indeed, the observed shrinkage of glaciers, contributing to sea-level rise, has occurred despite a general increase in wintertime snowfall in many places (Lemke et al., 2007). An erroneous paragraph about Himalayan Glaciers in the IPCC assessment from Working Group II in 2007 was identified by a distinguished scientific team with ties to the IPCC (Cogley et al., 2010), and this in no way changes the reality that strong glacier melting has been occurring, with more warming expected to cause more melting (Meehl et al., 2007).

Ice-sheet changes. The large ice sheets of Greenland and Antarctica are of special interest, because they are so big and thus could affect sea level so much. Melting of all of the world's mountain glaciers and small ice caps might raise sea level by about 1 foot (0.3 m), but melting of the great ice sheets would raise sea level by just over 200 feet (more than 60 m). We do not expect to see melting of most of that ice, but even a relatively small change in the ice sheets could matter to the world's coasts; roughly 10% of the world's population lives within 10 m of sea level (McGranahan et al., 2007).

Data collected recently show that the ice sheets very likely have been shrinking and contributing to sea level rise over 1993–2003 and with even larger loss by 2005 and more recently, as noted in the IPCC report and updated elsewhere (e.g., Allison *et al*., 2009). Thickening in central Greenland from increased snowfall has been more than offset by increased melting in coastal regions. Many of the fast-moving ice streams that drain Greenland and parts of Antarctica have accelerated, transferring mass to the ocean and further contributing to sea-level rise.

Measurements of mass loss from the ice sheets rely on multiple techniques, implemented by multiple groups. Techniques include repeatedly "weighing" the ice sheets using the GRACE gravity satellites, measuring changes in surface elevation using radar or laser altimeters from satellite or aircraft, and comparing snow delivered to the ice sheets (estimated from measurements on the ice or from atmospheric models) to loss of ice by melting or flow into the ocean; the results are checked against changes in the ocean level (together with estimates of sea-level rise from other sources) and against changes in Earth's rotation caused by the water moving from ice sheets into the ocean (e.g., Allison et al., 2009; Cazenave et al., 2009; Lemke et al., 2007). To date, sea-level rise has been controlled more by mountain-glacier melting and expansion of ocean water as it warms, but ice sheets have the greatest potential to increase their contribution in the future.

Ice-sheet behavior. An ice-sheet is a two-mile-thick, continent-wide pile of snow that has been squeezed to ice under the weight of more snowfall. All piles tend to spread under their own weight, restrained by their own strength (which is why spilled coffee spreads on a table top but the stronger table beneath does not spread), by friction beneath (so pancake batter spreads faster on a greased griddle than on a dry waffle iron), or by "buttressing" from the sides (so a spatula will slow the spreading of the pancake batter). Observations in Greenland have shown that meltwater on top of the ice sheet flows through the ice to the bottom and reduces friction there. More melting in the future thus may reduce friction further, speeding the production of icebergs or exposing more ice to melting from warmth at low altitude, and thus speeding the increase in sea level (Parizek and Alley, 2004).

Some early gothic cathedrals suffered from the "spreading-pile" problem, in which the sides tended to bulge out while the roof sagged down, with potentially unpleasant consequences. The beautiful solution was the flying buttress, which transfers some of the spreading tendency to the strong earth beyond the cathedral. Ice sheets also have flying buttresses, called ice shelves. The ice reaching the ocean usually does not immediately break off to form icebergs, but remains attached to the ice sheet while spreading over the ocean. The friction of these ice shelves with local high spots in the sea floor, or with the sides of embayments, helps restrain the spreading of the ice sheet much as a flying buttress supports a cathedral. The ice shelves are at the melting point where they contact water below, and are relatively low in elevation hence warm above. Ice shelves thus are much more easily affected by climatic warming than are the thick, cold central regions of ice sheets. Rapid melting or collapse of several ice shelves has occurred recently, allowing the "gothic cathedrals" behind to spread faster, contributing to sea-level rise. Many additional ice shelves remain that have not changed notably, and these contribute to buttressing of much more ice than was supported by those ice shelves that experienced the large recent changes, so the potential for similar changes contributing to sea-level rise in the future is large.

Although science has succeeded in generating useful understanding and models of numerous aspects of the climate system, similar success is not yet available for ice-sheet projections, for reasons that I would be happy to explore with the committee. We do not expect ice sheets to collapse so rapidly that they could raise sea level by meters over decades; simple arguments point to at least centuries. However, the IPCC (2007) is quite clear on the lack of scientific knowledge to make confident projections of ice-sheet behavior. The changes in ice-sheet flow that have been contributing to sea-level rise were not projected in the 2001 assessment (see Lemke et al., 2007), part of the reason why best-estimate projections of sea-level rise have fallen below observations (Rahmstorf et al., 2007). For 2007, the IPCC noted that the sea-level-rise projections provided excluded contributions from "future rapid dynamical changes in ice flow" (Table SPM–3) "because a basis in published literature is lacking" (page SPM14), so that it was not possible to "provide a best estimate or an upper bound for sea level rise" (page SPM15). (The 2007 report also noted a similar difficulty arising from lack of knowledge of feedbacks in the carbon cycle, referring to the possibility that warming will cause much release of methane and carbon dioxide from soils in the Arctic, sediments under the sea, or elsewhere, contributing to more warming.)

In the absence of an assessed estimate of sea-level rise, various "back-of-the-envelope" estimates have been provided. Without in any way representing an assessed projection, these estimates show that a meter or more of sea-level rise this century, with additional and probably faster rise beyond that, falls within the realistic scientific discussion (e.g., Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009).

Tipping Points, and Abrupt Climate Change. A golden retriever leaping to the side will force a canoe to lean, but usually the canoe will remain upright. If an ice chest slides across the seat towards the retriever, this positive feedback will cause the canoe to lean further. In exceptional circumstances a tipping point may be crossed, leading to an abrupt change as the canoe dumps the dog, ice chest, and paddlers into the water.

Much scientific and popular discussion has focused on the possibility that human-caused climate change may force the Earth to cross one of its tipping points. Paleoclimatic history shows clearly that very large, rapid and widespread changes occurred repeatedly in the past (e.g., National Research Council, 2002; CCSP, 2008). An ice-sheet collapse, a large change in the circulation of the North Atlantic Ocean, a rapid outburst of methane stored in sea-floor sediments, a sudden shift in rainfall patterns, or others are possible based on available scientific understanding (CCSP, 2008).

The available assessments, and in particular that of the U.S. Climate Change Science Program (CCSP, 2008), do not point to a high likelihood of triggering an abrupt climate change in the near future that is large relative to natural variability, rapid relative to the response of human economies, and widespread across much or all of the globe. However, such an event cannot be ruled out entirely, and rapidly arriving regional droughts seem more likely than the others considered, with potentially large effects on ecosystems and economies.

Projections of warming from a given release of greenhouse gas generally include a best estimate, the possibility of a somewhat smaller or somewhat larger rise, and the slight possibility of a much larger rise; because of the way feedbacks interact in the climate system, very large changes remain possible if unlikely, and are not balanced by an equal probability of very small changes (e.g., Meehl et al., 2007). The possibility of an abrupt climate change gives a similar shape to the uncertainties about damages from whatever warming occurs, with a chance of very large impacts.

Synopsis. With high scientific confidence, human CO_2 and other greenhouse gases are having a warming influence on the climate, and the resulting rise in temperature is contributing to changes in much of the world's ice. Shrinkage of the large ice sheets was unexpected to many observers but appears to be occurring, and the poor understanding of these changes prevents reliable projections of future sea-level rise over long times. Large, rapid changes in the ice sheets, or in other parts of the Earth system, may be unlikely but cannot be excluded entirely, and such an event could have very large effects.

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BIOGRAPHY FOR RICHARD B. ALLEY

Dr. Richard Alley is Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute at The Pennsylvania State University, University Park, where he has worked since 1988. He was graduated with the Ph.D. in 1987 from the University of Wisconsin-Madison and with M.Sc. (1983) and B.Sc. (1980) degrees from The Ohio State University-Columbus, all in Geology. Dr. Alley teaches, and conducts research on the climatic records, flow behavior, and sedimentary deposits of large ice sheets, to aid in prediction of future changes in climate and sea level. His experience includes three field seasons in Antarctica, eight in Greenland, and three in Alaska. His awards include election to the US National Academy of Sciences, the Tyler Prize for Environmental Achievement, the Revelle Medal of the American Geophysical Union and the Horton Award of their Hydrology Section and Fellowship in the Union, the Seligman Crystal of the International Glaciological Society, the Agassiz Medal of the European Geosciences Union Cryospheric Section, Fellowship in the American Association for the Advancement of Science and the American Academy of Arts and Sciences, the US Presidential Young Investigator Award, the Public Service Award of the Geological Society of America, the Easterbrook Award of their Quaternary Geology and Geomorphology Division and Fellowship in the Society, the American Geological Institute Award For Outstanding Contribution To Public Understanding of the Geosciences, and at Penn State, the Eisenhower Teaching Award, the Evan Pugh Professorship, the Faculty Scholar Medal in Science, and the College of Earth and Mineral Sciences Wilson Teaching Award, Mitchell Innovative Teaching Award and Faculty Mentoring Award. Dr. Alley has served on a variety of advisory panels and steering committees, including chairing the National Research Council's Panel on Abrupt Climate Change and participating in the UN Intergovernmental Panel on Climate Change (which was co-recipient of the 2007 Nobel Peace Prize), and has provided requested advice to numerous government officials in multiple administrations including a US Vice President, the President's Science Advisor, and committees and individual members of the US Senate and the House of Representatives. He has published over 200 refereed papers, and is a "highly cited" scientist as indexed by ISI. His popular account of climate change and ice cores, The Two-Mile Time Machine, was chosen science book of the year by Phi Beta Kappa in 2001. Dr. Alley is happily married with two daughters, two cats, two bicycles, and a pair of soccer cleats.

Chairman BAIRD. Thank you, Dr. Alley.

Dr. Feely.

STATEMENT OF RICHARD A. FEELY, SENIOR SCIENTIST, PACIFIC MARINE ENVIRONMENTAL LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. FEELY. Good morning Chairman Baird, Ranking Member Inglis, and Members of the Subcommittee. Thank you for giving me the opportunity to speak today about ocean acidification, its impacts on marine life, and our economic values.

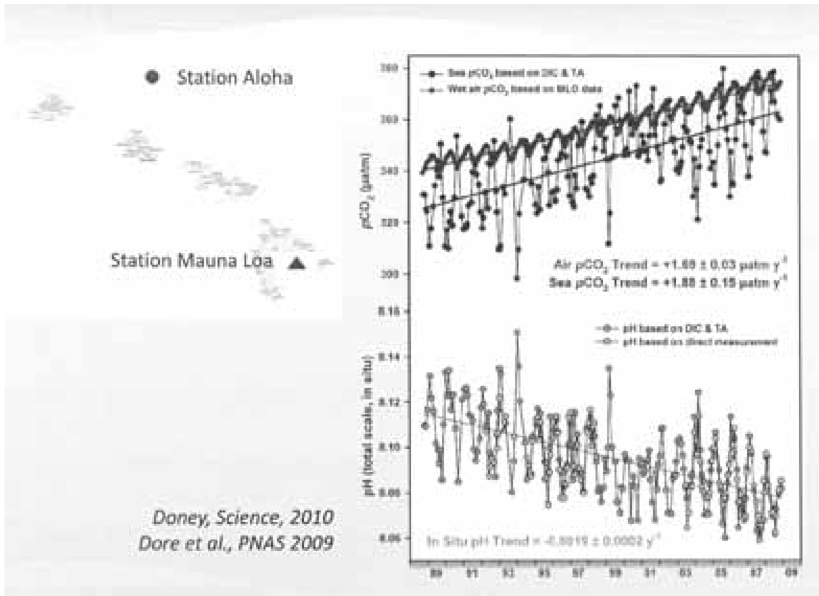
I know this issue is one that this subcommittee has the strongest interest in; and I would like to recognize and thank you for your bipartisan leadership in passing the seminal legislation, the *Federal Ocean Acidification Research and Monitoring Act of 2009*, that is now the driving force behind a NOAA, interagency, and academic effort throughout this country to understand this new phenomenon.

Fundamental changes in seawater chemistry are occurring throughout the world's oceans. Over the past two-and-a-half centuries, the release of carbon dioxide from the industrial, agricultural activities has resulted in atmospheric carbon dioxide concentrations that have increased from 280 to about 390 parts per million.

To date, the oceans absorbed about one-third of the carbon dioxide emissions by human activities during this period. This natural process of absorption has benefited humankind by significantly reducing global warming in the atmosphere and reducing some of the impacts of global warming as well. However, decades of ocean observation and research from NOAA, the National Science Foundation, and the Department of Energy has shown that the daily uptake of 22 million tons of carbon dioxide is having a significant effect on the oceans' chemistry and biology.

When carbon dioxide reacts with seawater, chemical changes occur that causes a decrease in seawater pH and carbonate ions. These chemical changes are largely referred to as "ocean acidification" because of the direction of change involved. Scientists have estimated that ocean pH has fallen about .1 pH units since the beginning of the industrial period.

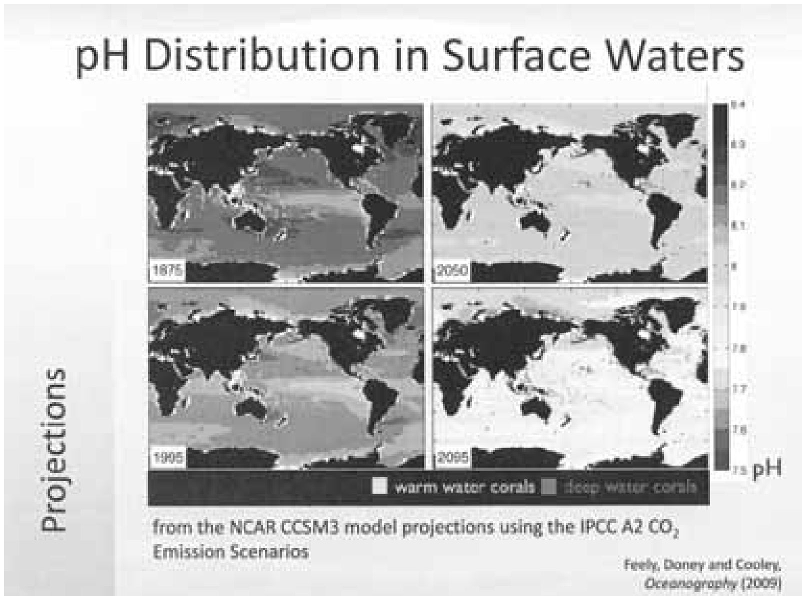
[The information follows:]



This first slide want to I show you shows the atmospheric concentration of CO_2 at the Mauna Loa site that Dr. Charles Keeling started in 1957, and underneath it you find the Hawaiian Ocean Time-Series data that's maintained by the University of Hawaii under the direction of the National Science Foundation. You can see the increase in surface ocean CO_2 is commensurate in terms of the rate of change with the atmospheric CO_2 concentration, about 1.7 parts per million per year. Underneath that is the corresponding pH measurements from this site, and we see a .02 pH change at this site over the last decade. So you can see from measurements alone we can see the acidification process.

Since the pH scale is like the Richter scale, it is logarithmic. This change in pH represents a 20 percent increase in the hydrogen ion concentration of seawater or the acidity of seawater. Further predictions out through the end of the century suggest that we could have a 150 percent increase in the acidity of seawater using the IPCC business-as-usual scenario.

[The information follows:]



Now, it's important to note that at present we are exceeding the CO_2 emission scenarios to date. Many marine organisms that produce calcium carbonate shells and skeletons are negatively impacted by increasing ocean acidification and have been shown to reduce their ability to produce their shells and skeletons. For example, in a recent paper just published last week, coral reef biologists have shown that acidification could compromise fertilization and settlement of elkhorn coral. Elkhorn coral is an endangered species, and we are causing further harm to these organisms. These research results suggest that ocean acidification could severely impact the ability of coral reefs to recover from any kind of disturbances, including major storms.

Other research indicates that by the end of this century coral reefs may erode faster than they can be rebuilt. This could compromise the long-term viability of those particular ecosystems that perhaps impact over a million species that depend on coral reefs for their survival.

Ongoing research that decrease in pH may also negatively affect commercially important fish and shellfish species is well under way. Both crab and sea bream larvae exhibit high mortality rates in a high CO_2 world. The calcification rates of edible mussels and Pacific oysters decline linearly with increasing CO_2 levels. Since 2006, some oyster hatcheries in the Pacific Northwest along Washington, Oregon, and California have experienced massive mortalities of oyster larvae in association with a combination of factors, including the upwelling of cold, high CO_2-rich waters.

Scientists have also seen a reduced ability of some types of marine plankton that produce calcium carbonate shells, and these organisms are food sources for many marine species. One type of free-swimming mollusk called the pteropod is eaten by organisms ranging in size from all the way from krill to whales. Pteropods are the major food source for North Pacific salmon and are a major food for mackerel, herring, and cod.

You can see the importance of these species to our ocean ecosystem as they rise through the food chain. The impact of ocean acidification in our fisheries and coral reef ecosystems could reverberate through the United States and global economy. The United States is the third largest seafood consumer in the world, and total consumer spending on fish and shellfish is about $70 billion per year. Coastal and marine commercial fisheries generate up to $35 billion per year and employ 70,000 people.

In conclusion, ocean acidification is caused by the buildup of carbon dioxide in the atmosphere and can have significant impacts on marine ecosystems. Ocean acidification is an emerging scientific issue and much research is needed before all the ecosystem responses are understood. However, to the limit of the scientific understanding we have about this issue right now, the potential for environmental, economic, and societal risks are very high, hence demanding serious and immediate attention.

Thank you for your attention, and I look forward to your questions.

[The prepared statement of Dr. Feely follows:]

PREPARED STATEMENT OF RICHARD A. FEELY

Introduction

Chairman Baird and members of the Subcommittee, thank you for giving me the opportunity to speak with you today on the evidence of climate change and ocean acidification. My name is Richard Feely. I am a Senior Scientist at the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) in Seattle, WA. My personal area of research is the study of the oceanic carbon cycle and ocean acidification processes. I have worked for NOAA for 36 years and have published more than 300 peer-reviewed scientific journal articles, book chapters and technical reports. I serve on the U.S. Ocean Carbon and Biogeochemistry Scientific Steering Committee and I am the co-chair of the U.S. Repeat Hydrography Program Scientific Oversight Committee. I am also a member of the International Scientific Advisory Panel for the European Program on Ocean Acidification and the Interagency Working Group on Ocean Acidification, under the Joint Subcommittee on Science and Technology. Today I will discuss observed ocean acidification, its impacts on marine life, and potential economic impacts.

What is Ocean Acidification?

Over the past two and a half centuries, the release of carbon dioxide (CO_2) from our collective industrial and agricultural activities has resulted in atmospheric CO_2 concentrations that have increased from about 280 parts per million (ppm) to 392 ppm. The atmospheric concentration of CO_2 is now higher than experienced on Earth for at least the last 800,000 years, and is expected to continue to rise, leading to significant temperature increases in the atmosphere and oceans by the end of this century. To this day, the oceans have absorbed more than 500 billion tons of carbon dioxide from the atmosphere, equivalent to about one third of the anthropogenic CO_2 emissions released during this period (Sabine and Feely, 2007). This natural process of absorption has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and reducing the magnitude of global warming experienced thus far.

Unfortunately the ocean's daily uptake of 22 million tons of CO_2 is having a significant impact on the chemistry and biology of the oceans. Over the last three decades, NOAA, the National Science Foundation and the Department of Energy have co-sponsored repeat hydrographic and chemical surveys of the world's oceans, documenting their response to increasing amounts of carbon dioxide being emitted to the atmosphere by human activities. These surveys have confirmed the oceans are absorbing increasing amounts of carbon dioxide. Both the hydrographic surveys and modeling studies reveal that chemical changes in seawater resulting from absorption of carbon dioxide are increasing the acidity of seawater or lowering of its pH. A drop in pH indicates an increase in acidity, as on the pH scale 7.0 is neutral, with points lower on the scale being "acidic" and points higher on the scale being "basic" (Raven *et al*, 2005; Feely *et al*., 2009). Scientists have estimated that the pH of our ocean surface waters has already fallen by about 0.1 units from an average of about 8.2 to 8.1 since the beginning of the industrial revolution. Because the pH scale, like the Richter scale, is logarithmic, a 0.1 unit decrease represents approximately a 26 percent increase in acidity.

Future predictions indicate that the oceans will continue to absorb carbon dioxide and become even more acidic. (Feely *et al*., 2004; On *et al*., 2005; Caldeira and Wickett, 2005; Doney *et al*., 2009a; Feely *et al*., 2009). The United Nation's Intergovernmental Panel on Climate Change emission scenarios and numerical circulation models indicate that by the middle of this century, future atmospheric carbon dioxide levels could reach more than 500 ppm, and near the end of the century they could be as much as 700–800 ppm (On *et al*., 2005). This would result in a surface water pH decrease of approximately 0.3 pH units as the ocean becomes more acidic, which is equivalent to a doubling of acidity. To put this in historical perspective, the resulting surface ocean pH would be lower than it has been for at least the last 20 million years (Feely *et al*., 2004). When CO_2 reacts with seawater, fundamental chemical changes occur that cause seawater to become more acidic. The interaction between CO_2 and seawater also reduces the availability of carbonate ions, which play an important role in shell formation for a number of marine organisms such as corals, marine plankton, and shellfish. This phenomenon, which is commonly called "ocean acidification," could affect some of the most fundamental biological and geochemical processes of the sea in coming decades. This rapidly emerging issue has created serious concerns across the scientific and marine resource management communities.

Evidence of Ocean Acidification Effects on Coral Reefs

Many marine organisms that produce calcium carbonate shells are negatively impacted by increasing carbon dioxide levels in seawater (and the resultant decline in pH). For example, increasing ocean acidification has been shown to significantly reduce the ability of reef-building corals to produce their skeletons, affecting growth of individual corals and making the reef more vulnerable to erosion (Kleypas *et al*., 2006; Doney *et al*., 2009a; Cohen and Holcomb, 2009). Some estimates indicate that, by the end of this century, coral reefs may erode faster than they can be rebuilt. This could compromise the long-term viability of these ecosystems and perhaps impact the thousands of species that depend on the reef habitat. Decreased calcification may also compromise the fitness or success of these organisms and could shift the competitive advantage towards organisms that are not dependent on calcium carbonate. Carbonate structures are likely to be weaker and more susceptible to dissolution and erosion in a more acidic environment. Furthermore, recent findings suggest that the calcium carbonate cementation that serves to bind the reef framework together may be eroded (Manzello *et al*., 2008). Such effects could compromise reef resiliency in the face of other threats, such as thermal stress, diseases, storms, and rising sea level (e.g., Silverman *et al*., 2009). For example, in CO_2-enriched waters around the Galapagos Islands, reef structures were completely eroded to rubble and sand in less than 10 years following an acute warming disturbance (1982–83 El Nino event; Manzello *et al*., 2008). In long-term laboratory and mesocosm experiments, or contained laboratory model ecosystems under controlled conditions, corals that have been grown under lower pH conditions for periods longer than one year have not shown any ability to adapt their calcification rates to the lower pH levels. In fact, two studies showed that the projected increase in CO_2 is sufficient to dissolve the calcium carbonate skeletons of some coral species (Fine and Tchernov, 2007; Hall-Spencer *et al*., 2008).

Evidence of Ocean Acidification Effects on Fish and Shellfish

Ongoing research is showing that decreasing pH may also have deleterious effects on commercially important fish and shellfish larvae. Both king crab and silver seabream larvae exhibit very high mortality rates in CO_2-enriched waters (Ishimatsu *et al*., 2004). Some of the experiments indicated that other physiological stresses were also apparent. Exposure of some fish and shellfish to lower pH levels can cause decreased respiration rates, changes in blood chemistry, and changes in enzymatic activity. The calcification rates of the edible mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) decline linearly with increasing CO_2 levels (Gazeau *et al*. 2007). Squid are especially sensitive to ocean acidification because it directly impacts their blood oxygen transport and respiration (Portner *et al*., 2005). Sea urchins raised in lower-pH waters show evidence for inhibited growth due to their inability to maintain internal acid base balance (Kurihara and Shirayama, 2004). The supply of these commercially valuable species is in jeopardy from ocean acidification.

Scientists have also seen a reduced ability of marine algae and free-floating plants and animals to produce protective carbonate shells (Feely *et al*., 2004; On *et al*., 2005; Doney *et al*., 2009b). These organisms are important food sources for other marine species. One type of free-swimming mollusk called a pteropod is eaten by organisms ranging in size from tiny krill to whales. In particular, pteropods are a major food source for North Pacific juvenile salmon, and also serve as food for other salmon species, mackerel, pollock, herring, and cod. Other marine calcifiers, such as coccolithophores (microscopic algae), foraminifera (microscopic protozoans), coralline algae (benthic algae), echinoderms (sea urchins and starfish), and mollusks (snails, clams, and squid) also exhibit a general decline in their ability to produce their shells with decreasing pH (Kleypas *et al*., 2006; Fabry *et al*., 2008).

Evidence of Ocean Acidification Effects on Marine Ecosystems

Since ocean acidification research is still in its infancy, it is impossible to predict exactly how the individual species responses will cascade throughout the marine food chain and impact the overall structure of marine ecosystems. It is clear, however, from both the existing data and from the geologic record that some coral and shellfish species will be negatively impacted in a high-CO_2 ocean. The rapid disappearance of many calcifying species in past extinction events has been attributed, in large part, to ocean acidification events (Zachos *et al*., 2005; Vernon, 2008). Over the next century, if CO_2 emissions continue to increase as predicted by the IPCC CO_2 emissions scenarios, humankind may be responsible for increasing oceanic CO_2 and making the oceans more corrosive to calcifying organisms than at anytime in the last 20 million years. Thus, the decisions that are made about carbon dioxide emissions over the next few decades will probably have a profound influence on the makeup of future marine ecosystems for centuries to millennia.

Potential Economic Impacts of Ocean Acidification

The impact of ocean acidification on fisheries and coral reef ecosystems could reverberate through the U.S. and global economy. The U.S. is the third largest seafood consumer in the world with total consumer spending for fish and shellfish around $70 billion per year. Coastal and marine commercial fishing generates upwards of $35 billion per year and employs nearly 70,000 people (NOAA Fisheries Office of Science and Technology; *http://www.st.nmfs.gov/stl/fus/fus05/index.html*). In a recent study by Cooley and Doney (2009) the total value of U.S. commercial harvests from U.S. waters and at-sea processing was approximately $4 billion in 2007. Almost a quarter (24%) of all U.S. commercial harvest revenue was from harvesting fish that prey directly on calcifying organisms. Different species dominate different regional revenues; mollusks are more important in the New England and mid- to south-Atlantic regions, crustaceans contribute greatly to New England and Gulf of Mexico fisheries, and predators dominate the Alaskan, Hawaiian, and Pacific territory fisheries. On the west coast shellfish industries bring in more than $110 million in revenue each year. Bivalves, such as oysters, also filter marine and estuarine waters and create habitat for other species, serving important ecosystem services (NOAA OA Plan, 2009; Feely *et al*., 2010). Since 2006, some oyster hatcheries in the Pacific Northwest region have experienced mass mortalities of oyster larvae in association with a combination of factors, including unusually saline surface waters and the upwelling of cold, CO2- and nutrient-rich waters (Feely *et al*., 2008).

Healthy coral reefs are the foundation of many viable fisheries, as well as the source of jobs and businesses related to tourism and recreation. Increased ocean acidification may directly or indirectly influence the fish stocks because of large-scale changes in the local ecosystem dynamics. It may also cause the dissolution of the newly discovered deepwater corals in the West Coast and Alaskan Aleutian Island regions, where many commercially important fish species in this region depend on this particular habitat for their survival. In the Florida Keys alone, coral reefs attract more than $1.2 billion in tourism annually (English *et al*., 1996). In Hawaii, reef-related tourism and fishing generate $360 million per year, and their overall worth has been estimated at close to $10 billion (Cesar *et al*., 2002). In addition to sustaining commercial fisheries, tourism, and recreation, coral reefs also provide vital protection to coastal areas that are vulnerable to storm surges and tsunamis.

NOAA Ocean Acidification Research

Ocean acidification is an important new scientific frontier which we must understand better given its potentially adverse consequences. NOAA research activities offer significant contributions to improving our understanding and assessing the impacts of this rapidly emerging issue. In response to the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act), NOAA is in the process of hiring a permanent ocean acidification program director as a final step to the establishment of a new NOAA ocean acidification program, per section 12406 of the FOARAM Act. NOAA has also developed an integrated Ocean Acidification and Great Lakes research and long-term monitoring plan for assessing climate change impacts on living marine resources and the businesses and communities that depend on their sustainable use. The primary goals of this plan are to:

- Assess the ecological and socioeconomic effects of ocean acidification on commercial fish species and the greater ecosystems on which they rely;
- Develop and provide sensors to monitor ocean acidification both for fixed platforms and for mobile use by researchers and coastal managers in the field;
- Determine and monitor the status and potential effects of ocean acidification on coral reefs and other protected areas such as National Marine Sanctuaries; and
- Expand carbonate analytical capabilities at NOAA science centers in order to meet the growing demand for quality control on samples being collected both in the field from U.S. waters and from researchers studying the impacts of ocean acidification on critical species through laboratory experiments.

The results of this research will help to inform future strategies to help communities, ecosystems, and industries respond to ocean acidification. The increased research capabilities will complement, accelerate, and enhance current NOAA ocean acidification activities within the Office of Oceanic and Atmospheric Research, National Ocean Service, and National Marine Fisheries Service.

Interagency Planning

The FOARAM Act directed the Joint Subcommittee on Ocean Science and Technology (JSOST) of the National Science and Technology Council to create an Interagency Working Group on Ocean Acidification (IWG–OA), chaired by NOAA. The IWG–OA was charged with developing a strategic plan for Federal research and monitoring on ocean acidification that will provide for an assessment of the impacts of ocean acidification on marine organisms and marine ecosystems and the development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems. The IWG–OA has developed a draft strategic plan that is presently undergoing review, in preparation for delivery in early spring 2011 as requested by the FOARAM Act.

Conclusion

In conclusion, ocean acidification is caused by the buildup of carbon dioxide and other acidic compounds in the atmosphere and is expected to have significant impacts on marine ecosystems. Results from laboratory, field and modeling studies, as well as evidence from the geological record, clearly indicate that marine ecosystems are highly susceptible to the increases in oceanic CO_2 and the corresponding decreases in pH. Because of the very clear potential for ocean-wide impacts of ocean acidification at all levels of the marine ecosystem, from the tiniest phytoplankton to zooplankton to fish and shellfish, we can expect to see significant impacts that are of immense importance to humankind. Ocean acidification is an emerging scientific issue and much research is needed before the breadth and magnitude of ecosystems" responses are well understood. However, to the limit that the scientific community understands this issue right now, the potential for environmental, economic and societal risk is quite high, hence demanding serious and immediate attention. Thank you for giving me the opportunity to address this Subcommittee. I look forward to answering your questions.

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BIOGRAPHY FOR RICHARD A. FEELY

Dr. Richard A. Feely is a Senior Scientist at the NOAA Pacific Marine Environmental Laboratory in Seattle. He also holds an affiliate full professor faculty position at the University of Washington School of Oceanography. His major research areas are carbon cycling in the oceans and ocean acidification processes. He received a B.A. in chemistry from the University of St. Thomas, in St Paul, Minnesota in 1969. He then went to Texas A&M University where he received both a M.S. degree in 1971 and a Ph.D. degree in 1974. Both of his post-graduate degrees were in chemical oceanography. He is the co-chair of the U.S. CLIVAR/CO2 Repeat Hydrography Program. He is also a member of the Steering Committee for the U.S. Carbon and Biochemistry Program. He is a member of the American Geophysical Union, the American Association for the Advancement of Science and the Oceanography Society. Dr. Feely has authored more than 200 refereed research publications. He was awarded the Department of Commerce Gold Award in 2006 for research on ocean acidification. In 2007, Dr. Feely was elected to be a Fellow of the American Geophysical Union. He recently was awarded the Heinz Award for his pioneering research on ocean acidification.

DISCUSSION

Chairman BAIRD. Thank you, Dr. Feely. Thanks to all the witnesses.

At this point, I will recognize myself for five minutes and follow-up questions from my colleagues.

OCEAN ACIDIFICATION AND CORAL DAMAGE

Dr. Feely, you focused on the evidence of ocean acidification. It appears to be a pretty strong connection. Two questions for you, one tangential. There has, my understanding, been an enormous coral die-off worldwide, particularly in the Caribbean, as we have seen coral bleaching from high sea temperatures. Can you very briefly comment on that?

And then, secondly, are there alternative explanations that seem credible to explain the acidification levels that you have been measuring?

Dr. FEELY. To answer your first question, because of the increasing level of temperatures in the ocean, we have seen coral die-offs of as much as 16 percent globally. And the projections are that out to the end of this century we may not see very many of the coral reefs be able to survive. That's the dire situation we are faced with.

The concern we have in terms of the acidification is that some of the preliminary research has shown that the combination of increased CO_2 and the increased temperature associated with global warming enhances the bleaching impact on those corals. So their risk of survival is even greater.

Chairman BAIRD. Do you want to—are there other alternatives? What is another alternative explanation for the measured increase in acidity or, in other words, lowered pH, other than the CO_2 hypothesis?

Dr. FEELY. The major alternative suggestion is that perhaps CO_2 evolution from volcanic activity, hydrothermal activity in the deep sea, could be enriching the CO_2 levels in the surface oceans. But we have published papers on this subject to show that the amount of CO_2 from volcanic activity in any given year is 1/100 of the amount of CO_2 that enters the atmosphere.

Chairman BAIRD. Thanks, Dr. Feely.

MEASURING GLACIAL CHANGES

Dr. Alley, two questions. One, tell us a little bit about how—from your graph, it looked like you feel pretty confident that the data suggests the ice sheets, glaciers around the world are melting, with a few exceptions. Tell us a little bit about the methodology by which that is measured first.

And secondly, haven't there been times in the past when we have seen receding glaciers and receding ice sheets and comments about my goodness, things seem to be going in the opposite direction. Glaciers—you know. And what is the difference now?

Dr. ALLEY. Right. So for measuring, say, what Greenland is doing, some of that work is done by weighing the ice sheet using the GRACE gravity satellites, which is truly wonderful. It is like watching cars on a roller coaster and the one going down gets away from the one that is going up, and then the one going down catches up. And you watch——

Chairman BAIRD. As I understand it, it is fascinating with satellites sort of pursuing each other and gravitational attraction slows one down, relative to the other. And by measuring the rate of that different speed, you can tell how much mass is underneath you. And as that mass declines, there is less slowing down.

Dr. ALLEY. Perfect. I should retire and let you teach this.

Chairman BAIRD. I just think it is beautiful.

Dr. ALLEY. So you weigh them using GRACE, but then you measure changes in surface elevation, is it going down or up, using a radar or a laser from a plane or a satellite, and all of those have been done. And then you figure out how much snow is being added and how much melt water is leaving and how much ice is leaving. And then you compare all of these to see if they give the same answer. And all of them indicate shrinkage of Greenland.

You are certainly correct that the ice has grown and shrunk in the past. And I had the honor of serving for the United States Government on the Climate Change Science Program on a report of the history of the arctic. And what we found was very clear for Greenland. When nature made it warmer, Greenland got smaller. And when nature made it colder, Greenland got bigger. And we are now making it warmer and Greenland is getting smaller.

EVIDENCE OF ANTHROPOGENIC CHANGE

Chairman BAIRD. How do we know it is we, not nature? I mean, we have the increase in CO_2. But the skeptic would argue, well, wait a second, I can go back to 1927 and find articles about glaciers retreating. What is the difference? I mean, you know, you can look at a football team and say they were losing back then and they are losing now, so what is the difference?

Dr. ALLEY. Right. So the first one is the physics. We just cannot get away from the warming effect of CO_2. It has been known for over a century. It was really clarified by the Air Force who were actually interested in what wavelength should I use for the sensor on my heat-seeking missile. But CO_2 interacts with radiation and there is enough CO_2 to make a difference. And we just can't get away from that physics.

The second one is—is looking at is there any other possible thing to explain this. And it really took—I am sorry, sir, it took a few billion dollars of your money and about 30 years to say that there is nothing else that we can find in nature to do this. And this is because satellites are expensive.

But someone says it is the sun. Well, then you need a satellite to watch the sun to see if the sun is getting brighter, but it isn't. And if someone says, well, it is volcanoes, then we need a history of volcanoes and we need to know what they are doing. And someone says it is cosmic rays, we need cosmic ray monitors. And it has taken sort of 30 years to get to the point of saying, no, we have looked really hard, we can't find anything else.

And there is a third piece, which is the fingerprinting, which is what Dr. Santer was discussing. If you were to say, okay, yeah, I know we spend a lot of money on satellites and the satellites say the sun is not getting brighter, but maybe, maybe, maybe the satellites are wrong and the sun is getting brighter and we can't see it. That makes a prediction. It gets warmer down here and it gets warmer way up at the top of the stratosphere. CO_2 says warm down there or colder up there. What is going on is warmer down here and colder up there? So the fingerprinting and time in space says that we got it right on the other two pieces. It is mostly us now.

Chairman BAIRD. I want to be clear. It is not my money. It is your money.

Dr. ALLEY. Thank you, sir. Absolutely.

Chairman BAIRD. It is the taxpayers' money. I never forget it. But I think at the same time, if we don't address our energy dependence and if we don't address appropriately, then by my judgment, real impacts of this will vastly exceed a billion dollars. And if we can make some measured changes to reduce that impact, the savings will exceed the expenditures by—Dr. Santer, you might want to comment, Dr. Michaels? And then I will recognize my colleague.

Dr. SANTER. Yeah. I just wanted to comment briefly on what Dr. Alley said about the fingerprinting. We have known that increases in CO_2 have this characteristic fingerprint of warming the lower atmosphere, the troposphere, and cooling the upper atmosphere since about the late 1950s, early 1960s, when people performed the first numerical model experiments and doubled CO_2. And they saw this characteristic pattern of cooling of the stratosphere and warming of the troposphere. Very robust. We see that in virtually every model experiment that has been performed. And as mentioned, we also see it in observations, too. We see it in satellite data. We see it in weather balloon data.

Now, people often say these computer models are not falsifiable. They make predictions that we can't test. That is not true. Back in the 1960s, when Suki Manabe and his colleagues at the Geophysical Fluid Dynamics Lab in Princeton made these calculations and doubled atmospheric CO_2 and saw this fingerprint, we didn't really have the observational data to see whether the stratosphere was actually cooling, whether the troposphere was warming. They have. The stratosphere has cooled. The troposphere has warmed. That fingerprint is robust and it is just not consistent with other natural causes.

Chairman BAIRD. Dr. Michaels, did you care to comment on any of this?

Dr. MICHAELS. I have several comments I would like to make. It would probably take up the rest of the day. So I will just limit—that won't happen, no, it certainly won't. I will limit it to the notion of—what we are talking about here, you've noticed, is everybody says that the planet has warmed up and that people have something to do with it. So what really matters is the magnitude of it.

If I can have the clicker, this is just going to take a second. It is not going to be as bad as you think. There it is. Right there. This is the warming from the IPCC—from the CRU record from 1950. And our Environmental Protection Agency which, as you know, has taken over the regulatory aspect of this because of what happened in the Congress, issued an endangerment finding on warming. And they asserted in their endangerment finding that more than half of the warming of the late 20th century is a result—very likely a result of human greenhouse gases. More than half means more than 50 percent. Late 20th century means after 1950. Do you agree with that?

Second—sorry. I said second half of the 20th century. Well, in fact there are four different factors that are totally independent of the greenhouse effect. One that we overestimated—underestimated sea surface temperatures from 1944 to 1965. That was published by Thompson in Nature Magazine. Number two, that there are nonclimatic subtle effects on the temperature history. That was published by McKitrick in the Journal of Geophysics Atmospheres. Susan Solomon found that water vapor in the stratosphere is responsible for a lot of the secular changes. And we don't know why water vapors fluctuate in the stratosphere. It is not a greenhouse effect. I mean, it is not—it is not, apparently, from greenhouse gas emissions. And number four, Rominoffon at Stanford said, well, about 25 percent of the warming is a result of black carbon going in the atmosphere. That is also not a greenhouse gas.

When you add all of those up, the warming drops from .7 to .3 degrees. So the assertion that over half the warming is a function of greenhouse gases is challenged by four completely independent factors. I think we have got a lot more work to do on this frankly.

Chairman BAIRD. Any very quick response to that? And then Mr. Inglis.

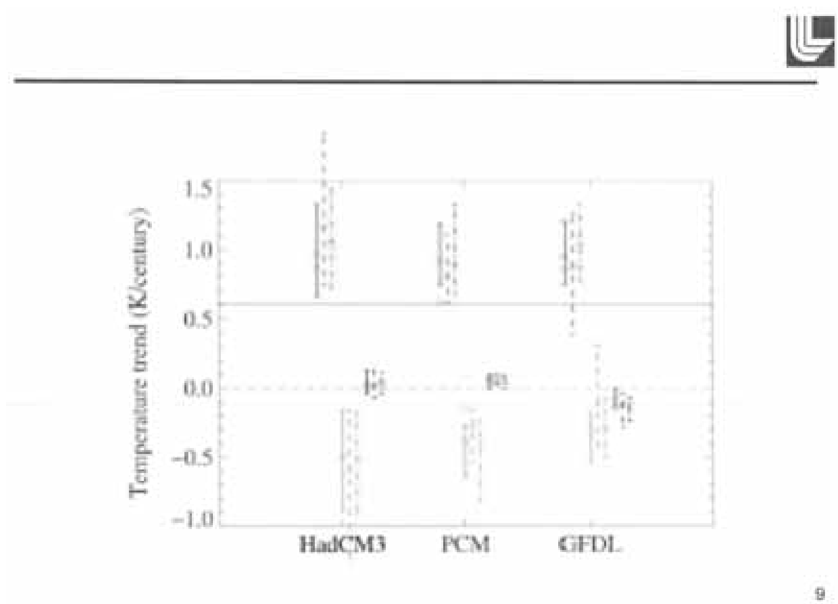
Dr. SANTER. Yes, might I respond to that?

Chairman BAIRD. Very quickly.

Dr. MICHAELS. Dr. Michaels' analysis is wrong. I am sorry. It is just completely incorrect. What he has attempted to do here is explain the observed temperature change over the last 60 years from 1950 through 2010. And he said that the estimated total change in temperature is .7 degrees. Now, he has identified four things—economic activity, black carbon, errors in the sea surface temperature data and stratospheric water vapor—and he said, I think all of those things have had a warming influence, so I am going to subtract them from this .7 degrees and I am left with .3. Point 3 is less than half of .7, therefore the IPCC is wrong. And the conclusion that more than half of the observed warming over the 20th century was very likely due to increases in greenhouse gases is one of the central conclusions of the IPCC. So if Dr. Michaels is right, that central conclusion is wrong.

What Dr. Michaels did not mention either here or in his written testimony is the cooling effect of sulfate aerosols, which has already been discussed at this hearing. If you indulge me for a moment, I am just going to bring up one slide here.

[The information follows:]



Now, this is a slide from a paper published in 2006 by Peter Stott at the Hadley Center. So what you see in the bottom are three different climate models, and it is the estimate of their sulfate cooling caused by the scattering effects of sulfate aerosols over the 20th century. It is negative.

Now, if you assume conservatively that that cooling effect over 1950 to 2010 period Dr. Michaels looked at was, say, minus .4 degrees Celsius over that 60-year period and you assume that Dr. Michaels was completely correct in estimating the magnitude of the four factors that he removed from the observations, you would be adding minus .4 and plus .4. You would get to zero. So you still need to explain .7. You need to get to the observed total temperature change over the 60-year period.

What could that be? Could it be the sun? No way. It couldn't be the sun. If solar effects were that large on the 60-year time scale, we could see a huge 11-year cycle in the temperature data. We don't. Could it be volcanoes? No, it couldn't be volcanoes. Could it be some mode of natural variability, some internal oscillation of the climate system that could generate that .7 degree temperature increase? Not plausible.

The most plausible explanation is an increase in atmospheric CO_2. We know CO_2 has changed. Again, that is not some assertion. That is not supposition. We know that. So what the IPCC found here and what they reported on was that actually the change in temperature due to greenhouse gases, which is what you see in red, was larger than the actually observed change in temperature, which is that horizontal black line. So the greenhouse gas signal was offset. That is our best understanding by the cooling caused by these sulfate aerosols. They scatter incoming sunlight and they also change cloud properties.

Dr. MICHAELS. Excuse me. Excuse me. I beg your pardon for a second. The IPCC gives the range of prospective forcing from sulfate aerosol at zero, a range from zero to minus two watts per meter square. That gives you an incredible wiggle room any time you want to make an argument, doesn't—doesn't it now?

It is very interesting to look at sulfate aerosol in terms of the history of science. The first book I ever read at the University of Chicago was "The Structure of Scientific Revolutions" by Thomas Kuhn. I recommend it to everyone. It predicts that when a paradigm experiences anomalous data, then increasingly strange explanations are brought forth.

In 1985, Tom Wigley, who was Ben's advisor, recognized in a paper that the greenhouse gas models were producing too much warming and invoked sulfates. And then you can tune models with sulfates and get things to work perfectly well. Well, the fact of the matter is that our understanding of what the radiative effects of these things are is so wide that I can give you virtually any answer. And So I am just assuming to leave that alone.

Chairman BAIRD. I recognize Mr. Inglis.

Mr. INGLIS. And I think it is worth following up on that because—and this is why this hearing is so valuable, because these are the kind of things that confuse people and confuse the public a great deal. So, Dr. Santer, do you want to continue with your—what is your retort?

Dr. SANTER. Yes, if I could. Dr. Michaels was wrong again. He claimed that the IPCC's published estimate of the radiative effect of sulfate aerosols was zero to minus two watts per square meter. That serves for the indirect effect. That is for the effect of aerosols on clouds, on cloud cover and on cloud brightness, which is very uncertain.

The IPCC's estimate of the direct scattering of effect of aerosols, how they scatter incoming sunlight back into space, does not intersect with zero. It is negative. And the best estimate is an order of minus .5 watts per square meter.

The cooling effect of sulfate aerosols has been established not only observationally and in models and theoretically. In dozens of studies, we can see these things from space. They are not supposition. This is not science fiction. And leaving out this negative forcing in his testimony to you is misleading you. I am sorry.

Dr. MICHAELS. The problem here is that the error bars around these things are very, very large. And furthermore, there is an issue with the sensitivity. Excuse me. I would like to finish.

This discussion is really about the sensitivity of temperature to various and sundry forcings. And there is quite a discussion as to, in fact, what the change in temperature is per change in watt per meter squared down while in flux. If it is on the order of I think what Lindzen thinks it is, then the sulfates aren't going to be all that important. So this is just—this is an open matter for discussion. I am sorry. We just don't know everything.

Chairman BAIRD. Dr. Santer.

Dr. SANTER. Might I respond very quickly? I am glad that Dr. Michaels raised the issue of uncertainties. In the fingerprinting work that we do, we constantly look at uncertainties. They are part and parcel of our lives. We look at uncertainties in the fingerprints, those patterns I showed you that arise from use of different models. We look at uncertainties in model estimates of natural climate noise. And we look at uncertainties in the statistical methods that we use to compare models and observations. We spend all of our time looking at uncertainties.

In this analysis here on Dr. Michael's slide, you will see there are no error bars. In this subtraction exercise, no error bars, and the temperature changes are given to within a thousandth of a degree C.

Now, to me, again, that is just completely ignoring the significant scientific uncertainties in this partitioning of natural and human effects. You have to account for them. You have to look at all effects, both positive and negative. You can't forget sulfate aerosols. This analysis has not done that. And anything that claims to overturn the central finding of the IPCC's fourth assessment report should do it as thoroughly and comprehensively as possible. This analysis fails in that regard.

Dr. MICHAELS. Is that why one would use 1963 through 1987, when there was data through 1995? Is that why one would, in fact, begin a volcanic analysis in 1883 when the atmosphere was loaded with volcanic junk prior to then?

Chairman BAIRD. I am going to intervene just a little bit. I think for understandable reasons, people have published different papers. And the challenge is if two individuals are sort of in the scientific community going at it with each other, it is an interesting and important discussion.

So I want Dr. Santer to respond to that because you addressed it earlier, Mr. Michaels. But I don't want to dominate. I am interrupting my colleague's time here. But I just want to set a little bit of ground rules. We won't go on forever with this particular debate. Is that all right with you, Bob?

Mr. INGLIS. Yeah.

Chairman BAIRD. I will give my colleague more time to finish.

Dr. SANTER. Thank you, Chairman Baird. I really appreciate the opportunity go on the record on this issue. I thank Pat Michaels for referring to this as the most famous paper published in climate science. And he criticized this analysis back in 1996 when it was published.

I would like to address three aspects of that criticism very briefly. The first aspect was that the editorial process of *Nature* magazine had been interfered with, that somehow I had imposed on *Nature* to publish this paper shortly before the conference of the parties. That is wrong. That is incorrect.

The second claim is that there was selective data analysis that we looked at a time period from 1963 to roughly 1988 in observational weather balloon data, compared computer model output with that. And then if you looked at a longer period of record, you got different results.

First of all, Professor Michaels was right. If you looked at a longer period of record, you did get different results. Had there been intent to fool people to manipulate data? No. We were doing a fingerprint analysis pattern—observational data, grided data. And at that time they were only available from one source. That source extended from 1973 through to 1988.

When Professor Michaels criticized our paper, we responded as scientists do, we addressed the scientific criticism. What we found was that when we looked at a newly available weather balloon data set that went through to 1995, he was right, and this change in the temperature asymmetry between the Northern Hemisphere and Southern Hemisphere had this sort of u-shape.

What we were able to show and what others have convincingly repeated since then is that that change is forced behavior. If you look at models with combined changes in greenhouse gases and sulfate aerosols, indeed the Stott paper that I mentioned earlier shows that models—including greenhouse gases and aerosol changes—replicate that behavior. It was not, as Professor Michaels mentioned, some representation of natural causes alone.

Actually doing the additional science strengthened our confidence in the ability of the models to reproduce this subtle interhemispheric temperature change difference. He has not reported, unfortunately, on those responses to his scientific criticism, which I do not think is correct.

Dr. MICHAELS. Can I—one thing.

Chairman BAIRD. I am going to recognize Mr. Inglis.

Dr. MICHAELS. Ask me questions after the hearing on this, written questions.

Mr. INGLIS. Okay. Good. I think it is very interesting to kind of back-and-forth because it does show that scientists are involved in trying to criticize each other's work and hope to reach better science, which is very helpful. And then there are some things that are sort of basic.

OCEAN ACIDIFICATION AND ECONOMIC IMPACTS

And so, you know, I am not a scientist, but I play one on the Science Committee when I am here. So we did this little science experiment that I hope to convince some folks about the ocean acidification. You know, what it is is an egg that we put in vinegar, a vinegar water. And you come back in a couple of days and—this is a science experiment you did in seventh grade. There is no more shell. Now, this is of rather worldly concern, because—rather than other-worldly and perhaps academic debate in that—you know, my brother is a shrimper. If he had his choice in what he would like to do. He has got to do other things because you really can't make a living in South Carolina shrimping. And so he has got a pickup truck in the back. And the back of it says no wetlands, no seafood. Richard is no tree-hugging environmentalist, but he is a guy who loves to go shrimping. And he knows that if you don't have wetlands, you don't have any seafood. And he is, I think, beginning to see that if you melt the shells of these calcium-based plankton, you end up with a hole in the bottom of the food chain. It is a little bit of a problem to have a hole in the—at the top of the food chain. You lose a polar bear, it is a really bad day. But if you open a hole in the bottom of the food chain—Dr. Feely, I think it is what you are talking about—you have really ruined a lot of people's day. Because as I understand it, there is something like a billion people around the world that depend on the ocean for food, right? It is something like that.

Dr. FEELY. About 20 percent of the protein resources that we as humans require come from the oceans.

Mr. INGLIS. Yeah. And so—why don't you speak to the—am I right about this, that this is sort of a seventh grade science explanation of how it might work and the risk that we face and the real-world consequences of Richard Inglis, a shrimper off of Hilton Head?

Dr. FEELY. Well, if we start at the marine phytoplankton level which is the marine plants, about 11 percent of the abundance of marine plants form calcium carbonate shells. These are called coccolithophores. And they clearly show that the formation of shell is decreased in a higher CO_2 world. It is anywhere from nine to 45 percent. And then we go up at the next level. The coccolithophores are generally eaten by the zooplankton, and the zooplankton such as protozoans, such as foraminifera, for example, or the pteropods that I talked about, these free-swimming pteropods, you can see them with your naked eye. That is the primary food source for juvenile fish. That is what they want to eat because they don't want to eat plankton per se. So they are dependent on those pteropods and those species.

While living pteropods are placed in high CO_2 water while still alive, well, the shell will begin to dissolve within 48 hours. And the shell will be gone within a few weeks. So this is a significant problem for that ecosystem.

Mr. INGLIS. Is there doubt about the chemistry of higher CO_2 levels and impact on ocean acidification?

Dr. FEELY. There is no doubt about that. And let me explain why. We have worked at the international level with—through the 1990 WOCE program, a Lowes hydrographic survey, with 8 countries working together, collecting over 72,000 samples in the 1990s from surface to bottom along every portion of the ocean, from Antarctica to the Arctic Ocean, from Japan to the United States. All these countries worked together. The data sets were brought to my laboratory. We processed the entire data set and made all the corrections to the data set and that allowed us to determine exactly where all the anthropogenic CO_2 was going. We did this by determining the changes in anthropogenic CO_2 since pre-industrial times, using a combination of observations and models working together.

We also had colleagues on those same cruises collecting samples for the isotopic signature of that CO_2, and the changes in the isotopic signature were consistent with the increase in anthropogenic carbon dioxide, which has a very unique isotopic signature. And that penetration of the anthropogenic CO_2 goes down to, for the most part, the upper 1,500 meters of the water column. So most of the anthropogenic CO_2 is still in the upper part of the water count where most of our organisms live. And we know that extremely well.

Now, in this decade, in 2000–2010, we have been repeating those cruises. So we can see the direct changes to the uptake of carbon dioxide from the atmosphere from the 1990s to the present. And on those cruises, we see the same rate of change of pH that we do at the time series sites at HOTS and BATS. So we know now from the large extended surveys across our oceans that we are seeing an exact rate of change of pH and CO_2 increases in the water column. This is the only extreme one. There is no debate about that at all.

Mr. INGLIS. I think I am way over time, Mr. Chairman.

Chairman BAIRD. Thank you. I am not sure if it would be Dr. Bartlett or Mr. Rohrabacher. Mr. Rohrabacher. Thank you, Dr. Bartlett for your——

SCIENCE AND THE FEDERAL GOVERNMENT

Mr. ROHRABACHER. Thank you very much. And for the record, I would like to place in the record a——

Chairman BAIRD. I cannot hear.

Mr. ROHRABACHER. Can you hear me now? Let me—I would like to place in the record a portion of President Eisenhower's farewell remarks to the country in which he warned about what happens when science and politics gets too intertwined and government grants become the goal for various researchers.

Chairman BAIRD. Will that include the military-industrial complex portion of it?

Mr. ROHRABACHER. This was—that is exactly right.

Chairman BAIRD. I understand. I read the whole document. I would never object to Mr. Eisenhower being entered into the record.

[The information follows:]

President Dwight D. Eisenhower

Excerpt from Farewell Address delivered 17 January 1961

Good judgment seeks balance and progress. Lack of it eventually finds imbalance and frustration. The record of many decades stands as proof that our people and their Government have, in the main, understood these truths and have responded to them well, in the face of threat and stress.

But threats, new in kind or degree, constantly arise. Of these, I mention two only.

In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist. We must never let the weight of this combination endanger our liberties or democratic processes. We should take nothing for granted. Only an alert and knowledgeable citizenry can compel the proper meshing of the huge industrial and military machinery of defense with our peaceful methods and goals, so that security and liberty may prosper together.

Akin to, and largely responsible for the sweeping changes in our industrial-military posture, has been the technological revolution during recent decades. In this revolution, research has become central; it also becomes more formalized, complex, and costly. A steadily increasing share is conducted for, by, or at the direction of, the Federal government.

Today, the solitary inventor, tinkering in his shop, has been overshadowed by task forces of scientists in laboratories and testing fields. In the same fashion, the free university, historically the fountainhead of free ideas and scientific discovery, has experienced a revolution in the conduct of research. Partly because of the huge costs involved, a government contract becomes virtually a substitute for intellectual curiosity. For every old blackboard there are now hundreds of new electronic computers. The prospect of domination of the nation's scholars by Federal employment, project allocations, and the power of money is ever present -- and is gravely to be regarded.

Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific-technological elite.

It is the task of statesmanship to mold, to balance, and to integrate these and other forces, new and old, within the principles of our democratic system -- ever aiming toward the supreme goals of our free society.

Mr. ROHRABACHER. What you need to understand is that Eisenhower equated the threat of the military-industrial complex with—similarly, with intertwining science and the government.

Chairman BAIRD. Without objection.

MORE ON GLACIERS AND EVIDENCE OF ANTHROPOGENIC CHANGE

Mr. ROHRABACHER. All right. Dr. Alley, with all due respect, you didn't answer the Chairman's question. You know, can—the question was a very good question. There have been these back-and-forth between—on glaciers and the melting that we have seen over and over again. Why did it happen, then, if these same factors that you are blaming it on didn't exist then?

Dr. ALLEY. I can give you as much or as little answer that you would like.

Mr. ROHRABACHER. Give me 15 seconds.

Dr. ALLEY. Okay. Give me 30 if I may.

Mr. ROHRABACHER. Okay. Go ahead.

Dr. ALLEY. The ice ages are caused by features of Earth's orbit. Your brightness is the sun. This, my head, is the earth. This, through my nose, is the equator. Here, the top of my head, is the North Pole. If the North Pole stood straight up, you could never give me a sunburn on my bald spot. But in fact as you know, it is tipped over a little bit and it nods a little more and a little less over 41,000 years. Now, when it nods more, my bald spot ice melts and the equator is a little more shaded and now the ice grows and now the ice melts. But it takes 41,000 years for this change to happen. We know what that is doing right now and it is not fast enough to explain what we are seeing.

Mr. ROHRABACHER. No. You are trying to tell me all of the other melts and backs-and-forth took all those thousands of years? There wasn't a situation where on Mount Kilimanjaro you had it—10 years you had this much ice and then the next year you didn't and vice versa?

Dr. ALLEY. On Kilimanjaro, the records are fairly short. It would be not the best one to lean on, unfortunately. You know, what you do with glaciers—and I had hoped that I had made that point—is that one glacier can do interesting things. The world's glaciers tend to listen to the climate. And so you need to take a large data set of glaciers to know what is going on. What you then do find is that——

Mr. ROHRABACHER. We all know that these things happen. The major question that we will debate today—and I am again very grateful to the Chairman for bringing this and having an honest exchange of ideas—is what role mankind is playing. And thus if mankind is playing a minor role, how does that then justify some of what we consider to be Draconian solutions in controlling human behavior that has been offered to us by people who are espousing this particular theory?

Mr. Santer, I—let me ask you this. You said—I think it was you who said—the sun—or some people try to say the sun explains everything. No. A lot of people are trying to say the sun explains a lot. Maybe you could explain to me why we have noticed that there are similar trends of these meltings of the polar ice cap that are going on on Mars. If it is not the sun that is a major factor and human activity, why is that?

Dr. ALLEY. If I—if I may?

Mr. ROHRABACHER. Sure. Go ahead.

Dr. ALLEY. Mars actually is linked a lot to the orbit as well. It also has some dust storm issues to deal with.

Mr. ROHRABACHER. Well, of course it does. But if we have the same thing going on at the same time, and you are blaming human activity for what is going on on Earth but you see it at the same time on Mars, why do you automatically assume, well, that must be human activity?

Dr. ALLEY. If, sir, I wanted to get a measure of how bright the sun was and whether it was getting brighter or dimmer, looking at an ice cap on Mars, which is changing its orbit, has features which would change the sunshine, and it has dust storms which change the sunshine. That is a very, very indirect, imprecise measure when we have very precise satellites that the people paid for with their taxpayer money, which are measuring and then show no increase in the sun's brightness.

Mr. ROHRABACHER. You will have to correct me if I am wrong because I am not a Ph.D.

Dr. ALLEY. Mars is a bad solar sensor and the satellites are actually very good solar sensors.

Mr. ROHRABACHER. But if you have a situation on Mars that—you have that situation, is it just—when people talk about solar activity, are we just talking about the brightness? Are we talking about other type of solar activity that has an impact on human—or not human climate, but the climate of this planet and the other planets of the hemisphere?

Dr. ALLEY. It is a very interesting question that you ask, sir, because at some level we know that we see the sun spot cycle and we see a very weak response in the temperature. So we know that the sun spots are affecting the climate. And it actually looks like they are affecting it just a tiny bit more than you would expect from the change in the brightness. So there is a little possibility of a fine-tuning knob on the sun, which is not just the brightness, it is other factors.

Mr. ROHRABACHER. But we do know there has been these changes because we do know that there was a medieval warming period, even though we can see that there has been attempts over the research—history of this research into global warming of trying to basically negate the changes that took place between the medieval period and the current period of time. But was the temperature higher on the Earth during the medieval period? Is there any evidence that the temperature got to be as high? And if it did, how could we blame that, then, on the production of CO_2?

Dr. ALLEY. Yeah, we have fairly high confidence that—that is why we call it the medieval climate anomaly. And it reflects a low in volcanos blocking the sun and a slight high in the brightness of the sun. And the best reconstructions that we have indicate that it is not as warm as what we are having now. But with uncertainties, that if you sort of go to the far fringe, it just might be about where you are.

Now, this is a very interesting thing you bring up because nature—you know, when the snow melts and the glaciers melt and then they reflect less sun and they soak up more heat and get us warmer, those positive feedbacks don't care whether we made it warmer or whether the sun made it warmer, other things made it warmer. They just care that it got warmer. So we actually use the size of the medieval anomaly as one of many ways to find out how much warming we might get from CO_2.

Mr. ROHRABACHER. That is the essence of the discussion today. It comes down to whether or not this has—it is Mother Nature or the master of the universe versus human beings doing something that now—they now need to be controlled about. Dr. Michaels, before my time is up, I should give you a chance to comment.

Dr. MICHAELS. On that one? Well, I would look beyond the medieval warm period and I would look at the end of the—what is called the beginning of the postglacial period, for several millennia where we know, based upon fallen trees—when a tree falls in the tundra—or in the northern part of the distribution—falls into acid, an acid environment and it is saved, it is preserved so we can date the tree with carbon dating and find out when it existed. We know that the boreal forest, the north woods extended all the way to the Arctic Ocean in Eurasia and, in fact, on to the Arctic Ocean islands. We know that it has to be about 6 to 7 degrees Celsius. That is, like, 12 degrees warmer in July for that forest to exist. That is how much warmer it had to be.

Mr. ROHRABACHER. And that is before human kind had any type of impact on this. And let us note this.

But let us note this. Okay. Let us note this. But let us note this. The actual statistics when you start your statistics of how much warmer it is getting now, you are starting—you are starting your calculations at the bottom of a 500-year decline in world temperature which is the mini Ice Age. Is that right, Dr. Michaels or Dr. Alley?

Dr. ALLEY. Yeah. No, it is very, very clear. A lot of my work is reconstructing the history. Nature has changed climate a lot by itself, for reasons that we understand reasonably well, and we know are not active in this one.

Mr. ROHRABACHER. That is the point.

Dr. ALLEY. If we were not here—you know, if humans weren't here and we didn't care about anything that lives here—If this were a video game, I would push the button and see what happens, because it would be really exciting. But it is not a video game.

Dr. MICHAELS. Well, the reason I brought up the Eurasian arctic is because—again, it appears it was quite warmer for millennia up there, and the only way you can get it—get it that warm is to run water into the Arctic Ocean that is very warm. And there is only one gate for the water. It is the strait between Greenland and Europe. So that means the temperature of at least eastern Greenland had to be quite a bit warmer for a very long time, and the integrated warming is probably greater than what we could produce if we tried to burn as much carbon fuel as we could. And the ice still didn't rapidly fall off of Greenland, as some people are saying it is going to fall off in 100 years. Well, it didn't fall off a couple of thousand years.

Dr. ALLEY. Central Greenland was about one degree warmer, 1–1/2 degree warmer based on about five lines of evidence that I could summarize for you. Greenland was smaller during this warm time by something like half a meter of sea level.

Dr. MICHAELS. But again, the scenario of the rapid loss of ice simply didn't occur and that is—that is what is really driving the policy on this. It is not the gradual warming that is driving it.

Chairman BAIRD. For the record here, the stenographer here can't record that Dr. Alley is periodically pointing to the top of his head. And it is actually substantive, because his argument was illustrated by the point that the angle of the Earth relative to the sun can change over time with a bit of a wobble and axis of the Earth. And the top of Dr. Alley's head presumably represents the North Pole. I won't speculate where the South Pole is. But the symbolism is apparently that the Earth tips towards the sun and that may be accounting for some of these prior periods in the absence of anthropogenic CO_2. I want to recognize——

Mr. ROHRABACHER. Which is fine.

Dr. MICHAELS. And the polar bear survived and the Inuit culture developed.

Chairman BAIRD. I want to recognize Dr. Bartlett.

FOSSIL FUEL RESOURCES AND CLIMATE CHANGE

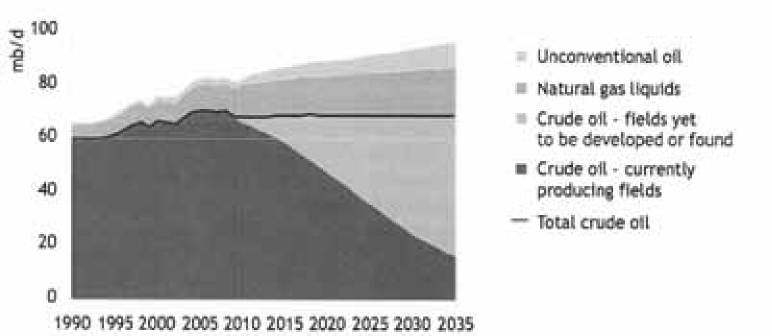
Mr. BARTLETT. Thank you very much. I apologize for my absence. The Chevy Volt is on the Mall and I have been scheduled for quite some time to speak briefly to the group there at the introduction of the Chevy Volt to the Capitol Hill. So I am very sorry that I missed your testimony.

You know, in the past, the Earth has been very much warmer. We had subtropical seas at the north slope of Alaska or we wouldn't have oil there, and there weren't any humans there then. So clearly something else caused it. That does not mean that our activities today aren't enormously important in climate change because you are at—if you are at the tipping point—if a car is half way over a cliff and it is at the tipping point and then a little baby comes up and pushes on the rear end of it, it is going over, isn't it? So if we are at the tipping point, it is irrelevant whether our contribution is small or great. If we are at the tipping point and we tip it over, we have done it.

I had a chart that I had hoped that the staff could get up on the screen. Can you get that up on the screen? Okay.

[The information follows:]

World oil production by type in the New Policies Scenario



Global oil production reaches 96 mb/d in 2035 on the back of rising output of natural gas liquids & unconventional oil, as crude oil production plateaus

And I want to apologize for my question to the first panel because I know—I am a scientist. I know that scientists shouldn't be concerned with policy. But the only reason you are here is because we are concerned with policy and we would like science to illuminate our policy. And so my question was better directed to other people, you know, regardless of what the science is, whether you agree with it or you disagree with it.

What the people want to do who want to move to less fossil fuels is exactly the right thing to do for two other very good reasons. If we can get that—this was the chart—and this is quite a startling chart because just a few years ago nobody would have predicted that—that we would be saying this today, because our USGS was predicting that oil was going to be ever more and more abundant, that the consumption of oil is going up and up forever. That is in spite of the fact that in 1956 M. King Hubbert predicted the United States would peak in 1970, and we did right on schedule.

There is the chart up on the little screen over there. The dark blue area—here it is on the screen behind you. The dark blue area is conventional oil that we now know about that peaked in 2006. And for the three or four years before the recession, the production of oil worldwide was static and demand was going up. With static supply and increasing demand, the price went up 50, 100, $150 a barrel. Then we had the recession which we should have capitalized on because it gave us a little breather.

Of course we did none of that. And SUVs and pickup trucks are back on the road in grand style in our country. But you look at that chart there and what we are predicting—you see that light blue area? You know, that is a dream. That is a dream that says that we are going to find enough—more oil or produce more oil from the sites that we have found. And many of these new sites are deepwater sites, enormously difficult to get at, enormously expensive to get at. I don't think that there is even a prayer that we are even going to come close to producing as much oil as they say we are going to produce by developing the fields we now know and finding new fields.

If you look at the oil chart in the discovery zone, most of them were in the past. The new oil—by the way, a large discovery of oil is 10 billion barrels of oil. Every 12 days, the world uses a billion barrels of oil. That is pretty simple arithmetic. But 84 million barrels a day—84 goes into a 1,000 roughly 12 times, doesn't it? So if you have a 10 billion barrel discovery of oil, oh, you breathe a sigh of relief. It is all over, guys, we have got oil, 120 days that will last the world. Big deal.

So, you know, what we are trying to do—I know the scientists are concerned about science and I am a scientist, but we are concerned about policy. And the only reason you are here is because we want you to illuminate our policy. And whether you agree with my colleague that we are a major factor in this or not is totally irrelevant, because the right policy is to do exactly what people want to do. If you believe that human activity is increasing CO_2 and changing the climate, you want to move to fossil fuel. That is exactly the same thing that those are concerned about national security want to do. We have only two percent of the oil. We use 25 percent of the oil. We import 2/3 of what we use. Exactly the same thing that people want to do who recognize—by the way, the first person to recognize this was Hyman Rickover in 1957. Pull up his speech. You can find the link on our website or do a Google search for Rickover and energy speech. And one of the really important things he said in that speech was that how long the age of oil lasted was important in only one regard. The longer it lasted, the more time we would have to plan an orderly transition to other sources of energy.

I will close, Mr. Chairman, by noting that we in this country have now blown 30 years. We knew of an absolute certainty in 1980—when we look back to 1970, which is when M. King Hubbert said that oil would peak in this country, we knew with an absolute certainty that he was right about the United States. Now, we tried to make him out a liar by doing a lot of things. We have drilled more oil wells than all the rest of the world put together. We have found oil, a lot of it, in Alaska and the Gulf of Mexico. But in spite of those things, today we produce half of the oil, less than half the oil than we did in 1970. He predicted the world would be peaking about now and we are.

And so—if the policy we are looking for is whether or not we have got to be moving away from fossil fuels to alternatives, absolutely.

Just one more word. There are two kinds of energy that we use—electricity and liquid fuels. The future will have all the electricity that we need with more nuclear plants producing 80 percent with nuclear, with more wind and solar and micro hydro and true geothermal. That is not your heat pump looking at 50, 60 degrees rather than 90 degrees in the summer and 10 degrees in the wintertime. We will use as much electricity as we would like to use.

The real crunch is going to be liquid fuels. If you are wildly optimistic about every one of the possibilities for liquid fuels, they don't—alternatives—they don't even come close to 84 million barrels a day. Two bubbles have already broken. One is the hydrogen bubble. Have you heard anybody talk about hydrogen anymore? They finally figured out it is not an energy source. It is just the equivalent of a battery that carries energy from one place to another. Although real clean when you use it. You get water when you burn it.

The second bubble that broke was the corn ethanol bubble. The National Academy of Sciences has said that if we could turn all of our corn into ethanol and discount it for a fossil fuel input, still leaves you to pretend you are displacing fossil fuels if you are simply using them in another form.

We would displace 2.4 percent of our gasoline—this is not Roscoe Bartlett—this is the National Academy. They further said—and this is their statement—that we would save more gas than we would by turning all of our corn into ethanol if we just tuned up our car and put air in the tires.

Now, the next bubble that is going to break is going to be the cellulosic ethanol bubble. We will get something from biomass. It will not even come close to what they hoped to get. Life on this Earth is dependent largely, except what comes from the sea, on about 8 or 10 inches of topsoil. That is topsoil because it has organic material in it. This year's weeds grow largely because last year's weeds died and are fertilizing them. We can only for a short period of time rape the topsoil and get away with it.

What is the sustainability of cellulosic ethanol? That is the next bubble that will break. We just have to come to the realization that fossil fuels or liquid energy in the amounts that we would like to use it just aren't going to be there. We are going to go largely to an electric world, an electric car. You can't electrify the airplane, by the way. And big trucks won't run on batteries very well. So we are going to have a very—and this is a very challenging future for me, Mr. Chairman, because every six hours we go another billion dollars in debt and every 12 hours we have another billion dollar trade deficit.

The jobs that went overseas aren't coming back, so we have got to create new ones. And my dream is that we can create those new jobs in the green area and we can once begin—become a major exporting country. And this Committee is going to be very important in that regard in sponsoring the basic science that will make this green technology.

I am sorry I ran over my time, but this is something obviously that I am kind of passionate about. Thank you very much for holding the hearing.

Chairman BAIRD. One would not detect the passion. Dr. Bartlett, I appreciate the eloquence and the sentiments and echo them myself. I share them. And as I mentioned at the outset, you have embodied them in your own choices about how you power your own life. And it is admirable that you do.

THE IMPACTS OF CURRENT CO_2 EMISSIONS

One last question for Dr. Feely, if I may. One of the concerns that many of us have about—about this phenomenon is to what extent are we making decisions now that put us well down the road of a long-term impact even if we make changes today? And so the—sort of at what point do we start bending the curve in the right direction?

My understanding is that—is that—well, enlighten us. To what extent is the CO_2 already present going to cause problems for the ocean?

Dr. FEELY. That is the exact question that the scientific community is wrestling with right now. And there is already evidence from looking at organisms in sea water; we already see that we have already had an impact. Foraminifera shells are getting smaller. You can compare shells that are collected at present with living organisms to which shells that were on the bottom of the sea from 200 years or longer ago; there is a significant difference. So we already know that we are having impacts.

We know with our own shellfish industry on the west coast that we are having significant impacts. Have we reached a tipping point yet? This is the question we are really asking ourselves. And it is very hard to answer that question. What we do know for sure, if we get above 450 parts per million, we will cause the Arctic Ocean and the Antarctic Ocean to go corrosive from top to bottom. That is a tremendous impact on that——

Chairman BAIRD. Say that again. To go corrosive——

Dr. FEELY. Corrosive from top to bottom throughout the entire water column.

Chairman BAIRD. Corrosive to the marine organisms at——

Dr. FEELY. To the calcifying organisms, which means that the pH would be about 7.7 or so. And consequently, that is not too far away. And we have to begin to concern ourselves of whether or not we will go much farther in terms of CO_2 levels beyond that which would impact large areas of the Pacific and Atlantic Oceans as well.

The projections out to the end of the century say that we would have CO_2 levels as high as 800 parts per million, which would have impacts on the entire southern ocean, would impact the coral reefs throughout the world oceans, and would even impact our deep-water corals which we know very little about.

Chairman BAIRD. So let me just make sure I understand. We are already having problems with current rates of CO_2 in the atmosphere. At projected increases with economic development, et cetera, if we don't change, as Dr. Bartlett has been talking about, if we don't change our energy system to a less fossil fuels-based energy system, the projected levels could reach levels where in the major polar regions and elsewhere in the oceans, the water itself would become corrosive to the organisms that have evolved over many millions of years to live there, and the base food chain for much of ocean life could be significantly impacted. Is that a fair statement?

Dr. FEELY. That is absolutely correct.

Chairman BAIRD. Now, this highlights something that is fundamental to this hearing and it is this. It goes back to my friend Dr. Bartlett's analogy. If your car might be at the tipping point and even if there is some uncertainty about that, do you tell the baby to stop pushing? It just seems to me if the car is going to go off the bloody cliff, if there is doubt, you stop pushing, especially when the solution can be beneficial to your economy, beneficial to your national security perspective, beneficial to your environment, beneficial to human health. Why not stop pushing, for goodness' sake, if there is doubt?

And Bob Inglis had the example earlier, the analogy. We have bent over backwards on this Committee and this hearing today to include folks like Dr. Michaels, Dr. Lindzen. But the reality is surveys of topflight scientists have shown the vast majority suggest that there is real reason for concern. And if there is real reason for concern, should we not tell the baby to stop pushing if we have ways to do it?

So I thank this panel. We are now going to talk further about what possible impacts might be. I thank the panel. It has been a spirited discussion, a constructive one. Again, as I have done before for folks—please, Dr. Bartlett.

Mr. BARTLETT. I cannot stay. But I would like to note that the importance of these hearings is not the fact that some Congressman is up here listening to you. The importance of this hearing is that it is on the record. And so thank you very much for coming.

The next panel will be on the record. I really regret that I can't be here. But my Chairman will ask the questions that I might have asked and do it better than I.

Chairman BAIRD. Well, Doctor, I can't do it better than you, I am sure, my friend. But one thing I am certain of—and I was going to say—you anticipated it. The transcript, the written transcripts, the oral transcripts, the video of this will be on the record. So people can actually access the Committee website if you can't sit through the whole thing or don't want to.

And having had the privilege to read all the transcripts. I note for example, Dr. Cullen, if you want to get a really marvelous, understandable grasp of the history of this, I think Dr. Cullen's testimony is just spectacular in that regard. And all of the others are. Some of it is, frankly, too deep for me and others, but you will get the sense. And I think it is good. And, Dr. Bartlett, thanks.

With this, I thank our panelists for their presentations today and their years of scientific work. We will take a five-minute recess followed by the final panel. Let's reconvene in about 30 seconds if we can. I know we are having spirited discussion. But let's try to reconvene so that we can hear from our extraordinarily distinguished final panel whose patience I greatly appreciate and—as do I appreciate that of our guests in the audience today and my colleagues who have, for very understanding reasons, had to depart. But I am very, very grateful, again.

This is available to Members of Congress, their staff, and to the general public and media on our website. And so I hope you will not consider the fact that we have very important and unfortunately timed organizational meetings on both the Democratic and Republican side happening as we speak. Again, we did our level best to be sure people were here and in the process made sure people were somewhere else, which was a misfortune. But the fact that you are all here is what matters the most in my judgment. And the fact that our colleagues who care—and I hope they do care—will have a chance to review all of the testimony is tremendously important. And thus we begin our final panel as soon as I can find the introductory page.

[Recess.]

Panel III

Chairman BAIRD. Thus we begin our final panel, as soon as I can find the introductory page.

Here we go. Again, appreciate the witness's presence.

Rear Admiral David W. Titley is the Oceanographer and Navigator of the United States Navy. I love that title. The Navigator for the United States Navy. Every time a ship crashes into another ship it's your fault, right?

Admiral TITLEY. Yes, sir.

Chairman BAIRD. Mr. James Lopez, Senior Advisor to the Deputy Secretary for the U.S. Department of Housing and Urban Development. Mr. Lopez, thanks for being here.

Mr. William Geer is the Director of the Center for Western Lands of the Theodore Roosevelt Conservation Partisanship; and Dr. Judith Curry, the Chair of the School of Earth and Atmospheric Sciences at Georgia Institute of Technology. Thank you, Doctor, for being here.

We will begin our testimony. As you saw, we will try to limit the initial comments to around five minutes, and then we will follow up with questions. Thank you.

We will begin with Admiral Titley. Thank you.

STATEMENT OF REAR ADMIRAL DAVID W. TITLEY, OCEANOGRAPHER AND NAVIGATOR OF THE U.S. NAVY

Admiral TITLEY. Thank you, sir.

Mr. Chairman, and distinguished colleagues, I want to thank you for the opportunity to address you today regarding why the Navy cares about climate change and how we are responding to the opportunities and challenges it presents. Rather than read from my written statement, sir, I will provide brief introductory remarks on the topic and invite any questions from you.

The 2010 Quadrennial Defense Review, or——

Chairman BAIRD. You have a voice that I could hear, but without the mic apparently the others didn't.

Admiral TITLEY. Are we on? Okay. Have to be five percent smarter than the microphone.

The 2010 Quadrennial Defense Review, or QDR, and 2010 National Security Strategy both require the Department of Defense to take action regarding climate change by recognizing the effects climate change may have on its operating environment, roles, missions, facilities, and military capabilities. Taking into account this guidance, the Navy recognizes the need to adapt to climate change and is closely examining the impacts that climate change will have on military missions and infrastructure.

The Navy is watching the changing Arctic environment with particular interest. The changing Arctic has national security implications for the Navy. The Navy's maritime strategy identifies that new shipping routes have the potential to reshape the global transportation system.

The QDR identifies the Arctic as a region where the influence of climate change is most evident in shaping the operating environment and directs the Department of Defense to work with the Coast Guard and the Department of Homeland Security to address gaps in Arctic communications, domain awareness, search and rescue, and environmental observation and forecasting capabilities.

There are other impacts of climate change on missions that the Navy must consider, including water resources and fisheries redistribution, shifting precipitation patterns, and implications for humanitarian assistance and disaster relief. The Navy must understand where, when, and how climate change will affect regions around the world and work with Federal partners to develop the capabilities needed to ensure readiness in the 21st century.

The Navy must also be aware of impacts to military infrastructure both within and outside the continental United States due to increased sea level rise and storm surge. The Navy's operational readiness hinges on continued access to land, air, and sea training and test spaces; and many overseas bases provide strategic advantage to the Navy in terms of location and logistic support. Any adaptation efforts undertaken are required to be informed by the best possible science and initiated at the right time and cost.

The Navy is currently beginning assessments that will inform Navy strategy, policy, and plans. The Department of Defense is already conducting adaptation efforts through a variety of activities, including two Navy roadmaps on the Arctic and global climate change and the leveraging of cooperative partnerships to ensure best access to science and information. For example, the Navy is partnering with the National Oceanic and Atmospheric Administration [NOAA] and the United States Air Force to advance U.S. environmental prediction capability to mitigate the impact of severe weather and answer operational requirements facing our Nation.

The Navy understands the challenges and opportunities that climate change will present to its missions and installations. We are beginning to conduct the assessments necessary to inform future investments and are initiating adaptation activities in areas where we have enough certainty with which to proceed.

Thank you, sir, and I stand ready to answer any questions the Subcommittee may have.

[The prepared statement of Admiral Titley follows:]

PREPARED STATEMENT OF DAVID TITLEY

Mr. Chairman, members of the subcommittee and distinguished colleagues, I want to thank you for the opportunity to address you today regarding the Navy's climate change interests. My name is Rear Admiral David Titley and I am the Oceanographer of the Navy and the Director of Navy's Task Force Climate Change. The Chief of Naval Operations, Admiral Gary Roughead, established Task Force Climate Change in May of 2009 to address implications of climate change for national security and naval operations. Today I am speaking about why the Navy cares about climate change and how we are responding to the challenges and opportunities it presents.

The 2010 Quadrennial Defense Review (QDR) identifies climate change as an issue that will play a significant role in shaping the future security environment, and directs the Department of Defense to take specific action to reduce the risks associated with climate change, while also identifying climate change and energy security as "inextricably linked." In addition, climate change is addressed in the 2010 National Security Strategy, which states that the issue is a key challenge requiring broad global cooperation.

The QDR discusses how climate change will affect the Department of Defense (DoD) in two broad ways: first, by shaping the operating environment, roles, and missions that we undertake due to physical changes such as rising temperature and sea level, retreating glaciers, earlier snowmelt, and changing precipitation patterns and geopolitical impacts resulting from these changes; and second, the QDR describes the need for DoD to adjust to the impacts of climate change on our facilities and military capabilities by constructing a strategic approach that considers the influence of climate change.

In addition, DoD participates in the Interagency Climate Change Adaptation Task Force. In October, the Task Force submitted a progress report to the President with recommendations for how Federal policies and programs can better prepare the Nation to respond to the impacts of climate change. The Task Force recommended that Agencies and Departments, including DoD, make adaptation a standard part of planning to minimize climate risks and damages and to ensure that resources are invested wisely and that services and operations remain effective in a changing climate.

Taking into account the DoD guidance and Interagency Climate Change Adaptation Task Force recommendations, the Navy recognizes the need to adapt to climate change and is closely examining the impacts that climate change will have on its military missions and infrastructure.

In terms of climate change impact on missions, the Navy is watching with great interest the changing Arctic environment. September 2007 saw a record low in sea ice extent and the declining trend has continued—September 2010 was third lowest extent on record and the overall trend has shown an 11.2 percent decline per decade in seasonal ice coverage since satellites were first used to measure the Arctic ice in 1979. Perhaps more significantly, estimates from the University of Washington's Applied Physics Lab show that the amount of sea ice continues to decrease dramatically. September ice volume was the lowest recorded in 2010 at 78 percent below its 1979 maximum and 70 percent below the mean for the 1979–2009 period. Regardless of changes to sea ice, the Arctic will remain ice covered in the winter through this century and remains a very difficult operating environment. The changing Arctic has national security implications for the Navy. The QDR identifies the Arctic as the region where the influence of climate change is most evident in shaping the operating environment and directs DoD to work with the Coast Guard and Department of Homeland Security to address gaps in Arctic communications, domain awareness, search and rescue, and environmental observation and forecasting capabilities. The Navy's Maritime Strategy identifies that new shipping routes have the potential to reshape the global transportation system. For example, the Bering Strait has the potential to increase in strategic significance over the next few decades as the ice melts and the shipping season lengthens, and companies begin to ship goods over the pole rather than through the Panama Canal.

While the Arctic is a bellwether for global climate change, there are other impacts of climate change on missions that the Navy must consider, including water resources, fisheries, and implication for humanitarian assistance and disaster relief. Availability of freshwater will change with the redistribution of precipitation patterns and saltwater intrusion resulting from sea level rise. Furthermore, alterations in freshwater systems will present challenges for flood management, drought preparedness, agriculture, and water supply. On the other hand, some areas of the world, such as Russia, will likely see longer growing seasons and an increase in water availability, potentially providing opportunities for economic growth. In addition to water supply, large scale redistribution of fisheries catch potential is a concern in areas of the world that depend heavily upon this industry as a primary food source. Leading fishery scientists estimate decreases of up to 40% in overall catch potential for most major fisheries near the tropics over the next four decades due to warming and changes in ocean chemistry, while the Arctic region may see an increase in overall catch potential. Further impacts to marine ecosystems will be caused by ocean acidification, often referred to as "global warming's silent partner." Shifting precipitation patterns and frequency of floods and droughts may generate humanitarian assistance and disaster response requirements and the Navy, with its expeditionary capabilities, may be tasked to support these requests in accordance with the 2010 National Security Strategy, which states that "a changing climate portends a future in which the United States must be better prepared and resourced to exercise robust leadership to help meet critical humanitarian needs." The Navy must understand where, when, and how climate change will affect regions around the world and work with federal partners to develop the capabilities needed to ensure readiness in the 21st century.

In addition to impacts to Navy missions, we must be aware of impacts to military infrastructure, both within and outside of the Continental United States. The recent National Research Council Report, "Advancing the Science of Climate," notes that many United States military bases are located in areas likely to be affected by sea level rise and tropical storms. The Navy's operational readiness hinges on continued access to land, air, and sea training and test spaces. Coastal infrastructure is particularly vulnerable because it will be affected by changes in global and regional sea level coupled with a potential increase in storm surge and/or severe storm events. Overseas bases may be impacted by sea level rise, changing storm patterns, and water resource challenges. Bases such as Guam and Diego Garcia provide a strategic advantage to the Navy in terms of location and logistics support.

The potential impacts of climate change on Navy missions and infrastructure require adaptation efforts that are informed by the best possible science, and initiated at the right time and cost. For example, the Strategic Environmental Research and Development Program (the DoD's environmental science and technology program) is currently funding four research projects, situated in different geophysical settings along the US coastline, that collectively are developing the physical process models and assessment methodologies needed to assess the impacts of sea level rise and associated storm surge on DoD coastal installations. In addition, via its recently submitted Strategic Sustainability Performance Plan mandated by Executive Order 13514, DoD has articulated is strategy for a QDR-directed, comprehensive assessment of military installations to assess the potential impacts of climate change on DoD's missions. The associated research and development aspects of this effort will result in impact and vulnerability assessment tools designed for military installations, regionally applicable climate change information, and adaptation strategies appropriate for DoD requirements. The Defense Science Board's Task Force on Trends and Implications of Climate Change for National and International Security is making recommendations on the role DoD should play in dealing with other U.S. government agencies to mitigate potential consequences of environmental change in areas important to U.S. national security. The Navy has sponsored the National Research Council's Naval Studies Board to study the national security implications of climate change on U.S. Naval forces, and is currently conducting a Capabilities Based Assessment for the Arctic to identify capabilities required for future operations in the region and possible capability gaps, shortfalls, and redundancies. Assessments such as these will inform Navy strategy, policy, and plans to guide future investments.

The Navy is already executing adaptation efforts through a variety of activities. The Navy is conducting wargames that include climate change impacts on future tactical, operational, and strategic Naval capabilities. Within the last year the Navy promulgated two roadmaps concentrated on the Arctic and global climate change. The roadmaps guide strategy, future investment, action, and public discussion on the Arctic and global climate change. The Navy Arctic Strategic Objectives, released in May 2010, specify the objectives required to ensure the Arctic remains a safe, stable, and secure region where U.S. national and maritime interests are safeguarded and the homeland is protected. This past summer, the Navy participated in Canada's largest annual Arctic exercise, Operation NANOOK, which provided our sailors valuable operating experiencing in the region. The Navy established Task Force Energy to meet the growing energy challenges that we face as a service and a nation, and subsequently, the five energy goals as outlined by the Secretary of the Navy. Task Force Climate Change and Task Force Energy work closely to ensure that overlapping issues of climate change and energy security are addressed.

Furthermore, the Navy is actively leveraging interagency, international, and academic partnerships to ensure it has access to the best science and information and to avoid duplication of efforts. We are participating, in coordination with appropriate DoD offices, in many of the interagency efforts being conducted on climate change, including the National Science and Technology Council's Roundtable on Climate Information and Services, co-chaired by the Office of Science and Technology Policy, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey and the U.S. Global Change Research Program's National Climate Assessment, which in part are coordinating agency climate science needs and adaptation efforts across the federal government. Finally, the Navy is joining an effort with the Air Force and the National Oceanic and Atmospheric Administration to advance U.S. environmental prediction capability to mitigate the impact of the severe weather and answer operational requirements facing our nation. This capability will combine the forecasting skills of the Navy's and the National Weather Service's global numerical weather, ocean, and ice models to provide a better Earth Systems Prediction Capability.

I would like to close with a quote from Vice Admiral Richard Truly, former NASA Administrator, and Director of Department of Energy's National Renewable Energy Lab. "The stresses that climate change will put on our national security will be different than any we've dealt with in the past . . . this is why we need to study this issue now, so that we'll be prepared and not overwhelmed by the required scope of our response when the time comes." The Navy understands the challenges and opportunities that climate change presents to its missions and installations. We are beginning to conduct the assessments necessary to inform future investments and are initiating adaptation activities in areas where we have enough certainty with which to proceed.

Thank you Mr. Chairman and I look forward to answering any questions the Subcommittee may have.

BIOGRAPHY FOR DAVID TITLEY

A native of Schenectady, N.Y., Rear Admiral Titley was commissioned through the Naval Reserve Officers Training Commissioning program in 1980. While aboard USS *Farragut* (DDG 37) from 1980–1983, Titley served as navigator, qualified as a surface warfare officer, and transferred to the Oceanography community the following year.

Subsequent sea duty included tours as oceanographer aboard USS *Belleau Wood* (LHA 3) 1985–1987, USS *Carl Vinson* (CVN 70) in 1990, Carrier Group 6 1993–1995 and U.S. 7th Fleet 1998–2000. Titley has completed seven deployments to the Mediterranean, Indian Ocean and Western Pacific theaters. His Belleau Wood deployment included winter-time amphibious operations north of the Aleutian Islands.

Titley has commanded the Fleet Numerical Meteorological and Oceanographic Center in Monterey Calif., and was the first commanding officer of the Naval Oceanography Operations Command. He served his initial flag tour as commander, Naval Meteorology and Oceanography Command.

Previous shore tours include assignments at the Regional Oceanography Centers at Pearl Harbor and Guam, the Naval Oceanographic Office, on the staff of the Assistant Secretary of the Navy (Research, Development and Acquisition), Office of Mine and Undersea Warfare, as the executive assistant to the Principal Deputy Assistant Secretary of the Navy (Research, Development and Acquisition) and as chief of staff, Naval Meteorology and Oceanography Command.

Titley also served on the U.S. Commission on Ocean Policy, as Special Assistant to the Chairman (Admiral (ret.) James Watkins) for Physical Oceanography and as senior military assistant to the Director of Net Assessment in the Office of the Secretary of Defense.

In 2009, Titley assumed duties as oceanographer and navigator of the Navy.

Education includes a Bachelor of Science in meteorology from the Pennsylvania State University, a Master of Science in meteorology and physical oceanography and a Ph.D in meteorology, both from the Naval Postgraduate School. His dissertation concentrated on better understanding Tropical Cyclone Intensification. In 2003–2004, Titley attended the Massachusetts Institute of Technology Seminar XXI on Foreign Politics, International Relations and National Interest. He was elected a Fellow of the American Meteorological Society in 2009.

Chairman BAIRD. Thank you very much, Admiral.

Mr. Lopez.

STATEMENT OF JAMES LOPEZ, SENIOR ADVISOR TO THE DEPUTY SECRETARY, U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Mr. LOPEZ. Thank you very much.

Is that on? No? How about now? Good?

Good morning, Chairman Baird, Ranking Member Inglis, Members of the Subcommittee. My name is Jim Lopez, and I am the Senior Advisor to Deputy Secretary Ron Sims at HUD. Thank you for the opportunity to testify today.

On behalf of Secretary Shaun Donovan and Deputy Secretary Sims, I appreciate this opportunity to tell you how HUD—individually and in partisanship with other federal agencies—is working to develop more sustainable, resilient communities across the Nation. In fact, we believe that sustainable communities are resilient communities.

Before coming to HUD, I worked on climate change issues in King County, Washington State; and over the past year, I have had the opportunity to serve as part of the President's Interagency Climate Change Adaptation Task Force, which is chaired by the Council on Environmental Quality, NOAA, and the Office of Science and Technology Policy and includes 20 federal agencies and executive branch offices.

The Council last month released its progress report, with charts and a roadmap for federal action on climate adaptation and resilience. The report highlights the need to better understand and prepare for climate change and offers a flexible framework for federal agencies to engage in that important work.

The fact is that even if we could halt greenhouse gas emissions today, the scientific evidence, as we have heard today, suggests that the world would still experience changing climate for decades to come. While government efforts have tended to focus on reducing greenhouse gas emissions, climate mitigation, there should be an increasing focus on preparing for and responding to the threat that climate change impacts already represent to our social well-being, the economy, and the environment. That is climate resilience, and that is where I would like focus my remarks today.

I would like to make three quick points.

First, as noted before above, we must continue to work to reducing GHG emissions. We must also step up our efforts to prepare for and respond to climate change. Across the country, cities, counties, and states are putting in place strategies to adapt to risks and stresses caused by climate change such as flooding and extreme precipitation, temperature spikes, and urban heat island effects, water shortages and drought, and rises in sea level in coastal communities.

Second, there is a growing recognition that if we are to make progress on climate change, we need to focus on the built environment. That is on where we build, how we build, and how we move people and goods to the places we live, work, and play.

And, third, it's important that we tackle climate change in ways that respect and protect the most vulnerable populations: infants and children, pregnant women, the elderly with chronic medical conditions, low-income households, and outdoor workers.

And I am pleased to report to you that the Federal Government is paying attention to climate resilience. Federal agencies are supporting local efforts to adapt the built environment to these new challenges and to protect vulnerable populations through innovative programs and partnerships.

In HUD, we have formed an unprecedented partisanship with EPA and DOT, the Partisanship for Sustainable Communities, which will, we hope, result in reduced carbon emissions as we draw attention to the benefits of more compact, walkable, and climate-friendly communities.

We also hope to show that sustainable communities are resilient communities as HUD requests for proposals explicitly encourage communities to address climate adaptation and resilience as part of their regional planning efforts.

Another important component of HUD and the Federal Government's work to support sustainable communities is in the area of energy efficiency and green building. Properly implemented and maintained, investments in energy retrofits can significantly reduce energy use in existing buildings, improving comfort for residents and lowering carbon emissions.

Let me conclude by briefly touching on what we are doing to foster similar cooperation between federal agencies on climate adaptation. The Interagency Climate Change Adaptation Task Force, of which HUD is a member, submitted a report to the President emphasizing the importance of this issue to the Federal Government. President Obama signed an executive order in October, 2009, that called on the task force to recommend how federal agencies could play a role in a national climate change adaptation strategy. In the progress report we released last month, we reaffirmed the Obama Administration's commitment to mitigating greenhouse gas emissions and in the long term to improve our ability to manage the impact these emissions have on our lives. Mitigation and adaptation are inextricably linked and both are required in order to reduce the impacts of climate change.

The task force recommended in its progress report that federal agencies make adaptation a standard part of strategic planning to ensure that resources are invested wisely and that federal programs, services, and operations remain effective in a changing climate. In short, the federal response is rising to the level of the challenges before us.

Thank you, Mr. Chairman. I looked look forward to answering your questions.

[The prepared statement of Mr. Lopez follows:]

PREPARED STATEMENT OF JAMES C. LOPEZ

Good morning, Chairman Baird, Ranking Member Inglis, members of the Subcommittee. My name is Jim Lopez, and I am Senior Advisor to Deputy Secretary Ron Sims at HUD, who has been tasked by Secretary Donovan to lead HUD's climate change efforts. Thank you for this opportunity to testify today.

On behalf of the Deputy Secretary and Secretary Donovan, I want to thank and commend you for your leadership in developing and pushing for innovative and integrated approaches to the critical issue of climate change. I appreciate this opportunity to tell you how we at HUD—individually and in partnership with other federal agencies—are working to develop more sustainable, resilient communities across the nation.

I should note that this is an issue with which I've had hands-on experience at the local level. Before coming to HUD, I coordinated King County's climate change preparedness initiative in Washington State and I was a contributing author to *Preparing for Climate Change. A Guidebook for Local, Regional and State Governments*.[1] My experience at the county level has given me an important perspective on what the federal government could and should be doing on this critical issue.

Efforts to curb greenhouse gas emissions, known as climate change mitigation, have become a widespread imperative for all levels of government. However, scientific evidence indicates that even if we could halt greenhouse gas (GHG) emissions today, the world would still experience a changing climate for decades to come due to the long-lived nature of carbon dioxide and other greenhouse gases as well as the absorption of heat by oceans.[2] While federal, state, and local efforts, including HUD's, have tended to focus on reducing GHG emissions, there is an increasing focus on developing complementary climate resilience strategies, defined by the National Research Council of the National Academy of Sciences as the "capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy and the environment.[3]"

Climate Change and the Built Environment

The consequences of climate change are complex and far reaching. It is becoming increasingly clear that GHG emissions, the primary cause of climate change, are in large part a result of energy use in our built environment—either as a result of energy use in buildings themselves, or transportation energy used to move people and goods.[4]

Climate change is affecting many aspects of our society, our livelihoods and our environment. Communities across the nation are experiencing climate change im-

[1] ICLEI, University of Washington, 2007.

[2] Council on Environmental Quality, *Progress Report of the Interagency Climate Change Adaptation Task Force*, p. 15.

[3] National Academy of Sciences, National Research Council, *Adapting to the Impacts of Climate Change*, Prepublication Copy.

[4] Energy Information Administration, *http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html*. Buildings generate about 40 percent of emissions overall, and transportation generates 28 percent.

pacts, such as changes in average temperatures, more extreme weather events, and rising sea levels.[5]

The effects of climate change are expected to be significant for both rural communities and metropolitan regions (where most of the built environment is located). As a federal cabinet agency focused on the built environment, on strengthening metropolitan areas as well as rural communities, and expanding opportunity for all Americans, we at HUD recognize the need to take action.

Reducing GHG emissions in the built environment is essential to making progress on climate change at the speed and scale required. Across the country, cities, counties and States are finding innovative solutions to climate change that involve the built environment—from King County to Miami-Dade County, from Chicago to Los Angeles, from Milwaukee to New York City, and from Phoenix to San Francisco. In addition, home builders and community- and faith-based organizations, public housing authorities and private building owners, and financial institutions and foundations are taking action to prepare the built environment for climate change.[6]

These communities—and many others—are putting in place strategies to adapt to risks and stresses caused by climate change, such as flooding and extreme precipitation; temperature spikes and urban heat island effects; water shortages and drought; and rises in sea-level in coastal communities.[7]

Addressing Vulnerable Populations

Critical to all of these efforts is the need to pay particular attention to the impact of climate change on vulnerable populations. As noted in the National Research Council's Report, *Adapting to the Impacts of Climate Change*, groups with increased vulnerability to climate change are infants and children, pregnant women, the elderly with chronic medical conditions, low-income households, and outdoor workers.[8]

Low-income, often minority, families are frequently most at risk from the effects of extreme heat that will become more frequent due to climate change. They may be unable to afford the high cost of utilities in these conditions, or invest in the cooling equipment needed to mitigate these effect—often with tragic results.[9]

As noted by the U.S. Global Science Research Program, "in the future (as in the past), the direct impacts of climate change are likely to fall disproportionately on the disadvantaged. People with few resources often live in conditions that increase their vulnerability to the effects of climate change. The fate of the poor can be permanent dislocation, leading to the loss of social relationships and community support networks provided by schools, churches and neighborhoods."[10]

That's why we asked grant applicants for HUD's new regional sustainability planning grants (described below) to pay particular attention to addressing the needs of low-income and underserved populations; and why we are expanding our efforts to lower carbon emissions through improved energy efficiency in the affordable housing sector. Let me describe these initiatives in more detail.

HUD's Role—Sustainable Communities Initiative

I am pleased to report that through the Sustainable Communities Initiative HUD is supporting a new generation of community and regional planning that we think will result in more climate resilient communities. Just last month Secretary Donovan announced the first *Regional Planning Grants* to be awarded under the Sustainable Communities Initiative—our flagship effort to enable communities to develop more integrated regional responses to both mitigating, and adapting to the effects, of climate change.

This initiative is being implemented through an unprecedented partnership with EPA and DOT, the Partnership for Sustainable Communities. This important cross-agency collaboration is designed to encourage integrated solutions to the multi-

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[5] Karl, Thomas R, Melillo, Jerry M. Peterson, Thomas C *Global Climate Change Impacts in the United States* (2009), cited in *Progress Report, of the Interagency Climate Change Adaptation Task Force*, p. 15 (2010).

[6] Center for Clean Air Policy, *Ask the Climate Question: Adapting to Climate Change Impact in Urban Regions* (June 2009).

[7] Ibid, p. 11–14.

[8] *Adapting to the Impacts of Climate Change*, National Academies of Sciences, 2010, pp.32–33.

[9] Center for Clean Air Policy, *Ask the Climate Question: Adapting to Climate Change Impact in Urban Regions*, p.12, June 2009. In Chicago, for example, upward of 600 mostly poor, elderly and African American persons died in the wake of a sever heat wave in that city. As a result, Chicago has adopted an aggressive plan to enhance its capability to manage heat waves.

[10] Karl, Melillo and Peterson, *Global Climate Change Impacts in the United States* (2009).

dimensional environmental, housing and transportation challenges faced by cities and suburbs and rural areas.

The initiative will foster collaboration across jurisdictional lines and enable metropolitan leaders to "join up" housing, transportation, and other policies to address the critical issues of affordability, competitiveness, and sustainability. Moreover, our partnership with EPA encourages recipients to consider water infrastructure planning and conservation along with their housing and transportation plans. As noted in the National Academy of Sciences Report, climate change will place additional burdens on already stressed water resources. More intense droughts and flooding events are projected to become common in some regions.[11]

HUD's Notice of Funds Availability (NOFA) for the regional sustainability planning grants encouraged communities to address climate adaptation and resilience as part of their regional planning efforts. Eligible activities include:

> *Conduct comprehensive climate change impacts assessments* to guide regional planning and implementation strategies. Assessments may comprehensively evaluate a range of likely climate change impacts or may focus on an impact area of special concern in the region (e.g.: sea level rise or reduced water availability. Findings from climate impact assessments should be used as a basis for defining adaptation actions to be implemented in appropriate plans and strategies.

Some of the grant awards were to regional planning bodies in areas most vulnerable to flooding and extreme weather conditions: the South Florida Regional Planning Council (Hollywood, Florida), the Houston-Galveston Area Planning Council and the Gulf Regional Planning Council (Gulfport, Mississippi). The goal of these grants is not just to develop plans—it is to articulate a vision for growth tailored to specific metropolitan markets that federal housing, transportation, and other federal investments can support.

Funding to these metropolitan regions and rural communities can be used to support the development of integrated, state-of-the-art regional development plans that use the latest data and most sophisticated analytic, modeling, and mapping tools available.

In addition to these regional sustainability grants, HUD collaborated with DOT to award another $75 million in Community Challenge grants for local communities to initiate innovative housing, transportation, rural development and urban revitalization initiatives that are also likely to yield lower carbon emissions in these communities.

These efforts will benefit urban, suburban and rural communities alike. The 2007 American Housing Survey estimates that nearly 50 percent of people who live in rural places today live within the boundaries of metropolitan statistical areas. This requires a level of integrated planning that spans jurisdictional boundaries in new and unprecedented ways.

Energy Efficiency and Green Building

Another important component of HUD's work to support sustainable communities is in the area of energy efficiency and green building. Properly implemented and maintained, relatively modest investments in energy retrofit improvements can significantly reduce energy use in existing buildings, as well as improve comfort for residents.[12]

HUD itself spends more than $5 billion on utilities in public housing and other federally-assisted and public housing, and is taking steps to lower energy consumption in this stock, which houses some of our more vulnerable populations, including the elderly.

Through the Recovery Act, we have invested heavily in energy efficiency in housing, including, for example through the Green Retrofit Program, which has provided grants and loans to owners of privately-owned multifamily buildings. Average expenditure will be approximately $10,000 per unit, and we expect to retrofit some 20,000 units through the program.

In addition, significant investments have been made in public housing. Through the Recovery Act, 1,500 new units will be built to green standards or achieve the Energy Star for New Homes and another 35,000 units of public housing should

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[11] National Academy of Sciences, *Adapting to the Impacts of Climate Change*, p.34 (2010).

[12] Hendricks, Goldstein, Detchon and Shickman, *Rebuilding America: A National Policy Framework for Investment in Energy Efficiency Retrofits*, Center for American Progress (August 2009). In the residential sector, investments of $5,000 to $20,000 per unit can achieve energy savings of 20—40 percent on average. In commercial properties, investments of $10 to $30 per square foot can deliver energy savings of up to 40 percent.

lower energy use by at least 20 percent[13]. We also provide incentives for public housing authorities to utilize third-party Energy Performance Contracts, and plan to retrofit another 15,000 units through this mechanism over the next two years. We have also established a partnership with the Department of Energy to lower barriers to the use of DOE's Weatherization Assistance Program in housing stock supported by HUD.[14]

Interagency Climate Change Adaptation Task Force and the Federal Role

The same level of interagency cooperation that underlies the Partnership for Sustainable Communities and our partnership with DOE to improve the energy efficiency of our buildings is now shaping federal actions to address climate adaptation and resilience. Last month, the Interagency Climate Change Adaptation Task Force, of which HUD is a member, submitted a report to the President emphasizing the importance of this issue to the Federal government.

The Task Force began meeting in the Spring, 2009. It is co-chaired by the Council on Environmental Quality (CEQ), the National Oceanic and Atmospheric Administration (NOAA), and the Office of Science and Technology Policy (OSTP.) Recognizing the important role of the Federal Government in adaptation, President Obama signed an Executive Order on October 5, 2009 that called on the Task Force to recommend how the policies and practices of Federal agencies can be made compatible with and reinforce a national climate change adaptation strategy. The Executive Order charged the Task Force with delivering a report through the Chair of the CEQ to the President within one year.

The Task Force's Report to the President reiterated the scientific consensus that climate change is a scientific fact, and that human activities are a major contributing factor. It re-affirmed the Administration's commitment to both take steps to mitigate greenhouse gas emissions, as well as develop adaptation strategies to enable communities to withstand and respond to the effects of climate change:

> There is scientific consensus that the Earth is warming due to increased concentrations of greenhouse gases (including carbon dioxide) in the atmosphere (IPCC 2007, GCCI 2009, NRC 2010). Increased energy trapped in the atmosphere and the oceans due to these higher concentrations of greenhouse gases is already leading to impacts, in the United States and globally, including warmer average water and air temperatures.
>
> The Obama Administration is committed to mitigating (i.e., reducing) greenhouse gas emissions to minimize the future impacts of climate change. However, the climate impacts we are observing today will continue to increase, at least in the short-term, regardless of the degree to which greenhouse gas emissions are managed. Even under lower emissions scenarios, global average temperatures are predicted to rise by over 2°F over the next 100 years (Figure 2) due to factors such as the long-lived nature of certain greenhouse gases in the atmosphere and the absorption of heat by the Earth's oceans. In the long-term, the ability to manage greenhouse gas emissions and moderate or reduce atmospheric concentrations of greenhouse gases will affect the magnitude of the impacts that we will need to adapt to (NRC 2010). Therefore, mitigation and adaptation are inextricably linked, and both are required in order to reduce the impacts of climate change.[15]

The Federal Role

The Task Force found that the Federal Government has an important and unique role in climate adaptation—but it is only one part of the broader effort that must be supported by multiple levels of government and various other private and nongovernmental partners throughout the country.

In particular, "Federal leadership, guidance, and support are vital to empowering others to act and to enabling decisions based on the best available information and science. Just as importantly, the Federal Government can learn from and build off the efforts of others, as many cities and states within and outside the United States have already begun to implement adaptive measures."

The Task Force also acknowledged that the Federal Government has an important stake in adaptation because climate change directly affects a wide range of

[13] U.S. Department of Housing and Urban *Development Capital Fund Recovery Competition Grants, Notice of Funds Availability*, May, 2009.

[14] See *www.hud.gov/recovery/weatherization*.

[15] Council on Environmental Quality, *Progress Report of the Interagency Climate Change Adaptation Task Force: Actions and Recommendations In Support of a National Climate Change Adaptation Strategy*, October 5, 2010.

Federal services, operations and programs, particularly those associated with management of public lands, infrastructure, and national security, among others.

The Task Force recommended in its Progress Report that Federal Agencies make adaptation a standard part of strategic planning to ensure that resources are invested wisely and that Federal programs, services and operations remain effective in a changing climate.

The Task Force also recommended that the Government continue to enhance climate services that enable informed decisions based on the best available science, and to work with the international community to improve knowledge sharing and coordinate adaptation investments.

We also need to pay more attention to the unintended consequences of policies that may increase our vulnerability to climate risks and thus make adaptation more costly and difficult; for example, certain policies may lead to high risk activities in the very areas that climate science would suggest people avoid.

The Interagency Task Force adopted a set of Climate Adaptation Principles (see Attachment A), as well as five Policy Goals that we hope will shape federal action in this arena. In addition, we expect to initiate a number of pilot projects where these principles and goals can be tested in partnership with local communities.

Thank you Mr. Chairman, and members of the Committee—I look forward to answering your questions.

Attachment A: Federal Interagency Task Force Climate Adaptation Principles

Adopt integrated approaches. Climate change preparation and response should be integrated into core policies, planning, practices, and programs whenever possible.

Prioritize the most vulnerable. Adaptation plans should prioritize helping people, places, and infrastructure that are most vulnerable to climate impacts. They should also be designed and implemented with meaningful involvement from all parts of society. Issues of inequality and environmental justice associated with climate change impacts and adaptation should be addressed.

Use best-available science. Adaptation should be grounded in best-available scientific understanding of climate change risks, impacts, and vulnerabilities. Adaptive actions should not be delayed to wait for a complete understanding of climate change impacts, as there will always be some uncertainty. Plans and actions should be adjusted as our understanding of climate impacts increases.

Build strong partnerships. Adaptation requires coordination across multiple sectors, geographical scales, and levels of government and should build on the existing efforts and knowledge of a wide range of stakeholders. Because impacts, vulnerability, and needs vary by region and locale, adaptation will be most effective when driven by local or regional risks and needs.

Apply risk-management methods and tools. A risk management approach can be an effective way to assess and respond to climate change because the timing, likelihood, and nature of specific climate risks are difficult to predict. Risk management approaches are already used in many critical decisions today (e.g., for fire, flood, disease outbreaks), and can aid in understanding the potential consequences of inaction as well as options for risk reduction.

Apply ecosystem-based approaches. Ecosystems provide valuable services that help to build resilience and reduce the vulnerability of people and their livelihoods to climate change impacts. Integrating the protection of biodiversity and ecosystem services into adaptation strategies will increase resilience of human and natural systems to climate and non-climate risks, providing benefits to society and the environment.

Maximize mutual benefits. Adaptation should, where possible, use strategies that complement or directly support other related climate or environmental initiatives, such as efforts to improve disaster preparedness, promote sustainable resource management, and reduce greenhouse gas emissions including the development of cost-effective technologies.

Continuously evaluate performance. Adaptation plans should include measurable goals and performance metrics to continuously assess whether adaptive actions are achieving desired outcomes. In some cases, the measurements will be qualitative until more information is gathered to evaluate outcomes quantitatively. Flexibility is a critical to building a robust and resilient process that can accommodate uncertainty and change.

Attachment B: Federal Interagency Task Force Policy Goals

Encourage and mainstream adaptation planning across the Federal Government.

Improve integration of science into decision making.

Address key cross-cutting issues.

Enhance efforts to lead and support international adaptation.

Align and coordinate capabilities of the Federal Government to support national adaptation.

BIOGRAPHY FOR JAMES C. LOPEZ

James (Jim) Lopez is the Senior Advisor to Deputy Secretary Ron Sims at the Department of Housing and Urban Development. Under the Deputy Secretary's Office, he has played a leading role in creating and implementing several of HUD's interagency initiatives including HUD's work on sustainable and livable communities, climate change adaptation, and energy efficiency.

Before joining HUD, Jim served in various senior advisor positions for King County in Seattle, Washington. Of note, he was the Director of Strategic Planning and Performance Management in the office of King County's former Executive Ron Sims. He also served as Executive Sims' Deputy Chief of Staff and key policy strategist. Jim led King County's internationally recognized Climate Change program and helped create the county's award winning Health Reform Initiative.

Prior to his entry into government, Jim practiced law for nine years in Boston, Massachusetts.

Jim received a law degree from Case Western Reserve in 1992 and a M.P.A. from Harvard University's John F. Kennedy School of Government in 2003. He resides in Gaithersburg, MD with his wife and two daughters.

Chairman BAIRD. Thank you, Mr. Lopez.

Mr. Geer.

STATEMENT OF WILLIAM GEER, DIRECTOR OF THE CENTER FOR WESTERN LANDS, THEODORE ROOSEVELT CONSERVATION PARTNERSHIP

Mr. GEER. Thank you, Mr. Chairman.

We appreciate the opportunity to sit before this committee and share the concerns we have on climate change and recite what we are doing about it, what we see in the field, what we are doing about it today.

I have no PowerPoint slides, but I represent a community of people, both professionally and in terms of passionate views, that have a great concern about what's happening in environmental change.

Professionally, I represent fish and wildlife biologists. I have been one for 38 years, and so I have had a chance to work on a lot of impacts and a lot of development projects, and I have seen changes. I don't always know the causes of all those changes, but the people in my field always have to deal with the consequences and manage accordingly, even if we can't always decide where exactly did that change come from.

In terms of the passionate users, I represent hunters and anglers. Many of these hunters and anglers are not scientists. Some in fact are; most are not. But they have a passion for use of the resource, and we often feel that they also are some of the first observers of change in the field. They see things in a natural environment because it affects the distribution of animals, or perhaps they pursue hunting and fishing, and of course they want us to do something about it.

I live in Montana, where about half the population actually hunts and fishs. Twenty percent still hunt, and about half of them hunt or fish. And that's a sustainable outdoor recreation economy, in a state of less than a million people, of over a billion dollars a year. It's economically pretty significant.

And I meet frequently with these sportsmen in more than 32 cities scattered around the state on a regular basis. I talk about many conservation issues, climate change being one. And what I have found over the past few years in talking about climate change is, while some sportsmen won't utter the words climate change—it's partisan right now and it's almost a toxic phrase—most of them will readily acknowledge that the shorter winters, reduced snow pack, increasing spring rainfall, lower stream flows, melting glaciers, and mountain pine beetle epidemic reflect an environmental change that does not bode well for fish and wildlife or hunting and fishing as recreational activities.

As a consequence, in 2008, nine of the Nation's leading hunting and fishing conservation organizations released a book called *Seasons' End*, a report predicting the impacts of climate change on fish and wildlife habitat and its implications for sustainable hunting and fishing, and some of the conclusions are based on the best available predictions from scientists.

We heard earlier that upland birds face disruptions in life cycles that will sever reproduction and the emergence of critical food resources. In cold, wet springs, young birds sometimes suffer fatal exposure to cold from loss of thermal snow cover. Reduced nesting success leading to losses in specific age classes and eventually to population instability, coupled with increased predation and an influx of invasive species, result in fewer birds in the hunters' bags.

In Montana, though, we have some complications. Because climate change isn't the only stressor on the landscape. We find that sage grouse declines have also been tied to natural gas drilling disturbance too close to leks and brood rearing areas. So we have to integrate many sources of stress on a resource and try to manage around them and be successful.

There are species like mountain goats and bighorn sheep that have a much more narrowly defined habitat and are much more sensitive to a changing climate. They will have to compete for increasingly isolated, fragmented, and diminished habitat. Rising temperatures in the Rockies potentially will allow trees and shrubs to overwhelm sagebrush ecosystems that now provide desirable winter forage for pronghorn, elk, and mule deer; and big game hunters in Montana are already having less success because winter snows are arriving later in the fall, keeping elk and mule deer at a higher elevation and less accessible areas for most of the hunting season.

It's not just a matter of we enjoy hunting. Hunting is a necessary management tool. If you are in the business of managing wildlife, many of our hunts are based on population management and migrations downhill into areas where people can get to provide the hunting necessary for herd size management.

Shorter winters will affect the availability of waterfowl food and cover and quality of habitat. Longer ice-free seasons will lead to changes in migratory timing, routes, and wintering locations. Sea level rise on the coasts certainly will inundate coastal wetlands and squeeze waterfowl into narrowing bands of habitat. And the prairie pothole region, of which Montana is part, could lose up to 90 percent of its wetlands—small wetlands to climate change and reducing the region's breeding ducks by as much as 69 percent in an area that we call America's duck breeding factory. Hunters throughout the country now report that waterfowl migrations are occurring later in the season and in some cases not occurring at all.

Warming waters will slow trout growth rates, increase stress and susceptibility to toxins, parasites, and disease. Trout will be forced to congregate in constricted habitats and compete with invasive species.

Nonnative smallmouth bass have already moved 40 river miles upstream in the Yellowstone River, displacing Yellowstone cutthroat trout, a very cold water species, because of warming water. The physical habitat was there, but now the water's warmed up. There is lower June runoff, lower August precipitation, lower August flows. Water warms up, we change the species mix.

Declining stream flows with less snow pack have already decimated fishing opportunities in some western states, where trout populations could be reduced by up to 50 percent. Trout fishing spots and success will change significantly, and mostly not for the better.

Climate change could fundamentally change the participation rates of America's 13 million hunters and 28 million freshwater anglers. As fish and wildlife habitat, abundance, and distribution shift in response to a changing climate, patterns of recreational activities will shift as well. The loss of big game and upland bird hunting opportunities in Idaho, Montana, and Wyoming in the northern Rockies would impair a sustainable recreational economy that currently supports more than 4.3 million hunter days annually and generates more than $3.45 billion annually in economic value. Nationally, outdoor recreation, including hunting and fishing activities, contribute 6.5 million jobs, which are pretty necessary in today's economy, and a total economic value of $725 billion per year.

We have another new report now. It's not just a matter of reporting impacts, but it's what are we going to do about it? We are in the business of doing adaptive management; and we have presented ideas and adaptation strategies which we distributed in a book called *Beyond Seasons' End* yesterday to the committee in which we identify candidate types of strategies and projects that we could do, along with the likely costs, to help alleviate and ameliorate the effects of climate change.

There is going to be species that win and species that lose. We can't change the climate necessarily. We are not the greenhouse gas emission experts. What we specialize in is how do we adapt to what's left.

The report gives numerous examples of what can be done on the ground, real-world stuff to restore and protect crucial habitat for waterfowl, warm and cold water fisheries, big game and upland birds and saltwater fish and to secure connective corridors between habitats, allocate water for sport fish, adjust population management and harvests and develop state and national adaptation plans.

We already have some mechanisms that you fund through Congress called state wildlife grants, state wildlife action plans—they are now at landscape level—that will help become fundamental tools for managing landscapes of changing environment in the field. We estimate that the cost of such an adaptational plan nationally is likely at the start to be in the neighborhood of, nationwide, at $1 to $3 billion a year.

But we think that the consequences of not taking action now are going to be much more expensive in the future. It will have economic consequences to the economy, and certainly the quality of living for our children and grandchildren are going to be affected.

I have one statement I would like to make, one sentence I thought was pertinent that economists made back in March, not biologists like me. I think it reflects today's attitude somewhat: Action on climate is justified not because the science is certain, but precisely because it is not.

Thank you.

[The prepared statement of Mr. Geer follows:]

PREPARED STATEMENT OF WILLIAM H. GEER

I want to thank the chairman and members of the committee for the opportunity to present testimony on this important issue.

I live in Montana, where 20 percent of the population hunts and fishes, supporting a sustainable outdoor recreation economy exceeding a billion dollars every year. In fact, the hunting-and-fishing economy in Montana is at least as big as the state's energy economy. A bumper sticker recently spotted in Montana said, "Hunting is not matter of life or death—it's much more important than that." Needless to say, we place great value on our sporting traditions in the Treasure State.

I meet frequently with sportsmen across Montana and have traveled to rod and gun clubs in 32 towns throughout the state to discuss climate change and its impacts on fish and wildlife. Sportsmen tell me that they both feel and see the effects of the average air temperature increase of 2.3 degrees Fahrenheit that has occurred since 1951. They are observing delayed onset of winter conditions, a snowpack that has declined 17 percent over the past 60 years and spring rainfall amounts that have increased nearly 6 percent. They also are experiencing late summer precipitation that has declined more than 20 percent and flows in coldwater streams that are declining noticeably throughout Montana. They realize that the glaciers in Glacier National Park are likely to disappear by 2030 (at this time, only 26 remain of the 150 that existed in 1850). And, finally, they see that Montana's warmer winters and drier summers have allowed the mountain pine beetle to expand its natural infestation of Montana's lodgepole pine forests to epidemic levels, resulting in 2 million acres of beetle-killed trees.

While some of these sportsmen might never utter the words "climate change," they readily acknowledge that the later and shorter winters, reduced snowpack, increasing spring rain, lower streamflows, melting glaciers and widespread pine beetle epidemic reflect an environmental change that is beyond rational debate. They also know that this magnitude of environmental change will eventually result in serious declines in many species of fish and wildlife. Global climate change does not bode well for the future of fish and wildlife and recreational hunting and fishing.

The Theodore Roosevelt Conservation Partnership's fundamental beliefs regarding climate change are

- Global climate change is real.
- Sportsmen likely will be the first to experience the repercussions of climate change.
- We need to safeguard fish and wildlife resources from climate change with adaptation strategies.
- How we address global climate change now will dictate whether future generations will continue to enjoy sporting traditions.

In 2008, the Wildlife Management Institute and eight of the nation's leading hunting and fishing organizations released *Seasons' End: Global Warming's Threat to Hunting and Fishing* (*www.seasonsend.org*), a report detailing the predicted impacts of climate change on fish and wildlife habitat and its implications for sustainable hunting and fishing. Some of the report's conclusions follow.

Upland birds face a severe future as climate change progresses. Disruptions in life cycles likely will sever reproduction and the emergence of critical food sources. Young birds could suffer fatal exposure to winter cold from loss of thermal snow cover, with reduced nesting success and increased predation leading to major population reductions. These declines coupled with an influx of invasive species will result in fewer birds in the hunters' bags. Increasing droughts could devastate food sources for upland birds, with prairie chickens, sage grouse, sharp-tailed grouse and pheasants among the species most likely to be diminished in number. Many eastern Montana ranchers consider the prime prairie grouse and pheasant hunting on their lands to be an important cash crop, along with cattle and wheat.

Big game likely will be adversely impacted in several ways. Mountain goats and bighorn sheep will compete for increasingly isolated, fragmented and diminished habitat. Rising temperatures in the Rocky Mountains will allow trees and shrubs to overwhelm sagebrush ecosystems that in the past provided desirable winter forage for pronghorn, elk and mule deer. As fragmentation and loss of critical winter range continues, mule deer and elk could dwindle in numbers, particularly in Montana, Wyoming, Utah, Colorado and New Mexico. Forage becomes less nourishing in prolonged droughts, and elk and mule deer are likely to remain at higher elevations longer. Big-game hunters in Montana already are having less success because winter snows are arriving later in the fall, keeping elk and mule deer at higher elevations and in less accessible areas through most of the hunting season.

Unlike big game, waterfowl can move quickly and cover vast distances. Nevertheless, shorter winters will affect the availability of waterfowl food and cover and quality of habitat. Longer ice-free seasons will lead to changing migratory timing, routes and wintering locations. Sea level rise inundating coastal wetlands will squeeze waterfowl into narrowing bands of habitat. The prairie pothole region, which includes portions of Iowa, Minnesota, Montana and the Dakotas, could lose up to 90 percent of its wetlands to climate change, reducing the region's breeding ducks by as much as 69 percent in an area often called North America's duck breeding factory. No species can withstand the loss of 90 percent of its critical habitat base. Hunters throughout the United States report that waterfowl migrations are occurring later in the season and, in some cases, not occurring at all.

The outlook for trout in the West is warming water that will slow trout growth rates, increase stress and increase susceptibility to toxins, parasites and disease. Trout will be forced to congregate in constricted habitats and compete with invasive species. Diminishing streamflows from declining snowpack already have decimated trout populations and fishing opportunities in some Montana streams, such as Lolo Creek south of Missoula where low flows have reduced once-thriving populations of cutthroat, rainbow, brown and brook trout. Western trout populations could be reduced by 50 percent. Trout fishing spots and success will change significantly—and not for the better.

Global climate change has the power to fundamentally change the participation rates of America's 13 million hunters and 28 million freshwater anglers, as well as the geography of hunting and fishing in North America. As fish and wildlife habitat, abundance and distribution shift in response to a changing climate, patterns of recreational activities will shift as well. Today's carefully delineated protected areas may not even be encompassed within the new habitat zones where the mobile species of wildlife may be forced to migrate under a changing climate.

Collectively, Idaho, Montana and Wyoming still harbor the finest hunting for big game and upland bird and trout fishing resources in the country. The loss of big game and upland gamebird hunting opportunities in these northern Rocky Mountain states would impair what has been a sustainable recreational economy that currently supports more than 4.3 million hunter-days annually and annually generates more than $3.45 billion in total economic value (*Backcountry Bounty*, Sonoran Institute, June 2006).

Now, *Beyond Seasons' End* (*www.seasonsend.org*), a new report released in 2010 by 10 of the nation's leading hunting and fishing organizations, along with the TRCP, presents adaptation strategies, measures and costs to aid fish and wildlife in adapting to global climate change. The common-sense and science-based recommendations that are spelled out and "cost out" in *Beyond Seasons' End* are well-conceived, field-tested and can be accomplished if funding can be provided. This application of science shows what can be done on the ground to restore and protect crucial fish and wildlife habitat, secure migration corridors and connectivity between habitats, allocate water for sport fish and develop regional and national adaptation plans.

A number of state fish and wildlife agencies are in the process of revising their state wildlife action plans (funded largely by State Wildlife Grant appropriations from Congress) to incorporate comprehensive strategies for fish and wildlife adaptation to climate change. The state wildlife action plans, when based on landscape-level habitat management and conservation, will become one of the fundamental tools of state agencies for improving the resiliency and sustainability of fish and wildlife under a changing climate, particularly when they are developed in concert with neighboring states that share the habitat ranges and connective corridors for wildlife that do not recognize political borders.

The Montana Department of Fish, Wildlife & Parks is updating its comprehensive fish and wildlife conservation strategy to include adaptive measures to better sustain and manage fish and wildlife across broad landscapes in a changing climate, using strategies presented in *Beyond Seasons' End*. The revised strategy will emphasize crucial areas, such as new areas of winter range for elk, and corridors that will enable mobile fish and wildlife species to move to suitable habitat. The agency's new Crucial Areas Planning System integrates many computer databases that provide wildlife managers with the physical, biological and social information to better predict impacts of climate change and development on fish and wildlife—and hunting and fishing—and develop more effective mitigation and adaptive management measures.

The Yellowstone River Strategy is one example of the landscape-level approaches identified by Montana Fish, Wildlife & Parks and a working group comprised of non-agency specialists to help Yellowstone cutthroat trout survive in a warming river environment. The June runoff and late summer flows have been declining since the early 1950s, and the water now is favoring smallmouth bass over cutthroats. The main factors behind a decline in Yellowstone cutthroat trout in the Yellowstone River have been contraction of coldwater habitats in upper reaches, increasing temperatures and loss of connectivity from reduced flows in lower reaches, loss of tributary connectivity from reduced flows and diversion dams and a decline of Yellowstone cutthroat trout with encroaching smallmouth bass upstream to Reed Point. The Yellowstone River System strategy would safeguard genetically pure Yellowstone cutthroat trout by conserving their strongholds in headwater tributaries; constructing temporary, high-elevation water storage to augment downstream flows in the summer; re-establishing stream connectivity to allow fish to disperse in mid-elevation downstream reaches; removing fish passage barriers and restoring riparian areas, wet meadows and wetlands in lower-elevation downstream reaches while maintaining the prime coldwater fishing opportunities for which the river is famous.

Another example of a Montana Fish, Wildlife & Parks landscape-level climate adaptation project is the Sagebrush Steppe System Initiative in southwestern and eastern Montana. The sagebrush habitat community provides critical habitat to many of the big-game, waterfowl and upland bird species prized by hunters. These are the likely effects of climate change on these species in the sagebrush steppe area: elk, mule deer and pronghorn overwinter survival might improve with milder winters, but recruitment to the population likely will decline due to forage nutritional deficiencies; Greater sage-grouse are likely to be hurt by the declining extent and density of sagebrush for food and shelter; and waterfowl likely will decline from drier climate and loss of small wetlands.

In the Sagebrush Steppe System Initiative, Montana Fish, Wildlife & Parks more closely coordinates with agencies, namely the U.S. Forest Service and Bureau of Land Management, which manage the majority of Montana's publicly owned habitat and which now are required to consider impacts of their management on the climate. Also, the agency will work closely with private agricultural landowners using private-land conservation incentives in the 2008 Farm Bill, such as the Conservation Stewardship, Environmental Quality Incentives and Farm and Ranchland Protection programs. Conserving and maintaining crucial areas and migratory corridors will receive special emphasis.

As Congress develops climate and energy legislation, I urge you to ensure that such legislation establishes a national program to mitigate the causes of global warming by reducing emissions of greenhouse gases and sequestering carbon from the atmosphere.

The unavoidable adverse effects of climate change on fish and wildlife and their habitats may be minimized or prevented in some cases through adaptation measures and management actions initiated at the earliest time possible. There is a compelling and urgent need for fish and wildlife managers to initiate specific conservation actions—such as ensuring crucial habitat availability and connectivity—that would help fish and wildlife maintain self-sustaining populations through an ongoing flexible management process of adaptive management. Specifically, a House bill should establish a national policy framework to help protect, reconnect and restore public and private lands; provide increased scientific capacity; identify wildlife migration corridors; coordinate and share information; and dedicate a sufficient amount of funding to federal, state and tribal agencies to implement identified actions needed assure the resiliency and sustainability of our fish and wildlife resources.

The activities of the federal resource agencies needed to restore and protect fish and wildlife from the impacts of climate change should be directed and coordinated through a comprehensive national strategy, developed in close consultation with states, tribes and other stakeholders and with advice from the National Academy of Sciences and a science advisory board.

The activities of the state resource agencies should be directed and coordinated through individual, state-based, comprehensive strategies for fish and wildlife adaptation to climate change that are approved by the Secretary of the Interior and integrated into state wildlife action plans, state coastal zone management plans and other state wildlife species or habitat plans. Opportunities should be provided for scientific and public input during the development and implementation of these strategies.

Most sportsmen pay homage to President Theodore Roosevelt because he had the courage and foresight to advance a strong conservation agenda and restore depleted fish and wildlife against a political tide, bequeathing to us the rich fish and wildlife heritage sportsmen cherish to this day. Roosevelt had the foresight to recognize that Congress must take action at a critical time to safeguard this legacy for future generations of Americans. For the sake of our children and grandchildren, we now must act at what is another critical time. While no one has all the answers to the challenge of climate change, we know we are dealing with a rapidly changing world. We must step up today to do the conservation work that will ensure the future—not only of hunting and fishing, but of our very quality of life.

Thank you.

BIOGRAPHY FOR WILLIAM H. GEER

William Geer joined the TRCP staff full time in 2005 as policy initiatives manager. After earning a bachelor of science from the University of Montana School of Forestry and a master of science in limnology from Montana State University, Bill has spent the past 38 years as a professional fish and wildlife conservationist. Before joining the TRCP, he served as the director of the Utah Division of Wildlife Resources, coordinator for the North American Waterfowl Management Plan for the National Fish and Wildlife Foundation, vice president for both field operations and conservation programs for the Rocky Mountain Elk Foundation, Inland Northwest conservation manager for the Nature Conservancy in Idaho and executive director of the Outdoor Writers Association of America.

Chairman BAIRD. Thank you, Mr. Geer.

Dr. Curry.

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

Dr. CURRY. I would like to—Hello? Okay.

I would like to thank the Chairman and the Committee for the opportunity to participate in this hearing.

You have heard forceful arguments from climate scientists for a looming future threat from anthropogenic climate change. Anthropogenic climate change is a theory whose basic mechanism is well understood but whose magnitude is highly uncertain. This conflict regarding this theory is over the level of our ignorance regarding what is known about natural climate variability, about what is unknown about natural climate variability, and the feedback processes.

Based on the background knowledge that we have, the threat from global climate change does not seem to be an existential one on the time scale of the 21st century, even in its most alarming incarnation. It seems more important that robust policy responses be formulated than to respond urgently with policies that may fail to address the problem and whose unintended consequences have not been adequately explored.

How to deal with this complex problem presents many challenges at the interface between science and policy. Over the past 20 years, scientists have become entangled in an acrimonious scientific and political debate where the issues in each have become confounded. Debates over relatively arcane aspects of the scientific argument have become a substitute for what should be a real debate about politics and values.

I have been publicly raising concerns since 2003 about how uncertainty surrounding climate change is evaluated and communicated. At this point, it seems more important to explore the uncertainties associated with future climate change, rather than to attempt to reduce the uncertainties in a consensus-based approach.

It's time for climate scientists to change their view of uncertainty. It's not just something that is merely to be framed and communicated to policymakers while mindful that doubt is a political weapon in the decision-making process. Characterizing, understanding, and exploring uncertainty is at the heart of the scientific process; and, further, the characterization of uncertainty is critical information for robust policy decisions.

It's important to broaden the scope of global climate change research to develop a better understanding of natural climate variability and the impact of land use changes; and far more attention needs to be given to establishing robust and transparent climate data records, particularly the paleoclimate record. Regional planners and resource managers want accurate, high-resolution climate model projections to support local climate adaptation plans and climate-compatible development. The need for such models is unlikely to be met at least in the short term.

In any event, anthropogenic climate change on time scales of decades is arguably less important in driving vulnerability than increasing population, land use practices, and ecosystem degradation. Regions that find solutions to current problems of climate variability and extreme weather events and address challenges associated with an increasing population will be better prepared to cope with any additional stresses from climate change.

Climate researchers need to engage with regional planners, economists, military intelligence organizations, development banks, energy companies, and governments in the developing world. Such engagement can develop a mutual understanding about what kind of information is needed, promote more fruitful decision outcomes, and to find new scientific challenges to be addressed by research.

The need for climate researchers to engage with social scientists and engineers has never been more important, and there is an increasing need for social scientists and philosophers of science to scrutinize and analyze our field to prevent dysfunction at the science-policy interface, which has been so evident this past year.

Climate scientists and the institutions that support them need to acknowledge and engage with ever-growing groups of citizens, scientists, and extended peer communities that have become increasingly well organized by the blogosphere. The more sophisticated of these groups are challenging our conventional notions of expertise and are bringing much-needed scrutiny particularly into issues surrounding historical and paleoclimate data records. These groups reflect the growing public interest in climate science and a growing concern about possible impacts of both climate change and climate change policies.

And, further, this interest has illuminated the fundamental need for improved and transparent historical and paleoclimate data sets and improved information systems so that these data are easily accessed and interpreted. We need to identify and secure the common interests in dealing with the climate, energy, and ocean acidification problems.

A diversity of views on interpreting the scientific evidence and a broad range of ideas on how to address these challenges doesn't hinder the implementation of diverse, bottom-up solutions. Securing the common interest on local and regional scales provides a basis for the successful implementation of climate adaptation strategies and successes on the regional scale and then national scale make it much more likely that global issues can be confronted in an effective way.

Thank you.

[The prepared statement of Dr. Curry follows:]

PREPARED STATEMENT OF JUDITH A. CURRY

I thank the Chairman and the Committee for the opportunity to offer testimony today on "Rational Discussion of Climate Change." I am 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 feedback processes in the Arctic, energy exchange between the ocean and the atmosphere, the role of clouds and aerosols in the climate system, and the impact of climate change on the characteristics of hurricanes. 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 year, I have been actively engaging with the public (particularly in the blogosphere) on the issue of integrity of climate science, and also the topic of uncertainty.

The climate change response challenge

Climate change can be categorized as a "wicked problem."[1] Wicked problems are difficult or impossible to solve, there is no opportunity to devise an overall solution by trial and error, and there is no real test of the efficacy of a solution to the wicked problem. Efforts to solve the wicked problem may reveal or create other problems.

The United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) have framed the climate change problem (i.e. dangers) and its solution (i.e. international treaty) to be irreducibly global. Based upon the precautionary principle, the UNFCCC's Kyoto Protocol has established an international goal of stabilization of the concentrations of greenhouse gasses in the atmosphere. This framing of the problem and its solution has led to the dilemma of climate response policy that is aptly described by Obersteiner et al.[2]:

> The key issue is whether "*betting big today*" with a comprehensive global climate policy targeted at stabilization "*will fundamentally reshape our common future on a global scale to our advantage or quickly produce losses that can throw mankind into economic, social, and environmental bankruptcy*."

[1] Rittel, Horst, and Melvin Webber; "Dilemmas in a General Theory of Planning," pp. 155–169, Policy Sciences, Vol. 4, Elsevier Scientific Publishing Company, Inc., Amsterdam, 1973. *http://www.uctc.net/mwebber/Rittel+Webber+Dilemmas+General_Theory_of_Planning.pdf*

[2] *http://helda.helsinki.fi/bitstream/handle/1975/292/2001-Managing_climate_risk.pdf?sequence=1*

In a rational discussion of climate change, the question needs to be asked as to whether the framing of the problem and the early articulation of a preferred policy option by the UNFCCC has marginalized research on broader issues surrounding climate change, and resulted is an overconfident assessment of the importance of greenhouse gases in future climate change, and stifled the development of a broader range of policy options.

The IPCC/UNFCCC have provided an important service to global society by alerting us to a global threat that is potentially catastrophic. The UNFCCC/IPCC has made an ambitious attempt to put a simplified frame around the problem of climate change and its solution in terms of anthropogenic forcing and CO_2 stabilization polices. However, the result of this simplified framing of a wicked problem is that we lack the kinds of information to more broadly understand climate change and societal vulnerability.

Uncertainty in climate science

Anthropogenic climate change is a theory in which the basic mechanism is well understood, but in which the magnitude of the climate change is highly uncertain owing to feedback processes. We know that the climate changes naturally on decadal to century time scales, but we do not have explanations for a number of observed historical and paleo climate variations, including the warming from 1910–1940 and the mid-20th century cooling. The conflict regarding the theory of anthropogenic climate change is over the level of our ignorance regarding what is unknown about natural climate variability.

I have been raising concerns [3] since 2003 about how uncertainty surrounding climate change is evaluated and communicated. The IPCC's efforts to consider uncertainty focus primarily on communicating uncertainty, rather than on characterizing and exploring uncertainty in a way that would be useful for risk managers and resource managers and the institutions that fund science. A number of scientists have argued that future IPCC efforts need to be more thorough about describing sources and types of uncertainty, making the uncertainty analysis as transparent as possible. Recommendations along these lines were made by the recent IAC [4] review of the IPCC.

Because the assessment of climate change science by the IPCC is inextricably linked with the UNFCCC polices, a statement about scientific uncertainty in climate science is often viewed as a political statement. A person making a statement about uncertainty or degree of doubt is likely to become categorized as a skeptic or denier or a "merchant of doubt," [5] 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" [6] that has turned against my colleagues.

Climate change winners and losers

A view of the climate change problem as irreducibly global fails to recognize that some regions may actually benefit from a warmer and/or wetter climate. Areas of the world that currently cannot adequately support populations and agricultural efforts may become more desirable in future climate regimes.

Arguably the biggest global concern regarding climate change impacts is concerns over water resources. This concern is exacerbated in regions where population is rapidly increasing and water resources are already thinly stretched. China and South Asia (notably India, Pakistan, and Bangladesh) are facing a looming water crisis arising from burgeoning population and increasing demand for water for irrigated farming and industry. China has been damming the rivers emerging from Tibet and channeling the water for irrigation, and there is particular concern over the diversion of the Brahmaputra to irrigate the arid regions of Central China. China's plans to reroute the Brahmaputra raises the specter of riparian water wars with India and Bangladesh.

The IPCC AR4 WGII makes two statements of particular relevance to the water situation in central and south Asia:

> *"Freshwater availability in Central, South, East and South-East Asia . . . is likely to decrease due to climate change, along with population growth and ris-*

[3] *http://curry.eas.gatech.edu/climate/pdf/crc-102103.pdf*
[4] *http://reviewipcc.interacademycouncil.net/*
[5] Oreskes, N. and E.M. Conway, 2010: Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco to Global Warming. Bloomsbury Press, 368 pp.
[6] *http://www.scientificamerican.com/article.cfm?id=climate-heretic*

ing standard of living that could adversely affect more than a billion people in Asia by the 2050s (high confidence)." [7]

"Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 km2 by the year 2035 (WWF, 2005)." [8]

The lack of veracity of the statement about the melting Himalayan glaciers has been widely discussed, and the mistake has been acknowledged by the IPCC.[9] However, both of these statements seem inconsistent with the information in Table 10.2 of the IPCC AR4 WG II and the statement:

"The consensus of AR4 models . . . indicates an increase in annual precipitation in most of Asia during this century; the relative increase being largest and most consistent between models in North and East Asia. The sub-continental mean winter precipitation will very likely increase in northern Asia and the Tibetan Plateau and likely increase in West, Central, South-East and East Asia. Summer precipitation will likely increase in North, South, South-East and East Asia but decrease in West and Central Asia." [10]

Based on the IPCC's simulations of 21st century climate, it seems that rainfall will increase overall in the region (including wintertime snowfall in Tibet), and the IPCC AR4 WGII does not discuss the impact of temperature and evapotranspiration on fresh water resources in this region. The importance of these omissions, inconsistencies or mistakes by the IPCC is amplified by the potential of riparian warfare in this region that supports half of the world's population.

A serious assessment is needed of vulnerabilities, region by region, in the context of possible climate change scenarios, demographics, societal vulnerabilities, possible adaptation, and current adaptation deficits. A few regions have attempted such an assessment. Efforts being undertaken by the World Bank Program on the Economics of Adaptation to Climate Change to assess the economics of adaptation in developing countries are among the best I've seen in this regard. This is the kind of information that is needed to assess winners and losers and how dangerous climate change might be relative to adaptive capacities.

Climate surprises and catastrophes

The uncertainty associated with climate change science and the wickedness of the problem provide much fodder for disagreement about preferred policy options. Uncertainty might be regarded as cause for delaying action or as strengthening the case for action. Low-probability, high-consequence events in the context of a wicked problem provide particular challenges to developing robust policies.

Extreme events such as landfalling major hurricanes, floods, extreme heat waves and droughts can have catastrophic impacts. While such events are not unexpected in an aggregate sense, their frequency and/or severity may increase in a warmer climate and they may be a surprise to the individual locations that are impacted by a specific event. Natural events become catastrophes through a combination of large populations, large and exposed infrastructure in vulnerable locations, and when humans modify natural systems that can provide a natural safety barrier (e.g. deforestation, draining wetlands). For example, the recent catastrophic flooding in Pakistan [11] apparently owes as much to deforestation and overgrazing as it does to heavy rainfall. Addressing current adaptive deficits and planning for climate compatible development will increase societal resilience to future extreme events that may be more frequent or severe in a warmer climate.

Abrupt climate change [12] is defined as a change that occurs faster than the apparent underlying driving forces. Abrupt climate change, either caused by natural climate variability or triggered in part by anthropogenic climate change, is a possibility that needs investigation and consideration. Catastrophic anthropogenic climate change arising from climate sensitivity on the extreme high end of the distribution has not been adequately explored, and the plausible worst-case scenario has not be adequately articulated. To what extent can we falsify scenarios of very high climate sensitivity based on our background knowledge? What are the possibili-

[7] *http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-es.html*
[8] *http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-6-2.html*
[9] *http://www.ipcc.ch/pdf/presentations/himalaya-statement-20january2010.pdf*
[10] *http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-3.html#10-3-1*
[11] *http://judithcurry.com/2010/09/20/pakistan-on-my-mind/*
[12] *http://www.nap.edu/openbook.php?isbn=0309074347*

ties for abrupt climate change, and what are the possible time scales involved? What regions would be most vulnerable under this worst-case scenario?

Weitzmann[13] characterizes the decision making surrounding climate change in the following way:

> *"Much more unsettling for an application of expected utility analysis is deep structural uncertainty in the science of global warming coupled with an economic inability to place a meaningful upper bound on catastrophic losses, from disastrous temperature changes. The climate science seems to be saying that the probability of a system-wide disastrous collapse is non-negligible even while this tiny probability is not known precisely and necessarily involves subjective judgments."*

When a comprehensive decision analysis includes plausible catastrophes with unknown probabilities, the policy implications can be radically different from those suggested by optimal decision making strategies targeted at the most likely scenario. Weitzmann argues that it is plausible that climate change policy stands or falls to a large extent on the issue of how the high impact low probability catastrophes are conceptualized and modeled. Whereas "alarmism" focuses unduly on the possible (or even impossible) worst-case scenario, robust policies consider unlikely but not impossible scenarios without letting them completely dominate the decision.

In summary, the IPCC focus on providing information to support the establishment of an optimal CO_2 stabilization target doesn't address two important issues for driving policy:

- reducing vulnerability to extreme events such as floods, droughts, and hurricanes
- examination of the plausible worst case scenario.

There are no "silver bullet" solutions

Xu, Crittenden et al.[14] argue that "gigaton problems require gigaton solutions." The wickedness of the climate problem precludes a gigaton solution (either technological or political). Attempts to address the climate change problem through a U.N. treaty for almost two decades have arguably not been successful. The climate change problem now walks hand-in-hand with the ocean acidification problem, the link between the two problems being the proposed stabilization of atmospheric CO_2. The proposed solution to the wicked climate problem and ocean acidification in terms of stabilization of atmospheric CO_2 has revealed and created new problems in terms of energy policy. Energy policy is driven by a complicated mix of economics and economic development, energy security, environmental quality and health issues, resource availability (e.g. peak oil), etc.

Even if climate change is not the primary driver in energy policy, the climate-energy nexus is a very important one. Not just in the sense of anthropogenic climate change motivating energy policy, but weather and climate are key drivers in energy demand and even supply. On the demand side, we have the obvious impact of heating and cooling degree days. On the supply side, we have oil and gas supply disruptions (e.g. hurricanes in the Gulf of Mexico) plus the dependence of hydro, solar, and wind power on weather and climate. What is perhaps the most important connection, and one often overlooked, is the energy-water nexus, whereby power plants requiring water for cooling compete with domestic, agricultural, industrial, and ecosystems for the available water supply.

The complexity of both the climate and energy problems and their nexus precludes the gigaton "silver bullet" solution to these challenges. Attempting to use carbon dioxide as a control knob to regulate climate in the face of large natural climate variability and the inevitable weather hazards is most likely futile. In any event, according to climate model projections reported in the IPCC AR4, reducing atmospheric CO_2 will not influence the trajectory of CO_2 induced warming until after 2050. The attempt to frame a "silver bullet" solution by the UNFCCC seems unlikely to succeed, given the size and the wickedness of the problem. The wicked gigaton climate problem will arguably require thousands of megaton solutions and millions of kiloton solutions.

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[13] *http://dash.harvard.edu/bitstream/handle/1/3693423/Weitzman_OnModeling.pdf7 sequence=2*

[14] *http://www.spp.gatech.edu/faculty/marilynbrown/sites/default/files/attachment/Gigaton%20Problems %20Need%20Gigaton%20Solutions.pdf*

Moving forward

Climate scientists have made a forceful argument for a looming future threat from anthropogenic climate change. Based upon the background knowledge that we have, the threat does not seem to be an existential one on the time scale of the 21st century, even in its most alarming incarnation. It is now up to the political process (international, national, and local) to decide how to contend with the climate problem. It seems more important that robust responses be formulated than to respond urgently with a policy that may fail to address the problem and whose unintended consequences have not been adequately explored.

The role for climate science and climate scientists in this process is complex. In the past 20 years, dominated by the IPCC/UNFCCC paradigm, scientists have become entangled in an acrimonious scientific and political debate, where the issues in each have become confounded. This has generated much polarization in the scientific community and has resulted in political attacks on scientists on both sides of the debate, and a scientist's "side" is often defined by factors that are exogenous to the actual scientific debate. Debates over relatively arcane aspects of the scientific argument have become a substitute for what should be a real debate about politics and values.

Continuing to refine the arguments put forward by the IPCC that focus on global climate model simulations projections of future climate change may have reached the point of diminishing returns for both the science and policy deliberations. Further, the credibility of the IPCC has been tarnished by the events of the past year. It is important to broaden the scope of global climate change research beyond its focus on anthropogenic greenhouse warming to develop a better understanding of natural climate variability and the impact of land use changes and to further explore the uncertainty of the coupled climate models and the capability of these models to predict emergent events such as catastrophic climate change. And far more attention needs to be given to establishing robust and transparent climate data records (both historical and paleoclimate proxies).

Regional planners and resource managers need high-resolution regional climate projections to support local climate adaptation plans and plans for climate compatible development. This need is unlikely to be met (at least in the short term) by the global climate models. In any event, anthropogenic climate change on timescales of decades is arguably less important in driving vulnerability in most regions than increasing population, land use practices, and ecosystem degradation. Regions that find solutions to current problems of climate variability and extreme weather events and address challenges associated with an increasing population will be better prepared to cope with any additional stresses from climate change.

Hoping to rely on information from climate models about projected regional climate change to guide adaptation response diverts attention from using weather and climate information in adaptive water resource management and agriculture on seasonal and subseasonal time scales. Optimizing water resource management and crop selection and timing based upon useful probabilistic subseasonal and seasonal climate forecasts has the potential to reduce vulnerability substantially in many regions. This is particularly the case in the developing world where much of the agriculture is rain fed (i.e. no irrigation). It would seem that increasing scientific focus on seasonal and subseasonal forecasts could produce substantial societal benefits for tactical adaptation practices.

The global climate modeling effort directed at the IPCC/UNFCCC paradigm has arguably reached the point of diminishing returns in terms of supporting decision making for the U.N. treaty and related national policies. At this point, it seems more important to explore the uncertainties associated with future climate change rather than to attempt to reduce the uncertainties in a consensus-based approach. It is time for climate scientists to change their view of uncertainty: it is not just something that is merely to be framed and communicated to policy makers, all the while keeping in mind that doubt is a political weapon in the decision making process. Characterizing, understanding, and exploring uncertainty is at the heart of the scientific process. And finally, the characterization of uncertainty is critical information for robust policy decisions.

Engagement of climate researchers with regional planners, economists, military/intelligence organizations, development banks, energy companies, and governments in the developing world to develop a mutual understanding about what kind of information is needed can promote more fruitful decision outcomes, and define new scientific challenges to be addressed by research. The need for climate researchers to engage with social scientists and engineers has never been more important. Further, there is an increasing need for social scientists and philosophers of science to scrutinize and analyze our field to prevent dysfunction at the science-policy interface.

And finally, climate scientists and the institutions that support them need to acknowledge and engage with ever-growing groups of citizen scientists, auditors, and extended peer communities that have become increasingly well organized by the blogosphere. The more sophisticated of these groups are challenging our conventional notions of expertise and are bringing much needed scrutiny particularly into issues surrounding historical and paleoclimate data records. These groups reflect a growing public interest in climate science and a growing concern about possible impacts of climate change and climate change policies. The acrimony that has developed between some climate scientists and blogospheric skeptics was amply evident in the sorry mess that is known as Climategate. Climategate illuminated the fundamental need for improved and transparent historical and paleoclimate data sets and improved information systems so that these data are easily accessed and interpreted.

Blogospheric communities can potentially be important in identifying and securing the common interest at these disparate scales in the solution space of the energy, climate and ocean acidification problems. A diversity of views on interpreting the scientific evidence and a broad range of ideas on how to address these challenges doesn't hinder the implementation of diverse megaton and kiloton solutions at local and regional scales. Securing the common interest on local and regional scales provides a basis for the successful implementation of climate adaptation strategies. Successes on the local and regional scale and then national scales make it much more likely that global issues can be confronted in an effective way.

BIOGRAPHY FOR JUDITH A. CURRY

Dr. Judith Curry is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology and President of Climate Forecast Applications Network (CFAN). Dr. Curry received a Ph.D. in atmospheric science from the University of Chicago in 1982. Prior to joining the faculty at Georgia Tech, she has held faculty positions at the University of Colorado, Penn State University and Purdue University. Dr. Curry's research interests span a variety of topics in climate; current interests include air/sea interactions, climate feedback processes associated with clouds and sea ice, and the climate dynamics of hurricanes. She is a prominent public spokesperson on issues associated with the integrity of climate science, and has recently launched the weblog Climate Etc. Dr. Curry currently serves on the NASA Advisory Council Earth Science Subcommittee and has recently served on 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.

DISCUSSION

Chairman BAIRD. Thank you, Dr. Curry.

I apologize. Our AV unit, which none of you, apparently, requires, is deciding to cool itself off, perhaps metaphorically. It may be smarter than we think.

Thank you all for your testimony.

The structure of today's hearing, as I mentioned from the outset, was to talk first about the basic science. Are we seeing impacts and then what are the impacts? What is happening and how does it impact our lives? We have got outstanding witnesses, and what I would like to do is follow up with each of you sort of on individual themes, but then, if there are crosscurrents to that, please address those.

THE U.S. NAVY AND WEATHER CONDITIONS

Admiral Titley, I have had the privilege when I have been to Afghanistan, Iraq, and other theaters, you know, there are command daily briefings. And the idea is that a regional commander gets to look at all sorts of things: What's our force strength, what's our availability mobility, et cetera, et cetera.

One of the key elements of that is always weather. You know, are there going to be dust storms? Are there going to be clouds? Can the drones see what their targets are? Will we have air cover? Et cetera.

It must be especially acute in the Navy for your mission, and what occurs to me is you would be irresponsible as a commander if you did not take into account weather changes. The things you have talked to us today about, including the infrastructure commands, the changing potential in sea lanes, available access to ports, et cetera, that's a longer-term frame. But would you not be equally irresponsible if you didn't look ahead to that and try to make long-term strategic plans, not just tactics but strategy on the ground?

Elaborate on how the Navy views this issue.

Admiral TITLEY. Yes, sir. I am not sure I can say it much better than what you did, but at the risk of going downhill from here, I will try.

You are absolutely right, sir. I have done weather forecasting in the Navy now for over 30 years. It starts off sort of at the unit level or the tactical level. We look at both the safety of the forces—really, you know, the Navy has learned that really from time immemorial going to sea.

But certainly, in the typhoon of 1944, Admiral Halsey tragically lost three destroyers and over 700 sailors because we didn't know there was a typhoon out there. We fixed that. We have a Joint Typhoon Warning Center staffed by the Navy and the Air Force, and we have not had a repeat of that situation, thank God, since then.

As you get more senior, you start looking at operational level. What will be weather and the ocean be in three, four, or five days? Where do I put my units to best have my chance of success?

I think Heidi Cullen mentioned that climate is putting the odds in your favor, and that's how I look at the weather. I talk about the weather as we all operate in nature's casino, and I intend to count the cards. The bad news is there is a lot more than 52 cards. The good news, if you can do it, nobody breaks your kneecaps. So that is really what we are trying to do, is to put the odds in our favor.

And now, sir, as you absolutely have it spot on, we are looking strategically out. So not just three, four, or five days, but what are the next 20, 30, 50 years going to look like?

We can see the signal in the Arctic. The observations tell us what's going on. We see that the percentage of what's called multiyear, the thick ice has dropped to levels that, frankly, we have not recorded before. So although 2007 was in area extent the least amount of sea ice that was recorded, in '08, '09, and '10 the levels were slightly higher, when you look at the volume of ice, the volume as of last September has never been lower.

And in respect to Congressman Rohrabacher, I should not say never. In the last several thousand years, it has not been lower.

So we see the probable, probable opening of the Arctic. I have told Admiral Gary Roughead, our Chief of Naval Operations, that we expect to see about four weeks of basically ice-free conditions in the Arctic in the mid to late 2030s. By the middle of the century, we could be seeing quite easily two to three months of ice-free conditions. That's enough time to allow the trans-ocean shippers, assuming they have governance, search and rescue, charting, insurance, all of those other conditions, but by the middle of the century that's very, very possible.

When I talk to my colleagues in Iceland, Iceland is actively thinking about how do they become the Singapore of the 21st century? How do they become that southern terminus? This becomes a very different ocean and a very different world for our Navy to operate in.

So this is just one example. I could talk about sea level. I could talk about ocean acidification. In the interests of time, sir, I will stop here.

But you are exactly right. This is looking at what we believe, not guaranteed, but is likely to happen and looking at consequences, times probabilities, and planning for those kinds of situations. And that's what we have embarked on, sir.

Chairman BAIRD. That's a very, very helpful summary.

CLIMATE MONITORING INSTRUMENTATION

A context of that also is that not with infrequency people here on the Committee will hear a suggestion that all the money that has been spent on climate change research has been wasted. Well, a fair bit of the instrumentation that has been used to gather the data that leads to the analysis came from Defense applications, whether it's satellites in the air, whether it's sensors on equipment. And certainly my hunch would be that down the road you folks will be mighty glad to have those sensors and the data that they have given you as you make your planning.

Admiral TITLEY. Yes, sir. The data are very useful.

We use data from a wide variety of sources. I am sure you know, sir, that the submarine missions that we had run not only in the Cold War but in the 1990s, they provide very, very valuable ground truth observations of how thick is that ice so we can then calibrate or basically tune our satellites.

I would be remiss, though, sir, in saying this does not also work in the other direction. The Department of Defense is a big user of the civil structure that in part is appropriated from your committee. We work very closely with NOAA. I have a great relationship with Dr. Lubchenco.

And one of the things, sort of on the practical adaptation side we are jointly looking at between the Navy and NOAA and the Air Force, also have Department of Energy and NASA involved, is how do we look at a next generation of weather, ocean, ice coupled prediction models so that by roughly 2020, in about ten years from now, we can predict that system as a whole and really going—spanning between weather time frames, say hours to days, out to say roughly about two or three decades.

Because as we are planning for our infrastructure—or let's say if you are the port of New York and New Jersey, you are planning for your infrastructure. You want to be looking at that. There are—for very, very good reasons there are boundaries in the science community between the weather folks, the oceanographers, the glaciologists, the climatologists. But if you are a decision-maker, if you are running a business, if you are running a government agency, you know, with all due respect, you don't really care what those boundaries are. You need an answer, and your answers span these time frames.

I wish I had thought of putting it this way, but the words of Rick Anthes, a former Director of the National Center for Atmospheric Research, he said, hey, Titley, what you are trying to do is go between a condition forced by initial conditions, you know, what is today's weather, to one forced by boundary conditions. What is the Sun doing? What are the greenhouse gases doing? How do we get through there? Open science questions.

Big challenge. But I think it's a great challenge for this Nation of ours and one that will help us as we adapt in a cost-constrained environment.

Thank you, sir.

Chairman BAIRD. Thank you. Thank you, very much.

ADAPTATION CHALLENGES AND POOR COMMUNITIES

Mr. Lopez, I am intrigued by this issue of mitigation and adaptation, particularly as things apply to perhaps disadvantaged communities. And it seems there are two—well, there are multiple factors, but one is not only domestically in the United States but globally a lot of the folks who are going to get—if there are the impacts which are projected, which seems more probable than not, in many cases, anyway, if those impacts happen, they are going to impact some of the people who had the least to do with causing the problem and the fewest resources to cope with the problem. Can you elaborate on that domestically within our own sociodemographic span but also if you have insights into it globally how that impacts the world?

Mr. LOPEZ. I think that's absolutely correct. I think that's of particular concern for us at HUD.

As we implement our programs and policies, we want to make sure that the populations that we serve, we are thinking through adequately about the future stresses that might be imposed on those populations, knowing that the more stresses you have today the more likely you are impacted to be tomorrow. And I think there is a couple of points of insight, focusing more on the domestic side of things, that I would like to make.

And, first, as the Admiral points out, you know, these decisions, they are being made today. It's not like we can wait. Moving beyond the military example, the hundred-year flood plan, the management of goods and services, agricultural economic development, the built infrastructure, which is what we deal with at HUD, we have to make decisions now about the future. And those decisions can't wait. So our challenge is how do you take that fact and build a system or a process that helps to mainstream or integrate the climate change variable? And I would suggest a couple of things.

One, and I think it's endemic to these grants we put out, is to find the triggers. There are those communities that are aware of the assumptions of climate change, but there are opportunities that happen, planning opportunities like the challenge grants and the Regional Planning Grants that we have put out. Disaster recovery is an opportunity where you open up and start to say, okay, what does the future look like when we have to rebuild? Infrastructure investments. When you have to spend a billion dollars on a wastewater treatment facility you want to make the best decision you can. And it's really about learning as much as you can right now about what you need to know about the future.

So I really think, Mr. Chairman, it comes down to better decisions. And for us it's the populations in large measure that you identified. So it's about scenario planning, and it's really about how do you help communities make a decision most compatible with uncertainty?

We know there is uncertainty. Local governments and governments at all levels make decisions with uncertainty every day. It's about making the assumptions about climate in those decisions transparent, understanding them better, and making decisions in uncertainty.

And one guiding lesson we learned, in my perspective coming from local government to the Federal Government, is to think on the margin. It's about the marginal cost of what you need do next. It's not necessarily about building a whole new system. It's about the marginal cost of building the reclaimed water system to the billion dollar investment you already made. And when you reach that point you can do a cost-benefit analysis based on the margins to see how much you know, how much you understand about the future, and whether or not the investment is worth it.

And the final point I would make is you always have to consider the co-benefits. For us, we are acutely aware of where you build, how you build, how you help communities prepare for the future. That's what we do. Green roofs, green space, energy efficiency, water. It's reuse. It's conservation. All of these things are co-benefits to decisions that have to be weighed in I think when you are analyzing the marginal cost of the decision.

Chairman BAIRD. Very well put.

I had the privilege of riding on a cross-country flight with Secretary Sims, who I have great respect for and served our region very well. You mentioned the co-benefits. One of the things that I was so impressed with was the Secretary's analysis of things like health benefits from healthier communities. If we do if right, there is a positive synergy to this. If we preserve green space, that, if properly planted, can take up CO_2. If we change how roofs are colored, that can produce greater reflectance, et cetera, and reduce temperatures inside homes, et cetera.

One of the things I would hope we don't do as a body is those who are antagonistic to the climate change scenario, that they don't say anything that was ever done in the name of climate science we are going to reverse, sort of analogous to taking the photovoltaic panels off the White House as a statement. Well, if we do that, we are going to roll back a lot of things that have co-benefits in and of themselves, and I think that would be really unfortunate for all of the interests we have heard today.

Briefly, I will particularly direct this to Rear Admiral Titley and Mr. Lopez, but if others want to comment as well, and then I will get back to specific questions.

A NATIONAL CLIMATE SERVICE

We in this committee have had significant discussion over whether or not a climate service is needed. If so, what would its benefits be? From Admiral Titley and then Mr. Lopez and then Mr. Geer and Dr. Curry, what are your thoughts about with whether or not a climate service would be useful to you? And what would be useful about it if it existed?

Admiral TITLEY. Sir, thanks very much for the question.

A climate service, I believe, would be very useful for the Navy. It provides—I almost hate the phrase—but a one-stop shop, if you will, or at least a source of both coherent and authoritative data. It would be ideally staffed by people who would be conversant with those data, as well as, of course, machine to machine ways of pulling these.

We have lots of different places with very good quality that produce various types of climate models. The National Centers for Atmospheric Research, the Department of Energy have some tremendous programs, as do academia, et cetera. As a DOD, I do not want to replicate or duplicate. We cannot spend our taxpayers' dollars doing things that have already been done well, but I need access to that.

Chairman BAIRD. But you need that data.

Admiral TITLEY. But I need access, and I need to be able to get it without sort of the hunt and peck method, or whatever we call Google now on the hunted. Back when you and I were growing up, it would be the hunt and peck method.

So having that, you know, probably in one agency. I know NOAA has looked at this. And, you know, that would make sense to us. So whatever the Committee and the Congress and the administration ultimately decide, the concept of a climate services would be very, very useful.

Chairman BAIRD. The model of that would be that it would interface with a number of other areas like Agriculture, conceivably Fish and Wildlife, conceivably HUD, obviously, the Defense applications. That's the model that we had in mind. And you know, it's not a one-way street. It's not that the climate service tells you what's happening. Ideally, the climate service gathers information from your resources and expertise and data sets, and it's a synergistic model.

Mr. Lopez or any others want to comment on that issue? Mr. Geer?

Mr. GEER. Yes. From the Fish and Wildlife perspective, we support heavily the establishment of a national climate service. We feel that as additional information becomes available on a scientific basis we need to have that information to make intelligent management prescriptions on specific places around the country geographically. What's pertinent in the intermountain west, which is a relatively arid environment in a changing climate, may still be different than what it is in the Southeastern U.S. And what we need is geographically specific information, the best prediction we can get.

So the strategies that we put on the ground are the ones that are pertinent and applicable for that particular area so we don't waste the money either for them to be effective. We need a information central kind of area where we can store the information, we can retrieve the information, we can find out where it comes from, we consult with others, we have a much better information base, we are better informed as professionals, and we can do a more effective job.

We think that such a climate service ought to be coordinated among the state and federal agencies so everyone can—this is a worldwide issue. We can all participate in the data gathering and the data sharing and the interpretation.

Chairman BAIRD. Dr. Curry and then Mr. Lopez.

Dr. CURRY. With regards to climate service, I think the fundamental need is really the information system. For example, the sea ice issue that was raised earlier, which of the 12 sea ice data sets that are out there should we be looking at? I mean, there is a bunch of different data sets. The average user doesn't know which one to use. There is no error assessments. And then they look at it and they see sea ice in Mediterranean and how are they supposed to interpret that? I mean, these data sets are not—

Chairman BAIRD. There is no sea ice in the Mediterranean.

Dr. CURRY. I know, but some data sets give it to you there.

Chairman BAIRD. Is that true?

Dr. CURRY. Oh, yeah.

Chairman BAIRD. That's obviously not a data set.

Dr. CURRY. Certain satellite products, if there is clouds, they will mistake clouds for sea ice.

Chairman BAIRD. Got you. Okay.

Dr. CURRY. And you can get sea ice in the Mediterranean. So how useful are those kind of data sets?

Chairman BAIRD. Could we ski in it?

Dr. CURRY. My point is we need to establish authoritative climate data records, where people sift through the information, look at the uncertainties, and give somebody one data set that they can use.

Chairman BAIRD. With some error boundaries.

Dr. CURRY. With some error bounds on it.

And, also, it's an issue of accessibility. People need to be able to search and use the data sets. And, otherwise, trying to—even for somebody like me, sometimes trying to get the climate data I need, it's like—it's torture——

Chairman BAIRD. Yeah.

Dr. CURRY. Okay—compared to somebody who is not even a climate researcher, who is just trying to use the data set. We have a very fundamental need for a climate data information system.

Chairman BAIRD. So some kind of combination of open source but with a qualitative filter to it.

Dr. CURRY. Open source would be an interesting route to go.

Chairman BAIRD. Mr. Lopez?

Mr. LOPEZ. Thank you, Mr. Chairman.

I think I would like to stay within the confines of the task force report, part of our charge, and what we were calling is a National Climate Change Adaptation Strategy. And I think a lot of the principles that we have discussed—the need to get information out, the need for a dialogue with the scientific community, a process by which we can evaluate that information and embed it into our mission of each agency and across the Federal Government and down to the states and local governments—is part of that process. And I think moving forward we hope to continue a dialogue with you as we work on that.

Chairman BAIRD. Okay. Thank you.

THE IMPACTS OF CLIMATE CHANGE ON RECREATIONAL FISHING

Mr. Geer, I want to ask you specifically, I represent an area where hunting and fishing is huge. The southwest Washington people love to hunt. I grew up as a hunter. We literally fed our family by hunting and fishing. That was our main source of protein, was venison or elk or antelope or rabbit or duck, whatever. If it moved, we shot it. If we shot it, we ate it. And we ate all of it. And that's the case in a lot of my district.

And, in addition, the recreational pursuit is tremendously important to people. I had the opportunity to talk to—one of the ongoing fights back home is gill nets versus sports fishermen. I had a long conversation with a bunch of sports fishermen concerned about gill netting, and I think it's a legitimate and important debate. But, at the end of it, we began to talk about ocean acidification; and these folks really hadn't heard much about it. And it struck me that, you know, we are focusing so much on one issue sometimes.

What impact do you see—if we have ocean acidification, as you heard Dick Feely testify to earlier, and you lose pteropods, you lose the basic food chain for salmonids, and if you increase the temperature of the water—back home, we go nuts, appropriately so, providing shade, et cetera, for streams and other tributaries so that the salmon can spawn in cool water. What do you see is the combination with more acidic water and higher temperature water on just, say, for example, salmonids to take one example?

Mr. GEER. Well, I think it's a fairly simple prediction in some regards. If you have less food, you have a smaller population base perhaps of less healthy fish who are able to go upstream and spawn. Then you have an environment upstream that's not particularly inviting for them in the first place. There are some questions to be asked on whether or not, for example, will the chemical makeup of the water at that time change to the point they do not recognize their homing stream anymore, which will upset their spawning behavior? And if they do find the correct stream, or a stream, will they have a physical environment that still enables them not only to spawn—it's not just the act of spawning, the act of recruitment is you also have to have egg hatch.

One of the things, if you have worked in fish hatcheries, we deal with things called degree days. A degree day is one Centigrade for one day. And, typically, an egg for a salmonid is going to require a little over 300 degree days to hatch. And if you have a species that's spawning in spring and is tied to the flow, you have fewer days with warming water than a species that spawns in the fall and has cold water for a longer time.

But those cycles are timed to not only when the eggs hatch but what physical environment for the young-of-the-year fish exists at that time. Is there side water for younger-than-year fish, which are not muscular, they are small, they are prone to being washed away and to be preyed upon by big fish. Are there areas of flow at the time of year that they can escape to so you have successful recruitment, spawning, hatching, and survival of young fish to the next age class so they can go downstream?

So it's a whole series of factors. But if you start with the fact that you have fewer fish to move upstream because you have a smaller body of fish in the ocean and they are of poorer health, they have physiologically a less suitable condition, you have a smaller population going up, you have a reduced spawn size, perhaps a less favorable environment, a lower recruitment, and you have a decline of salmonid populations. You are talking steelhead and Pacific salmon.

ADAPTATION OF ANIMAL SPECIES TO A CHANGING CLIMATE

Chairman BAIRD. What you have hit upon seems so important to me. Because when we talk about this issue sometimes people say to themselves—I hear it a lot—wait a second, you are talking one degree, two degrees. My understanding of the biology of many species is that many of them live fairly near the upper bounds of their temperature tolerance. And a one degree change in water temperature over a period of time can be lethal. A change in pH level can be lethal. Integrated, they can have a terribly negative synergy. And now you are adding in all the of the other variables about stream flow, other habitat issues, nutrition supplies, et cetera. Even small changes can produce those impacts?

Mr. GEER. Depending on where they are on the tolerance curve. If you have something, for example, like rainbow trout, that, if you are looking Fahrenheit, that have an optimal temperature of 55 degrees Fahrenheit, you have some wiggle room on either side where you can still have either good growth or slower growth and a viable population. But when you get up five degrees or something, you are getting to smallmouth bass range. Suddenly, you have physiologically less adaptable fish, you have lower reproductive success, and you have the opportunity for what we are calling invasive species, species that don't normally belong there intruding on their territory, which is what's happening in the Yellowstone River, the Clark Fork River, the Bitterroot River, and some other areas. You have species that are more competitive, that operate in a higher temperature range. When you get on the upper edge of their thermal tolerance, that's when you get the higher level of risk.

One of the things I have noted over the years as sort of a general observation, though, that as humans we tend to think as the center of the universe, and we tend to think that what we understand is really what's important. We confuse lack of understanding with lack of importance. We don't understand how a small temperature difference can make a large difference to something else where it may not to us.

We are in an insulated environment. We are in a comfortable room, thermostat controlled, comfortable. Well, if you are outside living in the environment without a thermostat, things are a little bit different, and they don't respond to the same stimuli that we respond to.

And one of the things that we work on in animals, we can debate, for example, whether or not the science is exactly right, whether or not they are at the upper ends of the thermal tolerance or whatever. We can debate the policy outcomes that come out of this and even the range of the economy. But the animals don't get that vote.

Chairman BAIRD. They don't get to turn the thermostat up.

Mr. GEER. They go where the environment is within their life history and their tolerance. If their habitat's not here, if they are mobile enough, they will go to where it is. And some of them will not enjoy that advantage. They are already at the limits of their tolerance, and there is nowhere else to go. If you are a mountain goat, where do you go? You are already at the high end. So they go to where the habitat suits them. If it no longer suits them, then we have a decline in the species.

Chairman BAIRD. And they don't have time to evolve to adapt at the pace of change.

Mr. GEER. No, at the pace that we are changing things right now, we are talking evolutionary changes, maybe a hundred years or perhaps thousands of years. But we are talking things that are going to change much more rapidly, and they simply haven't got time to physiologically adapt in many cases to the environment that we predict may occur. And I hope that we are all wrong, actually, and that we have overestimated that. But the odds aren't looking good.

Chairman BAIRD. Yeah.

COMBINED FACTORS AFFECTING CLIMATE

Dr. Curry, I was intrigued by one of your observations I thought was very telling and I think important. It's not just CO_2. There are other factors. I caught at least two of them, population and land use. Those are also integrated, however, with CO_2 output. Can you elaborate? I mean, there is—they combine to have combined effects. Can you elaborate on that somewhat?

Dr. CURRY. Well, our vulnerability to global warming is largely associated with ever-increasing population, where we choose to build and what we do to our ecosystems and how we engineer our, you know, we get rid of some of our barriers. At the same time, as population increases this is, you know, a big part of the carbon dioxide problem. So it's a big, complex, wicked problem that's coupled in very complicated ways.

And, again, I tried to make the point that there is no silver bullet solution. And there is all these intersecting problems. I mean, the climate problem doesn't stand alone. It's coupled to population, it's coupled to energy, increasingly to ocean acidification. And we need to look at the broad solution space, possible solution space for all these issues and try to figure out what makes sense.

Chairman BAIRD. This population issue seems so important to me. Because if each individual has their own personal carbon footprint, if you will, the popular term, but basically what it takes for you to live your lifestyle, add a lot more people wanting a more carbon-intensive lifestyle, you just magnify the impact.

Dr. CURRY. Okay. And the population—where the population is growing is in central and south Asia. That's where the rapid, rapid,

rapid population is growing. This is where economic development is huge. And what's going on there is going to totally dominate—well, it's already dominating the CO_2 story, and it's going to explode really in terms of dominating the carbon dioxide situation. And so that becomes a whole political issue about, you know, what India and China does and how we deal with risks.

And the whole issue of who is a winner and loser, again, north China looks a lot more favorable in a warmer climate potentially, okay, with more water and a nicer climate, you know, during part of the year. And so what is going to be their motivation?

You know, we haven't really looked at, you know, the winners and losers part of this story in the way that we should and really understood vulnerabilities. I mean, in the United States we have a fairly good of it. But in a lot of the developing world that are either very vulnerable, or like India and China, South Asia, that are going to be the big powerhouses in terms of emissions and populations, we just really haven't done a lot of the analysis that we need to do to really sort this out.

Chairman BAIRD. What about the argument that, well, you know, there are so many Chinese, so many people in India and Indonesia, et cetera, they are going to pump out so much CO_2 that what we do here doesn't matter?

Dr. CURRY. Well, superficially, it doesn't, but the Chinese have already poisoned their environment in pretty serious ways. So their big motivation for doing something about it is really trying to stop the poisoning of their soil, water, and air. Okay. So that's their motivation.

And on one hand it doesn't. But everybody's going to need—there is no way that the developing world is going to be able to compete for, like, petroleum, you know, in terms of dollars, especially when we see peak oil or whatever. So there is going to have to be alternative energy sources of some sort. And the people who take the leadership in that area is going to be less vulnerable to price swings and global security issues and whatever. So there is a lot of motivation for being out there in front and taking a leadership position on all these alternative energy strategies.

BLOGGING, SCIENTIFIC INTEGRITY, AND PUBLIC INFORMATION

Chairman BAIRD. One final question for you, and then we will bring it to a close, I suppose.

I had the opportunity in almost every case here to look online at other things that you had done. And you mentioned the blogosphere. I will tell you I was pretty troubled by—I went on a few climate sites on both sides, and it was not the scientific dialogue that I am trained in. It was snarky, it was nonsubstantive, it was ad hominem, it was juvenile, and it was unconstructive.

Dr. CURRY. A lot of it is. Okay. But there is what I would call the technical climate blogs that have spun up, and these are people who have an interest in analyzing the data and looking into the science, and people from both sides of the debate show up. So some of the more high-profile ones are very snarky and polarizing. But the blogosphere has sort of developed this sort of lukewarmer technical blogging community where people are actually looking at the data, debating scientific papers, people from both sides in a fairly civilized way. And so I view this as something that it's important to tap into and acknowledge this interest, and there is potential for reducing polarization.

Chairman BAIRD. Somehow there has got to be. And I mentioned at the outset—and I know you have written on this. I mentioned at the outset this issue of science integrity. We literally wrote it into the America COMPETES bill. Now you can't get a NSF grant. But you can blog with nothing. It's an important point. And the reason it's so important and the reason we are having this hearing is to try to say, look, this idea of science by ad hominem attack, by politicization, by false accusations, by conspiratorial theories, by labeling things hoaxes, that ain't science.

Dr. CURRY. I know it's not. But it's going to happen whether the blogosphere is there or not.

I am just saying by engagement, a lot of it—so many people distrust climate scientists and climate science. I mean, they view them as arrogant and whatever, and they were worried about U.N. policies taking over everything, and they were sort of scared. And then when Climategate struck with the e-mails, you know, then people really had more of a concrete reason that they felt not to trust scientists.

Chairman BAIRD. Would you say that that, though, obliterates all the legitimate data——

Dr. CURRY. Not at all. But it is an issue of the public trust, and a lot of the things like the IPCC assessment report is a heavy dose of expert judgment in those conclusions. And if you don't trust the experts, you know, what are we to make of their judgment? So the data and the fundamental research is there. It is how it is assessed, communicated, and by whom it becomes an issue.

Chairman BAIRD. This is helpful.

You know, I thank you all.

AN ANECDOTE ON RISK MANAGEMENT

I will share an anecdote that occurs to me. Some years ago, I was climbing Mount Rainier. We were going up in the springtime. It was early and these wicked whiteouts happened. And if you have never been in a whiteout, it is really quite an experience. You literally have no sense of vertical, up or down. And we were walking with ski poles in front of us so we don't walk off. We are literally sort of probing because you can't see the earth. It is bizarre. And I had had the good fortune and maybe good sense to actually when we left this hut at Camp Muir to actually take my compass out and take a compass reading. And so we follow this compass reading.

Everybody else was just walking the way they think we should walk, and I had the compass reading. And at some point I said, I just don't like the feel of this. We haven't come back across the trail I thought we should have and our intuition says we should go this way. If we are wrong, I knew from many climbs previously, there is about a 1,500 foot drop down to the Nisqually Glacier.

Now, I said, you know, maybe what we ought to do is gather together and check our instruments. I happened to have an altimeter with me and a top map. It was mighty handy. So I had the top map. I had the topographic map, I had the altimeter, and I had the compass reading from where we had gone.

Everybody else in the party pretty much was saying we are going to go this way. We are sure it is this way. And I said, well, here is the point on the map where my instruments tell me we are. If we walk another 200 meters this way, I think we walk off a 1,500 foot cliff as many others have done in equal conditions. The alternative, unfortunately—because we had gone this way this far—was unpleasant. We had to actually go uphill. And when you have climbed all day and you have got a heavy backpack on and it is deep snow and it is spooky and it is—you don't want to go back uphill. You hate it. It is hard work. You are tired. It is not what you want. Relative to a 1,500 foot downhill——

Well, we trusted the instruments because I had them, and we walked back. And I have never been so happy as I have in my life to see some spilled Gatorade on the snow about a half hour later. We had to literally change direction and walk uphill. The instruments gave us the data. And we could have gone where we wanted to go, where it seemed easy to go, where our intuition and our experience seemed to suggest it would go, but the data suggested something otherwise and we followed the data. And I probably wouldn't be here today because I was on the lead of the sharp end of the rope.

The point of our hearing today—and I think the point of this committee I hope, which I am loath and sad to leave—is that we have an obligation to approach decision making in a constitutional democratic republic with rationale, empirical judgment and information, imperfect and uncertain but the best we can do. And the hope today was we had a model of how that can happen. We won't reach any conclusions.

I don't think anybody is going to say, well, dang, I was a complete skeptic before, now it has turned. Maybe some will go the other way. But the process that we try to follow and the process of science is what is going to get us there. And I would hope that that process, that legacy on this committee, if no other, is one based on empirical decision making, mutual respect, critical analysis, objective analysis.

I am grateful for the witnesses on all sides that have helped us put this forward, and I hope for the sake of the two 5-1/2-year-old boys on which I make every fundamental decision in my life and countless others that are near and dear to you that we will weigh the consequences of inaction or inaccurate action against the consequences of acting in responsible, reasonable, rational ways for the broader good of not only our society but the globe itself. And the stakes are pretty darn high, and we have really got to get it right.

I thank all of you for being here today and all of you who are—the audience for your perseverance and your patience and your expert input.

Customarily, there will be two weeks allowed for anyone who wishes to enter additional extraneous comments into the record.

And with that—thanks. And I would like finally to thank the staff on both the Majority side and Minority side for their participation in making this hearing in this last session of Congress so successful.

With that, the hearing stands adjourned.

[Whereupon, at 2:35 p.m., the Subcommittee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Ralph J. Cicerone, President, National Academy of Sciences

Questions submitted by Chairman Brian Baird

Human actions and climate change

In your testimony you describe the basic energy balance of the Earth. In that explanation you state that the Earth's calculated temperature is lower than the measured temperature. You then state something must be missing in the calculated temperature of the Earth.

Q1. Does this mean that global warming due to anthropogenic effects is the missing factor and that the increase in Earth's temperature is due to human activity?

A1. The big gap that I referred to is that the temperature which we calculate for the surface of the Earth by balancing the incoming energy from the Sun, with that which is emitted by the Earth, is about 30°C lower than our actual temperature and this is due to the natural greenhouse effect. It does not include a human impact. The gap illustrates the fact that the greenhouse effect is a natural force and that if we calculate the temperature of Earth's surface or the temperature of Venus's surface without the greenhouse effect, we obtain answers which are far lower temperatures than are actually measured. The cause of this discrepancy is that we have ignored the greenhouse effect of gases in the atmospheres of Earth and Venus and of clouds in those atmospheres. The reason that we can calculate the correct temperature for Mars in this simple way is that Mars has such a thin atmosphere with so little carbon dioxide and water. This evidence for the existence of a natural greenhouse effect is one indication of why the human-enhanced greenhouse effect is also capable of changing Earth's climate.

Q2. It is important to understand what the human contribution to the greenhouse effect means. Your testimony states that human's direct influence is small but we must consider all human energy usage (i.e. nuclear power, the burning of all fossil fuels, the burning of wood, etc). What sort of human impact does this translate into for the greenhouse effect and global warming?

A2. I hope that I did not confuse the issue by mentioning the fact that all of human energy usage today on Earth that is due to all fossil-fuel burning, coal, petroleum, and natural gas added to all the energy used from nuclear power plants, hydroelectricity, all renewable sources of energy together, add up to only about 1/100th, that is one percent, of the extra energy trapped near the surface of the Earth by the human enhanced greenhouse effect. I mention this comparison to show how powerful the greenhouse effect is as leverage over Earth's physical climate. I also mentioned it because sometimes I encounter people who when they hear "fossil-fuel burning" think that it is the waste heat from all of that fossil-fuel burning to which we refer as a possible cause of planetary climate change. Instead, of course, it is the extra greenhouse effect caused by the growth in atmospheric concentrations of the byproducts of fossil fuel usage such as carbon dioxide and methane which represents human leverage over the climate. Just to provide one more comparison, I note that all of human energy usage today is approximately 1/9000th of the energy Earth receives from the Sun while the human-enhanced greenhouse effect is approximately 1/90th of the solar energy received by the planet.

Questions submitted by Representative Ralph M. Hall

Of the many revealing aspects of the ClimateGate email scandal, perhaps none are as disappointing as the great lengths at which scientists worked to block other researchers from gaining access to scientific data associated with key global warming findings.

Climate scientist Phil Jones exemplified this attitude when he responded to a fellow researcher's request by saying "Why should I make the data available to you, when your aim is to try and find something wrong with it?"

This behavior is, at its core, unscientific. The National Academy of Sciences' Guide to Responsible Conduct in Research states that "When a scientific paper or book is published, other researchers must have access to the data and research materials needed to support the conclusions stated in the publication if they are to verify and build on that research . . . [G]iven the expectation that data will be accessible, researchers who refuse to share the evidentiary basis behind their conclusions, or the *materials needed to replicate published experiments, fail to maintain the standards of science."*

As President of the National Academies, you are obviously very influential in how scientists apply this basic principle of openness and data sharing. In an interview after ClimateGate, however, you said some climate scientists "are now receiving requests that are bordering on harassment. They're being asked for all the data that went into a publication, sometimes in addition to all data analyses, all equations, used in interpretations, detailed descriptions of all statistical techniques, all computer programs used—even access to any physical samples. These are fishing expeditions."

Q1. Please help us reconcile your statement calling these requests "fishing expeditions" with the Academies' guidance stating that researchers who refuse to share materials needed to replicate published experiments fail to maintain the standards of science.

Q2. Do you think the Federal government should withhold funding from researchers that refuse to make their data and materials available for public scrutiny? Should such research be excluded from use in policy debates and scientific assessments such as those by the National Academies or IPCC?

A1, 2. I will address this array of questions and observations by outlining to you some of the things that the National Academy of Sciences and I have been doing in the last several years. First, we published in late 2009 a new report authored by a superb committee of academic scientists, people from corporations and legal experts, entitled *Ensuring the Integrity, Accessibility, and Stewardship of Research Data in the Digital Age*. This "data integrity" report dealt with a very large array of questions about the form, volume, and value of various kinds of research data. One of the findings was very similar to the statement which you quoted from the National Academy of Sciences' Guide to Responsible Conduct and Research, namely, that "research data, methods, and other information integral to publicly reported results should be publicly accessible." Implementing this principle would encourage scientific research to proceed more efficiently and openly, which is a goal that we all share. The report notes that in many fields of science, especially those which are of practical importance such as pharmaceutical development, intellectual property and software and manufacturing, many kinds of medical research, and environmental issues where there are sometimes competing forces at work, there are also specific factors which make it difficult for all data to be provided to all parties at all times. For example, there are proprietary restrictions on research that has been supported by industry. Similarly, there are issues of personal privacy in some kinds of medical and social research. Third, for example in climate change, there are datasets which are now the property of individual governments due to a move that began two or three decades ago to nationalize meteorological services so that the data and the weather forecasts can be sold to recover the costs of the government in establishing meteorological stations and meteorological satellites and models. Each of these limitations is potentially serious and they must be dealt with in ways which are appropriate for each field.

Our "data integrity" 2009 report noted that in some scientific fields the individuals most knowledgeable in that particular field of research have created uniform standards to be employed by researchers in each specific field and in the journals where they publish. The report provides examples from a number of fields including space research, crystallography, and in molecular biology and genetic databases. In some cases, these field-by-field standards are promulgated and enforced through research journals, in other cases by Federal funding agencies, and in still further cases, by leading scientists in the field who have created a supportive culture for those standards. In several examples, Federal agencies have provided funds to create and maintain data repositories which accept data from scientists who are publishing results and the data repositories provide professional and permanent archiving of data. The National Academy of Sciences–National Research Council data integrity report of 2009 also noted that in the digital age, forms of data are becoming more varied and numerous, and data storage now involves the maintenance of supporting data (metadata) required to interpret the data such as statistical techniques, computer programs to maintain metadata or housekeeping data, for example, on the position of an Earth-orbiting satellite or other features of the research protocol that went into obtaining the data in the first place.

I also note that it was in 2007 when the NAS and the NRC decided to launch the study that led to our 2009 data-integrity report. The study was funded by ourselves, several journals and scientific societies and private foundations, with about one third of the funding from Federal agencies.

In the last couple of years I have focused my own efforts on how to create the most uniform set of standards we can in the field of climate science. For example, in February 2010, I made a special trip to the annual meeting of the American Association for the Advancement of Science in San Diego, to propose the need for such standards and to stimulate discussion among scientists from different disciplines. I also spoke at public meetings in San Diego on how and why these standards must be achieved. Just before that San Diego meeting, I wrote the enclosed editorial for SCIENCE magazine where I addressed these issues.

In my 2010 annual address to the members of the National Academy of Sciences, I focused on the issue of the need for standards for data access across fields of science, again in our desire to advance science and also to be as responsible as possible to members of the public, to people with commercial and proprietary interests as well as to protect scientists from potential harassment. Also early in 2010, I met with the editors-in-chief of three of the world's major scientific journals to describe these issues to the journal editors and to learn what they were already doing to help to promulgate and maintain standards for access to data on which research publications are based. Following that meeting, I wrote to and telephoned the elected officers of two strong American scientific societies who publish important climate research papers, namely, the American Geophysical Union and the American Meteorological Society.

In these meetings and contacts, it has become clear that climate science is an especially challenging field for which to create standards of data access because the field is comprised of many subfields such as remote sensing by Earth-orbiting satellites, by observations of the Sun, by observations of oceanography, of meteorology both on continents and ocean, and by observations from paleo objects such as fossilized biological specimens at the bottoms of lakes, oceans, and soil. The field of climate also includes mathematical modeling of Earth's climate which in turn generates enormous datasets, certainly of the order of a few terabytes per computer run. The field also includes records from sea-level changes from glaciology and isotopic data from biological and physical specimens worldwide. Accordingly, climate research is published in many, many different journals, some of which are owned by the private sector and are commercial enterprises, other journals of which are published by scientific societies which are nonprofit. And the rules governing these publications vary.

In the fall of 2010, I have arranged for more meetings between myself and officials of the AGU and the AMS to continue to pursue these questions, and I have begun to reach out to individual leading scientists to ask them to identify best practices in their field and the potentials for creating more uniform standards for data access along with learning from them the pitfalls of trying to implement what might be seen as simple solutions of a one-size-fits-all nature but which would be counterproductive and extremely difficult to implement. I mentioned earlier that there are some kinds of requests for data, which appear to be harassing because the authors and the scientific researchers in question have provided reasonable amounts of data to requestors but have not been able to give away access to individual physical samples when, for example, the conditions under which the samples were obtained mitigates against the free distribution of the samples (as does their scarcity) and expense of distributing the samples intervenes.

Some of our Federal agencies that conduct research and sponsor research extramurally, have already put in place standards and data repositories which are enabling some climate data to be archived, maintained, and made available in ways which are exemplary. For example, two of the leading providers of global temperature records, NASA and NOAA in the United States, have documented very well in a public way the sources of all of their data, the numbers involved, and any mathematical operations that they have applied to the data, including data which have been omitted or otherwise altered before being used in the dataset. These records are easily available through NASA and NOAA websites, and I think they have encouraged research by other people as well as making the results easily visible to anyone who will take the time to look. Similarly, there are procedures in place for certain NASA missions which have long time latency, that is, times during which satellite instruments are being conceived, being built before they can be flown, and then after the initial flight until the results can be presented in geophysically meaningful ways. There are rules promulgated and enforced by NASA on how to make those data accessible to the public as soon as possible. There are other rules in place at the National Institutes of Health on molecular, biological, and genetic data, so-called genebanks, as well as databanks for protein structures and crystallographic information on the crystals of proteins. There are additional rules and processes implemented by the National Science Foundation in certain fields, and these developments, some of which were summarized in our 2009 data integrity report, are very impressive and very encouraging. On the other hand, there is certainly additional financial cost associated with the curating, archiving, maintaining, and distributing these datasets, some of which are quite large and heterogeneous in nature.

Accordingly, in response to your question as to whether the Federal government should withhold funding in various ways, I think the reply would be more that the Federal government should help to pay for constructive ways to provide better access to data which were generated with public funds especially those data which have appeared publicly in publications, in ways that are compatible with field-by-field standards that are now being developed. I worry that a one-size-fits-all solution could turn out to be clumsy and counterproductive. Instead, we require standards as specific as possible to be applied field-by-field in recognition of the different kinds, types, values, restrictions, and volumes of data in each research field.

Thank you for attention to this important issue.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Richard S. Lindzen, Alfred P. Sloan Professor of Meteorology, Department of Earth Atmospheric and Planetary Science, Massachusetts Institute of Technology

Questions submitted by Representative Ralph M. Hall

Q1a. What is the contribution of clouds to global warming compared with the contribution of greenhouse gases to global warming?

A1a. Global warming refers to the response to external forcing. Thus, one doesn't usually refer to clouds as causing global warming. Clouds, however, can act as feedbacks that could amplify or reduce global warming. In models, clouds amplify the response, but explicit measurements suggest that they actually reduce the response.

Q1b. Are the uncertainties in the effects of clouds large enough to upset model results?

A1b. Doubling CO_2 is associated with a 2% change in the earth's energy budget. Clouds are associated with a 40% contribution to the earth's energy budget. Thus, small changes in cloud distribution can easily swamp the contribution of CO_2, and uncertainties as well as identifiable errors in model simulated cloudiness are large.

Q2a. Approximately what percentage of current and expected future warming is anthropogenic, and what percentage is natural? Is it 50%? 75%?

A2a. At this point, we don't know, but as I noted in my testimony, even if the answer were 100%, it would still be consistent with small warming. Remember, we are talking about tenths of a degree. My own work suggests that about 33% of current warming is anthropogenic. For the future, this implies that the contribution of added CO_2 will be much less than 1C. No percentages can be offered because the natural internal climate variability is, itself, not currently predictable.

Q2b. And how much are estimates on this question based on actual climate observations versus computer modeling?

A2b. High estimates are based on models. Low estimates are based on observations. All estimates for future are based on either models or theory.

Q2c. If we don't know the answer to this question with any precision, how can we have any idea whether policies aimed at addressing projected warming will have any impact?

A2c. Actually, almost all proposed policies will have so little impact on levels of CO_2, that it is widely acknowledged that they will have no discernible impact on climate regardless of what one believes about climate. Only policies that involve almost complete elimination of fossil fuels will have significant impacts on CO_2 levels so that they might have some impact on climate if sensitive climate models are correct, but this too seems doubtful.

Q3. Some members of the scientific community seem to discount the affects clouds and aerosols have on global warming. In fact, the IPCC states that "Confidence, in attributing some climate change phenomena to anthropogenic influences is currently limited by uncertainties in radiative forcing, as well as uncertainties in feedbacks and in observations."

a. Can you explain what is currently known and what is not known about the effect of clouds and aerosols on climate change?

A3a. The uncertainty in both the nature of aerosols and their distribution is on the order of a factor of 10. This means that sensitivity cannot be derived from observed temperature time series. It also means that there is enough scope for arbitrary adjustment in aerosols to permit any model to be consistent with any observations. As to clouds, there is enough known to be confident that all models badly misrepresent clouds, and that the misrepresentation is sufficient to swamp anthropogenic influences. Observations of clouds and aerosols are improving and strongly suggest that many models are exaggerating the influence of aerosols and that clouds are, indeed, constituting a negative rather than a positive feedback, and that this negative feedback is sufficient to dominate the response of the climate system to anthropogenic forcing..

Q3b. Can you describe the level of uncertainty related to radiative forcing and feedbacks?

A3b. There is, by now, ample evidence that feedbacks in nature are negative rather than positive (which is what they are in models). Radiative forcing by greenhouse gases is reasonably well determined, but the contribution of aerosols to radiative forcing is poorly constrained (see previous answer).

Q4. It has been reported that global average temperatures have increased 0.6°C in the last century.

a. How much of that increase is attributable to each of the following: natural variability, land-use change, and emissions of greenhouse gases?

A4a. Precise attribution is currently impossible. What can be said is that it is possible to simulate the observed change in global mean temperature anomaly by natural internal variability (ie El Nino, Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation), and it is also possible to simulate it with anthropogenic effects—provided that one is allowed to adjust unknowns like aerosol forcing and solar forcing arbitrarily. With respect to land use change, it is entirely possible that it is a significant contributor to the small observed change in global mean temperature anomaly—as are changes in instruments and changes in instrument placement.

Q4b. What is the level of uncertainty in each of these answers?

A4b. The commonly stated uncertainty in the temperature record, itself, is +/- 0.2C. This is probably an underestimate, and already constitutes a significant part of the total change. As concerns attribution, the presence of large adjustable factors makes attributions totally unreliable, though, at least, the attempts to simulate the past with natural internal variability do not need the egregious adjustments that the attempts to simulate with anthropogenic forcing need.

Q5a. Do you believe the current IPCC processes are working?

A5a. It depends on what one thinks the purpose of the IPCC is. The stated purpose is to produce summaries of the research in support of the negotiating process. Given the intrinsic bias of this purpose, the IPCC is doing what it is supposed to do. That said, the work of IPCC working groups II and III is pretty useless since it assumes the worst for the science and proceeds to spin implausible impacts and responses. The full Working Group I report on the science is not terrible (though an index would make it vastly more accessible). Unfortunately, for most people, however, the only science from Working Group I that they hear about comes from the press release that accompanies the release of the Summary for Policymakers (which generally precedes the release of the full report). For last three reports, the iconic statements have been that current warming is unprecedented for for 400 years (the infamous hockey stick), that the balance of evidence points to a human role in recent warming, and that it is highly likely that man has contributed most of the warming over the past 50 years. None of these statements (whether true or not) is actually alarming, but the public is made to think otherwise.

Q5b. If so, why?

A5b. See preceding answer.

Q5c. If not, what specific actions can be taken to repair them, and in the meantime, why should the product of a process that isn't working be relied upon as the basis for policy actions that would impose enormous costs on the United States economy?

A5c. Frankly, the IPCC reports are not the basis for various proposed policies. Rather, the IPCC is exploited to claim the existence of a scientific argument for the proposed policies. Thus, the problem is the existence of the IPCC, and its statutory authority derived from the Rio Framework Convention of 1992 plus the fact that policymakers never try to understand what is actually in the WG I report or even to understand how vacuous the iconic statements are.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Patrick J. Michaels, Senior Fellow in Environmental Studies, Cato Institute

Questions submitted by Chairman Brian Baird

Q1. Please explain how you get increased levels of black carbon without also having increased greenhouse gases.

A1. You don't. Black carbon is a result of incomplete combustion of hydrocarbon fuels or vegetation. My point was that this is not a *greenhouse-gas-induced* warming effect, and my point was in response to EPA's December, 2009 Endangerment Finding in which it states,

> *Most* of the observed increase in global average temperatures *since the mid-20th century* is *very likely* due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations. [italics added]

Black carbon is not a gas, nor does it cause an "observed increase in global average temperature" through absorption of upwelling infrared radiation (i.e. an enhanced greenhouse effect). Whether or not black carbon is a result of the combustion of fossil fuels is not germane to this point.

Q2. How is water vapor in the atmosphere not connected to increased greenhouse gases?

A2. I don't believe I ever stated that. However, there is an emerging stream of evidence based upon actual observation of what happens in the atmosphere during major El Nino/La Nina cycles indicating that the carbon dioxide-water vapor-cloud feedback may have been overestimated, and even possibly of the wrong sign. (Spencer and Braswell, Journal of Geophysical Research, 2010, article D16109).

If you are referring to stratospheric (rather than "atmospheric" water vapor), Solomon states that she sees variations in stratospheric water vapor that are not monotonic as are changes in carbon dioxide; in fact the sign of the relationship with sea surface temperature changes with time. (Solomon et al., Science, March 5, 2010).

Questions submitted by Representative Ralph M. Hall

Q1. There have been claims that the models and observations of average surface temperature are in agreement and there have been claims that they are not. Which is it? Can you explain how they are or are not in agreement? How do you explain a different interpretation of the numbers.

A1. I showed in my written and spoken testimony that the IPCC's midrange suite of models predicts that warming should be taking place at a constant rate. Indeed, if one looks at the East Anglia temperature history since 1975, the rate has been remarkably constant. Mathematically, any departure from a constant rate is not statistically significant. So the models have the "form" of the warming right.

However, if you look at the *magnitude* of the warming it is clearly below the mean and median values projected by these models going back at least 15 years. So you might say that we have the form correct, but not the size. This latter should be very important to policymakers.

Q2. During the hearing, you and Dr. Santer were engaging in a debate regarding his 1996 paper. Dr. Santer brought up 3 aspects of the criticism laid against his paper, specifically: the editorial process of the scientific journal Nature *had been interfered with; the selected data analysis that showed an upward trend in temperature, and; the additional scientific work conducted since then that has strengthened confidence in the ability of the models to reproduce the temperature change first characterized in the 1996 paper. Unfortunately, time limitations prevented you from having a chance to respond to Dr. Santer's claims: Please provide the response to these claims that you were unable to testify to at the hearing.*

A2. Dr. Santer claimed that I stated that the editorial process at Nature had been interfered with.

I have written much on his 1996 *Nature* paper. The core error was using data from 1963 through 1987, when data were available from 1957 through 1995. Using the complete data set completely invalidates his headline-making finding.

Either peer-reviewers did in fact note this problem and were ignored, or they simply did not note it, which would mean that each of the peer-reviewers missed a glaring and obvious error. I can't tell which it was—perhaps you should ask the appropriate editors at *Nature* for the peer reviews and their response. Whatever happened, it was the most egregious error I have ever seen in a major climate paper.

Santer's claim that our criticism was invalid in using all the data at the time is simply false. I know of no other word to describe this. In fact, as is shown in my testimony, the behavior of the important warm spot in the Southern Hemisphere changes in *sign* when all the data are used!

I should point out that Dr. A. H. Oort, of MIT, who assembled the upper-air record that began in 1957 was in fact one of the co-authors of the infamous 1996 Santer paper. I think it is impossible to believe that Oort did not know of the problem. He either mentioned it and was ignored, or chose not to mention it.

With regard to the timing of the paper, I believe its publication just days before the Geneva UN conference was no accident. Perhaps the peer reviewers wanted it rushed to print, perhaps the editors ignored negative reviews in order to do so . . . we will never know until you ask *Nature*.

Q3. In your testimony, you talk about publication bias. That a substantial number of the papers published today (at least in Science and Nature) claim that future climate prospects are worse than previously suggested. How does one regain some balance in a particular science field's publication rate?

a. Is it appropriate for scientists to encourage or lobby other-scientists to not publish in a particular journal because that journal published something that was contrary to their thinking?

b. Is it appropriate for scientists to conspire to stack editorial boards so that only one view of a scientific field is accepted for publication?

c. Is it ethical to then refuse to consider papers for larger assessments that were not published in popular journals with skewed editorial boards because their content went against the "consensus"?

A3. You ask, "How does one regain some balance in a particular science field's publication rate"?

My thesis is that an additional finding with regard to a previously unbiased projection has an equal probability of essentially raising or lowering the forecast. This is clearly true for weather forecasting models; climate models share many of their characteristics, as was noted by other witnesses at your Hearing.

The problem probably lies in the nature of modern science. It is almost all taxpayer-funded, and individual "problems" compete for finite resources. As a result, the "problems" have to be portrayed in increasingly stark and dire terms, and whole fields are financed upon the *premise* of disaster. What incentive is there for anyone to write a paper that would argue otherwise? What incentive is there for *Science*, the journal of the American Association for the Advancement of Science, to publish such a result? The Association is the scientific community's Washington lobby. They should be expected to be make it very difficult to publish anything counter to the interests of its supporters.

You ask if it is appropriate for scientists to encourage their colleagues to not publish in a journal because it published something they disagree with. Of course it is not appropriate; in fact it is deadly wrong and poisons the free exchange of ideas. I think it would be appropriate for you to ask Dr. Mann of Penn State University this question. A counter witness should be Chris deFreitas from Auckland University, whom Mann claimed was inserting papers into the journal *Climate Research* that were inappropriate. The two should testify together, despite the problems with bringing Dr. deFreitas in from New Zealand.

While it is inappropriate to stack editorial boards in favor of the disastrous view of climate change, that is the natural result of the incentive structure, is it not? We spend billions of dollars per year on this "problem", which results in promotion, tenure, and honors at major Universities. This will never stop until Congress stops feeding it. Rather, the distortions of science will grow ever larger and louder.

Of course it is not ethical to bar papers in the peer-reviewed literature from assessments like those of the IPCC. Even if these papers were disproven it is important to note their existence, and the subsequent arguments against them. But, again, is there any incentive to include things that disagree with the hypothesis that global warming is a terrible problem?

Q4. Do you believe the current IPCC processes *are working? If so, why? If not, what specific actions can be taken to repair them, and in the meantime, why should the* product *of a process that isn't working be relied upon as the basis for policy actions that would impose enormous costs on the United States economy?*

A4. In a word, “no”; in two words, “they can’t”. Again it is the problem of incentives. Congress has been presented with the disaster that it bought. Corrective action will take much decades, and will probably impossible to achieve. You will never get a strong counter-consensus as long as it is professionally dangerous to espouse it. My profession knows well of the treatment of climate scientists who have not bought into the apocalyptic view of climate change.

I would not rely on any of these large-scale assessments unless the editorial panels showed some semblance of balance—but again, that is very difficult to achieve this given that the professional rewards handed out on one side, while punishment is meted out to the other. .

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Benjamin D. Santer, Atmospheric Scientist, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory

Questions submitted by Chairman Brian Baird

Terminology—climate change versus global warming

Some people are unclear or unhappy about the use of "climate change" instead of the less-precise term "global warming."

Q1. Can you explain why "climate change" is a more accurate representation of the phenomenon?

A1. "Global warming" is a potentially misleading term. In my opinion, use of the term "global warming" implies two different expectations about the "climate signal" arising from human-caused changes in the atmospheric concentrations of greenhouse gases. The first is that climate scientists expect every location on Earth's surface—and every layer of Earth's atmosphere and oceans—to warm in response to human-caused changes in greenhouse gases. The second is that climate scientists expect each year to be successively warmer than the previous year (in some global average sense).

Neither expectation is correct.

Consider first the "every location should warm" expectation. Since the late 1980s, climate scientists have known that this expectation is incorrect. Pioneering work at a number of different research groups around the world (1, 2, 3, 4, 5, 6) helped scientists to understand the complex of effects of sulfate aerosol particles on climate.

The main source of sulfate aerosols is fossil fuel burning (7). Sulfate aerosols affect climate in two ways—by direct scattering of incoming sunlight back to space, and by influencing the optical properties and lifetime of clouds. In areas where the atmospheric burdens of sulfate aerosol particles are high, they can cause local or regional cooling of the Earth's surface.[1] The cooling effects of sulfate aerosols on surface temperatures have been identified in many different "fingerprint" studies, which involve rigorous statistical comparisons of modeled and observed patterns of climate change (8, 9, 10, 11, 12, 13, 14, 15).

The local and regional-scale cooling caused by sulfate aerosols is occurring against the backdrop of the broad, global-scale surface warming arising from human-caused changes in greenhouse gases.

Other human influences can also have important local or regional effects on climate. Examples of such influences include human-caused changes in black carbon aerosols (which cause warming), and in the properties of the land surface (which can cause either cooling or warming, depending on the nature of the modification to the land surface) (7).

The bottom line is that human effects on climate are complex over space and time. The human-caused climate change "fingerprint" is a mixture of climate forcings which cause global-scale warming of the Earth's surface (like changes in well-mixed greenhouse gases) and forcings which cause local to regional-scale surface cooling (like changes in the atmospheric concentrations of sulfate aerosols). In a global average sense, the net human-caused forcing of climate is positive. The warming effects of greenhouse gases and soot aerosols *more than compensate* for the cooling influences of sulfate aerosols, other reflective aerosols, and land use changes (7). But at individual locations—such as in heavily-polluted areas, where atmospheric burdens of sulfate aerosols are large—the cooling effects associated with negative forcing factors can predominate. Thus the term "global warming" does not capture the very complex nature of human effects on climate, and does not convey the message that even local or regional surface cooling can be human-induced.

As I mentioned above, "global warming" also implies that each year will be inexorably warmer than the previous year. This is *not* what climate scientists expect to observe.

Climate change is not an either/or proposition—either all due to human factors, or all due to natural causes. It is due to both human and natural factors. The human-caused climate change "signal" is embedded in the background "noise" of

[1] Because of the dynamic nature of the atmospheric general circulation, sulfate aerosols can also induce "far field" climate effects, at locations remote from regions where there are high atmospheric burdens of sulfate aerosol particles. The IPCC Fourth Assessment Report (7) concluded that the best current estimate of the radiative forcing associated with the direct scattering effects of sulfate aerosols is -0.4 ± 0.2 Wm^{-2}. The indirect effects of sulfate aerosols on clouds are more uncertain.

natural climate variability.[2] As has been recognized since the late 1970s, identifying human effects on climate is a signal-to-noise problem (16), requiring the application of signal processing techniques similar to those used in electrical engineering.

Because of the effects of climate noise, we do not expect each year to be warmer than the preceding year. For example, during a year with a large La Niña event, climate scientists expect global-mean surface temperature to be slightly cooler than average. One could not infer from a single cool "La Niña" year that the gradual warming of the Earth's surface over the past 150+ years had ceased!

This is why climate scientists look at signal-to-noise behavior over many decades rather than over very short periods (10 years or less). Over longer periods of time (decades to centuries), there are larger changes in the human-caused factors which influence climate, leading to larger climate-change "signals". Furthermore, the "climate noise" in most meteorological and oceanographic time series tends to be largest on year-to-year timescales, and becomes smaller over longer averaging periods (17, 18). So when analysts search for a human effect on climate, they focus their attention on long, multi-decadal records, with more favorable signal-to-noise ratios.

If there were more widespread understanding of such basic signal-to-noise concepts, little attention would be paid to invalid claims that a single cool year—or even a single cool decade—provided "evidence of absence" of a human effect on climate.

The key point here is that even in the presence of strong human-caused "forcing" of the climate system, natural climate variability will continue. Because of this natural variability, each of the next 90 years in the 21st century will not be warmer than the preceding year—which is the expectation that "global warming" conveys.

IPCC reliable information

Q1. Based on your experience as a contributor to four previous IPCC assessments, do you regard the IPCC as an effective means of providing policymakers with reliable information on the nature and causes of climate change?

A1. Yes.

First let me explain why I believe I am qualified to answer this question.[3] I contributed to all four Scientific Assessment Reports of the Intergovernmental Panel on Climate Change. I served as Convening Lead Author of Chapter 8 of the 1995 IPCC Second Assessment Report (19).[4] I was also a Contributing Author to the "Detection and Attribution" chapters of the IPCC's First, Third, and Fourth Assessment Reports.

Since its inception in 1988, the IPCC—and many climate scientists who have worked in its service—have been the subject of much unjustified criticism. I'd like to briefly address three areas of criticism. All relate to issues I am directly familiar with.

"Political interference" and "scientific cleansing" allegations

After publication of the IPCC's Second Assessment Report (SAR), parties critical of the IPCC's finding of a "discernible human influence" on global climate alleged that Chapter 8 of the SAR had been modified for political purposes, and "cleansed" of all scientific uncertainties. Such allegations are baseless. They have been rebutted in many different fora. Chapter 8 was not subjected to "political tampering" or "scientific cleansing". Changes made to Chapter 8 after the November 1995 IPCC Plenary Meeting in Madrid were made for scientific reasons, not for political reasons. Changes were in response to Government review comments and to the scientific discussions which took place in Madrid.

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[2] This "climate noise" has both externally-forced and internally-generated components. The externally-forced contributions to "climate noise" are caused by natural changes in 1) the Sun's energy output; and 2) the amount of volcanic dust in the atmosphere. The internally-generated component of "climate noise" arises from natural oscillations of the coupled atmosphere-ocean-sea ice system. Examples of such "unforced" oscillations include El Niños and La Niñas, the Pacific Decadal Oscillation, and the Atlantic Decadal Oscillation.

[3] I note that many of the public commentators on the reliability of the scientific information provided by the IPCC have little or no direct IPCC experience.

[4] This chapter was entitled "Detection of Climate Change and Attribution of Causes". Chapter 8 concluded that "the balance of evidence suggests a discernible human on global climate". After publication of the Second Assessment Report in 1996, I spent over a year of my scientific career defending the "discernible human influence" finding, and defending the process by which this finding had been reached.

Unfortunately, some individuals have persisted in resurrecting these false "political tampering" and "scientific cleansing" allegations. My response to these allegations (and the IPCC's response) is a matter of public record.[5]

Accommodation of the "full range of scientific views"

Some parties critical of the IPCC have claimed that the IPCC does not accommodate the full range of scientific views on the subject of the nature and causes of climate change. In my opinion, such claims are specious. I would contend that IPCC Scientific Assessment Reports have dealt with alternative viewpoints in a thorough and comprehensive way. For example, the IPCC has devoted extraordinary scientific attention to a number of highly-publicized claims. Examples include the claim that the tropical lower troposphere cooled over the satellite era; that the water vapor feedback is zero or negative; that solar irradiance variations explain all observed climate change. The IPCC and the climate science community have not dismissed these claims out of hand. Scientists have performed the research necessary to determine whether these "alternative viewpoints" are scientifically credible. They are not.

Furthermore, I note that holders of these "alternative viewpoints" are often directly involved in the IPCC process, either as Lead Authors or reviewers.

Openness and data sharing

Another frequent criticism relates to data sharing, particularly with regard to model data. This issue is discussed in my written testimony of November 17, 2010.

The database of coupled model output produced in support of the IPCC's Fourth Assessment Report (FAR) has transformed the world of climate science. At present, 35 Terabytes of data from the so-called CMIP–3 project are archived at Livermore, and nearly 1 Petabyte of data has been distributed to well over 4,300 users. To date, over 560 peer-reviewed publications have used CMIP–3 data. These publications formed the scientific backbone of the IPCC FAR. There is no substance to the criticism that the IPCC is some kind of "closed shop", and does not open its doors to detailed scrutiny of the climate model data used in its Assessment Reports.

"Groupthink"

Several public critics of the IPCC have argued that it engages in "groupthink". I fundamentally disagree with this criticism.

My own personal experience of the IPCC (obtained during my service as a Convening Lead Author and Contributing Author) is that the IPCC, like other scientific assessments, brings together a very diverse group of experts, with a diverse set of skills and knowledge. IPCC Lead Author meetings are the antithesis of "groupthink" encounters. Participants in such meetings do not engage in continuous self-congratulatory behavior. They behave like scientists at any other scientific meeting. They challenge accepted wisdom and orthodoxy. They revisit old academic debates and rivalries. They are combatants in an arena of scientific facts and theories. They argue over the robustness of different analysis methods and findings. They debate the strengths and weaknesses of simple and complex numerical models. They struggle to quantify and reduce scientific uncertainties. They spend many hours trying to explain difficult technical issues in plain English, trying to capture what is known with confidence and what is not.

Anyone who has witnessed such IPCC Lead Author meetings would never use the word "groupthink" to describe them.

In summary, I believe that the IPCC is the best mechanism we have for providing policymakers with reliable information on the nature and causes of climate change, the likely impacts of climate change, and possible mitigation and adaptation strategies. The scope and rigor of IPCC assessments is extraordinary.

Yet the IPCC is not infallible. Inaccurate information can make its way into an IPCC Report, despite exhaustive review procedures. Several inaccuracies in a 1,000-page Report do not undermine the entire science of climate change. The IPCC is working hard to further improve its review procedures, and to guard against the inclusion of erroneous information in subsequent Assessment Reports.

Peer review process

You noted in your testimony, "Extraordinary claims demand extraordinary proof." The scrutiny and study of climate change has been extraordinary.

[5] *http://www.realclimate.org/index.php/archives/2010/02/close-encounters-of-the-absurd-kind/*

Q1. Are most scientific claims subject to the same amount of scientific rigor and review before they are considered affirmed? Less?

A1. The IPCC's claim that "most of the observed increase in global average temperatures since the mid-20th century is very likely[6] due to the observed increase in anthropogenic greenhouse gas concentrations" (20) has indeed been subjected to extraordinary scrutiny. In my opinion, most scientific claims are *not* subject to a similar degree of review "before they are considered affirmed".

At its core, science is about reproducibility. Findings of a "discernible human influence" on global climate *have been independently reproduced* by many research groups around the world.

As I noted in my testimony of November 17, 2010, climate scientists have now analyzed changes in many different components of Earth's climate system. They have looked at surface and atmospheric temperature, ocean heat content, Atlantic salinity, sea-level pressure, tropopause height, rainfall patterns, atmospheric moisture, continental river runoff, and Arctic sea-ice extent. The general conclusion is that for each of these variables, natural causes alone cannot explain the observed climate changes over the second half of the 20th century. The best statistical explanation of the observed changes invariably involves a large human contribution. These results are robust to the processing choices made by different groups, and show a high level of physical consistency across different independently-monitored climate variables.

Findings of a "discernible human influence" on global climate do not rest on a single observational dataset, a single scientific study, or a single scientific assessment, as some uninformed commentators have claimed. Such findings are subject to multiple review phases during the course of developing an IPCC report. These review phases involve literally hundreds of climate scientists.

I would like to contrast this rigorous review of IPCC findings with the apparent absence of detailed peer review of the material presented to the House Science and Technology Committee by Professor Patrick Michaels. In his written testimony of November 17th, 2010, Professor Michaels showed an analysis of the causes of changes in global-average temperature over 1950 to 2009. He claimed that this analysis does not support the IPCC's 2007 finding that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (20). If Professor Michaels' claim were correct, and if the analysis he presented were sound, it would be a very serious matter.

Prior to casting doubt on one of the central findings of the IPCC's Fourth Assessment Report, most scientists would ensure that their work was subjected to rigorous review by their peers. They would check that their data, analysis methods, and inferences were sound.

Yet despite the extraordinary nature of the claim made in his testimony, Professor Michaels provides no information on the source of his analysis of the causes of global-mean temperature changes. It is unclear where (or even whether) his analysis has been published. He does not give any description of the method he used in subtracting the effects of four different factors[7] from an observed record of global-average temperature change. There is no discussion or treatment of uncertainties in his selected method of removing "non-CO_2" warming influences from observational data. His analysis provides no error bars.

One asymmetry is particularly troubling. Professor Michaels argues that black carbon aerosols—which cause net warming—are important. The warming effects of these soot aerosols are included in his analysis of the factors contributing to global-mean temperature change. However, Professor Michaels does not account for the cooling effects of sulfate aerosols. These cooling effects have been studied for over 20 years by dozens of research groups around the world (see response to "Questions for the Record" #1).

Professor Michaels does not provide a rigorous quantitative assessment of the contributions of different forcing factors to observed global-mean temperature changes. His analysis serves to highlight the differences between the thoroughly reviewed IPCC claim of a "discernible human influence" on global climate, and Professor Michaels' unreviewed claim of a very small human impact on climate.

[6] Where the term "very likely" signified >90% probability that the statement is correct.

[7] The four factors identified by Professor Michaels were 1) errors in sea-surface temperature data; 2) "non-climatic influences; 3) stratospheric water vapor changes; and 4) changes in black carbon aerosols.

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ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Judith A. Curry, Chair of the School of Earth and Atmospheric Sciences, Georgia Institute of Technology

Questions submitted by Representative Ralph M. Hall

I would like to thank the Committee for this opportunity to expand upon my testimony. I found the questions to be particularly insightful and profound. The answers to these questions about a very complex situation are not simple or straightforward. In preparing my answers to these questions, I sought input from participants in my blog Climate Etc. (at *http://judithcurry.com/2010/12/03/testimony-follow-up/*), which received 265 comments from a diverse group of scientists, other professionals and anonymous citizens, from the U.S. as well as internationally. The diversity of opinions and ideas regarding these questions is evidenced by the broad range of thoughtful and insightful viewpoints expressed on the blog, and I acknowledge the contributions expressed on my blog in preparing this statement.

Q1. It is clear from your public statements that you generally agree with the mainstream view of global warming and cannot easily be characterized as a climate change "denier" or "skeptic." Nonetheless, you have been quite critical of the process under which climate science is conducted, saying that "it is difficult to understand the continued circling of the wagons by some climate researchers with guns pointed at skeptical researchers by apparently trying to withhold data and other information of relevance to published research, thwart the peer review process, and keep papers out of assessment reports."

a. Why are so many scientists "pointing their guns" at skeptics when sharing data and embracing debate seems to be an obvious way for scientists to increase the credibility of their arguments and influence public debate?

A1a. While the majority of climate scientists are not engaged in these adversarial tactics, the CRU emails revealed a siege mentality adopted by a group of influential and highly visible climate researchers. Understanding how and why this situation evolved in the way it did is a topic that should be investigated by historians and sociologists of science.

My own understanding of this is described in the context of the IPCC/UNFCCC ideology. What I'm referring to as the IPCC/UNFCCC ideology is described in my blog post at *http://judithcurry.com/2010/11/07/no-ideologues-part-iii/* and is apparent in this interview with Michael Mann *http://bos.sagepub.com/content/66/6/1.full*. The basic elements of this ideology are outlined as:

1. Anthropogenic climate change is real.
2. Anthropogenic climate change is dangerous and we need to something about it.
3. The fossil fuel industry is trying to convince people that climate change is a hoax.
4. Deniers are attacking climate science and scientists, and their disinformation is misleading the public.
5. Deniers and the fossil fuel industry are delaying UNFCCC mitigation policies, providing a political motivation to counter the disinformation from the deniers.

The book "Merchants of Doubt" by Oreskes and Conway describes "how a loose-knit group of high-level scientists, with extensive political connections, ran effective campaigns to mislead the public and deny well-established scientific knowledge over four decades. . . showing how the ideology of free market fundamentalism, aided by a too-compliant media, has skewed public understanding of some of the most pressing issues of our era." The "circling the wagons" strategy revealed in the CRU emails was designed to counter the tactics of the merchants of doubt and other deniers in delaying the UNFCCC mitigation policies. This strategy was apparently designed under the tutelage of advocacy groups, learning lessons from the wars with big tobacco, etc.

While free market fundamentalism and "big oil" may have been a major source of skepticism in the past, the current dominant group of skeptics, enabled by the blogosphere, seeks accountability. Many of these skeptics have professional backgrounds and extensive experience with the practical application of science and regulation, without any particular political motivations and certainly without funding from "big oil." Failing to recognize this new breed of climate skeptics, and dismissing them as politically motivated deniers or merchants of doubt, led to the events that were revealed by the CRU emails.

An additional motivation for circling the wagons seems to be insecurity and fear that uncertain or flawed analyses will damage professional reputations, as a result of this extraordinary scrutiny of their research. This motivation is revealed by Phil Jones' email to Warwick Hughes saying: "Why should I give you my data when you only want to find fault in it?" Scientists who have invested considerable work and their professional reputations in developing a certain line of research want to be "right", and defend their research against challenges from skeptical researchers. The normal process of scientific debate eventually sorts things out. However, when the battle lines were drawn between the "virtuous" scientists and the anti-science deniers, other scientists lined up in a "consensus" to fight against the forces of anti-science, without a careful examination of the scientific issue at hand. The end result is that genuine skeptical arguments were marginalized and ignored, which diminishes the credibility of science that is being defended.

Another issue is the evolving importance and changing dynamic of climate research. Two decades ago, climate science was conducted in a purely academic environment and there were no data quality requirements or regulatory requirements for models. As climate science has become increasingly policy relevant, demands on quality and traceability (particularly retrospective ones) could not be met. This produced defensiveness amongst the scientists, who did not want to provide any ammunition for the merchants of doubt; they sought refuge in the "consensus" and argued by appealing to their own authority.

In the midst of all this, scientific best practices became compromised.

b. Given the potentially enormous influence of climate science on economic and environmental policy—which ultimately boils down to jobs—shouldn't it be held to a higher standard in the public debate? For example, should Congress consider blocking funding for researchers that do not make their data and materials available for public scrutiny?

A1b. The key issue is openness and traceability. Scientists supported by government funding should ensure that their data and methods are made available to any researcher for purposes of replication. However, the practical aspects of wholesale enforcement of this are not straightforward. U.S. agencies that supervise and fund climate research (e.g. USGCRP, NSF, NOAA, NASA) already have substantial requirement in place for data archival and full and open access to data. Many journals also have requirements for archiving data and ensuring that the data and methods used are made available for purposes of replication. These requirements are not uniformly enforced. How to enforce these requirements in a cost effective way is an important topic to address.

Climate science used for public policy should be held to a higher standard, in a manner similar to medical/pharmaceutical research that is used in the health marketplace. There is normal academic peer reviewed medical research, but higher standards are required in the context of regulated science before a drug or procedure can be marketed. The analogy for climate science is normal academic peer reviewed science, versus an accountable assessment process for policy makers. As part of the assessment process, greater accountability is required, which might consist of fact checking, statisticians auditing the statistical methods, computer scientists auditing the algorithms, etc.

With regards to funding, as part of the proposal process, scientists should state how they will archive their data or otherwise make available data and other information to others attempting to reproduce their results. Scientists should be held accountable for actually having made their data available in consideration for future funding. I am aware of some funding programs and program managers that actually do this, but overall this does not seem to be enforced.

The principal climate data records should be maintained by government agencies, with full documentation, quality and version control, complete documentation, and support to respond to user queries. University research groups are ill equipped to handle this, and researchers generally find the painstaking work of quality control to be scientifically boring.

c. Should such research be excluded from use in policy debates and scientific assessments such as those by the National Academies or IPCC?

A1c. There is no *prima facie* reason to exclude any relevant information from policy and scientific debates. The "scientific juries" of the IPCC and National Academies will use their own standards to decide which scientific studies are suitable for inclusion in their assessment reports. However, there is a significant gap between a scientific assessment of research and accountable information for actual policy making and regulatory purposes. Accountability for issuing regulations under the EPA endangerment finding could demand that all relevant information be independently assessed for its accuracy and reliability to determine its usefulness. Information that has not been assessed or cannot be assessed owing to unavailability of data and other source materials would not be used in this context. Such a requirement would motivate the science community to ensure that its products are useful in the context of policy making and government regulations.

Q2. You state in your testimony that the conflict regarding the theory of anthropogenic climate change is over the level of our ignorance regarding what is unknown about natural climate variability. For a long time, the scientific community did not consider uncertainty a bad thing. In fact, the word "certainty" was something that was almost never used (you are not certain the sun will rise tomorrow morning, but you are reasonably sure that it is very likely to occur).

a. At what point did uncertainty become a bad thing in the climate community?

A2a. Uncertainty became a bad thing in the climate science community with the creation of the UN Framework Convention on Climate Change (UNFCC) Treaty in 1992. The UNFCCC states that future greenhouse gas emissions are uncertain, as are climate change damages. However, following the precautionary principle, "lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." While lack of full certainty does not preclude action, the level of certainty needs to reach some sort of threshold before action is triggered under the precautionary principle. While this threshold of certainty is vague, reducing the uncertainty makes action more likely.

In the 1980's and 1990's, climate research programs were aimed explicitly at the reduction of uncertainties in future climate projections. By the mid 1990's, climate modelers were beginning to realize that the increasing complexity of climate models and the fundamentally chaotic nature of climate system precluded full predictability of the climate system. Nevertheless, the emphasis from policy makers and funding agencies was on the reduction of uncertainty. The U.S. Climate Change Science Program Science Plan (published in 2003) emphasized reducing uncertainty, using the phrase in many of its goals.

Classical decision making theory involves reducing uncertainties before acting. There has been a growing sense of the infeasibility of reducing uncertainties in global climate models owing to the continued emergence of unforeseen complexities and sources of uncertainties. While reducing the overall uncertainty isn't viable, at the same time not acting could be associated with catastrophic impacts. Since a higher level of confidence would make decision makers more willing to act, political opponents to action sold doubt and the scientists countered by selling certainty and consensus. Scientific statements about uncertainty became viewed as political statements.

b. How did this shift within the scientific community occur? How does it shift back?

A2b. Climate science got caught up in a highly charged political debate: the consequences predicted by the models were dire, and many of the climate scientists were persuaded by the predictions of the models. Climate science is a relatively young field, and one that was ill prepared for participation in such a highly charged political debate. The traditions of science in disclosing all of the weaknesses of their work were at odds with this adversarial political process.

The actual shift within the community seems to have occurred in the context of the IPCC process. The entire framing of the IPCC was designed around identifying sufficient evidence so that the human-induced greenhouse warming could be declared unequivocal, and so providing the rationale for developing the political will to implement and enforce carbon stabilization targets in the context of the UNFCCC. National and international science programs were funded to support the IPCC objectives. Scientists involved in the IPCC advanced their careers, obtained personal publicity, and some gained a seat at the big policy tables. This career advancement of IPCC scientists was done with the complicity of the professional societies and the institutions that fund science. Eager for the publicity, high impact journals such as *Nature*, *Science*, and *PNAS* frequently publish sensational but dubious papers that support the climate alarm narrative. Especially in subfields such as ecology and public health, these publications and the media attention help steer money in the direction of these scientists, which buys them loyalty from their institutions, who appreciate the publicity and the dollars. Further, the institutions that support science use the publicity to argue for more funding to support climate research and its impacts. And the broader scientific community inadvertently becomes complicit in all this. When the IPCC consensus is attacked by deniers and the forces of “anti-science,” scientists all join in bemoaning these dark forces fighting a war against science, and support the IPCC against its critics. The media also bought into this, by eliminating balance in favor of the IPCC consensus.

The bottom line is that scientists worked within the system to maximize their professional reputations, influence, and funding. Rather than blame the scientists for optimizing their rewards within the system, we need to take a careful look at the system, most particularly the climate science-policy interface and the federal funding of climate science.

How does it shift back? Change the system to improve the science-policy interface and change the funding priorities. A top priority for research funding should be exploring the significance and characteristics of uncertainty across the range of climate science, not only the climate models themselves, but also solar forcing, surface temperature datasets, natural internal modes of climate variability, etc. Change the decision making framework from the classical “reduce the uncertainty before acting” paradigm to a robust decision making framework that incorporates understanding of uncertainty as information in the contemplation and management of environmental risks.

Changing the funding priorities is key. We need to reduce reliance on building ever more complex climate models for being the primary source of reducing uncertainties regarding climate change. Climate researchers need to engage with a broader range of expertise in and build strong links to disciplines experienced in complex nonlinear modeling and statistical inference, among others. We need a much better understanding of natural climatic variability. More research is needed on understanding abrupt climate change and developing a more extensive archive of paleoclimate proxies. And finally, greater resources need to be provided to accelerating the establishment of definitive climate data records.

Openness and transparency enables critical examination by a broad range of scientists and citizens. Recognition of the extended peer review communities enabled by the blogosphere is essential, and frank discussions with skeptics are needed. We need to eliminate the elitism that argues that certain scientists are more “important” voices in the debate than others (by virtue of their academic recognitions, citations, etc), that scientists with expertise outside of the traditional climate disciplines can be ignored, and that the only valid contributions come in the form of peer reviewed journal publications. With regard to the latter point, well-documented analyses/audits of data sets occurring on technical blogs have provided significant contributions to understanding and improving data quality. This elitism is counter to the traditions of science, characterized by physicist Richard Feynman as “Science is the belief in the ignorance of the experts.” It is the merits of the scientific argument that count; not the qualifications of the person making the argument.

c. Are there any efforts within the scientific community to self-correct this paradigm shift? If there is not, what does this mean for the decision-makers needing objective and unbiased scientific information to inform their policies?

A2c. Science is subject to human fallibility, and such shifts have happened in the past. Science always manages to correct itself, but the process is not necessary quick or painless. Scientific professional societies and universities have a key role to play in setting the standards for scientific research and for establishing a useful interface between science and policy.

That said, the first reaction of the climate establishment to the release of the CRU emails and the errors identified in the IPCC reports has generally been one of defensiveness, and lacking introspection and discussion of correction. Some of the climate scientists at the center of “storm” seem to be battling a scientific version of post traumatic stress syndrome, overwhelming their ability to cope with the issues. Dealing with these issues requires active involvement by the broader climate research community and particularly by the institutions that include climate researchers but are not dominated by them, including the American Geophysical Union, the American Association for the Advancement of Science, the National Academies.

If the government wants objective and unbiased scientific information to inform their policies, then the guidelines and incentives need to be changed. Stop asking for scientists to reduce the uncertainties; rather, ask for our understanding of the range of risks that we might be facing from climate change (both natural and anthropogenic). Fund climate research that is much broader, not just studies designed to support the IPCC/UNFCCC. Support the development of improved connections with disciplines that conduct research into complex nonlinear systems, statistical inference, and decision making under uncertainty. Change the nature of the “carrot” and the scientific community will respond.

Finally, I have to state that my own efforts to stimulate such a correction have been highly controversial within the field of climate research, and relatively few climate researchers are speaking out publicly in support of what I am trying to do. I regard my own scientific reputation as secure, as well as my research funding, so I don't feel that I am risking anything that I can't afford to lose by speaking out. But other scientists feel much more vulnerable if they were to attempt to rock the boat in some way, and I have received many emails from scientists expressing this kind of concern. This culture that has developed in climate science that greatly concerns me, particularly in the context of university departments and government labs. Ten years ago, I used to think that university tenure was irrelevant in my field. Right now, the controversy surrounding climate science makes tenure seem essential. Scientific debate should be the spice of academic life; climate research lost this in the midst of the politicization of the subject.

Q3. Do you believe the current IPCC processes are working? If so, why? If not, what specific actions can be taken to repair them, and in the meantime, why should the product of a process that isn't working be relied upon as the basis for policy actions that would impose enormous costs on the United States economy?

A3. A number of people have put forth arguments that the IPCC is structurally unsound and fatally flawed, owing to its connection with the UNFCCC. Some people who have been supportive of the IPCC view its work as being finished. I view the major flaws of the IPCC to be:

- A focus on providing scientific information on anthropogenic climate change for use as justification of a Treaty, at the expense of a thorough assessment of natural climate variability, the limitations and uncertainties associated with climate model projections, etc.
- The requirement for broad based international participation in the IPCC assessment, resulting in a heavy emphasis on participation by scientists that are merely industrious rather than those that are exceptionally qualified, experienced and insightful. Compare the list of authors on the IPCC AR4 report with those involved in the 1979 Charney Report on Carbon Dioxide and Climate, which included the premier U.S. scientists of the time. The broad geographical and international distribution of authors, some with relatively meager qualifications and experience, seems motivated more by political reasons to gain support for the Treaty rather than by the needs of the scientific assessment itself.
- Working Groups II and III on impacts and mitigation have produced reports that are judged by many to be inaccurate and misleading. The emphasis of these reports seems to be to convince policy makers that anthropogenic climate change is dangerous and the problem of carbon mitigation can be addressed feasibly and without economic damage.

So in one sense, the IPCC process is "working" in terms of garnering support for the UNFCCC treaty. But as a scientific assessment of climate variability and change and the vulnerabilities to climate change, I would judge the IPCC process not to be working. I don't think that the IPCC can be repaired without a major overhaul of its justification and organization. For an IPCC under the auspices of the UN, I would recommend that the WG I assessment be undertaken under the auspices of the WMO/WCRP (and not the UNEP and UNFCCC).

Many other initiatives with international implications are undertaken without the involvement of the UN. An approach whereby disparate organizations conduct assessments would be beneficial, producing new ideas and new directions and a more diverse scientific and policy debate. An alternative to the IPCC is to conduct assessments within individual nations or a group of nations who share a common interest. However, the recent U.S. assessment reports seem to mostly parrot the IPCC assessment, with many of the people participating in the U.S. assessments having also participated in the IPCC. A broader base of scientists should participate in the assessments, including those whose scientific reputations and funding aren't tied to climate change. Skeptical perspectives should be sought and included.

Regarding use of the scientific assessments as a basis for policy actions, I argue that an intermediate step is required, analogous to that for regulated science such as pharmaceuticals, food safety, human genetic manipulation, etc. Independent assessment, auditing, due diligence, whatever you want to call it, can insure that quality standards are met and that the assessment addresses the wider interests of the public.

There are no simple answers to addressing the complex and wicked problem of climate change, but a rethinking of our broader strategies is needed.

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