CLIMATE SCIENCE IN THE POLITICAL ARENA

HEARING

BEFORE THE

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING HOUSE OF REPRESENTATIVES

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CLIMATE SCIENCE IN THE POLITICAL ARENA

THURSDAY, MAY 20, 2010

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
Washington, DC.

The committee met, pursuant to call, at 9:10 a.m., in Room 1334, Longworth, Hon. Edward J. Markey [chairman of the committee] presiding.

Present: Representatives Markey, Blumenauer, Inslee, Cleaver, Hall, Sensenbrenner, and Blackburn.

Staff Present: Ana Unruh Cohen, Jonah Steinbuck, Bart Forsyth and Rajesh Bharwani.

The CHAIRMAN. Good morning. Welcome to the Select Committee on Energy Independence and Global Warming. This hearing is called to order.

The disaster that is the BP oil spill continues to unfold in the Gulf of Mexico. Congress is focused on key questions: What happened and who is responsible? How much oil has spilled and what is the impact? How do we make decisions in the face of uncertainty?

We face similar questions when confronted with the looming disaster of climate change caused by carbon pollution. In both instances, lawmakers need to be informed by the best available science as they make decisions and seek clean energy solutions.

Today, we are joined by some of the world's foremost climate scientists, including the President of the National Academy of Sciences and a Nobel Prize winning atmospheric chemist. These scientists have been instrumental in informing the clean energy and climate change policy debate. Their work has helped identify the fingerprint of human activity on global warming amongst the background of natural variability. They have provided a risk framework to guide policymakers in the face of evolving science.

Just yesterday, the National Academy of Sciences issued three major reports about the science, the solutions, and the ways to adapt to climate change. These reports reinforce the overwhelming foundation of knowledge we have about the danger of carbon pollution. This is a foundation still unshaken by a manufactured scandal over stolen e-mails.

This knowledge was gained in an America that supports creative, inquisitive scientists. American scientists enjoy the freedom to follow the science where it leads and to work collaboratively and sometimes combatively with their colleagues. Preserving this freedom to explore new ideas and technologies is critical to understanding our world and finding solutions to our clean energy challenges.

Given the relevancy of their work to national priorities, our best scientists are increasingly drawn into the political arena. Disagreements over policies have led some to target both the science and the scientists themselves. The latest and most overt incident came earlier this month when Virginia's Attorney General Ken Cuccinelli demanded the materials be turned over by the University of Virginia relating to five grants that involved a former University of Virginia professor, Dr. Michael Mann. Although Dr. Mann's work has been examined by his peers and found to be sound, the Attorney General is using this controversy over his research as an excuse for a fishing expedition.

The request to UVA asks for materials related to 39 people. Some of these are critics of Dr. Mann. Some of them are far outside the field of expertise of the grants in question. Instead, their list reads like a Google search of climate, e-mails, and IPCC.

The Attorney General doesn't even ask for the records associated with all of Dr. Mann's co-investigators on the grants. If the investigation were truly about fraud, as the Attorney General claims, then you would expect him to seek all documents related to all of the scientists involved in the grants.

This week, over 800 Virginia scientists sent a letter to Cuccinelli suggesting his demand is transparently political and designed to intimidate. This attempt at intimidation is not new, but it is getting worse. Two weeks ago, 255 members of the National Academy of Sciences, including 11 Nobel Prize winners, published a letter in Science Magazine decrying the treatment of climate scientists and warning of the chilling effects on the greater scientific community.

The majority of climate research in the country is supported by Federal funding. Recipients of these funds have a duty to work in an ethical, transparent way and to communicate their findings in support of societal needs. Our witnesses today are dedicated to that premise, despite attempts to portray them to the contrary.

It seems fitting to close with a quote from the recent scientists' letter: "We can ignore the science and hide our heads in the sand and hope we are lucky, or we can act in the public interest to reduce the threat of global climate change quickly and substantively."

I would now like to recognize the ranking member of the Select Committee, the gentleman from Wisconsin, Mr. Sensenbrenner.

[The prepared statement of Mr. Markey follows:]

Statement of Chairman Edward J. Markey (D-MA)

Hearing on "Climate Science in the Political Arena"

Select Committee on Energy Independence and Global Warming

May 20, 2010

The disaster that is the BP oil spill continues to unfold in the Gulf of Mexico. Congress is focused on key questions: What happened and who is responsible? How much oil has spilled and what is its impact? How do we make decisions in the face of uncertainty?

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Given the relevancy of their work to national priorities, our best scientists are increasingly drawn into the political arena. Disagreements over policies have led some to target both the science, and the scientists themselves.

The latest and most overt incident came earlier this month. Virginia's Attorney General Ken Cuccinelli demanded that materials be turned over by the University of Virginia, relating to 5 grants that involved a former UVA professor, Dr. Michael Mann. Although Dr. Mann's work has been examined by his peers and found to be sound, the Attorney General is using the controversy over his research as an excuse for a fishing expedition. The request to UVA asks for materials related to 39 people. Some of these are critics of

Dr. Mann. Some of them are far outside his field of expertise or the grants in question. Instead, the list reads like a Google search of "climate," "emails," and "IPCC." The Attorney General doesn't even ask for the records associated with all of Dr. Mann's co-investigators on the grants. If the investigation were truly about fraud, as the Attorney General claims, then you would expect him to seek all documents related to all of the scientists involved in the grants. Cuccenilli's demand is transparently political and designed to intimidate.

This attempted intimidation is not new, but it is getting worse. Two weeks ago 255 members of the National Academy of Sciences, including 11 Nobel Prize winners, published a letter in *Science* decrying the treatment of climate scientists and warning of the chilling effect on the greater scientific community.

The majority of climate research in the country is supported by federal funding. Recipients of these funds have a duty to work in an ethical, transparent way and communicate their findings in support of societal needs. Our witnesses today are dedicated to that premise, despite attempts to portray them to the contrary.

It seems fitting to close with a quote from the recent scientists' letter:
"We can ignore the science and hide our heads in the sand and hope we are lucky, or we can act in the public interest to reduce the threat of global climate change quickly and substantively."

Mr. SENSENBRENNER. I thank the chair.

Unfortunately, I have to begin today by addressing conduct from the committee's last hearing.

Two weeks ago, the minority's witness, Christopher Monckton, argued that there had been three distinct periods of warming in the past 150 years and that the rates of warming in each of these periods were parallel. He demonstrated that both the EPA and the IPCC were wrong to claim that the rate of warming in the most recent period was higher than the two previous periods of warming.

Finally, he questioned whether CO_2 is the most likely cause of warming if previous temperature rises were identical when atmospheric concentrations were much lower than they are today.

Neither the majority nor its witnesses responded to any of these arguments. Instead, they attacked Lord Monckton for not presenting scientific information, even though he clearly did. They ridiculed his name, and they wrongly accused him of falsifying his credentials and then refused to allow him to respond.

I encourage everybody to read the transcript or watch the video on the committee's Web site. It was bullying, and it was embarrassing. And, as Lord Monckton said in response, a certain amount of politics has crept in on one side of this debate; and, therefore, inconvenient science has been dismissed as not being science at all.

I want to be clear that not all members of the majority stooped to these levels, and I thank the chairman in particular for his professionalism. But the politicization of science from some members of the committee is a legitimate threat to scientific understanding.

Sadly, last week's hearing echoed the shameful culture exposed by the Climategate e-mails. Climategate revealed a scientific culture that is more interested in defending its findings than in finding truth. It showed some of the most prominent scientists in the world actively working to sabotage legitimate scientists who dared to challenge their work.

The majority repeatedly tried to dismiss the Climategate e-mails, but no number of politically motivated studies will change what the e-mails actually say, and I want to read a few quotes:

"I tried to balance the needs of the science and the IPCC, which were not always the same."

"There is pressure to present a nice tidy story as regards apparent unprecedented warming in the thousand years or more in the proxy data, but, in reality, the situation is not quite so simple."

"If you think that Saiers is in the greenhouse skeptics camp, then, if we can find documentary evidence of this, we could go through official AGU channels to get him ousted."

"I got a paper to review written by a Korean guy and someone from Berkeley that claims that the method of reconstruction that we use in dendroid climatology is wrong, biased, lousy, horrible, et cetera. If published as is, this paper could really do some damage. It won't be easy to dismiss out of hand, as the math appears to be correct, theoretically. I am really sorry, but I have to nag about that review. Confidentially, I now need a hard and, if required, extensive case for rejecting."

"I can't see either of these papers being in the next IPCC report. Kevin and I will keep them out somehow, even if we have to define what the peer review literature is."

There are literally thousands of these. These e-mails expose an intolerant scientific culture, and they raise legitimate questions about the strength of the so-called "scientific consensus."

The minority witness today is Dr. William Happer. He is the Cyrus Fogg Brackett Professor of Physics at Princeton University and a member of the American Physical Society and National Academy of Sciences. He has spent his professional career studying the interactions of visible and infrared radiation with gases which are the physical phenomena behind the greenhouse effect. Dr. Happer has long argued that increased accumulations of CO_2 will not lead to the temperature increases that the IPCC predicts and that the results of climate change will not be as catastrophic as claimed.

Dr. Happer is very familiar with the politicization of science. Al Gore fired him from the Department of Energy because of his beliefs.

In a criticism of then Vice President Gore, Ted Koppel—no conservative—said, "The measure of good science is neither the politics of the scientists nor the people with whom the scientist associates. It is the immersion of hypotheses into the acid of truth. That is the hard way to do it, but it's the only way that works."

Finding errors in data and critiquing scientific work is the legitimate path to truth. Ridicule and attempts to besmirch reputations have no place in this debate.

I yield back.

The CHAIRMAN. The gentleman's time has expired.

The chair recognizes the gentleman from Missouri, Mr. Cleaver, for an opening statement.

Mr. CLEAVER. Thank you, Mr. Chairman, to you and Ranking Member Sensenbrenner.

I would like to welcome our witnesses today before this hearing. I would like to express appreciation to all of you for your efforts in the scientific arena.

Science is the basis of our knowledge of the wonderful world we inhabit, and without people like you we would be sitting in a greater degree of darkness. Personally, I believe that we need to act now to reduce greenhouse gas emissions and to take appropriate adaptation strategies for global effects that are on the way and are already being felt around the world. We have, I believe, a moral imperative to preserve this planet for future generations and for our progeny.

My concern is that we now exist in a Nation that has simply become mean spirited, and I think we look for ways in which to be mean. I think some of us get up in the morning and spend time revving up our anger, and then we express it in a variety of ways, some of them not very nice. And I think maybe you all are victims of what is going on. I don't celebrate disrespect for anyone, but certainly I do think that what has happened to you is happening in a variety of ways, including the United States Congress. And so I think we have got to take whatever steps we can to do the science and put in place measures that will aid in the healing of this planet.

Mr. Chairman, I yield back the balance of my time.

The CHAIRMAN. The gentleman's time has expired.

The chair recognizes the gentlelady from Tennessee, Mrs. Blackburn.

Mrs. BLACKBURN. Thank you, Mr. Chairman, and thank you for holding the hearing. To our witnesses, we welcome you. We are all pleased that you are here.

This committee is examining the role of climate science in political decision making. That is the topic for our hearing today. I think that perhaps we should have a hearing on the role of political decision making in climate science, and our ranking member has spoken eloquently to that effect.

All of the members on this panel agree that we need the best science available to make informed decisions. Unfortunately, recent investigations have shown how academic researchers misused Federal funds through distorting data to manipulate lawmakers into adopting certain positions on climate change.

Mr. Chairman, most of these problems are tied with the funding that agencies and academics receive for their research from climate science. Instead of producing objective analysis with scientific integrity, they seek to produce results that will lead to more funding in the future. That is really unfortunate and I think unfair for the American taxpayer.

Instead of exercising oversight over this analysis, bureaucracies like the EPA occupy themselves with sponsoring YouTube video contests and throwing away tens of thousands of taxpayer dollars in prize money. And now the receivers of Federal funding can breathe a little easier as the House majority has decided to not produce a budget resolution for this year. Instead of examining funding for climate science research objectively, the majority has decided to bypass the resolution process and go straight into deeming—deeming—spending levels. This is a first in 36 years.

They do not want to have to reveal to the American taxpayer the huge $1.5 trillion deficit for this year and for the upcoming 4 years. They would rather sweep it all under the rug and hope that the American taxpayers do not notice. But I know my constituents are aware of the tremendous financial problems the U.S. is in, and they want every program and every research grant to be scrutinized so that their money is not wasted.

On behalf of the American taxpayers, I ask my colleagues to put forth a budget resolution, and I yield the balance of my time.

The CHAIRMAN. The gentlelady's time has expired.

The chair recognizes the gentleman from New York, Mr. Hall.

Mr. HALL. Thank you, Mr. Chairman and Mr. Ranking Member.

I am very glad you are holding this important hearing today, and I want to apologize at the outset that I will have to leave shortly because I am chairing a hearing of the Veterans' Affairs Committee on the VA's efforts to deal with military sexual trauma, and that will be starting shortly. But thanks to our witnesses and other members of the scientific community who first brought to our attention the phenomenon of global climate change.

Regardless of where you stand on the science and what you believe is the truth, it happens to be that my colleague Ms. Blackburn's constituents and mine and others around the world are suffering already from the effects of climate change, in my opinion.

Computer models that show increased storm frequency and storm strength are being borne out.

The massive flooding in Tennessee, the massive rain event and flooding in Tennessee, in which many of my friends have lost everything—my mother-in-law's condo that she used to live in was up to the eaves in water.

The week before that, the Mississippi tornado that was a mile wide and killed many people in that State.

The week before that, the massive rain event and flooding in Stonington, Connecticut, and Warwick, Rhode Island. There were parts of New England that had six feet of water in the malls, in the Warwick Mall, and many businesses in downtown Stonington flooded out.

The week before that, Paterson, New Jersey, and my farmers in Orange County, New York, experiencing their fourth 50-year flood in the last 6 years.

The island of Madeira off the coast of Spain, where a rain event caused massive mudslides that washed people and homes and cars out to sea. The freak March hurricane Xynthia, months before the beginning of hurricane season, that hit the coast of France and killed 40 people, all seem to me to be evidence that the weather patterns are changing, regardless of what e-mails are going back and forth.

And, lastly, I would just say that the solutions, even if climate change were not true, the solutions that we need to look for are the ones that will provide us with a positive balance of trade, new jobs in this country, and independence and recovering our sovereignty from those countries that we now depend on for oil or to borrow the money to pay for that oil.

With that, I thank you, Mr. Chairman, and I yield back.

The CHAIRMAN. I thank the gentleman very much.

That completes opening statements from members. We will now turn on our witnesses.

STATEMENTS OF RALPH J. CICERONE, PRESIDENT OF THE NATIONAL ACADEMY OF SCIENCES, CHAIR OF THE NATIONAL RESEARCH COUNCIL, NATIONAL ACADEMY OF SCIENCES, 500 FIFTH STREET, NW, WASHINGTON, D.C. 20001; MARIO MOLINA, PROFESSOR, DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY, UNIVERSITY OF CALIFORNIA AT SAN DIEGO, 9500 GILMAN DRIVE, MC 0332, LA JOLLA, CALIFORNIA 92093–0332; BEN SANTER, RESEARCH SCIENTIST, PROGRAM FOR CLIMATE MODEL DIAGNOSIS AND INTERCOMPARISON, LAWRENCE LIVERMORE NATIONAL LABORATORY, MAIL CODE L–103, 7000 EAST AVENUE, LIVERMORE, CALIFORNIA 94550; STEPHEN H. SCHNEIDER, PROFESSOR, STANFORD UNIVERSITY, 371 SERRA MALL, STANFORD UNIVERSITY, STANFORD, CALIFORNIA 94305–5020; AND WILLIAM HAPPER, CYRUS FOGG BRACKETT PROFESSOR, DEPARTMENT OF PHYSICS, PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY 08544

The CHAIRMAN. Our first witness this morning is Dr. Ralph Cicerone. Dr. Cicerone is the President of the National Academy of Sciences and the Chair of the National Research Council. Previously, Dr. Cicerone was President of the American Geophysical Union and Chancellor of the University of California at Irvine. He has been the recipient of many awards. We welcome you, Doctor. Whenever you feel comfortable, please begin.

STATEMENT OF RALPH J. CICERONE

Mr. CICERONE. Thank you, Chairman Markey, for the invitation to appear before you and Ranking Minority Member Sensenbrenner and the other members of your Select Committee today. With your permission, I will read from my prepared testimony, but I will not read all of it due to time limitations.

As most of you know, the National Academy of Sciences was created by Congress under President Lincoln in 1863 with a mission to respond to requests from the Federal Government on all matters of science. Thus, we are not part of the Federal Government, but we were created by the Federal Government. We elect our members annually based on their original contributions to research in their fields of science; and today we operate largely through the National Research Council, which serves us and our partner, the National Academy of Engineering.

We are very proud of our history of independence and our objective analysis, and we work very hard to maintain it. The individuals who serve on our study committees are not compensated except for their direct expenses, such as travel.

I would like to present a brief summary of what scientists have learned about contemporary climate change, then go on to briefly describe our new National Research Council report, America's Climate Choices, and conclude with some remarks about how to protect and improve the ability of scientists in their research conduct and in their communications with the policymakers.

I will start with a brief summary on data, things we are actually measuring.

First, the temperatures of air and water. The most striking feature of these data is the rise in temperatures over all of the world since the late 1970s or perhaps 1980. The warming is strongest in the Arctic and over world land areas, with smaller warmings over oceans. When you average over the entire planet day and night, you find about one degree Fahrenheit since 1979 of warming.

There are several groups around the world who do this work, notably, in the United States, the Goddard Institute for Space Studies at NASA and the National Climatic Data Center of NOAA. To see these patterns clearly of temperature change requires continuous sustained efforts. For example, when we look at small regions in short periods of time, we can get fooled easily by the ups and downs of local weather or by changes that do not go on to persist. For example, this past winter in New York and Washington was relatively cold, while Montreal was relatively hot. The year 2009 as a whole was the warmest on record for the world south of the equator. So even with a variable as simple and familiar as temperature, we need sustained measurements from many places, as opposed to simply relying completely on our own senses to tell us what is happening where we live.

Ocean surface temperatures are also on the rise. We see this from shipboard measurements and from recent satellite observations. It is a global warming. Temperatures vary with water depth; and the most important one to keep track of is the total heat content of the upper oceans, the water that is in closest contact with the air.

Arctic sea ice. Most of us are aware that the horizontal extent of the ice covering the Arctic Ocean has shrunk, with especially rapid decreases in the amount of open water in the summertime Arctic in the past decade. This decreasing horizontal extent has been visible, literally, from satellite images and from reports of marine navigators. But a measure that has not been known as widely and is much more difficult to obtain is the thickness of the Arctic sea ice. We now know that the thickness has decreased by more than 50 percent in the last 50 years. These data come to us from recently declassified U.S. Navy work and recent satellite data.

Ice on Greenland and the Antarctica continent. There are massive amounts of ice perched on Greenland and Antarctica, and they are very important in Earth's climate. Just in the past few years, about 9 or 10 years, it has become possible to measure changes in the masses of ice in these two places. The data show that ice is being lost and at accelerating rates. Of course, snow is added during the respective wintertimes and lost in the following summers, but, rather than being in balance, the net annual change is negative, and increasingly so. These key measurements are from NASA satellites, which use ultrasensitive gravity measurements and sophisticated radars.

Sea level. Sea levels are rising worldwide. The measurements are now made by specialized radar ranging instruments on Earth-orbiting satellites. Prior to 1992, the best estimate of global average sea level rise was about 1.6 millimeters a year, and there were significant differences from continent to continent. Now the observed rate is twice as much, 3.2 millimeters a year, and the worldwide average is known more clearly. And we can explain this sea level rise much better than 10 years ago by simply adding the rates due to the warming of water—which expands the water in the ocean—the loss of ice from Greenland, the loss of ice from Antarctica, and the loss of ice from continental glaciers. So that picture is becoming clearer.

There are many other climate indicators which I won't go into now except that more high-intensity precipitation events are being recorded, as Representative Hall mentioned.

How do we explain and predict the climate change? Well, the greenhouse effect, the physics of it, has been known for about 100 years now, and we have obtained increasingly quantitative information on what is in the air, how it is changing, and where the chemicals are coming from, largely from human activity.

Not only does the greenhouse effect and the energy balance calculations from it tell us what is happening and explain reasonably well the warming that we are seeing, but there really is no other theory that has come forward, despite the best efforts of all of us over the last 30 years to come up with an alternative explanation. So we gain more confidence in the explanation that the greenhouse gases are the driving force.

Now the reports that we released yesterday, May 19, called America's Climate Choices, are broken into three pieces. One is called Advancing the Science of Climate Change, the second is called Limiting the Magnitude of Future Climate Change, and the third is called Adapting to the Impacts of Climate Change. I don't have time to summarize these reports, but I would be glad to try to answer any questions that might arise.

On the conduct of science, Chairman Markey, you asked us what policies might be necessary to protect and improve scientists' ability to conduct research and to share scientific information with policymakers.

First, on the conduct of climate research, the good news is that we have one of the essential ingredients, smart and motivated scientists, many of whom are very young and are drawn to this field. They are ready to go, and many of them are already involved. Of course, they need instruments and computers and access to data from all over the world.

I do know that some scientists have been harassed and threatened, but so far I do not see the need for protections aside from our normal civil laws. Instead, perhaps, as Representative Cleaver said, an atmosphere of civility and of encouraging scientists to seek the truth and to share their findings is always needed.

The biggest difficulty of sharing information I believe is one of communication. The scientific jargon, the scientific specialization which is necessary to make progress has made it more difficult for us as scientists to talk outside of our own circles, and we really need to do a better job.

But a final ingredient is what we call these assessments that have begun to occur. For example, the assessments conducted by the United States Federal Global Change Research Program and those of the IPCC. These are high-level evaluations of all the peer-reviewed literature in the field written in terms that are more generally understandable so that the state of the art, the state of the science is defined periodically and communicated as well as possible to the general public. I think those efforts, and of course those of the academy try to do the same thing, but those kinds of high-level assessments are essential for this sharing of information more effectively.

Thank you, Chairman Markey.

[The statement of Mr. Cicerone follows:]

Testimony of

Ralph J. Cicerone
President
National Academy of Sciences

before the

Select Committee on Energy Independence
and Global Warming
U.S. House of Representatives

May 20, 2010

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I became President of the National Academy of Sciences in 2005 for a six-year term. My own scientific research has been mostly in atmospheric chemistry and how the changing chemical composition of the air forces climate change. My academic background began in electrical engineering and physics and moved more into chemistry over time. In the early 1980s, I worked on the so-called radiative forcing of climate change caused by the enhanced greenhouse effect due to the rising worldwide concentrations of carbon dioxide, methane, chlorofluorocarbons, nitrous oxide and other gases. As President of NAS, I also chair the National Research Council.

I want to present a brief summary of what scientists have learned about contemporary climate change, then go on to briefly describe our new NAS/NRC report "America's Climate Choices" and conclude with some remarks about how to protect and improve the ability of scientists in the conduct of their research and in their communications with policymakers.

Measurements of Climate Change

Temperatures of Air and Water. The most striking feature of these data is the rise in temperatures all over the world since the late 1970's or 1980. The warming is strongest in the Arctic and over world land areas, with smaller warmings over oceans. When one averages over the entire planet and over day and night one finds an overall warming of 1.0 degree F (0.55deg C) since 1979. These data come from thermometers at many land stations, island and ship operations. Temperature data are very important and maintaining a record of global patterns and averages is a large job. There are several groups around the world who do this work: the Goddard Institute for Space Studies of NASA, the National Climatic Data Center of NOAA also in the U.S. and the University of East Anglia Climate Research Unit in the U. K. to name three of them. Each of these centers uses different methods of examining and analyzing the data, they have somewhat different sources of data and means of presenting them but they find closely the same results.

To see clearly the patterns of temperature change requires continuous, sustained efforts. When we look at small regions and short periods of time we can get fooled easily by the ups and downs of local weather or by changes that do not persist. For example, during this past winter New York and Washington were relatively cold while Montreal was relatively hot. The year 2009 was the warmest on record for the entire world south of the Equator. So even with a variable as simple and familiar as temperature, we need sustained measurements from many places as opposed to simply relying completely on our own senses where we live.

Ocean surface temperatures are also on the rise. Records from shipboard measurements and from recent satellite observations show a global warming. Temperatures vary with water depth and it is most meaningful to keep track of the total heat content of the upper oceans (above 700 meters depth), the waters that are in closest contact with the air. Oceanic heat content has increased significantly since 1980. The fact that oceans are warming more slowly than air is likely due to the retarding influence of the large heat capacity of water.

Arctic sea ice. Most of us are aware that the horizontal extent of ice covering the Arctic Ocean has shrunk with especially rapid increases in the amount of open water in the summertime Arctic in the past decade. The decreasing extent has been visible (literally) from satellite images and from reports of marine navigators. A measure that has not been known as widely and is more difficult to measure is the thickness of the Arctic sea ice. It is now known that the thickness has decreased by over 50% in the past 50 years. The extensive measurement record comes to us from recently declassified U.S. Navy data and from recent satellite data

Ice on the Greenland and Antarctic Continents.

Massive amounts of ice are perched on the land of Greenland and Antarctica and they are important to Earth's climate in several ways. One way is that water added to Greenland (as snow) or Antarctica ice lowers sea level and ice moved from Greenland and Antarctica, either as ice or liquid water, to the oceans raises sea level. Just in the past few years, it has become possible to measure changes in the masses of ice in these two places. The data show that ice is being lost, and at accelerating rates. Of course, snow is added during the respective wintertimes and lost in the following summers but rather than being in balance, the net annual change is negative, and increasingly so. The key measurements are from NASA satellites using ultra-sensitive gravity sensors and sophisticated radars. Such data were simply not available until approximately 2000-2005.

Sea Level. Measurements show that sea levels are rising worldwide. The measurements are being made by specialized radar-ranging instruments on Earth-orbiting satellites. Prior to 1992, such devices were unknown and data were gathered carefully but with more primitive instruments along coastlines. Prior to 1992, the best estimate of global-averaged sea-level rise was about 1.6 mm/year (17 cm in 110 years) and there were significant differences from continent to continent. Now the observed rate of rise is 3.2 mm/year, approximately double the earlier rise, and the worldwide average is known more clearly. This newer, larger rate of rise can be explained well by adding the rates due to ice losses from Greenland, Antarctica, and inland glaciers to the contribution from thermal expansion of (warming) ocean water. Current estimates of future rates of sea-level rise are larger than those of five years ago but they are still not viewed with confidence.

Other Climate Indicators.

Climate is a big word and many variables go into defining it. Some of them are very meaningful for human, animal and plant life. I will mention just a few. Growing seasons are becoming longer in many places and areas with snow cover in the early spring are decreasing. Dates of snow melt are coming earlier. The total snowpack mass is decreasing especially in the Pacific northwest and California. More new record maximum temperatures are being recorded than new record low temperatures. Precipitation amounts are increasing on average. More high-intensity precipitation events are being recorded. Observing these trends and defining them better requires a large commitment to measurements and to data analysis.

Explaining and Predicting Climate Change.

The Greenhouse Effect. For over 100 years, scientists have known the physics of the greenhouse effect, how certain gaseous chemicals in air absorb and re-radiate planetary infrared radiation, thus trapping more energy near the surface than would happen without these gases. The most important wavelengths of radiation and the chemicals that interact at these wavelengths are well known from laboratory and field measurements. The fact that the concentrations of such chemicals like carbon dioxide, methane, nitrous oxide and a number of synthetic fluorine-containing organic compounds have increased worldwide is well-established from direct measurements. In turn, it is well-established that human activities have caused these increases, for example, approximately 85 % of the current carbon dioxide increase is due to fossil-fuel burning and perhaps 15% from deforestation. Not only is there this "bottoms-up" information but there is also the predictive power of calculations using it; we can calculate how much global warming should have been expected from these changes to the atmospheric and we get very reasonable answers.

Not only does the well-understood greenhouse effect serve to explain the altered planetary energy balance that we are seeing, there is no alternative explanation which anyone has identified. Scientists continue to look for alternative explanations but no good ideas have come forward.

Similarly, scientists are performing increasingly detailed calculations of Earth's climate changes that are based on the greenhouse effect and trying to pin down more detailed manifestations of the changes in temperatures, precipitation, ice amounts and sea level, for example. These calculations use the equations of conservation of mass, energy, momentum, etc. and they solve the equations with differing geographical resolution on computers. Through these calculations, scientists are evaluating the various forces at play as the Earth system adjusts and moves further from the original balance. Some of these forces constitute stabilizing feedbacks and some of them are destabilizing.

America's Climate Choices.

America's Climate Choices is a National Research Council project in response to a request from Congress from over two years ago. America's Climate Choices is a fairly comprehensive and up-to-date report about major climate change topics. The first three topical reports were released on May 19. One is called *Advancing the Science of Climate Change*, the second is *Limiting the Magnitude of Future Climate Change*, and the third is *Adapting to the Impacts of Climate Change*. A fourth panel report will be released in several months on issues of communication involving the general public and policy makers and an overall general report from the parent committee will be released in the fall.

The panel report on *Advancing the Science of Climate Change* reviews the scientific evidence for climate change in more detail than I did today and it examines the status of the nation's current scientific research efforts. The report says "A strong, credible body of scientific evidence shows that climate change is occurring, is caused largely by human activities, and poses significant risks for a broad range of human and natural systems. As decision makers respond to these risks, the nation's scientific enterprise can contribute both by continuing to improve understanding of the causes and consequences of climate change, and by improving and expanding the options available to limit the magnitude of climate change and to adapt to its impacts. To do so, the nation needs a comprehensive, integrated, and flexible climate change research enterprise that is closely linked with action-oriented programs at all levels. Also needed are a comprehensive climate observing system, improved climate models and other analytical tools, investments in human capital, and better linkages between research and decision making."

The report on *Limiting the Magnitude of Future Climate Change* points out that for us to meet internationally discussed targets for limiting greenhouse gas emissions and the associated global climate changes will require a major departure from business as usual in how the world uses and produces energy from fossil fuels, for example. The report recommends that U.S. policy be based in terms of a budget for the cumulative greenhouse gas emissions over the period from 2012 to 2050. It identifies opportunities in the near term through energy efficiency and low carbon energy sources and longer-term opportunities through more basic research and development while it also describes a national policy framework that can assist progress towards this common goal and the development of policy mechanisms that are durable enough to persist for decades, but flexible enough to adapt to new information and understanding.

The report on adaptation calls for a new realization that considers a range of possible future climate conditions and associated impacts, some of which are outside the realm of past experience. It outlines the need for much more targeted information and the role of the federal government and other sectors in providing that information base and helping efforts which will be locally and regionally based to identify appropriate information as they make decisions. In short, it states the need for a national adaptation strategy to support and coordinate decentralized efforts.

In sum, there is a broad challenge before us. We must continue our efforts to observe climate changes and to understand them and to gain predictive capability while we also try to minimize the size of these changes by limiting our emissions of greenhouse gases and at the same time prepare thoughtfully for needed adaptation in response to climate changes which are not avoided.

Finally, Chairman Markey, you asked me what policies are necessary to protect and improve scientists' ability to conduct research and to share scientific information with policymakers. First, on the conduct of climate research, the good news is that we have one of the essential ingredients, smart and motivated scientists, many of whom are young. They are ready to go and many of them are already involved. To do their work, they need not only advanced graduate education, which they have, but access to modern instruments and computers and access to data from all over the world. I know that some scientists have been harassed and threatened but so far I do not see the need for protections aside from our normal civil laws. An atmosphere of encouraging scientists to seek the truth and to share their findings with others is always needed, as is a return to civility.

Climate research today is an increasingly international activity, an activity to which the U.S. wants to contribute and also to lead. We want to be at least advanced enough so that we can recognize and evaluate claims and breakthroughs that are made elsewhere. It is also important to have a climate research effort that is based on scientists in academia as well as in government labs and elsewhere pursuing as many independent techniques and independent lines of investigation as possible. Altogether, I think that our current effort is thin in this regard.

The sharing of information and communication with the general public and with policymakers is an increasingly difficult task. Part of the reason for this difficulty is that science itself has become so specialized and climate science is no exception. Climate science stretches over many fields of meteorology, oceanography, atmospheric physics, various kinds of biology and chemistry, geology, paleorecords and so forth. These pursuits are very specialized and it is increasingly difficult to communicate with generalists. Scientists have developed their own terminology, their own vocabularies, methods, and so forth, so the sharing of information is largely a communications problem. An essential ingredient to this sharing of information with policymakers is the conduct and maintenance of assessments which are high-level, peer-reviewed evaluations of the state of the science that are written intentionally in more general terms, more understandable to non-specialists. These assessments serve the dual role of periodically defining the state of the art and what is understood and accepted by all as well as communicating that state more widely. Examples of such assessments are those of the United States Global Change Research Program and the Intergovernmental Panel on Climate Change (IPCC) and, of course, a number of NAS-NRC reports. Through these more general assessments, the scientific results which appear in top-flight peer-reviewed specialized scientific journals internationally are made available to the general public and to policymakers.

Once again, Chairman Markey, thank you for the invitation to appear before you today and for all that you are doing on this very important issue for our nation and the world.

The CHAIRMAN. Thank you, Dr. Cicerone, very much.

Our second witness is Dr. Mario Molina. Dr. Molina is a professor in the Department of Chemistry and Biochemistry at the University of California at San Diego. He won the 1995 Nobel Prize in chemistry for his research on ozone layer depletion conducted at MIT. Dr. Molina is the founder of the Molina Center for Strategic Studies in Energy and the Environment in Mexico City. He serves on the President's Committee of Advisors in Science and Technology.

We welcome you, Dr. Molina. Whenever you are ready, please begin.

STATEMENT OF MARIO MOLINA

Mr. MOLINA. Thank you, Chairman Markey and members of the Select Committee, for giving me the opportunity to testify here today. I will attempt to summarize and briefly discuss here various questions concerning the current state of knowledge related to the climate change threat.

As we heard in various media reports as well as in these halls, some groups have stated in recent months that the basic conclusion of climate change science is not valid. This conclusion is that the climate is changing as a consequence of human activities with potentially very serious consequences for society. The basis of these allegations is mainly the exposure of stolen e-mails from the University of East Anglia and the discovery of some errors and supposed errors in the last report of the Intergovernmental Panel of Climate Change, the IPCC.

However, several groups of scientists have recently pointed out that the scientific consensus remains unchanged and has not been affected by these allegations. These groups include the one Chairman Markey referred to earlier on, namely, the statement from these 255 scientists published in Science Magazine.

The conclusion is that it is now well established that the accumulation of greenhouse gases resulting from human activities is causing the average surface temperature of the planet to rise at a rate outside of natural variability with potentially damaging consequences for society. I fully agree with this conclusion.

There are, in fact, some errors in the IPCC's report, but in my view, they certainly do not affect the main conclusion. I will not review the nature of these errors here. They have been discussed in detail elsewhere.

On the other hand, the science of climate change has continued to evolve. New findings since this IPCC report came out in 2007 indicate that the impacts of climate change are expected to be significantly more severe than previously thought.

There appears to be a gross misunderstanding of the nature of climate change science among those that have attempted to discredit it. They convey the idea that the science in question behaves like a house of cards. If you remove just one card, the whole structure falls part. However, this is certainly not the way the science of complex systems works. A much better analogy is a jigsaw puzzle. Many pieces are missing, some might even be in the wrong place, but there is little doubt that the overall image is clear, namely, that climate change is a serious threat that needs to be urgently addressed.

The scientific community is, of course, aware that the current understanding of the science of climate change is far from perfect and that much remains to be learned, but enough is known to estimate the probabilities that certain events will take place if society continues with "business as usual" emissions of greenhouse gases. As expressed in the IPCC report, the scientific consensus is that there is at least a nine out of ten chance that the observed increase in global average temperatures since the industrial revolution is a consequence of the increase in atmospheric concentrations of greenhouse gases caused by human activities.

The existing body of climate change, while not entirely comprehensive and with still many questions to be answered, is robust and extensive; and it is based on many hundreds of studies conducted by thousands of highly trained scientists with transparent methodologies, publication in public journals with rigorous peer review, et cetera. And this is precisely the information that society and decision makers in government need in order to process the risk associated with the continued emission of greenhouse gases.

I would like to emphasize that policy decisions about climate change have to be made by society at large, more specifically by policymakers. Scientists, engineers, economists, and other climate change experts should merely provide the necessary information. However, in my opinion, even if there is a mere 50 percent probability that the changes in climate that have taken place in recent decades is caused by human activities, society should adopt the necessary measures to reduce greenhouse emissions, but here I am speaking as an individual, not as a scientist.

It turns out that recent scientific studies have pointed out that the risk of runaway or abrupt climate change increases rapidly if the average temperature increases above about 8 to 10 degrees Fahrenheit. Certain so-called "tipping points" could then be reached, resulting in practically irreversible and potentially catastrophic changes to the Earth's climate system, with devastating impacts on ecosystems and biodiversity. We are talking about changes that would induce severe flood damage to urban centers and to island nations as sea level rises. We are talking about significantly more destructive extreme weather events, such as droughts and floods, et cetera. The risk associated with these tipping points is perhaps only 20, 30 percent, but we have only one planet; and, in my opinion, it is not reasonable to play Russian Roulette with this one planet we have.

I would also like to mention that some groups have stated that society cannot afford the cost of taking the necessary steps to reduce the harmful emissions. There are indeed significant uncertainties about the availability and costs of energy supply and energy-end-use technologies that might be brought to bear to achieve much lower greenhouse gas emissions than those expected on the "business as usual" trajectory. And yet there is a consensus among experts, namely, that the reasonable target to prevent dangerous interference with the climate system is to limit the average surface temperature increase above pre-industrial levels to about 4 degrees Fahrenheit. The cost is only of the order of 1 to 2 percent of global

GPD, and the cost associated with the negative impacts of climate change is very likely larger.

Furthermore, besides economic considerations, as we heard before, there is an imperative ethical reason to address the problem effectively: Our generation has the responsibility to preserve an environment that will not make it unnecessarily difficult for future generations in our planet to have an environment of natural resources suitable for the continued improvements of their economic well-being.

The global problem caused by greenhouse gas emissions has many similarities to the stratospheric ozone problem. In both cases, it is crucial to change business as usual by collaboration between nations as one global community. But the quick, effective, and highly successful implementation of the Montreal Protocol to protect the ozone layer stands in stark contrast with the Kyoto Protocol, the international treaty developed in 1997 to address the climate change challenge that is currently being reassessed. But society has yet to find a better way to agree on effective actions on climate change.

On the other hand, the extent of change necessary to phase out the ozone-depleting chemicals was relatively small and relatively easy to monitor. In contrast, climate change is caused mainly by activities related to the production and consumption of fossil fuel energy, which has so far been essential for the functioning of our industrialized society. Effective action, therefore, requires a major transformation not only in a few industries but in a great number of activities of society.

The Montreal Protocol stands out as an important precedent that demonstrates that an effective international agreement can indeed be negotiated. Thus, I believe that negotiating an effective climate change treaty is feasible, although very challenging. Nevertheless, such a treaty would undoubtedly benefit the entire world, as was clearly the case with the Montreal Protocol.

Thank you, Mr. Chairman.

[The statement of Mr. Molina follows:]

Testimony by Professor Mario Molina
University of California, San Diego

Hearing of
The Select Committee on Energy Independence and Global Warming
U.S. House of Representatives

May 20, 2010

Good morning, Mr. Chairman and members of the Committee. My name is Mario Molina; I am a Professor at the University of California, San Diego, and President of the Mario Molina Center for Studies in Energy and the Environment in Mexico City.

I will attempt to summarize and briefly discuss here various questions concerning the current state of knowledge related to the climate change threat, adding as well some comments on the lessons we have learned from the stratospheric ozone depletion issue that might be relevant to the climate change problem.

Integrity of climate change science

In various media reports, as well as in the Halls of Congress, some groups have stated in recent months that the basic conclusion of climate change science is no longer valid, namely that the climate is changing as a consequence of human activities with potentially serious consequences for society. Among others, the basis of these allegations is the discovery of some errors and supposed errors in the last report of the Intergovernmental Panel on Climate Change (IPCC), which was released in 2007.

However, several groups of scientists have recently pointed out that the scientific consensus remains unchanged and has not been affected by these allegations: it is now well established that the accumulation of greenhouse gases resulting from human activities is causing the average surface temperature of the planet to rise at a rate outside of natural variability.

I fully agree with this conclusion. I would like to clarify, though, that the scientific community is not absolutely certain that this conclusion is correct: the climate system is very complex, and as stated in the 4th Assessment Report of the IPCC (the last report) the consensus is that there is a "mere" 90% probability that this is indeed the case.

There are in fact some errors in the IPCC report, but they certainly do not affect the main conclusion. I will not review the nature of these errors here: they have been discussed in detail elsewhere. I just want to note that they do not appear in the Summary for Policy Makers of Working Group I, which is where the scientific consensus referred to in the previous paragraph is described in detail. On the other hand, the science of climate change has continued to evolve: new findings since 2007 indicate that the impacts of climate change are expected to be significantly more severe than previously thought. This has been documented, among others, by my colleagues at MIT and at the Scripps Institution of Oceanography.

Uncertainties in climate change science

There appears to be a gross misunderstanding of the nature of climate change science among those that have attempted to discredit it. They convey the idea that the science in question behaves like a house of cards: if you remove just one of them, the whole structure falls apart. However, this is certainly not the way the science of complex systems has evolved. A much better analogy is a jigsaw puzzle: many pieces are missing, and some might even be in the wrong place, but there is little doubt that the overall image is clear, namely that climate change is a serious threat that needs to be urgently addressed. It is also clear that modest amounts of warming will have both positive and negative impacts, but above a certain threshold the impacts turn strongly negative for many ecological systems, and for most nations.

The scientific community is of course aware that the current understanding of the science of climate change is far from perfect and that much remains to be learned, but enough is known to estimate the probabilities that certain events will take place if society continues with "business as usual" emissions of greenhouse gases. And this is precisely the information that society and decision makers in government need in order to assess the risk associated with the continued emissions greenhouse gases. I would like to emphasize that policy decisions about climate change have to be made by society at large, and more specifically by policymakers; scientists, engineers, economists and other climate change experts should merely provide the necessary information. In my opinion, even if there is a mere 50% probability that the changes in climate that have taken place in recent decades are caused by human activities, society should adopt the necessary measures to reduce greenhouse emissions; but here I am speaking as an individual, not as a scientist.

In fact, recent scientific studies have pointed out that the risk of runaway or abrupt climate change increases rapidly if the average temperature increases above about 8 to 10 degrees Fahrenheit. Certain so-called "tipping points" could then be reached, resulting in practically irreversible and potentially catastrophic changes to the Earth's climate system, with devastating impacts on ecosystems and biodiversity. These changes could induce severe flood damage to urban centers and island nations as sea level rises, as well as significantly more destructive extreme weather events such as droughts and floods; etc.

Economic considerations

I would also like to mention that some groups have stated that society cannot afford the cost of taking the necessary steps to reduce the harmful emissions.

There are indeed significant uncertainties about the availability and costs of energy-supply and energy-end-use technologies that might be brought to bear to achieve much lower greenhouse-gas emissions than those expected on the "business as usual" trajectory. And yet, the consensus among experts is that a reasonable target to prevent dangerous interference with the climate system is to limit the average surface temperature increase to about 4 degrees Fahrenheit; the cost is indeed significant, but only of the order of 1 to 2% of global GDP, and is very likely smaller that the cost associated with the negative impacts of climate change. Furthermore, besides economic considerations there is an imperative ethical reason to address the problem effectively: our generation has the responsibility to preserve an environment that will not make it unnecessarily difficult for future generations in our planet to have an environment and natural resources suitable for the continued improvement of their economic well being.

There is yet another excuse for inaction on the climate change issue that is sometimes presented by the critics, namely that climate change is not the only problem facing society, and hence that other more urgent problems such as poverty should be addressed first. Most of us agree, of course, that there are other problems and that society should strive vigorously to achieve, for example, the Millennium Development Goals articulated by the United Nations. But it would be an error to address these problems sequentially; in fact, if some of the changes to the climate system expected to occur as a consequence of continued emissions actually materialize it will be much harder for many sectors of society to reach the desired standard of living.

Lessons learned from the Montreal Protocol and the stratospheric ozone depletion issue

The global problem caused by greenhouse gas emissions has many similarities to the stratospheric ozone problem. In both cases it is crucial to change business as usual by collaboration between nations as one global community. But the quick and effective implementation of the Montreal Protocol to protect the ozone layer stands in stark contrast to the Kyoto Protocol, the international treaty developed in 1997 to address the climate change challenge that is currently being reassessed: this treaty has not been successful, and society has yet to find a way to agree on effective actions on climate change.

On the other hand, the extent of change necessary to phase out the ozone-depleting chemicals was relatively small and relatively easy to monitor. The ozone-depleting chemicals (mostly CFCs) were used mainly as refrigerants, solvents and as propellants for spray cans, and could be replaced with other compounds that industry was able to develop on a relatively short time scale. In contrast, climate change is caused mainly by activities related to the production and consumption of fossil fuel energy, which has so far been essential for the functioning of our industrialized society. Effective action therefore requires a major transformation not only in a few industries, but in a great number of activities of society.

Clearly, economic development cannot continue along the same path it has followed in the past, and something has to change quite drastically. While most developed nations agree that for equity reasons they have to enable this change by providing economic resources and technology transfer to developing nations, the main problems that are being currently experienced with international negotiations result from excessive demands from some industrialized countries for "binding commitments" by all developing nations, as well as excessive demands by some developing nations for economic contributions as a condition for change. But the Montreal Protocol stands out as an example that demonstrates that an effective international agreement can indeed be negotiated. An important precedent from the Montreal Protocol is the creation of the "Multilateral Fund", which was instrumental to effectively address the stratospheric ozone question by providing resources to developing nations to achieve a smooth transition to a CFC-free society. The stratospheric ozone and the climate change problems are truly global: in the case of stratospheric ozone the nations of the world realized that they all would benefit from an effective international treaty, and that they would all lose if no agreement was reached. Thus, I believe that negotiating an effective climate change treaty is feasible, although very challenging. Nevertheless, such a treaty would undoubtedly benefit the entire world, as was the case with the Montreal Protocol.

The CHAIRMAN. Thank you, Dr. Molina, very much.

Our third witness today is Dr. Ben Santer. Dr. Santer is a research scientist in the program for Climate Model Diagnosis and Intercomparison at the Lawrence Livermore National Laboratory.

Previously, Dr. Santer was on the staff of the Max Planck Institute for Meteorology in Hamburg, Germany. He served as a convening lead author for the 1995 report of the IPCC. He holds a Ph.D in climatology from the Climactic Research Unit at the University of East Anglia and has been a recipient of the MacArthur Fellowship.

We welcome you, sir. Whenever you are ready, please begin.

STATEMENT OF BEN SANTER

Mr. SANTER. Chairman Markey, I would like to thank you, Ranking Minority Member Sensenbrenner, and the other members of the House Select Committee for the opportunity to appear before you today. This is my first testimony.

I have been employed since 1992 at Lawrence Livermore National Lab's program for Climate Model Diagnosis and Intercomparison. Our group was established in 1989 by the U.S. Department of Energy. Our omission is to quantify how well computer models simulate important aspects of present day and historical climate and to reduce uncertainties in climate model projections of future changes.

As you mentioned, I have a Ph.D in climatology from the Climatic Research Unit of the University of East Anglia. I went to the Climatic Research Unit in 1983 because it was and still remains one of the world's premiere institutions for studying past, present, and future climate.

After completing my Ph.D in 1987, I devoted much of my scientific career to climate fingerprinting, which seeks to understand the causes of recent climate change. The basic strategy in fingerprinting is to search through observational records for the climate change pattern predicted by a computer model. This pattern is called the fingerprint. The underlying assumption is that each influence on climate, such as purely natural changes in the sun or human-caused changes in greenhouse gas concentrations, has a unique distinguishing fingerprint.

In the mid-1990s, fingerprint research focused on changes in land and ocean surface temperature. This research provided support for the Discernable Human Influence conclusion of the 1996 IPCC Second Assessment Report.

One criticism of the first fingerprint studies went something like this: If there really is a human-caused climate change signal lurking in observations, scientists should see this signal in many different aspects of the climate system, not in surface temperature alone.

Over the past 14 years, the scientific community has responded to this criticism. We have now performed fingerprint studies with many different properties of the climate system, such as the heat content of the ocean, the temperature of the atmosphere, the salinity of the Atlantic, large-scale rainfall and pressure patterns, atmospheric moisture, continental runoff, and Arctic sea ice extent. The message from all of these studies is that natural causes alone cannot explain the observed climate changes over the second half of the 20th century. The best explanation of the observed climate changes invariably involves a large human contribution.

Extraordinary claims require extraordinary proof. The IPCC's extraordinary claim that there is a discernible human influence on global climate has received extraordinary scrutiny. This claim has been independently corroborated by the U.S. National Academy of Sciences, the science academies of other nations, and the reports of the U.S. Climate Change Science Plan. Many professional scientific organizations have also affirmed the reality of the human influence on global climate.

Finally, I would like to make a few comments regarding some of the nonscientific difficulties I have faced. In April, 1994, I was asked to serve as convening lead author of chapter eight of the IPCC's Second Assessment Report. Chapter eight reached the now historic conclusion that there is a discernible human influence on global climate. This sentence changed my life.

Shortly after publication of the '96 IPCC report, I was publicly accused of political tampering, scientific cleansing, of abuses of the peer-review system, and even of irregularities in my own scientific research. Responses to these unfounded allegations have been given in a variety of different fora by myself, by the IPCC, and by other scientists, yet the allegations remain much more newsworthy than the rebuttals.

I firmly believe that I would now be leading a different life if my research suggested that there was no human effect on climate. I would not be the subject of congressional inquiries, Freedom of Information Act requests, or e-mail threats. I would not need to be concerned about the safety of my family.

It is because of the work I do and because of the findings my colleagues and I have obtained that I have experienced interference with my ability to perform scientific research. As my testimony indicates, the scientific evidence is compelling. We know beyond a shadow of a doubt that human activities have changed the chemical composition of the 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 and have had important effects on our climate.

Some take comfort in clinging to the false belief that humans do not have the capacity to influence global climate, that "business as usual" is good enough for today. Sadly, business as usual will not be good enough for tomorrow. The decisions we reach today will impact the climate future that our children and grandchildren inherit. I think most Americans want those decisions to be based on the best available scientific information, not on wishful thinking or on well-funded disinformation campaigns.

This is one of the defining moments in our country's history and in the history of our civilization. For a little over a decade, we have achieved true awareness of our ever-increasing influence on global climate. We can no longer plead that we were ignorant, that we did not know what was happening. Future generations will not care about the political or religious affiliations of the men and women in this room. What they will care about is how effectively we address the problem of human-caused climate change.

Thank you.

[The statement of Mr. Santer follows:]

Testimony for House Select Committee on Energy Independence and Global Warming

Benjamin D. Santer

May 20, 2010

1. Biographical information

My name is Benjamin Santer. I am a climate scientist. I work at Lawrence Livermore National Laboratory (LLNL) in Livermore, California.

I have been employed since 1992 in LLNL's Program for Climate Model Diagnosis and Intercomparison (PCMDI). 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 of 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 Max-Planck 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 seek to improve 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 by Dr. Stephen Schneider (1).

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"* (2).

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"* (3). 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) had partially masked the warming signal arising from increasing atmospheric concentrations of greenhouse gases (4).

A further major area of progress was the increasing use of "fingerprint" studies (5, 6, 7). 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 (5). They allow researchers to make rigorous tests of competing hypotheses regarding the causes of recent climate change.

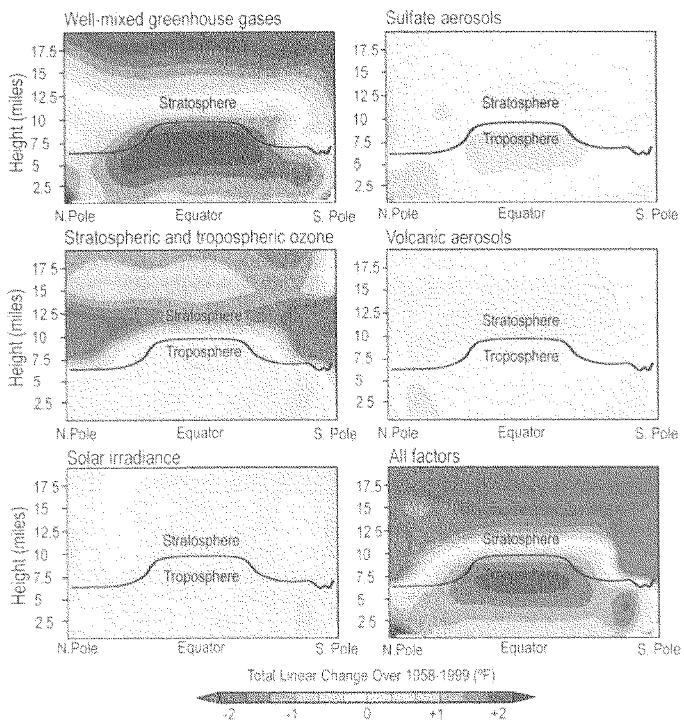

Figure 1: Climate simulations of the vertical profile of temperature change due to five different factors, and the effect due to all factors taken together. The panels above represent a cross-section of the atmosphere from the North Pole to the South Pole, and from the surface up into the stratosphere. The black lines show the approximate location of the tropopause, the boundary between the lower atmosphere (troposphere) and the stratosphere. This Figure is reproduced from Karl *et al.* (8).

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* <u>*very likely*</u> *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).

Extraordinary claims require extraordinary proof (12). 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 (13), the Science Academies of eleven nations (14), and the Synthesis and Assessment Products of the U.S. Climate Change Science Plan (15). Many of our professional scientific organizations have also affirmed the reality of a human influence on global climate (16).

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 (17) 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 the detected change to a specific cause or causes (18, 19, 20, 21).

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 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 (22, 23).

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, 24).

4. Evidence from rigorous quantitative fingerprint studies, which compare modeled and observed patterns of climate change.

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 (25) regarding the possible causes of recent climate change (18, 19, 20, 21).

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 ocean heat content (26, 27), Atlantic salinity changes (28), sea-level pressure (29), tropopause height (30), zonal-mean rainfall (31), surface humidity (32), atmospheric moisture (33, 34), and Arctic sea ice extent (35). 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 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 (36) are physically consistent with increases in ocean heat content (37, 38) and near-surface temperature (39, 40).

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 (41). 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 (42, 43, 44).

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 (45). 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 (46, 47, 48, 49).

Because regional-scale climate changes will determine societal impacts, fingerprint studies are increasingly shifting their focus from global to regional scales. 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 (50), so that identifying any human-caused climate signal 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 (51,52). Examples include human-induced changes in land surface properties (53) or in the concentrations of carbon-containing aerosols (54, 55). Neglect or inaccurate specification of these factors complicates D&A studies.

Despite these problems, numerous studies 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 (56, 57, 58, 59). Related work (60, 61) suggests that an human-caused climate signal has already emerged from the background noise at even smaller spatial scales (at or below 500 km) (62), and may be contributing to regional changes in the distributions of plant and animal species (63).

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 (64, 65, 66, 67, 68).

The Microwave Sounding Unit Debate

For over a decade, scientists critical of "fingerprint" studies have argued that tropospheric temperature measurements from satellites and weather balloons (radiosondes) show little or no warming of the troposphere over the past several decades, while climate models indicate that that the troposphere should have warmed markedly in response to increases in greenhouse gases (see Figure 1, upper left panel). This apparent discrepancy between climate model estimates and observations has been used to cast doubt on the reality of a "discernible human influence" on the climate system (69).

It is unquestionable that satellites have transformed our scientific understanding of the weather and climate of planet Earth. Since 1979, Microwave Sounding Units (MSU) on polar-orbiting satellites have measured the microwave emissions of oxygen molecules in the atmosphere. These emissions are proportional to atmospheric temperatures. By monitoring microwave emissions at different frequencies, scientists can obtain information about the temperatures of broad atmospheric layers. Most attention has focused on the temperatures of the lower stratosphere and mid- to upper troposphere (T_4 and T_2, respectively) as well as on an estimate of lower tropospheric temperatures (T_{2LT}) (70).

The first attempts to obtain climate records from MSU data were made by scientists at the University of Alabama in Huntsville (UAH) (71, 72, 73). Until recently, the UAH group's analysis of the MSU data suggested that the tropical lower troposphere had cooled since 1979. Concerns regarding the reliability of the MSU-based tropospheric temperature trends were countered with the argument that weather balloons also suggested cooling of the tropical troposphere (74), and constitute a completely independent temperature monitoring system (75, 76).

Throughout most of the 1990s, only one group (the UAH group) was actively working on the development of temperature records from MSU data. In 1998, the Remote Sensing Systems (RSS) group in California identified a problem in the UAH data related to the progressive orbital decay and altitude loss over the lifetimes of individual satellites. This introduced a spurious cooling trend in the UAH data (77). The RSS scientists (Wentz and Schabel) found that the lower troposphere had warmed over the satellite era.

The UAH group subsequently identified two new corrections that approximately compensated for the cooling influence of orbital degradation. The first correction was related to the effects of orbital drift on the sampling of Earth's diurnal temperature cycle. The second (the so-called "instrument body effect") was due to variations in measured microwave emissions arising from changes in the temperature of the MSU instrument itself, caused by changes in the instrument's exposure to sunlight (78).

Additional research cast doubt on the UAH results. Three separate groups found that the mid- to upper troposphere had warmed markedly over the satellite era (79, 80, 81, 82, 83, 84, 85), in contrast to the UAH results (74, 78). The UAH group, however, continued to claim close correspondence between their own MSU-based estimates of tropospheric temperature trends and trends derived from weather balloons ("radiosondes") (74). This raised critical questions regarding the quality of radiosonde temperature measurements. Were these measurements an unambiguous gold standard?

Recent research indicates that the answer to this question is "no". The temperature sensors carried by weather balloons have changed over time, as has the shielding that protects the sensors from direct solar heating. Solar heating of the sensors can affect the temperature measurements themselves. The introduction of progressively more effective shielding results in less solar heating, and this in turn imparts a non-climatic cooling trend to the daytime measurements.

Sherwood *et al.* (86) discovered this effect by comparing the radiosonde-based temperature trends based on nighttime ascents (with no solar heating effects) and daytime launches. When this solar heating effect was properly accounted for, weather balloons yielded tropospheric temperature trends that were in better agreement with RSS estimates than with UAH results (86, 87).

Two papers shed further light on these issues. The first paper was by the RSS group, and described a new MSU retrieval of lower tropospheric temperatures (88). RSS obtained substantially larger T_{2LT} trends than UAH (89). Mears and Wentz (88) attributed most of these differences to an error in UAH's method of adjusting for drift in the time of day at which satellites sample the Earth's daily temperature cycle. This error was acknowledged by Christy and Spencer (90). When the UAH group remedied this problem, however, their lower tropospheric trends increased by much smaller amounts than expected on the basis of the RSS analysis (91).

The second paper addressed the physics that governs changes in atmospheric temperature profiles. It compared the relationship between surface and tropospheric temperature changes over a wide range of observational and climate model datasets (92). The focus was on the deep tropics (20°N-20°S), where the UAH and RSS tropospheric temperature trends diverged most markedly. The intent was to investigate whether the simple physics that governs the vertical structure of the tropical atmosphere could be used to constrain the uncertainties in satellite-based trends.

This "simple physics" involves the release of latent heat when moist air rises due to convection and condenses to form clouds. Because of this heat release, tropical temperature changes averaged over large areas (and averaged over sufficient time to damp day-to-day "weather noise") are generally larger in the lower and mid-troposphere than at the surface of the tropical ocean. This "amplification" behavior is well-known from basic theory (93), observations (94), and climate model results (95).

The UAH amplification results were puzzling. For month-to-month fluctuations in tropical temperatures, UAH T_{2LT} anomalies were 1.3 to 1.4 times larger than surface temperature anomalies, consistent with models, theory, and other observational datasets. But for decade-to-decade temperature changes, the UAH T_{2LT} trends were smaller than surface trends, implying that the troposphere damped surface warming. In contrast, the computer model amplification results were consistent across all timescales considered, despite large differences in model structure. Like the models, the RSS observational data also showed similar amplification of surface warming on different timescales.

These results have at least two possible explanations (15, 20, 96). The first is that the UAH data are reliable, and different physical mechanisms control the response of the tropical atmosphere to "fast" and "slow" surface temperature fluctuations. Such time-dependent changes in the physics seem unlikely given our present understanding, and mechanisms that might explain such changes have yet to be identified.

A second explanation is that there are still non-climatic artifacts in the UAH tropospheric temperature records, leading to residual cooling biases in the UAH long-term trend estimates. This is both a simpler and more plausible explanation given the consistency of amplification results across models and timescales, our theoretical understanding of how the tropical atmosphere should respond to sustained surface heating (97), and the currently large uncertainties in observed tropospheric temperature trends (15).

The extraordinary claim that the tropical troposphere had cooled since 1979 has not survived rigorous scrutiny. We have learned that uncertainties in satellite estimates of tropospheric temperature change are far larger than originally believed, and now fully encompass computer model results (98). There is no longer a fundamental discrepancy between modeled and observed estimates of tropospheric temperature changes (15).

Assessing Risks of Changes in Extreme Events

Although we cannot confidently attribute any specific extreme event to human-induced climate change (99), we are capable of making informed scientific statements regarding the influence of human activities on the likelihood of extreme events (100, 101). This is an important distinction.

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 (102). Comparison of the frequencies of extremes in the control and perturbed experiments allows one to make probabilistic statements about how human-induced climate change may have altered the likelihood of the extreme event (48, 102, 103). This is sometimes referred to as an assessment of "fractional attributable risk" (102).

Recently, a "fractional attributable risk" study involving the European summer heat wave of 2003 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*" (102).

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. Conclusions

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 (26, 27, 37, 38, 39, 40, 104). Atmospheric moisture has increased (32, 33, 34, 36). Glaciers have retreated over most of the globe (105, 106, 107). Sea level has risen (108). Snow and sea-ice extent have decreased in the Northern Hemisphere (35, 109, 110). The stratosphere has cooled (111), and there are now reliable indications that the troposphere has warmed (15, 112). The height of the tropopause has increased (30). 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. Personal Thoughts on Harassment of Climate Scientists

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. We care about getting the science right – not about getting rich quick, retiring early, or altering global systems of government.

In April 1994, I was asked to act as Convening Lead Author of Chapter 8 of the IPCC's second assessment report. The chapter was entitled "*Detection of Climate Change and Attribution of Causes*". I did not seek this responsibility. It was offered to me after at least two other scientists had refused the Convening Lead Author job.

Chapter 8 reached the historic conclusion that there is "*a discernible human influence on global climate*". This single sentence changed my life. Immediately after publication of the second assessment report in 1996, I became the subject of Congressional inquiry and unwelcome media attention. I was wrongly accused of "political tampering" and "scientific cleansing", of abuses of the peer-review system, and even of irregularities in my own scientific research.

Responses to these unfounded allegations have been given in a variety of different fora – by myself, by the IPCC, and by other scientists. A complete record of these responses was recently posted on RealClimate.org (113). I refer this post to your attention.

I firmly believe that I would now be leading a different life if my research suggested that there was no human effect on climate. I would not be the subject of Congressional inquiries, Freedom of Information Act requests, or email threats. I would not need to be concerned about the safety of my family. I would not need to be concerned about my own physical safety when I give public lectures.

It is because of the research I do – and because of the findings my colleagues and I have obtained – that I have experienced interference with my ability to perform scientific research.

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 not rocket science. It is simple, basic physics.

Some take comfort in clinging to the false belief that humans do not have the capacity to influence global climate; that we do not need to make any changes in how we produce and use energy; that "business as usual" is good enough for today.

Sadly, "business as usual" will not be good enough for tomorrow. The decisions we reach today will impact the climate future that our children and grandchildren inherit. I think most American want those decisions to be based on the best-available scientific information – not on wishful thinking, or on well-funded disinformation campaigns.

This is one of the defining moments in our country's history, and in the history of our civilization. For a little over decade, we have achieved true awareness of our ever-increasing influence on global climate. We can no longer plead that we were ignorant; that we did not know what was happening. Future generations will judge us on how effectively we addressed the problem of human-caused climate change.

I respectfully request that you do everything in your power to permit my colleagues and I to continue studying the nature and causes of climate change. We need to follow the research wherever it leads us, without fear of the consequences of speaking truth to power.

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70 The designations T_4 and T_2 reflect the fact that the original MSU measurements employed MSU channels 4 and 2 (subsequently replaced by equivalent data from other channels in the latest Advanced Microwave Sounding Units). The bulk of the microwave emissions monitored by channel 4 is from roughly 14 to 29 km above Earth's surface (150 to 15 hPa). Channel 2 primarily samples emissions from the surface to 18 km (75 hPa). The T_{2LT} retrieval is constructed using the outer and inner "scan angles" of channel 2, and is a measure of temperatures from the surface to 8 km (350 hPa). For further details of the atmospheric layers sampled by MSU, see ref. 15.

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The CHAIRMAN. Thank you, Dr. Santer, very much.

Our fourth witness today is Dr. Stephen Schneider. Dr. Schneider is a professor of interdisciplinary environmental studies and biological studies at Stanford University. He has contributed to all four assessment reports of the IPCC and served as a coordinating lead author for the Fourth Assessment. He is as well a recipient of a MacArthur fellowship and is a member of the National Academy of Sciences.

We welcome you, Doctor. Whenever you are ready, please begin.

STATEMENT OF STEPHEN H. SCHNEIDER

Mr. SCHNEIDER. Thank you very much, Chairman Markey and the members of the Select Committee. The fact that the Select Committee has been designed to integrate across multiple committees of the Congress I think is a very excellent idea because climate change, like many other complex problems, including health care and defense and education, involves that integration, and we need to get out of our silos. So I appreciate this opportunity.

One of the things I want to do very fast in my oral testimony is to try to put a little bit of context on the cacophonous debate that we often see in the world out there, the political world and media world, and point out that frequently that debate has very little correlation with the debate that actually takes place within the knowledge community, most of which you have already heard described from colleagues.

This is not to say there aren't many uncertainties, and my written testimony dwells on the whole history of that. In fact, the IPCC, which you mentioned that I have been involved in all four—in fact, I jokingly call this my pro bono day job—has pioneered in pointing out that when we discuss any conclusion that the consensus that we are talking about is not simply the consensus about a conclusion, some of which may not be fully established, but the consensus is over the relative confidence we have in those conclusions. That is, we assess risk, what can happen multiplied by the probability, and then we leave the risk management judgments, the what to do about it, the value judgments, where they more properly belong, as Dr. Molina told us, in the decisions that are made by you and others, including private citizens. So let me begin with just a few slides to try to frame this context.

One of the questions that I am often asked is, is the science of global warming settled? And I like to ask my audiences what they think; and, depending on who you talk to, it is somewhere between 20 and 70 percent of people. But after asking how many believe that it is and isn't, I then ask how many think it is a stupid question. Because, in fact, it is a stupid question. Because most people think of science what they did in high school. You put in a piece of litmus paper and you can falsify whether it is an acid or a base in my cup of water. But you cannot do that in system science, and you certainly cannot do that for the future, because there is no data in the future until it rolls around. So the question that we have is what kind of risks are we willing to take with a projection of future that can only be validated by performing the experiment on that laboratory we call Earth?

So why is it a dumb question? Because when you have a system science, there will be well-established components, and there are many that are settled, and we have already heard from colleagues, that includes observed temperatures and so forth. There will also be competing explanations, those things we have narrowed down to a few, and there will be speculative. And as we heard from the house of cards analogy, just because there are speculative components does not refute the well-established, nor is it legitimate to take well-established components and ignore the fact that there are still elements that we don't know.

So let me give you a few examples in my remaining 2 minutes.

We have already referred to what IPCC called unequivocal warming. Well, there is the record. And you can see that there are, indeed, as the ranking member said, a number of pulses, but the most recent one is by far the largest and the one that stands out the highest.

But the aspect I want to talk about is on the next slide. Because I have heard this asserted many times in the public debate and even in congressional testimony by Members that since it hasn't warmed up much over the last 10 years that this falsifies global warming. However, if you took a look at what we call cherry-picking—that is, picking endpoints that are convenient to make a point—between 1992 and 2002, as the slide jokingly says, we are going to hell in a hand basket.

What we are looking at is the normal natural variability of the climate system on interdecadal time scales. All modelers, all measurers who understand climate science know this and assert it, and to cherry-pick out of context short-term records for political convenience is indeed not sound science and, unfortunately, is all too common. It was at a fever pitch when in January there was a snowstorm and cold weather here, which led certain people to assert that this cold snowstorm was therefore proof that there was no global warming.

The irony is it occurred in one of the warmest Januaries ever recorded, which no climate scientist would have said proves global warming. It is too short a record. But one snowstorm proves nothing except what the next cartoon does, which is slush for brains, or why is it going to be covered?

This is a serious problem, because the public and other people actually think there is credibility in the reference of short-term records when we know that there isn't any. That causes a confusion, and when the public is confused, it makes it difficult, I understand, for you to do your jobs of trying to think outside the box from a policy point of view.

Let me hurry to conclude.

Let me show you an example of competing explanations. There is no competing explanation that Greenland is melting very rapidly. It is. But why is that? Is that a natural internal variability in the north Atlantic climate system, as some have asserted? Undoubtedly, that is a component. Or is this due to global warming? The only way to answer that definitively is hang around another century performing the experiment on laboratory Earth. But there are other things that we can and will do and have done, which is to look at the melt of snow layers over the last thousand years.

And when you do that high on the Greenland glacier, you find that there are many areas that have never melted before. That is not absolute proof, but that tips my belief to it is much more likely than not that global warming is at least a significant component of this and you cannot rule out a very important part.

So let me conclude then by saying, in the future, how do we project? There are two fans of uncertainty. The one in this picture from the IPCC is human behavior—low, medium, high emissions. That is what your committee and the Congress and other people in the world are grappling with, how much in our risk management frame do we want to control?

But there is a second fan of uncertainty on the right side of the next to last slide; and that is, what is the internal dynamics of the climate system, the so-called "climate sensitivity?" If we double carbon dioxide, how much does it warm up?

Well, IPCC, which is very conscious of uncertainty, said it was very likely—meaning two-thirds to 90 percent chance—somewhere between 2 degrees Celsius and 4.5. That still leaves a 5 to 17 percent chance it could be below or above. And it is those tales of the possibility which are the most threatening and that have insurance companies and others worried. That gives us very clear belief that there is serious potential warming coming, but we still have an amazingly large range that will not be resolved any time soon.

And the last slide is basically one I borrowed from MIT to remind us that what we are really looking at is a wheel of fortune, where if we are "lucky," the lower slots are two to three times the warming that we are now experiencing, and that is not from business as usual but a substantial reduction in emissions. And that if we are unlucky and we have high sensitivity and we continue with business as usual, we could see warming of many, many degrees comparable to the differences between an Ice Age and an interglacial cycle occurring not in thousands of years but in a century. And it is those kinds of outlier cases which, when we are talking about the planetary life support system, that motivates scientists to reasons for concern.

Thank you, sir.

[The statement of Mr. Schneider follows:]

Written Testimony of:

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20 May 2010

Before

Select Committee on Energy Independence
& Global Warming

1334 Longworth House Office Building

9AM

Abstract: Uncertainty bedevils some—but by no means all--components of the science and impact assessments of climate change. Uncertainty will not be eliminated from many aspects any time soon, so the best way to help policy-makers is to try to forge a consensus about the degree of confidence that can be assessed to each important conclusion. Thus a risk-management approach seems the most effective strategy for managing risks to our planetary life support system associated with human activities that are changing our climate. Classifying conclusions into those that are *well established*, fall in a category of *competing explanations* or remain *speculative* is one established approach to classifying risk, which, in turn, allows risk management activities to be built on a firmer factual foundation.

It is already well established that human activities are changing the climate. But how large and how fast will these changes be? What systems will be only partly disturbed and what other systems seriously disrupted? And how can our policy choices reduce the threat they pose to natural and social systems?

The policy problem is hard because the global scale of climate change and its subtly intensifying impacts contrast uneasily with the short-term, local-to-national scales of most management systems. Furthermore, significant uncertainties plague projections of climate change and its consequences.

Such projections stretch the traditional scientific method to directly test hypotheses because there can be no data for the future before the fact. Any prognostication into that unknown territory is, by definition, a model of the factors that are believed to determine how the future will evolve. But even though we can never fully solve the climate prediction problem we can go a long way toward bracketing probable outcomes, and even defining possible outliers.

Progress here depends on an international community of scholars, who repeat what others have done with different computer models, make comparisons across models of various designs, compare relevant aspects of simulations to existing observational data to test model performance from retrodiction of past changes, and pioneer new models as data and theory advance. Back in the early 1970s, when a reporter asked how long this model building and validation process would take to achieve high confidence, I said that our models were "like dirty crystal balls, but the tough choice is how long we clean the glass before we act on what we can make out inside." That is still the issue, even as models become more sophisticated and simulate the Earth's conditions increasingly well. What constitutes "enough" credibility to act is not science but a subjective value judgment on how to gauge risks and weigh costs and benefits—often in incommensurate units like dollars versus species lost or inequity generated.

Modeling Future Climate. How large are the scientific uncertainties, though? People often say that meteorologists' inability to predict weather credibly beyond about 10 days bodes ill for long-range climate projection over decades. This misses a key difference between the instantaneous state of the atmosphere—weather—versus its time and space averages—climate. Even though the evolution of atmospheric conditions is inherently chaotic and the slightest perturbation today can make a huge difference in the weather a thousand miles away and weeks hence, large-scale climate shows little tendency to exhibit chaotic behavior (at least on timescales longer than a decade). Good models can thus make reasonable climate projections decades or even centuries ahead if the processes forcing change are large enough to detect above the background "noise" of the climate system—the unpredictable part. The Intergovernmental Panel on Climate Change (IPCC)'s laboriously compiled projections combine such modeling with scenarios for greenhouse gas emissions based on different assumptions about economic growth, technological developments, and population increase (IPCC, 2000).

These scenarios, despite major differences in emissions, show paths for global temperature increase that do not diverge dramatically until after the mid-21st century. This has led some to declare that there is very little difference in climate change across scenarios, and therefore, emissions reductions can be delayed many decades. That is a big mistake. It takes many decades to replace current polluting energy systems. There is also delay between emissions and temperature change due to the thermal inertia in the climate system caused by the large heat capacity of the oceans. After the mid-21st century, there are large differences based on emissions over the next few decades in the projected temperature increases—and the risks of associated dangers—for the late 21st century and beyond. Some of these risks imply irreversible changes.

Much of the uncertainty contributing to the ranges of projected future temperature increase derives from the so-called climate sensitivity. How much warming can we expect a given amount of greenhouse gas to cause? It is often estimated as the equilibrium global mean surface temperature increase due to a doubling of atmospheric CO_2 from pre-industrial levels of about 280 Parts Per Million (PPM). The IPCC estimates that it is "likely" (there is a 66-90 percent chance) that the climate sensitivity is between 2 and 4.5 °C and roughly a 5-17 percent chance that it is above 4.5 °C (with the remainder being the chance it is less than 2 °C). They also offered a "best guess" of 3 °C climate sensitivity.

Our uncertainty goes beyond scientific understanding of the scale and distribution of climate changes from any single scenario of increasing greenhouse gases to include the trajectory of human development and our adaptive capacity. Moreover, future greenhouse gas emissions are heavily dependent on policy choices worldwide. But we do know that if we wait to act until an increase in undesirable impacts occur, the inertia in the climate system and in the socioeconomic systems that produce greenhouse gas emissions will have committed us to even more severe impacts stretched out over many decades to centuries.

Risk management framing is a judgment about acceptable and unacceptable risks. That makes it a value judgment. As with the Bayesian approach to probability, many traditional scientists are uncomfortable with that. I am one of them, but I am more uncomfortable ignoring the problems altogether because they don't fit neatly into our paradigm of "objective" falsifiable research based on already known empirical data.

Systems science also alerts us to the possibility of "surprises" in future global climate—perhaps extreme outcomes or tipping points which lead to unusually rapid changes of state. By definition, very little in climate science is more uncertain than the possibility of "surprises." But it is nevertheless a real one. Even so, it took several long rounds of assessment just to get IPCC to mention surprises, let alone discuss formal subjective probabilistic treatment of such potentially irreversible, large changes.

Communicating Complex Science. We cannot eliminate all of the important scientific uncertainties, but we can be more precise about their extent. But that is only part of the scientists' job. We also have a responsibility to communicate all of this as well as we can. Communicating this complex systems science to policy makers and the public is difficult. Too often, confusion reigns when an advocate for strong policy cites a well-established severe outcome as the most important consideration, and another advocate from some enterprise institute disliking public control of private decisions cites speculative components of the systems analysis as if that is all there were. Not surprisingly, politicians, media, and just plain folks get frustrated by this "dueling scientists" mode of presentation, an unfortunate staple of the mainstream media.

Professional training also leads too many scientists to "bury our leads", as American journalists would put it, rather than finding effective ways to communicate complex ideas.

Being straightforward and understandable is a challenge given the strong scientific tradition of full disclosure, which makes us lead with our caveats, not our conclusions. But what I call the "double ethical bind"—be effective in public versus full disclosure of the caveats—is not unbridgeable. It calls for the scientist to develop a hierarchy of products—ranging from sound bites on the evening news to get our findings headlined on the agenda, to short but meatier articles in semi-popular journals like *Scientific American*, to more in-depth websites, to full length books in which that smaller fraction of the public or policy worlds that actually want the details about the nature of the processes and how the state of the art has evolved—can find them (e.g., as I do in *Science as a Contact Sport*--Schneider 2009). Yes, it is very time-consuming, but it is also necessary for those in complex systems science fields like climate science to simultaneously be effective in public messaging and to honestly separate the components of this complex systems science that are well established from those best characterized as competing explanations from those which are still speculative.

Along with climate projections, scientists also have to explain how systems science gets done. We cannot usually do traditional "falsification" controlled experiments. What we can do is assess where the preponderance of evidence lies, and assign confidence levels to various conclusions. Over decades, the community as a whole can "falsify" earlier collective conclusions—like the sporadic suggestions in the early 1970s that the world would cool. But in systems science it sometimes takes a score of years to even discover that certain data was not collected or analyzed correctly as well as continuing to identify new data and such discoveries are rarely by individuals but teams and even assessment groups.

Two Kinds of Statistics. When I first got involved in discussing the range of outcomes in climate change, I didn't understand Bayesian versus frequentist statistics, but in fact that was the heart of the matter— how to deal with objectivity and subjectivity in modeling and in projections.

The English clergyman and mathematician Thomas Bayes (c. 1702–1761) formulated an approach to probability now called Bayesian inference. His key theorem was published posthumously in 1764. In essence, it expresses how our knowledge base—and prejudices—establish an *a priori* probability for something (that is, a prior belief in what will happen based on as much data and theory as is available). As we further study the system, obtaining more data and devising better theories, we amend our prior belief and establish a new, *a posteriori* probability—after the initial facts. This is called Bayesian updating. Over time, we keep revising our prior assumptions until eventually the facts converge on the real probability.

Since we cannot do experiments on the future before the fact, prediction is wholly a Bayesian exercise. This is precisely why the Intergovernmental Panel on Climate Change produces new assessments every six years or so, since new data and improved theories allow us to update our prior assumptions and increase our confidence in the projected conclusions, unless new data actually reduces our confidence, which happens sometimes as well.

That confidence still falls short of certainty for most aspects of the problem. For example, there is only maybe a 50/50 chance of sea level rising many meters in centuries to come. The conclusion cannot currently be objective, since the future is yet to come. However, we can use current measurements of ice sheet melting. We can compare them with 125,000 years ago, when the Earth was a degree or two warmer than now and sea levels were four to six metres (13 to 20 feet) higher. Because that ancient natural warming had a different cause (changed orbital dynamics of Earth around the sun) from recent and near future warming caused primarily from current anthropogenic greenhouse gas increases, we can't say with high confidence that a few degrees warming from greenhouse gases will also cause a four-to-six-meter rise in sea levels. But it undoubtedly indicates an uncomfortable—maybe 50/50 or more-- Bayesian probability of something similar to that happening inexorably in the next few centuries. This indeed was the conclusion of the Synthesis Report of the IPCC's Fourth Assessment in 2007, for exactly those reasons.

Some statisticians and scientists are leery of Bayesian methods. They prefer to stick only with empirical data and well-validated models. But what do you do when you don't have such data? One analogous example is found in clinical trials in cancer treatments, a subject in which I have had a very personal interest (e.g., see *The Patient From Hell*—Schneider, 2005). The so-called "gold standard" is a double-blind trial where half the patients receive a placebo and the other half receive the drug being tested, and neither the patients nor the researchers know who got what until the data are analyzed. After five or ten years, if there is a statistically significant difference between the recovery rate of drug versus placebo the trial is declared successful. The trial isn't designed to pinpoint individual differences. Even if we knew the odds of recovery for the average person from different treatments, there is a wide spread in individual responses. So medicine should try to tailor treatments to the individual's idiosyncrasies. That makes some doctors—and many insurance companies—nervous, but in my view is by far best medical practice. Likewise, some scientists and many policymakers are nervous about Bayesian inferences based on the best assessment of experts, preferring hard statistics. But as there are no hard statistics on the future, Bayesian methods are all we have. They are certainly far better than no assessment at all and hoping that all will work out fine with no treatment—that is no climate policy in this analogy. If we care about the future, we have to learn to engage with subjective analyses and updating— there is no alternative other than to wait for "Laboratory Earth" to perform the experiment for us, with all living things on the planet along for the ride. Whether to take that chance what risk management is about.

Risk Management. The basics are that scientists can help policymakers by laying out the elements of risk, classically defined as ***consequence x probability***. In other words, what can happen and what are the odds of it happening? The plethora of uncertainties inherent in climate change projections clearly makes risk assessment difficult. The inertia in the climate and socioeconomic systems and the fact that greenhouse gases emissions will continue to rise given the absence of strong mitigation policies (or unexpected events like a prolonged global recession) indicate that globally, most policy makers have been reluctant to make long term investments beyond their expected terms in office. But that is changing both in some regions like the EU, and even in the US. These kinds of decision makers are increasingly wary of making what is known as a Type II error—fiddling while the earth burns. A Type I error is a false positive, which in this case would mean taking action against climate change which subsequently proved relatively needless. Scientists are often leery of making a Type I error when data are scarce for fear of misleading society into un-needed actions and being blamed for undue alarm. The other kind, a Type II error, is a false negative, and in this case would mean assuming it is preferable to do little or nothing until there is less uncertainty, and subsequently finding that serious climate change ensues unabated with much more damages than if precautionary policies had been undertaken to adapt to and mitigate the effects. So it appears that our scientists are often Type I and our future-oriented decision makers Type II error avoiders. A less charitable interpretation of those reluctant to invest in precautionary adaptation and mitigation measures is that they know that the really adverse outcomes will likely occur in the future when current decision makers are not in office and not likely to be held accountable. The short term incentives are to delay action and pass the risks and the recriminations on to the next generation. None of this is scientific risk assessment, but value judgments on where and how to take risks and make investments in policy hedges—in short, risk management. But risk management is put on a much firmer scientific basis when the managers are schooled in the best risk assessments that state of the art science can produce.

IPCC Guidance on Uncertainties. To help decision makers, the IPCC produced a Guidance Paper on Uncertainties (Moss and Schneider, 2000) which was a foundation for the 2007 Fourth Assessment Report. I prepared the original draft with Richard Moss, now at a DOE lab at the University of Maryland, after convening a meeting in 1996 in which about 2 dozen IPCC lead authors met with decision analysts to fashion a better way to treat uncertainties in scientific assessments. The final guidance eventually agreed to within IPCC was a quantitative scale. We would define "low confidence" as a less than 1-in-3 chance; "medium confidence," 1-in-3 to 2-in-3; "high confidence," above two-thirds; "very high confidence," above 95 percent; and "very low confidence," below 5 percent.

It took a long time to negotiate those numbers and those words—and they change somewhat from assessment to assessment cycle. There were some people who still felt that they could not apply a quantitative scale to issues that were too speculative or "too subjective" for real scientists to indulge in "speculating on probabilities not directly measured". One critic said, "Assigning confidence by group discussions, even if informed by the available evidence, was like doing seat-of-the-pants statistics over a good beer." He never answered my response—"Would you and your colleagues think you'd do that subjective estimation less credibly than your Minister of the Treasury or the president of the US Chamber of Commerce?"

So we had two things we wanted everyone to use—a set of numbers defining the probability ranges for words such as "likely", and a set of qualitative phrases for our confidence in the results, going from "well established" if there was a lot of data and a lot of agreement between theory and data to "speculative" when there wasn't much data and there wasn't much agreement. We had "established but incomplete" and "competing explanations" for the intermediate cases.

And then for the next two years Richard and I became what a journalist later called "the uncertainty cops." I read three thousand pages of draft material for the IPCC's Third Assessment Report. People did not always use uncertainty terms according to our simple rules. For instance, they would say that because of uncertainties, we can't be "definitive." I wrote back, "What is the probability of a 'definitive'?" Early drafts would put the range of outcomes anywhere from a one to five degrees Celsius change in temperature. And then they would say in parentheses "medium confidence". That was completely incorrect. It was "very high confidence," because they were talking about the fact that *between* one and five degrees was a very, very likely place to arrive. But people didn't want to say "very high confidence" because nobody felt very confident about the state of the science at the level of pinning it down to, say, one degree. So Richard or I would help them to rewrite, and say that we have "low confidence" in specific forecasts to a precision of a half degree, but we have "high confidence" that the range is one to five degrees. Simple things like that were needed to achieve consistency of message.

Media False Balance. Meanwhile the political chicanery of ideologists and special interests was shamelessly exploiting systems uncertainty by misframing the climate debate as bipolar—"the end of the world" versus "it's good for you." The media compliantly carried it in that frame much of the time, too. But those were and are the two lowest probability outcomes. The confusion that bipolar framing has engendered creates in the public at large a sense that "if the experts don't know the answers, how can I, a mere lay citizen, fathom this complex situation?" To this, industry-funded pressure groups added the old trick of recruiting non climate-scientists who are skeptical of anthropogenic climate change to serve as counterweights to mainstream climate scientists. This spreads doubt and confusion among those who don't look up the credentials of the apparently contending scientists—and that, unfortunately, includes most of the public and too much of the media. The framing of the climate problem as "unproved," "lacking a consensus," and "too uncertain for preventive policy" has been advanced strategically by the defenders of the status quo. This is very similar to the tactics of the tobacco lobby and its three-decade record of distortion that helped stall policy actions against the tobacco industry, despite the horrendous health consequences and eventually billions of dollars in successful lawsuits against big tobacco.

In the face of such tactics, the IPCC assessment reports are intended to be the best achievable statement of current scientific consensus. But "consensus" is not necessarily built over conclusions, but the *confidence* we have in a host of possible conclusions. With that kind of information policy makers can make risk management decisions by weighing both the possible outcomes and the assessed levels of confidence—we know it well, sort of know it, or hardly know it at all. Scientists should just say what we do know and don't, or what is even knowable in a reasonable amount of time, and not leave something out of our assessment because it isn't a well-established consensus yet. It is the job of society, through its officials, to make the risk management decisions informed by our conclusions and accompanying confidence estimates.

Where next: A Personal Assessment? As I've said, normally science strives to reduce uncertainty through data collection, research, modeling, simulation, and so forth. The objective is to overcome the uncertainty completely — to make known the unknown. Short of that, new information may narrow the range of uncertainty. No doubt further scientific research into the interacting processes that make up the climate system can and will eventually—several decades I speculate--reduce uncertainty about the response to increasing concentrations of greenhouse gases. This is very unlikely to happen quickly, however, given the complexity of the global climate and the many years of high quality data which will be needed. Meanwhile, even the most optimistic "business-as-usual" emissions pathway is projected to result in dramatic, potentially dangerous climate impacts like increased area of wildfires in the US West, rising sea levels, intensified storms, more acute air pollution episodes, etc. That means making policy decisions before this uncertainty is resolved, rather than using it as an excuse for delaying action.

Risk management also means understanding what is truly uncertain, and what is not. Sometimes critics claim that there should be no strong climate policy until the science is fully "settled" and all major uncertainties resolved, whereas supporters of strong policies suggest the science is already "settled enough" and it is time to proceed with action to reduce risks because taking that chance with our planetary life support system is foolhardy. The science which demonstrates a significant warming trend over the past century *is* settled; moreover, it is virtually settled that the past several decades of warming have been largely caused by human activity and that much more is being built into the emissions pathways of the 21st century (IPCC, 2007). Sounds like the "settled already" side has won the debate: warming is occurring and human activities are the primary driver of recent changes.

That leaves the uncertainty about how severe warming and its impacts will be in the future, especially when projections for "likely" warming by 2100 vary by a factor of 6. The task then is to manage the uncertainty rather than master it, to integrate uncertainty into climate research and policymaking. This kind of risk-management framework is often practiced in defense, health, business and environmental decision-making. But the thresholds for action often seem lower. The US has a military that evaluates security precautions against many very low probability—but potentially dangerous—threats. Well, the climate change threat is not 1%. It's better than 50% for really significant trouble, and maybe 10-20% for absolutely catastrophic trouble. Who would take a 10% risk of crossing the street in the middle if there were that chance of being hit by a vehicle? We'd do it at the corner with the light in our favor at dramatically lower risk. We buy fire insurance for only a few percent risk of our house burning down. Thus the thresholds for risk aversion in health and business and defense categories are already quite low, and in fact much lower than many potential thresholds for irreversible climatic changes.

In my personal value frame, it is already a few decades too late for having implemented some climate policy measures, especially national standards for energy efficiency and public-private partnerships in new technology development. Had we begun mitigation and adaptation investments decades ago, when a number of us advocated them, the job of remaining safely below dangerous thresholds would be easier and cheaper. Similarly, beyond a few degrees Celsius of warming—at least an even bet if we remain anywhere near our current course—it is likely that many "dangerous" thresholds will be exceeded. Strong action is long overdue, even if there is a small chance that by luck climate sensitivity will be at the lower end of the uncertainty range and, at the same time, some fortunate, soon-to-be discovered low-cost, low carbon-emitting energy systems will materialize. For me, that is a high-stakes gamble not remotely worth taking with our planetary life support system. Despite the large uncertainties in many parts of the climate science and policy assessments to date, uncertainty is no longer a responsible justification for delay in either adaptation or mitigation policies.

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The CHAIRMAN. Thank you, Doctor, very much.

Our final witness today is Dr. William Happer. Dr. Happer is a professor in the Department of Physics at Princeton University. His research focuses on the fundamental interactions between atoms, molecules, and light.

Previously, he served on the faculty of Columbia University. Dr. Happer served as Director of Energy Research in the Department of Energy under the first President George Bush. He received his Ph.D in physics from Princeton. He is a member of the National Academy of Sciences.

We welcome you, Dr. Happer. Whenever you are ready, please begin.

STATEMENT OF WILLIAM HAPPER

Mr. HAPPER. Well, thank you very much, Mr. Chairman.

I am going to do my best. I really had less than 24 hours to try to put this together, so I ask your indulgence.

When you wrote me, you asked three questions. I am going to try and answer them one by one.

So the first question, to what extent does CO_2 lead to global warming—and we just heard from Stephen that IPCC says between 2 and 4 is a reasonable guess—I personally think there are very strong arguments that it is less than 2 degrees centigrade. If I were to take an educated guess, I would say less than 1 degree centigrade for doubling CO_2. Let me explain why.

This is a plot of CO_2, left to right. And on the vertical scale is the rise in the temperature of the Earth that is caused by these changes in CO_2. And what you see here is that we are now at about 380 in the outside air, if it is well mixed, and so we are about one-third of the way through here. We are in a region of this curve where adding CO_2 makes very little difference. So people say this is a saturated curve. You know, we are reaching a point of diminishing returns.

Why does this happen? Let me show you the next curve.

So this is what the Earth looks like. Actually, this is a model, but there are satellite pictures that look almost exactly like that, lots of them. And what you see here is wavelengths or the color of the infrared radiation going down, the amount of radiation at each of these different colors, different wavelengths. And you can see, indeed, there is less radiation going out at the CO_2 band. That is in the middle of the figure. That is that big gap. And there is a region, the infrared window, which is pretty clear where radiation goes out almost unimpeded if there are no clouds. And, finally, there are regions on the left and right which are heavily attenuated by water vapor and methane and nitrous oxide.

Now, the question is, what happens—look at that CO_2 band that is between the two vertical lines. What happens if we change the concentration? Well, okay. This is where we are today, 380 parts per million, maybe a little more now. Now, suppose you double that.

Let me have the next one. I am sorry, I couldn't get these on the same scale.

But what is the difference? Look at the CO_2 gap. There is very little difference. In fact, what happens when you add CO_2 is that you slightly widen the CO_2 absorption band. There is no question about this physics. And it is really not enough to cause very much warming.

So the alarming figures of warming assume that somehow this little effect of CO_2 is greatly amplified by water vapor in clouds. So that is really the heart of the scientific debate.

Okay. Next transparency.

Question two, How important are climate systems—clouds, water, vapor—simulated in computer models that are used to predict climate change? And, as I mentioned, most models predict that water vapor and clouds will greatly amplify CO_2, but there is little support for these observations.

In my haste to write this down, I dropped a word after water vapor and clouds. I say water vapor and clouds "may" diminish—please correct the record here—may diminish the warming due to CO_2. There is some evidence that is suggestive of that.

And furthermore, and most importantly, the models don't predict the big changes of temperature in the past where no fossil fuels were being burnt.

Next, transparency three.

Well, first of all, what about the present? These are the various IPCC reports and the central warming trend at each report. There have been, I guess, four of them. And you can see every single report has overstated the warming that has been observed, all been overstated. So I think there is an upward bias on the predictions.

Next transparency.

This is the celebrated temperature record from the year 1000 to the present. The first IPCC report had the upper figure. This is from Dr. Lamb, the first Director of the East Anglia Institute, showing a very pronounced medieval warm period. That is when the Vikings settled Greenland and when Greenland had less ice than now, probably. And the lower is the IPCC report in 2001. They completely eliminated the 1990 one and a completely different curve, which shows no medieval warming, no little Ice Age. So this is a worry.

Next transparency.

We heard this morning CO_2 referred to as a pollutant. I actually brought along a CO_2 meter. If you will permit me, I will look at the reading in this room. Would anyone care to guess what the CO_2 level in the room is? Well, okay. I sometimes offer a $10 reward.

Mr. SCHNEIDER. Four hundred and fifty.

Mr. HAPPER. Good, Steve. You are a good sport.

Mr. CICERONE. Five hundred and fifty.

Mr. HAPPER. Ralph wins the golden ring. It is 590. That is because of all my hot air and my friends here.

You know, when we exhale air, it is 40,000 parts per million in our exhaled breath. So CO_2 really is not a pollutant. You can call it many things, but I think that is really not fair.

This is CO_2 in the past. Look at the vertical scale. That is the levels in the past. It is measured in thousands of parts per million. It has almost never been as low in the past as it is now. So we are really in a very unusual time with respect to CO_2.

Next transparency.

Okay, so this was the final question to me, what policies are necessary to protect and improve scientists' ability to conduct research and share scientific information? I would like to argue that this debate is so important that it really has not had the right adversarial review that it needs. And I don't mean Internet diatribes. I mean serious studies by scientists.

I think we need the equivalent of a team B approach that is so often used—and very successfully—in DOD and CIA on important questions. You put together a real tiger team that is charged with coming up with what is wrong with the leading position. So I would strongly urge that such a team be formed, that it be supported by the government, and that it be given every opportunity to make its case.

Actually, the church used to do that for saints. There was always a devil's advocate, right? And if you wanted to be a saint, you had to get through this hurdle. We have not done that with climate change.

So that concludes my testimony. Thank you.

[The statement of Mr. Happer follows:]

CLIMATE SCIENCE IN THE POLITICAL ARENA

Statement of

William Happer
Cyrus Fogg Brackett Professor of Physics
Princeton University

Before the

Select Committee on
Energy Independence and Global Warming
U.S. House of Representatives

May 20, 2010

Mr. Chairman and members, thank you for the opportunity to appear before the House Select Committee on Energy and Global Warming. My name is William Happer, and I am the Cyrus Fogg Bracket Professor of Physics at Princeton University. I have spent my professional life studying the interactions of visible and infrared radiation with gases – one of the main physical phenomena behind the greenhouse effect. I have published over 200 papers in peer reviewed scientific journals. I am a member of a number of professional organizations, including the American Physical Society and the National Academy of Sciences. I have done extensive consulting work for the US Government and Industry. I also served as the Director of Energy Research at the Department of Energy (DOE) from 1990 to 1993, where I supervised all of DOE's work on climate change. The views I express today are my own, and not official views of my main employer, Princeton University, nor of any other organization with which I am associated. I was given less than 24 hours to prepare this testimony, so I beg your indulgence for deficiencies in it.

Let me state clearly where I probably agree with the other witnesses. We have been in a period of global warming over the past 200 years, but there have been several periods, like the last ten years, when the warming has ceased, and there have even been periods of substantial cooling, as from 1942 to 1975. Atmospheric concentrations of carbon dioxide (CO2) have increased from about 280 to 385 parts per million over past 100 years. The combustion of fossil fuels, coal, oil and natural gas, has contributed to the increase of CO2 in the atmosphere. And finally, increasing concentrations of CO2 in the atmosphere will add a warming *trend* to the natural warmings and coolings of the earth's surface. The key question is: how much warming will there be, and will the warming, and any other effects of the CO2, be good or bad for humanity? I, and many other scientists, think the warming will be small compared the natural fluctuations in the earth's temperature, and that the warming and increased CO2 will be good for mankind.

In his invitation letter, Mr. Markey asked me to comment on three questions. I will address these questions with crisp answers followed by some discussion.

Question 1: To what extent does CO2 lead to global warming?

Answer: Doubling CO2 will probably lead to less than 2C surface warming.

The earth's climate really is strongly affected by the greenhouse effect, although the physics is not the same as that which makes real, glassed-in greenhouses work.

Without greenhouse warming, the earth would be much too cold to sustain its current abundance of life. However, well over half of the greenhouse warming is due to water vapor and clouds. There is little argument in the scientific community that a direct effect of doubling the CO2 concentration will be a small increase of the earth's temperature -- on the order of one degree Kelvin. Additional increments of CO2 will cause relatively less direct warming because we already have so much CO2 in the atmosphere that it has blocked most of the infrared radiation that it can. The technical jargon for this is that the CO2 absorption band is nearly "saturated" at current CO2 levels. Adding more CO2 is like putting an additional ski hat on your head when you already have a nice warm one below it, but you are only wearing a windbreaker. The extra hat makes you a little bit warmer but to really get warm, you need to add a jacket. The IPCC thinks that this jacket is water vapor and clouds.

Most of the greenhouse effect for the earth is due to water vapor and clouds,. To get the frightening global warming scenarios that are bandied about, the added CO2 must substantially increase water's contribution warming. The jargon is "positive feedback" from water vapor and clouds. With each passing year, experimental observations further undermine the claim of a large positive feedback from water. In fact, observations suggest that the feedback is close to zero and may even be negative. That is, water vapor and clouds may actually diminish the relatively small direct warming expected from CO2, not amplify it. The evidence here comes from satellite measurements of infrared radiation escaping from the earth into outer space, from measurements of sunlight reflected from clouds and from measurements of the temperature the earth's surface or of the troposphere, the roughly 10 km thick layer of the atmosphere above the earth's surface that is filled with churning air and clouds, heated from below at the earth's surface, and cooled at the top by radiation into space. My own educated guess is that doubling CO2 from our current value of about 380 ppm to 760 ppm will warm the atmosphere by less than 2 C – and perhaps less if there is negative feedback from water-vapor and clouds.

This leads to Mr. Markey's second question:

Question 2. "How are important climatic systems (e.g. the role of clouds, water vapor, etc.) simulated in computer models that are used to predict climate change."

Answer 2. Most models predict that water vapor and clouds will greatly amplify the warming due to CO2 alone. There is little observational support for these predictions. Furthermore, the models do not explain relative large climate changes in past when there was negligible combustion of fossil fuels.

The current warming period began about 1800 at the end of the little ice age, long before there was appreciable burning of fossil fuel. There have been similar and even larger warmings several times in the 10,000 years since the end of the last ice age. These earlier warmings clearly had nothing to do with the combustion of fossil fuels. It is hard for many scientists to understand why some significant fraction of the current warming might not also due to similar natural causes. Over the past ten years there has been no statistically global warming. This is not at all what was predicted by the IPCC computer models. The existence of large climate variability in the past has long been an embarrassment to those who claim that all climate change is due to man and that man can control the climate. To the best of my knowledge, none of the climate models designed to predict future climate have been successful in explaining these past fluctuations of the climate. If you can't model the past, where you know the answer pretty well, how can you model the future?

I was very surprised when I first saw the celebrated "hockey stick curve," in the Third Assessment Report of the IPCC. Both the little ice age and the medieval warm period were gone, and the newly revised temperature of the world since the year 1000 had suddenly become absolutely flat until the last hundred years when it shot up like the blade on a hockey stick. This was far from an obscure detail, and the hockey stick was trumpeted around the world as evidence that the end was near. We now know that the hockey stick has nothing to do with reality but was the result of incorrect handling of proxy temperature records and incorrect statistical analysis. There really was a little ice age and there really was a medieval warm period that was as warm or warmer than today. I bring up the hockey stick as a particularly clear example that the IPCC summaries for policy makers are not dispassionate statements of the facts of climate change. It is a shame, because many of the IPCC chapters are quite good.

Modelers have been wrong before. One of the most famous modeling disputes involved the physicist William Thompson, later Lord Kelvin, and the naturalist Charles Darwin. Lord Kelvin was a great believer in models and differential equations. Charles Darwin was not particularly facile with mathematics, but he took observations very seriously. For evolution to produce the variety of living and fossil species that Darwin had observed, the earth needed to have spent hundreds of millions of years with conditions not very different from now. With his mathematical models, Kelvin rather pompously demonstrated that the earth must have been a hellish ball of molten rock only a few tens of millions of years ago, and that the sun could not have been shining for more than about 30 million years. Kelvin was actually modeling what he thought was global and solar cooling. I am sorry to say that a majority of his fellow physicists supported Kelvin. Poor Darwin removed any reference to the age of the earth in later editions of the "Origin of the Species." But Darwin was right the first time, and Kelvin was wrong. Kelvin thought he knew everything but he did not know about the atomic nucleus, radioactivity and nuclear reactions, all of which invalidated his elegant modeling calculations.

Question 3: What policies are necessary to protect and improve scientists' ability to conduct research and share scientific information with policymakers.

Answer 3. Global-warming alarmists have tried to silence any who question the party line of impending climate apocalypse. We need to establish a Team B of competent scientists, charged with questioning the party line. The DoD and the CIA do this, there was a devil's advocate (promoter fidei) for sainthood, why not the same for climate change?

The climate-change establishment has tried to eliminate any who dare question the science. This was made very clear in the Climategate Letters, which reveal the blacklisting of research that strays from the party line with the aid of hostile peer reviewers and helpful editors, and threats to any journal that did not cooperate -- in some cases leading to the removal of editors. Climate change science needs a "team B." This happens in many other areas, for example, weapons systems for DoD, or intelligence assessments at CIA. Both of these organizations, and many others, routinely establish robust team B's, that is, groups of experts who work full time, sometimes for several years, to challenge the establishment position. This has given us much better weapons systems and intelligence. The team-B concept has not been embraced by the climate change establishment. Indeed, we read testimony by Dr. James Hanson in the Congressional Record, that climate skeptics are guilty of "high crimes against humanity and nature." There are many similarly intimidating statements made by establishment climate scientists and by like-thinking policy-makers – you are either with us or you are a traitor.

Let me turn to a few additional thoughts that concern me today. I keep hearing about the "pollutant CO2," or about "poisoning the atmosphere" with CO2, or about minimizing our "carbon footprint." This brings to mind a comment by George Orwell: "But if thought corrupts language, language can also corrupt thought." CO2 is not a pollutant and it is not a poison and we should not corrupt the English language by depriving "pollutant" and "poison" of their original meaning. Our exhaled breath contains about 4% CO2. That is 40,000 parts per million, or about 100 times the current atmospheric concentration. CO2 is absolutely essential for life on earth. Commercial greenhouse operators often use CO2 as a fertilizer to improve the health and growth rate of their plants. Plants, and our own primate ancestors evolved when the levels of atmospheric CO2 were at least 1000 ppm, a level that we will probably not reach by burning fossil fuels, and far above our current level of about 380 ppm. We try to keep CO2 levels in our US Navy submarines no higher than 8,000 parts per million, about 20 time current atmospheric levels. Few adverse effects are observed at even higher levels.

We are all aware that "the green revolution" has increased crop yields around the world. Part of this wonderful development is due to improved crop varieties, better use of mineral fertilizers, herbicides, etc. But no small part of the yield improvement has come from increased atmospheric levels of CO2. Plants photosynthesize more carbohydrates when they have more CO2. Plants are also more drought-tolerant with more CO2, because they need not "inhale" as much air to get the CO2 needed for photosynthesis. At the same time, the plants need not "exhale" as much water vapor when they are using air enriched in CO2. Plants decrease the number of stomata or air pores on their leaf surfaces in response to increasing atmospheric levels of CO2. They are adapted to changing CO2 levels and they prefer higher levels than those we have at present. If we really were to decrease our current level of CO2 of around 400 ppm to the 270 ppm that prevailed a few hundred years ago, we would lose some of the benefits of the green revolution. Crop yields will continue to increase as CO2 levels go up, since we are far from the optimum levels for plant growth. Commercial greenhouse operators are advised to add enough CO2 to maintain about 1000 ppm around their plants. Indeed, economic studies like those of Dr. Robert Mendelsohn at Yale University project that moderate warming is an overall benefit to mankind because of higher agricultural yields and many other reasons.

That we are (or were) living at the best of all CO2 concentrations seems to be an article of faith for the climate-change establishment. Enormous effort and imagination have gone into showing that increasing concentrations of CO2 will be catastrophic: cities will be flooded by sea-level rises that are ten or more times bigger than even IPCC predicts, there will be mass extinctions of species, billions of people will die, tipping points will render the planet a desert. Any flimsy claim of harm from global warming brings instant fame and many rewads.

This brings up the frequent assertion that there is a consensus behind the idea of an impending disaster from climate change, and that it may already be too late to avert this catastrophe --even if we stop burning fossil fuels now. We are told that only a few flat-earthers still have any doubt about the calamitous effects of continued CO2 emissions. There are a number of answers to this assertion. First, what is correct in science is not determined by consensus but by experiment and observations.

Historically, the consensus has often been wrong. Secondly, I do not think there is a consensus about an impending climate crisis. I do not believe we are facing a crisis unless we create one for ourselves. Before making policy on climate change, we should heed the ancient bit of wisdom, "First, do no harm!"

The sea level is indeed rising, just as it has for the past 20,000 years since the end of the last ice age. Fairly accurate measurements of sea level have been available since about 1800. These measurements show no sign of any acceleration. The rising sea level can be a serious local problem for heavily-populated, low-lying areas like New Orleans, where land subsidence compounds the problem. But to think that limiting CO2 emissions will stop sea level rise is a dangerous illusion. It is also possible that the warming seas around Antarctica will cause more snowfall over the continent and will counteract the sea-level rise. In any case, the rising sea level is a problem that needs quick local action for locations like New Orleans rather than slow action globally. Indeed, had we taken a few of the many billions of dollars we have been spending on climate-change research and propaganda and fixed the levees and pumps around New Orleans, most of the damage from Hurricane Katrina could have been avoided.

I regret that the climate-change issue has become confused with serious problems like secure energy supplies, protecting our environment, and figuring out where future generations will get energy supplies after we have burned all the fossil fuel we can find. We should not confuse these laudable goals with hysterics about carbon footprints. For example, when weighing pluses and minuses of the continued or increased use of coal, the negative issue should not be increased atmospheric CO2, which is probably good for mankind. We should focus on real issues like damage to the land and waterways by strip mining, inadequate remediation, hazards to miners, the release of real pollutants and poisons like mercury, other heavy metals, organic carcinogens, etc. Life is about making decisions and decisions are about trade-offs. The Congress can choose to promote investment in technology that addresses real problems and scientific research that will let us cope with real problems more efficiently. Or they can act on unreasonable fears and suppress energy use, economic growth and the benefits that come from the creation of national wealth.

The CHAIRMAN. Thank you, Doctor, very much.

Now we will turn to questions from the subcommittee members, and the chair will recognize himself.

The gentleman from Wisconsin has mentioned a number of issues surrounding climate e-mails. One that he didn't mention and which might be the most scandalous was Vice President Cheney's refusal to accept an e-mail transmitted by the EPA Administrator, Steven Johnson, during the Bush administration, finding that carbon dioxide is a threat to public health and welfare.

The CHAIRMAN. In other words, it was actually the Bush administration EPA that made that determination, made the endangerment finding, but the White House refused to accept that finding, which necessitated for Lisa Jackson and the Obama administration to begin again and to make that finding in 2009.

I would like to ask all of our witnesses if they believe that the scientific evidence is strong enough to support the adoption of policies that would reduce carbon pollution.

Dr. Cicerone.

Mr. CICERONE. Yes.

The CHAIRMAN. Dr. Molina.

Mr. MOLINA. Yes, very much. Clarifying this is a statement that is individual, but the science is very clear that the risk is large. As an individual, I think it is not wise to take that risk.

The CHAIRMAN. Dr. Santer.

Mr. SANTER. Yes.

The CHAIRMAN. Dr. Schneider.

Mr. SCHNEIDER. Yes. My value judgment is the same as my other colleagues. I have fire insurance on my house for a 2 percent risk, and we are talking about a planetary life support system. With coin flip odds, it is a very serious change, and I don't consider it responsible to ignore such odds.

The CHAIRMAN. Dr. Happer.

Mr. HAPPER. No, I don't. I have explained why. I have explained that we are sitting in a room that is heavily polluted with CO_2 and I think more CO_2 would be good for the Earth.

The CHAIRMAN. Now, you have just heard what Dr. Schneider said about the fact that he takes out insurance on his home, fire insurance, even though there is only a 2 percent chance that he will ever have a fire. Is your conclusion based on your analysis that climate—your climate science conclusions are right and the consensus is wrong and, as a result, we shouldn't take measures that reduce the likelihood that this can happen, that is, more investment in renewables and carbon capture and sequestration and other technologies that can reduce this risk?

Mr. HAPPER. I am certainly in favor of further research in climate change. It is very important. But I do not believe that CO_2 is a problem, and I think more CO_2 would be good. And that is based on my scientific judgment.

The CHAIRMAN. More CO_2 would be good?

Mr. HAPPER. Yes.

The CHAIRMAN. Dr. Schneider, could you respond to that, please?

Mr. SCHNEIDER. You know, I am not sure that most of my marine biology colleagues would agree with that statement because there has already been a demonstrated increase in the acidification of the oceans. The lab experiments are suggesting that this is not only a threat to coral reefs but to the bottom of food chain for the carbon-based shells and that if we continue on past doubling of CO_2 it could very well threaten the bottom of the food chain in the ocean.

So whether you like CO_2 as a fertilizer of green plants or not—by the way, it also fertilizes weeds—you certainly would not like it in the oceans, and I would consider that to be a highly dangerous experiment to perform on the Earth.

The CHAIRMAN. Dr. Happer, how do you respond to Dr. Schneider in terms of——

Mr. HAPPER. Well, I am glad he brought that up, because the Earth has already done that experiment. I just showed you pictures of CO_2 in the past where the levels were, you know, 5,000 parts per million, 7,000 parts per million.

One of the ways we know that is from looking at carbonate shells in the mud and looking at the pH. You can infer that from the boron-tin or on 11 isotope ratios. So the ocean has already coped with that. Life flourished, you know. So I don't see the problem.

And the changes are very small. At levels of several thousand, the pH maybe gets down to 7.6. It is 8.1 now. That is half a unit of the pH scale. It is trivial.

The CHAIRMAN. Dr. Santer, how would you respond to Dr. Happer in terms of the oceans or any other part of his concerns?

Mr. SANTER. Well, I think my major disagreement with Dr. Happer relates to the feedbacks. Dr. Happer and I agree that, in the absence of positive feedbacks, the warming that we would expect due to a doubling of pre-industrial levels of CO_2 is relatively modest, less than 2 degrees Celsius. It is the feedbacks that concern me. They are primarily associated with water vapor, with clouds, and with snow and with sea ice.

I respectfully disagree with Dr. Happer's testimony relative to those feedbacks. His testimony indicates that the science indicates that the feedbacks associated with water vapor and clouds are likely to be close to zero. That is not the case.

Many assessments which have looked at the water vapor feedback, for example, have showed clear evidence, for example, from the special sensing microwave imager, that water vapor has been increasing in Earth's atmosphere since 1988. Those increases are consistent with very basic physical theory, with what we call the clausius clapeyron relationship.

Water vapor is a greenhouse gas. We expect it to amplify the CO_2-induced heating of the planet, and that is what we see in observations in climate models. We see that operating on a range of different time scales, on monthly time scales, between La Nina and El Nino, and even on decadal time scales. So, unfortunately, I think the observational evidence for a zero or close to zero water vapor feedback is just not there.

The CHAIRMAN. Thank you.

Dr. Molina, do you have a comment.

Mr. MOLINA. Yes. I again respectfully disagree—disagree very strongly with Dr. Happer's statements.

Take, for example, the geological record. I think if you—we certainly don't have very much time here to look at all the details, but here again, if you take a very serious scientific analysis of the record—I am talking about millions and millions of years—as carried out, for example, by Dr. Richard Alley, who recently has talked about these issues, it is very clear that this record shows indeed carbon dioxide is a very important component of the climate.

And, of course, we have seen very different environments in the past. We fund the experiment. Life also thrived in our environment before there was any oxygen, but that is many millions of years ago. It doesn't mean that we could do that again.

So relatively small changes in the system, the planetary system, at the moment on a short-time scale—we are talking about decades—could certainly have devastating consequences in principle for society. Certainly the climate has seen very large extremes millions of years ago, but we certainly would not want to go again through those extremes. It would be exceedingly unwise.

The CHAIRMAN. Dr. Cicerone, I would like to get your comments before my time expires.

Mr. CICERONE. Thank you.

Yes, I think the forcing due to carbon dioxide increases is significant, but when we add in the destabilizing effects of adding the increased water vapor is when the future predictions get worse.

Now, I disagree with what Dr. Happer said. We all know that, as we heat up water, it evaporates faster. In the wintertime, when we go around in very cold air, one of the reasons we have static electricity and so forth is that the air is so dry. It is a fundamental physical principle that—Dr. Santer mentioned the equation, but we don't need the equation to see it. We can measure it. Water does increase as the temperatures go up. Evaporation gets faster. The evidence in the atmosphere we are seeing shows that it is happening.

The burden of proof for such a strong statement that there is no increase in water vapor with warming temperature, the burden of proof has to be on those who claim that, because it is against not only theory but hundreds of years of observations.

Finally, about the paleoclimate changes when you go back hundreds of millions of years, Dr. Molina is right, that life on this Earth has thrived in all kinds of extremes, including a complete lack of oxygen. That doesn't mean that we would thrive.

Also, the changes, the rate of those changes, they took 50 million years to happen, 100 million years to happen. The changes that we are driving now are happening in decades. It is not clear that any living form can adjust so fast.

The CHAIRMAN. Thank you.

My time has expired. The chair recognizes the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

Dr. Happer, you and I do agree on some things; and, even if we didn't, I am one of the silly people who believe that we ought to be able to have a civil and intellectual discussion without calling names and threatening and that kind of thing, which is one of the tragedies at this moment in U.S. history that I will not contribute to.

You and I agree that atmospheric concentrations of CO_2 have increased over the last century and that combustion of fossil fuels has contributed to the amount in the atmosphere and that increasing amounts of CO_2 will increase the global temperature. I think our disagreement begins after that. You are saying that that—and this is a question—that that does not pose any danger to either the environment or the creatures on this planet; am I correct?

Mr. HAPPER. That is correct.

Mr. CLEAVER. In a garage that has been—with the doors closed and even with a reasonable amount of oxygen coming in and the car is left running, will that do any damage to an occupant in that garage?

Mr. HAPPER. Yes, of course. But not because of CO_2, because of CO, for carbon monoxide. I am not in favor of carbon monoxide.

Mr. CLEAVER. I am not, either. We agree again.

The point is—you may have just drawn it even clearer. So CO_2 is as harmless as oxygen.

Mr. HAPPER. CO_2—I am sorry. I just didn't hear.

Mr. CLEAVER. Is just like oxygen. It is harmless. It is not——

Mr. HAPPER. It is more than harmless. It is good. It is good for plants.

And just to follow your analogy, it is very common for greenhouse operators to buy lots of propane, not to warm the greenhouse but to burn the propane to make CO_2, which they funnel into the greenhouse like your carbon. They burn it so there is no carbon monoxide, you know, with excess oxygen. And the plants do just fine. You know, the CO_2 levels go from 380 to 1,000 at least, often 2,000, you know, in 15 minutes. The plants are very happy. They—it is worth doing that, because you get better product and all the little bugs and things do just fine. None of them die.

Mr. CLEAVER. Some plants don't seem to be happy. There are some plants that are not expressing joy, particularly when you go to some of the tropical areas, and there are some animals that are not happy. We were in Greenland and the Greenlanders were telling us how the little tiny shrimp are trying to get out of the warming waters. They don't seem to be happy. I mean, I don't want to have a theological discussion on happiness, but I am just——

Mr. HAPPER. Well, I think we are both for happiness and, you know, of course——

Mr. CLEAVER. I am for happiness without CO_2.

Mr. HAPPER. Animals are animals because they can move around in response to the environment. We do that ourselves. So do fish and shrimp.

Mr. CLEAVER. That is the point.

Mr. HAPPER. Yes. So what is new? They have always done that.

Mr. CLEAVER. Yes, I know. But they are doing it now.

Mr. HAPPER. Well, songbirds migrate from the cold to the warm, south when it is winter, you know. So migration has always——

Mr. CLEAVER. But they come back. They come back.

Mr. HAPPER. I am sure, yes.

Mr. CLEAVER. So you are saying that these tiny shrimp will come back?

Mr. HAPPER. They will find whatever part of the ocean is to their liking and that is where they will stay. And if it changes, they will move again.

Mr. CLEAVER. Dr. Schneider, please help.

Mr. SCHNEIDER. Yes, I am sorry—I agree with you about the importance of a civil dialogue, but I am sorry to say that the ecological naivete in what we just heard is legion. It is very, very well-known that the fragmentation of habitats into smaller and smaller places has nothing to do with climate. Land use and other areas as part of development are a significant threat to the preservation of species on Earth. That is well documented.

Now if you change the climate, as Dr. Happer correctly said, in the past species have been able to respond, though not all of them fully, but they didn't have to contend with 6½ billion people, some tightly locked into national boundaries, living in nutritional margins, and they didn't have to cross factories, farms, freeways, and urban settlements.

So it is the combination—as many reports at the National Academy of Science has shown, including some recent ones that Ralph Cicerone could tell you about, that it is what we call the synergism of the interaction of the fragmentation of habitat and then the forced migration across disturbed landscape threatens what the literature says somewhere between 10 and 40 percent of species going extinct, mountaintop species. This is not a happy situation if temperature change is more than a few degrees.

And while nobody can tell you whether it is at the 5 or 50 percent level, that is the kind of risk which, again, we are dealing with if we are going to have a business as usual. So it is in a sense absurd to argue that because things have happened before it is fine now, because we didn't have anywheres near the scale of the human enterprise, and this is a completely different time than any other in geologic history, and it always has to be analyzed relative to the human condition at the present.

Mr. CLEAVER. Thank you.

I yield back, Mr. Chairman.

The CHAIRMAN. The gentleman's time has expired.

The chair recognizes the gentleman from Washington State, Mr. Inslee.

Mr. INSLEE. I appreciate the panel in part because, where I live, we are already experiencing fairly dramatic negative changes associated with increase in carbon dioxide.

This is not a theoretical issue where I live. We have massive pine beetle kills in the forests of the State of Washington and Alaska, by the thousands and thousands of acres caused by changing climate today. This is not a theoretical issue.

Glacier National Park won't have any glaciers in it. It had 135 when I was born and will have zero when I die—I hope—if I live for the next several decades, anyway. We will have to call it the Park Formerly Known as Glacier.

The tundra is melting in Alaska. We are having to move cities. Shishmaref, Alaska, is having to be relocated because of the change in the shoreline.

This is not some abstract thing. We are already—and it is, frankly, a little stunning to me for anybody to say CO_2 increases are positive when we are already seeing these negative attributes happening to my constituents today. This is not some abstract thing.

But I want to ask about a specific one. Dr. Jane Lubchenco, who is an oceanographer from the Oregon State University, who now runs NOAA for us, she has testified that carbon dioxide, when we burn it, goes into the atmosphere, eventually ends up going into a solution in the oceans—and she didn't use this term—in what I will call an invisible oil spill. We have got a big visible one down in the Gulf, but it is an invisible one every time we burn oil, and that that CO_2 goes into the water, and it creates more acidic conditions in the water.

And during previous testimony we have been told that the concentration of acidic ions has increased about 30 percent in pre-industrial times, at levels that have never experienced this during humans' time on Earth.

So, first off, just a quick question. Does everybody on the panel agree that carbon dioxide, which has been caused by us burning fossil fuels, has dramatically increased the acidity of our world's oceans? If you can answer yes or no, if we can do this quickly. Thank you.

Mr. MOLINA. Yes.

Mr. CICERONE. Your numbers are correct, Representative Inslee.

Mr. SANTER. Yes.

Mr. SCHNEIDER. Yes, it has increased.

Mr. HAPPER. No, it has certainly not dramatically increased. It has changed——

Mr. INSLEE. Okay. Well—I am sorry——

Mr. HAPPER [continuing]. From 8.2 to 8.1 or 8.0, something——

Mr. INSLEE. Right. Well, that is a logarithmic scale as we know on the acidic, but the numbers of ions, it translates to about a 30 percent increase.

Could we have a chart? I want to say Dr. Happer suggested this is no big deal and nothing to worry about. Dr. Jane Lubchenco, who is our expert in the Nation on this—could we put a slide up on this?

This is a slide that shows, according to Dr. Lubchenco, what happens to terrapods—terrapods are these small plankton that constitute about 40 percent of the bottom of the food chain—and she has shown us experiments about what happened when you put terrapods in water that is as acidic as it will be at the end of this century if concentrations of carbon dioxide continue unabated, and what they do is that they dissolve.

You see on the left is a picture of the terrapod shell. It is made out of calcium carbonate that the little structure precipitates out of the water to form its body structure. It is a little shell. Now they put it in water that has the same acidity as the waters will have at the end of this century; and basically, over a period of 45 days, the shell essentially dissolves.

Now, Dr. Lubchenco has told us—who runs the National Oceanographic and Atmospheric Administration, who is a scientist from Oregon State University. She has told us that this presents a clear and present danger to the food chain of the oceans. Because, of course, this is the bottom of the food chain, these little plankton that end up feeding the whales eventually and the salmon and everything else. Now, she considers that a significant threat.

So if I can, if I could just ask the panelists, is it a realistic concern that the food chains of the oceans are in danger because of the changes in carbon dioxide which increase the acidity, not to mention the temperature—by the way, we have been told there will be no coral reefs during my grandson's lifetime because of the combination of acidity and temperature.

But forget temperature for a minute. Just because of acidity, is it clear that there is a relationship between carbon dioxide and the acidity of the oceans that does present a threat to creatures that use calcium carbonate in the oceans?

If we can start with Dr. Cicerone.

Mr. CICERONE. Yes. I have gone to several conferences where this early work has been discussed, and it is difficult to see any way around it. The changes are large enough, the sensitivity is high enough, and unless there is some unexplored niche which is going to stabilize things, it looks that serious, yes.

Mr. MOLINA. Yes, I totally think it is serious. Of course, if we have several million years to wait, hang around, maybe life would adapt okay. I mean, it wouldn't be a problem.

Mr. SANTER. Yes, I think it is a problem. And, again, the issue is the rapidity of these changes. While there have been changes in the past, as Dr. Happer showed, there is no analogue in the past for the current rapid changes that we are going through.

Mr. SCHNEIDER. It is certainly clear that there will be quite a large number of species percentage-wise that will be threatened. Not all will be, and we have to be careful of anyone who cherry-picks only one kind of species either entirely threatened or not threatened, but, as an integral, the ecosystem is an interconnected hole. Knocking out substantial percentages of it is a very high risk.

Mr. HAPPER. No, it is nonsense. Especially for the plankton, because they have a very high turnover rate. So they evolve extremely quickly because of the very short generation time. So they can easily adapt to anything we can do.

Mr. INSLEE. Maybe—if you will permit me one more question, Mr. Chair. Thank you. Or maybe even two.

Dr. Happer's statement is absolutely stunning to me because I think it is totally contrary to any accepted belief by any evolutionary biologist in the world today. I don't know how to say it in a more cataclysmic statement.

But I want to ask this to make sure we give you a chance to answer, Dr. Happer. You have basically said that we shouldn't worry about carbon dioxide because the only thing we really should worry about is if in fact it increases water vapor, if I understand your testimony, that that is where we really could have cataclysmic warming. But I want to make sure that my understanding is correct, and I will just go down through all the scientists here.

The increasing acidity of the oceans that we are experiencing through clear, unambiguous results—I met the NOAA ship when it docked in Seattle where it found some of these results off the coast of Washington and Oregon last year. I just want to make sure I understand that there is no question that this acidity will increase with increasing concentrations of carbon dioxide with or without any changes in the water vapor. Is that the correct scientific conclusion?

I will just go down the panel.

Dr. Cicerone.

Mr. CICERONE. Yes.

Mr. MOLINA. Yes, of course.

Mr. SANTER. Yes.

Mr. SCHNEIDER. Yes.

Mr. HAPPER. Well, let me qualify that. Changes in the water vapor means that the sea surface temperature has changed and that changes the solubility of CO_2. So there are slight correlations there, but the first approximation, that is correct.

And let me correct one thing. I didn't say that the key is water vapor. I said water vapor and clouds. I was careful to add clouds.

Mr. INSLEE. Yes. I think I understand.

Thank you, gentlemen.

The CHAIRMAN. The gentleman's time has expired.

The Chair recognizes the gentleman from Oregon, Mr. Blumenauer.

Mr. BLUMENAUER. Thank you, Mr. Chairman. I appreciate your courtesy. I was at two other meetings.

But I want to just see if I understand correctly, Dr. Happer, do you think the conclusion of many scientists, some of whom who are represented on this panel, whose research has tended to believe that climate change probably will have catastrophic impacts on the planet, do you think they are reaching this conclusion based on their interpretation of data to the best of their ability?

Mr. HAPPER. Yes, I think they are.

Mr. BLUMENAUER. And would you posit that of the many scientists that we have heard from in this committee before and the research that we have analyzed of those who believe that there are, in fact, serious impacts on the ecology and the economy of our planet and the impacts might actually be worse than we had anticipated while you think that changes will be small and may even be positive, would you agree that your position is, to be charitable, a minority position of the scientific community?

Mr. HAPPER. Oh, yes, I certainly agree. And in many cases in the history of science the minority has been right.

Mr. BLUMENAUER. But if you were a policymaker charged with making decisions based on what is a preponderance of evidence from people who in good faith are arriving at a starkly different and more serious conclusion where there is a catastrophic risk to the economy, the ecology, as opposed to taking remedial steps, many of which are things that experts are telling us we should do anyway—that we shouldn't continue to waste more energy than anybody on the planet, that we ought to be sensitive to the use of fossil fuels—wouldn't it be prudent for a policymaker to take action based on the overwhelming consensus of the scientific community to take steps that many think are important to do even if we weren't concerned about catastrophic climate change?

Mr. HAPPER. I think you should take steps that are independent of climate change. For example, energy independence is a good idea. You know, efficiency is a good idea. All of those are good ideas. Preserving the environment is something I am in favor of. But you should be careful about being stampeded into something.

It reminds me, I have often told my friends, of the prohibition frenzy, the temperance movement. So this is very similar to that. They were sincere people. They really thought it would help humanity.

Mr. BLUMENAUER. I will conclude on this point just because it is intriguing to me. I agree with you about the stampede for prohibition, but that wasn't driven by an overwhelming consensus of the scientific community with decades now of empirical research. It was largely ideological, political, sociological, without a scientific foundation. Wouldn't you agree that there is a slight difference between the political knee-jerk reaction to prohibition and listening to thousands and thousands of scientists who are interpreting very clear scientific trends? Isn't there a difference here?

Mr. HAPPER. Well, there is a little bit of difference. But, actually, you know, there are many scientists like me. I am not the only scientist. So there are many who feel the same as I do, and they are pretty good people.

Mr. BLUMENAUER. Thank you, Doctor.

Mr. Chairman, I appreciate your indulgence.

And I agree that you are a good person, and I agree that there are a few others who articulate similar positions. We have heard from some of them, because the Chairman and the Ranking Member have worked to make sure that in the course of 3 years we have had a broad cross-section of opinion.

But because we are legislating for the country and we are part of a global effort that—where actually most people think we are legislating for the planet, it seems to me that there is slightly a different standard and that it isn't an experiment with prohibition. This is based on science. This is based on stakes that are much higher.

And with all due respect to a few of the people, some of whom I have had a chance to meet and I find engaging and I think their evidence is worth listening to, but, for policymakers, it seems to me, Mr. Chairman, that it is not even close. And I do appreciate your indulgence here and what you have done to try to make sure that we look at the big picture.

The CHAIRMAN. I thank the gentleman very much.

I am going to recognize myself for a second round and other members as well, if they would like.

Dr. Santer, I thank you for your earlier comments on harassment, and I am wondering if you would be willing to share with us about the form of the harassment which you have experienced and, if you would, how this has affected your ability to do your job as a researcher at one of our national laboratories.

Mr. SANTER. Thank you.

This harassment, as I have indicated in my testimony, has really been ongoing since my role as convening lead author of the Detection and Attribution chapter of the IPCC's second assessment report back in 1996. Back then, I spent roughly 1½ years of my scientific career defending that balance of evidence conclusion of the IPCC and defending myself. Since then, I have encountered sporadic e-mail harassment. People like hiding behind the anonymity of their keyboards and think that, if you come up with results that they don't like, they can write to you, they threaten you.

Sometimes, this harassment has gone beyond e-mail threats. Several years ago, there was a knock on my door late at night, about 10 a.m.—10 p.m. I went downstairs to answer the door. There was no one there, but a dead rat had been left on my door-step, and a gentleman in a yellow Hummer drove off at high speed, shouting curses at me.

More recently, things have become a bit more serious in the aftermath of Climategate. The nature of these e-mail threats has been of more concern, and because of those concerns I have worried about the security and safety of my family. It is very troubling to me to think that, because of the job that I do and because of the findings I have obtained, my loved ones would be in harm's way. I don't know what to do about that.

Another concern is the use or, in my opinion, abuse of the Freedom of Information Act. The Freedom of Information Act is noble in intent to enhance transparency in government. I believe, however, that in the climate science arena and in other scientific arenas the Freedom of Information Act has been used not as a tool for valid scientific discovery but as a means of taking up the time of government-funded scientists engaging in fishing expeditions.

Many of the requests that I have seen in our community, some of the requests that I myself have received, have been frivolous. I don't know what to do about that, but the concern is that one or two individuals, if not constrained, could essentially use this kind of behavior to overwhelm us and prevent us from doing science in the public interest. That is a serious concern to me.

The CHAIRMAN. Dr. Schneider, what have you experienced?

Mr. SCHNEIDER. Well, there are flurries of very nasty e-mails. For example, a typical one would be, you communistic dupe of the United Nations' attempt to create a global government to take away American religious and economic freedom. You are a traitor and should be hung.

I mean, I get those fairly frequently. And, of course, you just ignore them. You never answer them.

The part that is most intimidating isn't so much to me but my young students and others do know this, so we discuss it, and some of them are concerned. There has been, as Congressman Cleaver mentioned, a loss in civil dialogue, which is very unfortunate, where people come to your meetings and, instead of listening, they just shout, you know, how you are unAmerican. I haven't had too many of those, but I have had colleagues that have, and that is unfortunate. So there has been substantial amounts of intimidation of that type.

I have had colleagues who have had letters written, myself included. Many of these e-mails are copied to my Deans and the President. Of course, it just leads us to have jokes about it, because they understand. But, by and large, this has never happened before. We have always had a spirited debate from the first—in the '70s when I testified to various bodies of this Congress on these issues. It was always civil. It was always bipartisan. And it has now gotten to the point where things have become accusatory and highly ideological, and that is very unfortunate.

The CHAIRMAN. Dr. Cicerone, both Dr. Santer and Dr. Schneider have been listed in the Virginia Attorney General request to the University of Virginia and you have mentioned about the impact that this level of politicalization of science could have upon young scientists. Could you expand a little bit upon that?

Mr. CICERONE. Yes. I do worry about the young scientists who I referred to earlier as a great asset we have in getting further the kinds of detailed information we need more and more in the future.

I remember several years ago when there were instances in our Federal Government of certain scientists whose testimony to Congress and in their reports was being reviewed at higher levels in the agencies by communications office. My big concern then, and I communicated with Science Advisor Marburger at the time, was that this would be a big discouragement of some of our scientists going to work in our government laboratories; and that is something that—we have to encourage the young scientists to work in our government labs. So I worry about this kind of intimidation.

In the case of Virginia, having been a university chancellor, I know that universities are pretty good at investigating all kinds of allegations. They can be sexual harassment. They can be racial bias. They can be political investigations. Universities know how to do them, and I think the University of Virginia is very capable of looking into these matters themselves without external threats and legal action, if there is any basis to them.

The CHAIRMAN. Thank you, Dr. Cicerone.

Dr. Molina, you won the Nobel Prize for your work in atmospheric chemistry of the ozone hole. Nobody disputes anymore that the ozone hole was caused by human activity and that the banning of ozone-depleting chemicals have helped to solve the problem. How do you compare the certainty of science related to the ozone hole to that of global warming?

Mr. MOLINA. Yes. The science of ozone hole started perhaps as a minority opinion, but then, of course, the scientific community examined it very carefully and experiments were carried out and so the science became very sound. In the case of atmospheric ozone, we have very clear experiments that show that that is the case.

In the case of climate change, I must say that there have been very impressive advances in recent years. But that several thoughts expressed here—we certainly acknowledge that there are uncertainties. That is why the research needs to be evaluated.

So the climate system is very complex, but I believe the scientific community with honesty and so on has really concluded that the problem is indeed very serious and needs assessing it in terms of probabilities. So the science is perhaps—it certainly is not perfect. Perhaps it is not quite as clear as in the case of the ozone hole, where you have this enormous phenomenon that you could directly examine with measurements. But, nevertheless, we have very striking evidence of increased frequency of floods, of droughts, and so on. So to me that is—as we have heard, of course, that is what you need as a policymaker to make decisions.

The CHAIRMAN. Dr. Molina, can you explain why you think there is so much manufactured controversy around the issue of global warming? What is special about this issue that draws so much controversy?

Mr. MOLINA. I think there are a number of factors.

There are certainly interest groups that feel they would lose—I am talking about perhaps business interests and so on. But there is also within the scientific community—perhaps there are some well-intended scientists that question the veracity, the authenticity of the science. But I think it is the fact that most of these questions have been examined in such a way that the news media has very much exaggerated the questions around it, the science itself.

And just the fact that this is a new situation for human society, that it is very clear that human society can actually affect the function of the planets—it was already clear with the ozone layer, but it was not as pervasive. All of our activities connected with energy are affecting this situation.

So I think it is just the science of the problem and the economic implications, which are also often not well understood, that explains the big difference.

The CHAIRMAN. Thank you.

The chair recognizes the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

Mr. Happer, let's go back to the garage. We both agree that carbon monoxide doesn't create joy, and so it will kill in a closed situation.

Mr. HAPPER. Right.

Mr. CLEAVER. You have got to help me. We have got the troposphere right here, down here, and then there is the ozone layer and then the stratosphere. Am I scientifically sound?

Mr. HAPPER. Yes. Yes.

Mr. CLEAVER. So do you agree that there are holes in the ozone layer?

Mr. HAPPER. Yes. Over South America—over the South Pole in the spring, southern spring.

Mr. CLEAVER. And so—stay with me and help me. So then we are not getting the protection that we would normally get in our atmosphere because some of the sun's rays are coming in. They are not able to bounce back into the stratosphere; am I right?

Mr. HAPPER. Well, I guess if we are talking about ozone, the concern there is the ultraviolet——

Mr. CLEAVER. Yes.

Mr. HAPPER [continuing]. Which is absorbed by ozone. And there are a couple of things to remember. It is over the South Pole. Not many people live there. And, also, you know, in the spring, the sun is just barely over the horizon. So it is just going over a very large slant path. So, in fact, the effects on living things are not very big.

Mr. CLEAVER. But you are saying that because it is over the Pole—South Pole?

Mr. HAPPER. South Pole.

Mr. CLEAVER. That essentially cancels out any negative impact?

Mr. HAPPER. Well, the point is that the sun is not shining from overhead in the south polar spring. It is just barely beginning to come above the horizon. You know, it has been below the horizon. So it is during that period that the ozone hole develops.

Mr. CLEAVER. Okay. So, in the garage, if we had a way for the carbon monoxide, the tailpipe emissions, to bounce out of the house, the person in the car might survive.

Mr. HAPPER. Yes, absolutely. Good ventilation, like this room has good ventilation. Without it, the CO_2 levels would be several thousand. You are right.

Mr. CLEAVER. Okay. Thank you.

The CHAIRMAN. The gentleman from Missouri's time has expired.

Mr. CLEAVER. Yes. My time has expired not—hopefully, we will get rid of some of the CO_2, and my time won't expire.

But the point I am trying to make, because I may be misunderstanding, tailpipe emissions are not bad. They are not creating a negative problem.

Mr. HAPPER. Yes, they create a negative problem because of the carbon monoxide, the CO, not the CO_2. They have CO_2 also in water and all sorts of other junk, but the CO is the bad stuff.

Mr. CLEAVER. So the carbon monoxide is getting out in the atmosphere?

Mr. HAPPER. Well, it gets into—lots of things put CO into the atmosphere, cars, as you mentioned, and it slowly gets oxidized because of the OH radicals and ozone, too, for that matter. But it doesn't last long.

Mr. CLEAVER. So it cancels it out.

Mr. HAPPER. It is eaten up by oxidants in the atmosphere.

Mr. CLEAVER. So the burning of fossil fuel is neutral. It creates no problem because we have got something eating it up.

Mr. HAPPER. Well, what gets eaten up is the carbon monoxide, which is very dangerous, very poisonous. And the CO_2 doesn't do anything because, as you and I breathe, we are exhaling CO_2, which is much more concentrated than you get in the exhaust of a car, at least comparable to that. It is 40,000 parts per million. It is a lot of CO_2. That is why the CO_2 in this meter is so high.

Mr. CLEAVER. I know, but the point I am trying to make is that tailpipe emissions are not doing any damage to the atmosphere.

Mr. HAPPER. Well, if you are in the Los Angeles basin, for example, they create smog, usually not because of the CO but because you don't burn all the hydrocarbons, and then with complicated—you know, change in reaction, it makes this horrible haze that covers Los Angeles.

Mr. CLEAVER. So if it is in Los Angeles, people in Waxahachie, Texas, shouldn't be concerned.

Mr. HAPPER. Well, I think they should be concerned. I have a daughter in Los Angeles, you know, and many people have relatives. You want them to have a healthy environment. So I am all for getting rid of smog, and you can do that by, you know, technical means.

Mr. CLEAVER. Dr. Molina.

Mr. MOLINA. My opinion of this, of course, I think we are talking about air pollution, which is clearly something that should be controlled. Fortunately, new devices, catalytic converters and so on, remove a significant fraction of the carbon monoxide that gets in the air. But air pollution is just a good analogy. It is something we have the knowledge to eliminate, and so society wouldn't question now the need to use catalytic converters.

We could not live in Los Angeles—the air in Los Angeles in the 1960s was just unbearable. So society had to invest to remove these pollutants. And even though that was questioned at that time by some sectors of society, some economic interests, nobody questions that now it is certainly a wise solution.

There is another important connection because air pollutants turn out to not only have a large impact from the public health perspective, but they also affect climate. Besides CO_2, tropospheric ozone and soot and so on are significant factors in the climate change issue. So we certainly need to take a very close look at all these activities of human society, many of them connected with burning fossil fuels, and they all point to a clear need to change the way society functions so that we preserve not just better human health in urban centers but a better functioning planet. That is very clear.

Mr. CLEAVER. Thank you.

The CHAIRMAN. The gentleman's time has expired.

The chair recognizes the gentleman from Washington State, Mr. Inslee.

Mr. INSLEE. Thank you.

I have just taken a look at this demand letter from Attorney General Cuccinelli of Virginia demanding correspondence of dozens of scientists, including Dr. Santer and Dr. Schneider, and it is the most clearly abusive thing that I have seen for a long time, basically trying to treat scientists, Nobel Prize winners, like members of the Corleone family. And I am just offended at the use of—and I used to prosecute cases. I have to tell you I am offended at somebody politicizing a science in an obvious attempt to try to intimidate people who are trying to get at the truth, and I just have to say that.

I want to read a letter that was published in Science Magazine May 7, and it is an open letter. It was signed by about 250 United States scientists. They are all members of the United States National Academy of Scientists. These are respected people.

Here is what they said, and I want to see if members of the panel agree with what they said. This is just a paragraph out of the letter:

We also call for an end to McCarthy-like threats of criminal prosecution against our colleagues based on innuendo and guilt by association, the harassment of scientists by politicians seeking distractions to avoid taking action and the outright lies being spread about them. Society has two choices: We can ignore the science and hide our heads in the sand and hope we are lucky or we can act in the public interest to reduce the threat of global climate change clear and substantively. The good news is that smart and effective actions are possible, but delay must not be an option.

Can I just ask the panelists if you agree with that statement. Dr. Cicerone?

Mr. CICERONE. I don't think I would have used the word "McCarthy-like" tactics. I think it just escalates. Otherwise, I agree with it.

Mr. MOLINA. I agree.

Mr. SANTER. I agree.

Mr. SCHNEIDER. I signed it. I agree.

Mr. HAPPER. Well, I agree with the first part. I am against harassment, and there has been too much of it for too long of science. But it didn't start with Virginia, you know. A lot of it started here on Capitol Hill. Many of us remember John Dingell's prosecution of David Baltimore, for example, which was every bit as bad as this. So I am certainly very much opposed to that, and I hope it can be stopped.

You know, I think the statement is conflated with taking immediate action on CO_2. I don't agree with that part.

Mr. INSLEE. So if Mr. Cuccinelli was here today, Dr. Happer, would you tell him to knock it off?

Mr. HAPPER. Yes, definitely.

Mr. INSLEE. Well, I appreciate that statement.

I wanted to talk again a little bit about ocean acidification. Dr. Happer has suggested that these are small changes in the acidity of the oceans, the relative acidity. Because, on the logarithmic scale, the changes are from about 8.2 to 8.1 and maybe it will go down to 8.0 at the end of the century. He suggested those are small changes.

Dr. Molina, could you give us a little chemistry lesson about why those—you may not think those are small changes?

Mr. MOLINA. I think it is misleading to say small or big. We are talking about small changes in the concentration of CO_2 in the atmosphere or very large changes, depending on the context you are talking about. So from the perspective as explained by Jane Lubchenco, those are very worrisome changes. That is what I would state clearly.

But you measure the effects on ecological systems and the effects are clearly noticeable and they would have a significant impact on the food chain. I would call those very worrisome changes. Whether small or large, that is just semantics, perhaps.

Mr. INSLEE. Thank you. And you have indicated worrisome enough to suggest we actually take action; is that right?

Mr. MOLINA. Yes.

Mr. INSLEE. Thank you.

Dr. Happer has suggested we need not worry about this problem because evolution will take care of it. As the oceans become more acidic, as the Arctic melts, as the tundra melts, as Greenland melts, as the pine beetles ravage the forests, as they have the forests of my State by the thousands of acres, that evolution will just solve these problems.

Is there any anything in the literature to suggest that the polar bear can evolve fast enough to maintain its continuity with no Arctic ice to live on and hunt from? Is there any suggestion that the polar bear can sort of just evolve in the next two or three generations to be a land-based species and find out how to build hunting traps of its own or something? Is there any suggestion in the literature that that can happen in the next two or three or maybe ten generations of polar bears?

Go ahead, Dr. Happer.

Mr. HAPPER. Well, it is pretty clear during the neolithic 4 or 5,000 years ago, the northern hemisphere was probably 3 degrees warmer—2 or 3 degrees warmer than now. The polar bears did just fine.

Mr. INSLEE. And how about coral reefs? Is there any suggestion in the literature that coral reefs—Dr. Ken Caldeira of Stanford, who is a world-renowned oceanographer, was here some time ago and said that at the acidity levels that we will experience by the end of this century because the acidity levels are changing and increasing in the ocean, at those acidity levels it is doubtful that there will be any healthy coral reefs on the planet Earth, looking at the way coral responds to changes in acidity.

Is there any suggestion that coral reefs within that period of time or some kind of—evolve a new way to precipitate calcium carbonate out of the ocean so that they can remain healthy? Is there any suggestion of that?

Mr. HAPPER. Well, again, most of the coral reefs that we see, the fossil coral reefs, were at much more acidic conditions by the standards we are talking about now because they evolved with CO_2 levels that were thousands of parts per million.

Mr. INSLEE. Well, this is one place, Dr. Happer, that I am going to have to respectfully disagree. I understand you are a man of science, but you are not an oceanographer or a biologist, and the biographers and the oceanographers tell us that, in fact, those life forms have not existed in anything close to levels of acidity that exist in the world's oceans.

Does anyone disagree with that statement other than Dr. Happer?

Dr. Schneider, yes.

Mr. SCHNEIDER. The biota that existed way back, you know, in the years of the dinosaurs and so forth when we had more CO_2 and warmer, were very, very different than now. They didn't also have to deal with all the other multiple stresses associated with humans like toxic runoff and warming oceans at high rates. It is the rates that really matter.

And, therefore, you cannot use that analogy. Because even though nobody would argue that all life will disappear, in fact, warming will make some species better off, the problem is how do you maintain the vast diversity of life to which we have had a co-evolution of climate and life when you have very, very rapid disturbance? That is the worry. The worry is losing tens of percents of the existing species, not that there won't be some species that will do better. And losing tens of percent is a very significant threat to the ecosystem, particularly when it provides services such as food that we need.

If we lose the coral reefs as we now know them, even though there will be some that will survive, then a major source of protein for poor people is lost, in addition to these little entries, as I think of them, as nature's books in the library of Alexandria, these existing species which have co-evolved over this time, and there is a fundamental ethical question whether we should risk losing them just so that one species gets so much richer a few years faster.

Mr. INSLEE. So if I can ask just—I was in Panama and met a scientist who was studying the effect of carbon dioxide on the rainforest, and he was up on one of these cranes that go around 2 acres. It was actually the first one ever in use. And he said that they have found that the lianas, which are the vines, have increased their acreage, that they cover at the top of the forest by as much as 30 percent because the lianas can metabolize carbon dioxide much faster than the other structures in the forest that take a structure. They don't really have any structure. They just grow leaves. So they go nuts. So he basically said the lianas are taking over the forest canopy of the rain forest. So it is good for lianas but bad for the structural stuff that it can eventually choke out.

Now, what he told me—and this has stuck with me. He said, you know, we are involved in the largest experiment in the history of the planet Earth and we are the guinea pigs and we don't know how this is going to turn out.

I am just going to ask your comments, if the panelists agree with that assessment.

Mr. CICERONE. I think that is a pretty fair assessment. Roger Revelle and other people said it 30 years ago, referring to this great geophysical experiment.

For example, on the ability of some plant species to prosper, carbon dioxide is not the only limiting nutrient. They also have to have water. They have to have nitrogen, fertilizer, trace minerals. And indeed the paths to photosynthesis in some cases don't even depend directly on the amount of carbon dioxide, the different paths to photosynthesis.

Mr. CICERONE. The different paths to photosynthesis of sorting all of this out is going to take a great deal of commitment, and the problem is the changes are happening faster so far than our ability to sort it all out. That is why people talk in these grandiose terms about conducting an experiment, that we don't know how it is going to turn out.

Mr. MOLINA. I certainly agree as well. We are conducting that experiment, and we already see some evidence.

But the thinking is, if the Earth warms only a little bit, clearly there might be beneficial effects and also effects that are not beneficial. But what seems to be a consensus—we see that from the frequency of droughts, floods, and so on—there seems to be a consensus that if we change the system significantly, because we are doing that very fast, and because of the fact that it is very vulnerable—that is another big change we have now with respect to 50 million years ago. We have 6 billion people on the planet, so society is very vulnerable now. It is very fast changes. We will certainly be limiting the feasibility for them to really have the economic well-being as they deserve.

Mr. SANTER. Yes, I believe we are performing a grand experiment, and there is no control, there is no parallel Earth without human intervention. That is a concern to me.

As Dr. Happer correctly pointed out, things have been different in the geological history. There have been changes in carbon dioxide, other greenhouse gases, clearly changes in the fauna and biota. But the key thing here is that we are now a forcing of climate, and the changes that are happening now have no geological analogue. They are too rapid. We don't know how this experiment is going to turn out, but it is happening.

Like you, I actually see evidence of this. I am a climber. I have spent a lot of my life, the last 35 years, in high alpine environments around the world. I have seen these changes in glacials. I have seen these changes in fragile high-alpine environments. They are real, they are happening now, and future generations will be experiencing these places in a quite different way from the way that you and I experience them. That is a cause for serious concern for me at least.

Mr. SCHNEIDER. Congressman Inslee, let me rephrase your correct insight that these things operate as a system. Remember, it is called an ecosystem because it is a system. If you take any individual plant and you put it in a chamber and you give it more CO_2, it generally likes that. When you go out in a system, as Ralph Cicerone said, with multiple nutrient variations, some plants are given competitive advantage over others. You can actually decrease some plants by crowding them out. So you are making a very rapid change to a system. And what that does to the structure and, most importantly, for us, the functioning of that system, is a great deal of uncertainty.

But this experiment that we are performing—and I would obviously have to agree with your question, because my 1997 book had the title, Laboratory Earth: The Planetary Experiment We Can't Afford to Lose, so clearly I agree with the metaphor. However, we are not entirely ignorant. And, remember, as I said earlier in my testimony and as the IPPC frames and National Academy studies, we can sort out components of this that are well-established, so we really are not ignorant at all. And if we didn't have many of them, you would not find the large numbers of climate scientists expressing concern as we are now. Then there are components with competing explanations where we worry about the coin flip odds, but there are still going to be speculative parts.

So we do not know the full outcome of this experiment, but we are absolutely certain that we are going to confer advantage to some species at the expense of others, which will cause extinction. And we are absolutely certain that most people don't think that that is a good idea.

Mr. HAPPER. Well, the climate has changed all the time over all of geological history on every time scale, from decade to decade, to century to century, millennium to millennium. So just during the past 10,000 years there have been many periods when it has been much warmer than now. In fact, there were periods when there were no glaciers in the West. So things like Glacier National Park are not an old feature. They are a fairly new feature, even during the last 10,000 years.

Mr. INSLEE. Thank you, Mr. Chairman.

The CHAIRMAN. The gentlemen's time has expired.

I am going to ask Dr. Cicerone a question; and then, after I finish with that, we are going to come back in reverse order and ask each of you to give us a 1-minute summation of what it is, a 1-minute, minute-and-a-half summation of what it is that you want this committee and the Congress to know as we move forward, taking into account the fact that Senator Murkowski may actually bring a resolution to the Senate floor within the next several days to overturn the endangerment finding made by the EPA on the question of the impact of CO_2 and greenhouse gases on our planet.

So this interaction of science and politics is very clear, and it is something that could be debated on the Senate floor almost immediately after the conclusion of their debate on the financial regulation overhaul bill, which they are now considering.

Dr. Cicerone, you mentioned that the National Academy of Sciences issued three reports yesterday. Can you briefly outline the recommendations of the reports on policies needed to reduce carbon dioxide and to adapt to climate change impacts?

Mr. CICERONE. Yes. The report that was released yesterday was requested by the previous Congress more than 2 years ago. And, as I said, we divided up—the request was basically, if I can paraphrase, to issue a report stating what we know about climate change, how real is it, what are the causes, what to expect, and then what should the country do about it. I am paraphrasing.

The Panel on the Science of Climate Change has received most of our attention this morning, what we have already known, how we know it, how we can improve our knowledge. The experts who wrote that report and our reviewers agreed that it is important to continue the physical science side of climate research, of course. We need a lot better information.

They think it is also important to tune some of our future research towards the needs of, for example, how do we limit the amount of climate change to happen in the future and how we adapt to the changes which cannot be managed. So the second and third part—and they said that the evidence for climate change is very credible and strong, and it has grown over the last 4 or 5 years as well.

The limiting part of the report focused on the need for, instead of doing something for 1 year, to come up with a longer-range strategy that could be sustained and improved with time. So they focused on, for example, carbon dioxide emissions over a period of the next 40 years and said that there is a need for a national target of what should be the cumulative emissions over the 40-year period and then come up with strategies to deal with it, starting with the easiest things like energy efficiency and the low-hanging fruit, all the way through to further out basic research to identify completely new technologies. Because they concluded, without any reasonable target for total emissions between now and the next 40 years, we don't have the technologies in place on the shelf to meet the energy needs of the growing world population.

The third part of the report was adaptation; and the goal there was, given that there will be some changes which cannot be limited, cannot be avoided, how should we adapt? And rather than trying to come up with a detailed strategy for every locality in the country, because the local needs and the regional changes are different, they emphasized the need for a national strategy which would play out locally, how to encourage and coordinate adaptation mechanisms which must be placed locally, the needs of the Gulf Coast being different from the Pacific Northwest and New York City, for example.

So, in essence, the report takes the problem seriously. It says, as Dr. Molina said a minute ago, that the future size of the problem looks unmanageable unless we commit now to a sustained strategy of limitation and adaptation.

The CHAIRMAN. Thank you, Dr. Cicerone, very much.

Now we will ask each of the witnesses to give us their summation statement to the committee, and I would ask you to limit it to 1 minute or so. And we will begin with you, Dr. Happer.

Mr. HAPPER. Well, my advice to policymakers here in Congress is that you take a deep breath and think a little bit more about the scientific evidence and remember the oath that you doctors used to have to take. It is, first do no harm. And in the case—I mentioned the similarity of this excitement to prohibition. And then, too, as I said, everybody was for it, and they were for sincere reasons. I can understand that. But it was the wrong thing to do. So it was the only amendment that has ever been repealed. So I hope you will remember that and be careful what you do.

The CHAIRMAN. Thank you.

Dr. Schneider.

Mr. SCHNEIDER. Yes. Just a few hanging points I will try to do quickly.

One is, we have been talking about this issue of skepticism, and some have done denial. I just want to very quickly put in perspective, there is no such thing as a good scientist who is not a skeptic. I began my career thinking that dust and cooling was more likely than warming, found out what was wrong with it, and I am very proud to have published first what was wrong with my own ideas. We evolve our ideas on the basis of evidence.

A denier is someone who does not admit the preponderance of evidence based upon the overwhelming amount that is out there. That is exactly what IPCC and National Academy of Sciences does, is it convenes teams to assess preponderance. Because individuals are not very good at assessing risk by itself as to what can happen, what are the odd parts? Our job in society is risk management, how to deal with it.

Number two is, I am disappointed that Congresswoman Blackburn left, because she made a statement that I hear all the time when I get these angry e-mails: Oh, you are just in it for the money. So what really is frustrating to those of us who do this is that if our strategy were to get money then the last thing we are going to say is that it is unequivocal that there is warming and very likely that humans are responsible most of the last 50 years. Because then you don't need us. Then you are now making risk management judgments. What we are saying is we don't know anything; fund us to do it. So not only are we being accused of dishonesty, but we are also being accused of being pretty dumb.

So what we do is separate out the relative components we know well from the others, and it is not at all about getting grants. That is just simply a political statement I would love to discuss with the congresswoman.

Also, Congressman Sensenbrenner made the comment that climate scientists are very frustrated and had inappropriate attempts to control things. Well, yes, they were very frustrated. They are a tiny minority of scientists, and their frustrations were never acted on by the IPCC.

But for those people who claim it is only climate scientists who express human emotions and frustration, why don't they just simply release the so-called "climate skeptics," all their interchanges of their own e-mails over the last 10 years and let the public decide which of them have been more strategic in their plans. And until they do that, their accusations have no merit whatever.

And, finally, I wanted to come out and say, from the committee's perspective, in the conversation that Congressman Cleaver was talking about about air pollution—and everybody agreed that getting the pollutants which are health threatening out of cities is a good idea—well, some of those pollutants are generated by inefficient processes. So let's look for co-benefits and win-wins.

And, obviously, in the legislation that you have been involved in, you are trying to find those elements where solving one problem also helped to reduce CO_2 emissions so that you can solve both at once at relatively lower costs. It is a very, very good operating principle.

And the final thing is, the question of civil dialogue. For a very, very long time there was an unwritten social contract between science and society, especially the Congress, where again our job was risk: What can happen and what are the odds? And your job is what to do about it. And this water gets muddied by the people who don't see preponderance, by the statements of attributing to people that they are doing it for money or other kinds of things. So then what happens is it becomes a political story, and the risk part and the risk management part get lost in the middle. The public is confused; and, unfortunately, that is the state that we are in now. And I appreciate the opportunity to try to see if we can get that restoration of civility and the separation of function between the science job of risk and the public policy job of risk management.

Thank you, sir.

The CHAIRMAN. Thank you, Dr. Schneider.

Dr. Santer.

Mr. SANTER. I would like to follow up on that briefly.

Like Steve, I believe that we are impelled by curiosity. Scientists want to figure out the way the world works. They want to get the science right. That is why I chose to be a scientist, not because I had any hidden agenda there. And the work that I do, fingerprinting, has been fascinating to me. It is like a big detective story. Who done it? Was it the sun? Was it volcanos, natural climate variability?

The powerful thing in that work is that you are looking not at just one global mean number, the average temperature of the planet. You are looking at very detailed geographical patterns of change, altitudinal patterns of exchange. You are looking at different variables, as I have said, not just the surface temperature but variables related to the ocean, to atmospheric moisture, to atmospheric circulation, to rainfall. And the bottom line from all of that work is the climate system is telling us an internally and physically consistent story, and the message in that story is natural causes alone cannot—repeat, cannot—explain the absurd changes we have seen.

You have a very difficult job. You have to figure out what to do about it. I believe that it is important for you to do that job based on the best available scientific information.

Again, some of the developments we have seen over the last 6 months in particular are worrisome to me. I think there are powerful forces of unreason, as I have called them out there, forces that would like to mandate the scientific equivalent of "no go" areas. You do research in that area and come up with findings we don't like, we will come down on you like a ton of bricks.

I do not think that that is in the best interests of the American public. I think that in order to take smart decisions on what to do about climate change we need an informed, scientifically savvy electorate, and I hope that you will allow us to let that happen.

The CHAIRMAN. Thank you, Dr. Santer.

Dr. Molina.

Mr. MOLINA. Just to summarize what I said in my testimony before, namely, that the science is very clear, namely, that the science of climate change, that there is a significant probability that if human activities continue unchanged that we will seriously impact the climate with potentially very negative consequences. And that is the type of information that allows decisionmakers to evaluate the risk.

I must add that there is another important component: What does it take to address this change? And that is for economic studies. And so there, again, it is clear that we are not talking about huge sacrifices. We are not talking about even, for developing countries, threatening economies so that everybody achieves that higher standard of living. If we do it cleverly, it is quite clear from this perspective that the risk of having serious damage to society is serious and the probability is much larger that we will suffer if the necessary actions to confront climate change are not taken by decisionmakers like yourself. So I think the case is quite clear from this perspective.

And, lastly, I just want to mention in the context of our testimonies here I certainly agree that we have to respect minority perspectives, and minority opinions in science have had important roles. But, in this case, why I challenged these minority opinions is I haven't seen reports or documents or articles in the literature recently that seriously question these challenges. Of course, I am not talking about the existence of uncertainties, but I think the incentive is precisely the other way around, and it is often said that you cannot get these articles published because of the peer-reviewed system. No, if you actually can document and make a strong case, clear, scientific and so on, that will be very valued by society. You will became famous. It is far from happening. There are practically no—I am sorry to say, but I haven't seen in recent years anything serious in the literature questioning these basic conclusions that we are reaching.

The CHAIRMAN. Thank you, Doctor Molina.

And Dr. Cicerone.

Mr. CICERONE. Yes, thank you.

First, I would like to say that the United States science effort on climate change is really admired around the world. We have been leaders, and we really would like to stay that way, partly because to be able to recognize claims that are made elsewhere in the world and to evaluate what the rest of the world is increasingly coming up with we have to be in a leadership position, and that is going to take a sustained commitment.

In my contacts with the business community, which are frequent, I think a lot of business leaders are willing to work with you and eager to work with you to create a sustained commitment not only to the scientific research but also to an effort to limit the size of these climate changes and to get on with preparing adaptation mechanisms for the ones that do occur, to take preemptive action and effective action. And I think the world markets that will develop for more energy efficient products, for example, and ways to deal with these issues are substantially positive, and the United States can and should be in a leadership position, but it is going to require a sustained commitment.

The CHAIRMAN. Thank you, Dr. Cicerone, very much.

We thank each of you for your testimony here today. It is especially relevant in a period of time that could be immediately preceding Senator Murkowski's resolution coming out onto the Senate floor, which would reject the EPA's finding that CO_2 is a danger to the planet. That kind of debate, in my opinion, is the same kind of debate that occurred during the Scopes trial in the 1920s over the issue of evolution. It is the same kind of denial that was based upon religion, and here it would be the religion of fossil fuels as opposed to the actual science of the time.

I think in the 1920s religion, unfortunately, was still given too much credence when it came to the questions of science. It was given too much credence in terms of prohibition. And, in both instances, history looks back and wonders why so much weight was given to religion and its impact on public policy, both on prohibition and on the question of evolution. Well, we are about to have that debate again in the United States Congress, as unbelievable as it may seem, given the scientific consensus that human activities are leading to a dangerous warming of our planet.

Your ability to be able to bring science to Congress ultimately is going to be essential to our ability to put the policies in place that will make it possible for us to avoid the most dangerous consequences of global warming. The planet is running a fever. There are no emergency rooms for planets. So, as a result, we have to engage in preventative care. And that will mean relying upon the science that will give us the impetus to put the policies in place that will reduce the chance that we will in fact inflict those dangerous global warming consequences on the planet.

We thank each of you for being here. This hearing is adjourned. Thank you.

[Whereupon, at 11:30 a.m., the committee was adjourned.]

Responses to June 11, 2010 Follow-up Questions from
House Select Committee on Energy Independence and Global Warming
Addressed to Dr. Ralph J. Cicerone

These responses refer to the numbered questions addressed to me from Minority Party Members.

1) 1. Did the panel report on "Advancing the Science of Climate Change" consider the works of scientists skeptical of the view that the earth is warming because of human activity?

A: Here are several examples of references to scientific works that take the view on which you focus.

(1a). That cosmic rays might affect climate, see page 155: Shaviv (2002), Svensmark (1998), Svensmark(2006) and Gray et. al. (2005). Counterevidence is provided by later references.

(1b). That decadal scale natural variability might explain some of the recent warming trend, see page 160: Swanson et. al. (2009).

(1c). Further discussion on alternative driving mechanisms that might underlie climate change and the lack of evidence for them is on page 168.

Also, some of the work of Dr. John Christy is referenced in the Science Panel Report:
(1d). Satellite-data records on temperatures a few kilometers above the Earth's surface from John Christy and colleagues, see page 164-165.

2) You're aware of the Climategate scandal which has cast a shadow on the integrity of the data from CRU. Similarly, concerns exist about data from NASA's GISS. For example, according to a recent article in *American Spectator*:

- Dr. Reto Ruedy of GISS admits in an email that "[The United States Historical Climate Network] data are not routinely kept up-to-date."
- In another email, he reveals that NASA had inflated its temperature data since 2000 on a questionable basis. "[NASA's] assumption that the adjustments made the older data consistent with future data... may not have been correct," he says. "Indeed, in 490 of the 1057 stations the USHCN data were up to 1C colder than the corresponding GHCN data, in 77 stations the data were the same, and in the remaining 490 stations the USHCN data were warmer than the GHCN data."

Do these revelations give you pause about the quality of the data from the above mentioned institutions?

A: No, because publicly available records from NASA's Goddard Institute and from the NOAA Climate Data Center provide detailed chronological accounts of how *data from all sources are received, treated and handled, and of all revisions to the records. This information is available from their Web sites and publications listed there. Further, the equal balance between positive differences and negative differences which you quote indicate that any uncertainty is random and not systematically biased.*

3) You speak highly of assessment reports, such as those put out by the IPCC.
   - Are you concerned about the errors in the 4th assessment?
   - Do you think the IAC review of the IPCC procedures is justified?
   -
   - *A: Yes, the errors seem to have been in Working Group II (Impacts and Adaptation). Peer review should have detected poorly based numbers in 2006-07 long before the items were noted in 2009-10. Also, as I noted in my May testimony, in the Working Group I report (Physical Science Basis), I was concerned about an underestimate. While not an error, WGI underestimated likely sea-level rise during the 21st Century. While this rise is not understood well, data after 2005 show that the rise is proceeding faster than IPCC (2007) reported.*

A: I favor the engagement of the InterAcademy Council to review IPCC for the United Nations and for the World Meteorological Organization. The IAC is drawing from the world's best scientists in their review. All organizations can benefit from external reviews.

4) What is the ideal level of atmospheric CO2? The current level of 385 ppm, the pre-industrial level of 280 ppm, the 1000 ppm used in many greenhouses to enhance plant vigor?

A: *I don't know. Some plants and animals do better at one level, others at other levels. Ice-core records show that carbon dioxide levels (measured directly from dated cores) have varied between 180 and 280 ppm over the last 650,000 years, never less and never more. This record includes four Ice Ages and the times in between them. So our current human-elevated level of 390 ppm is out of its natural range for this long period of time. Going back many millions of years, it is likely that CO2 was higher although we do not have any direct measurements.*

The rate of change of CO2 amounts is important in eventually answering your question. The answer probably depends on how fast CO2 amounts are changed from one level to another. Current rates of increase are very fast compared to geological changes.

5) If CO2 levels could be stabilized by massive changes in the world's economy, would this stop further climate change?

A: Stabilizing CO2 concentrations where they are now would result in further temperature increases because the Earth's energy budget is not yet in equilibrium with this artificially elevated concentration. A further warming of perhaps one degree F is to be expected even with immediate CO2 stabilization. Also, other greenhouse gases including methane, nitrous *oxide, and a variety of fluorinated chemicals will continue to cause global warming (unless their concentrations are decreased, not just stabilized). Furthermore, there will be continued naturally caused climate changes (from certain kinds of volcanoes and other agents).*

6) A March 4, 2010 e-mail (see below) from Professor Trevor Davies, Pro Vice-Chancellor of Research, Enterprise & Engagement, of the UK's University of East Anglia, to UK government Chief Scientist John Beddington, was obtained through a freedom of information request and is now available on the web.

   It states that Martin Rees, President of the UK Royal Society, was asking you to approach the two American members of the Oxburgh Panel that was to investigate the University of East Anglia in the aftermath of the release of the Climategate - Kerry Emanuel of MIT and Lisa Graumlich of the University of Arizona - to "warm them up," while Davies asked Beddington to "warm up" David Hand, another panel member.

   The Oxburgh Panel was supposed to be providing an independent appraisal and I find the idea that panel members were contacted ("warmed up") by presidents of their respective National Academies and the UK government Chief Scientist disturbing.

   - Did you indeed contact Drs. Emanuel and Graumlich?
   - If so, what was nature of those contacts?

A: I contacted Dr. Emanuel but not Dr. Graumlich.
A: Lord Martin Rees, President of the Royal Society, asked me to tell Emanuel and Graumlich that they would be invited to serve on the Oxburgh Panel, and to encourage them to accept the invitation. I told Dr. Emanuel that Oxburgh is highly respected as an earth scientist. Oxburgh is also known for his work at Shell Oil (non-executive chairman, 2004-05) and at the U. K. Ministry of Defence (chief scientific advisor, 1988-93).

Signed, Ralph J. Cicerone
July 6, 2010

Answers to additional questions submitted to Mario Molina by members of the Select Committee on Energy Independence and Global Warming.

June 17, 2010

1) *You have served as an author of the IPCC 4th assessment, which has received considerable attention lately for errors identified in that body of work; you are also the only person of the 12-member review committee established by the UN to evaluate the procedures and processes of the IPCC. Given your close association with the IPCC report, please explain to this panel how you expect to participate in this review in a fair and impartial manner?*

I believe I can indeed participate in the IPCC review committee in a fair and impartial manner. First of all, the Committee is not charged with assessing the validity of the criticisms, or with discussing the errors in question. The charge is to make constructive recommendations to improve the chances that the next review process (which has already started) is carried out as best as possible. In fact, some of the most constructive suggestions to improve the IPCC process come from experienced IPCC members. Needless to say, the plan is to take into account all reasonable suggestions.

In particular, the Committee is not charged with assessing the validity of the main conclusion of the 4th assessment, namely that there is a significant probability that the observed average surface temperature increase is a consequence of human activities, mainly (but not exclusively) the burning of fossil fuels. As I stated in my Testimony, I do agree with that conclusion, but this matter will not be taken up by the Review Committee. Furthermore, the fact that I am the only person who has served as an IPCC author makes it unlikely that the report will have some sort of bias, as the UN is counting on the integrity of all the members of the review committee.

2) *Do you believe the IPCC's 4th assessment included errors?*
   - *What procedural flaws do you believe led to those errors?*

I do believe the IPCC's 4th assessment included errors. For example, for the projected disappearance of the Himalayan glaciers the assessment reported the wrong year; also reported was the wrong percentage of 'land below sea level' in the Netherlands.

The IPCC process does have tight review and quality control procedures, which were not properly applied in these cases, and improvements on this issue are in order. These procedures are well documented and are described in the IPCC web page; every step in the preparation of all the components of the assessment is described as well, including the review process. Note, however, that the errors in question were not part of the Summary for Policy Makers of Working Group I and have little if any impact on the main scientific conclusions of the assessment.

3) *At the InterAcademy Council hearing in May, IPCC Chairman Rajendra Pachauri defended the use of grey literature (non peer-reviewed materials) as part of the scientific record on climate change.*
    - *Do you agree with him?*
    - *Should unproven science from such grey literature be allowed in IPCC reports?*

I do agree with the use of grey literature, if properly flagged, evaluated and validated by expert judgment.

Gray literature often contains relevant information not available in the scientific literature, but of course not all gray literature is reliable. Note that the peer-reviewed literature often contains erroneous results as well, so that it also needs to be carefully assessed. Clearly, peer review by itself does not guarantee high quality and reliability; it is by no means the case that peer-reviewed articles describe "proven" science and that in contrast gray literature contains "unproven" science.

In any event, practically no gray literature was employed by Working Group I, which dealt with the scientific aspects of climate change. On the other hand, the reports of Working Groups II and III would be clearly incomplete if based on peer-reviewed literature alone. For example, data provided by the International Energy Agency is internally reviewed and considered reliable by most experts; etc. The bottom line is that any reference –peer reviewed or not– needs to be properly evaluated by experts in the field, as prescribed by IPCC rules and procedures.

4) *Your testimony describes potentially catastrophic changes to the Earth's climate system if certain "tipping points" such as temperature increases of 8 to 10 degrees Fahrenheit are reached; in your opinion, what is the likelihood of that occurring if the world continues business as usual practices?*

In my opinion the likelihood that certain "tipping points" will be reached if the world continues business as usual practices is of the order of 10 to 30%. This opinion is based on my reading of the scientific literature; it is, of course, not a rigorous statistical conclusion, but rather it is based on the consensus opinion of experts on this topic. The point is that the risk is unacceptable –but, as stated in my testimony, here I am speaking as an individual, not as a scientist. It amounts to playing Russian roulette with the climate system, at least from the perspective of some of the most vulnerable population.

5) *Given the failures of the Kyoto Protocol and the recent climate change talks in Copenhagen, what suggestions do you have to require the GLOBAL community – particularly nations like India and China - to participate in CO2 reducing schemes?*

I believe that it is essential for developing nations to participate in greenhouse gas reducing schemes; developed nations alone cannot effectively deal with the problem. In fact, China is already the largest emitter of greenhouse gases; China, Brazil, Mexico, South Korea and other countries with emerging economies need to reduce emissions as well and cannot continue with business-as-usual growth if the problem is to be successfully addressed. On the other hand, most of the poorest countries need not participate at this stage.

It is indeed a challenge to effectively reach an international agreement involving both developed and developing countries. The main reason justifying such an agreement is that all nations would benefit, and that the overall cost to the economy would most likely be larger if no such agreement can be negotiated in the next few years. Fortunately most emerging economies appear to be ready to accept commitments to pursue low-carbon economic growth plans, and most developed nations agree that a significant transfer of funds to developing nations needs to be arranged to facilitate the implementation of such economic growth plans. There are unfortunately many problems with the specifics –binding versus voluntary commitments, accepting specific emission targets versus energy intensity targets, amount of economic resources needed, etc. I am, however, optimistic that a suitable international agreement will be negotiated sometime within the next several years, to be further refined in future years.

6) *What is the ideal level of atmospheric CO2? The current level of 385 ppm, the pre-industrial level of 280 ppm, the 1000 ppm used in many greenhouses to enhance plant vigor?*

First of all, let me clarify that the choice of best level of atmospheric greenhouse gases is not a matter of science alone; science can only estimate in probabilistic terms what is likely to happen if various levels are reached. Another important piece of information comes from estimates of the costs of reducing emissions, a fast and drastic reduction being more expensive. On the other hand, delaying emission controls could result in very high costs in the future. I thus agree with the consensus of experts, implicitly accepted in Copenhagen by more than a hundred heads of state, that a two degree Celsius target is reasonable; that is, society should strive to reduce emissions to an extent such that the average surface temperature does not increase more than about 4 degrees Fahrenheit, which corresponds approximately to 450 ppm CO_2.

Furthermore, I would like to connect the answer to this question to that of question 4: an important goal is to reduce significantly the risk of reaching dangerous tipping points. Furthermore, besides economic issues we should keep in mind ethical issues, that is, our responsibility to future generations. Thus, here again the 4 degrees Fahrenheit limit mentioned above appears reasonable.

7) *If CO_2 levels could be stabilized by massive changes in the world's economy, would this stop further climate change?*

Some climate change has already taken place, and some more is inevitable, because of the inertia of the system (the frequency of floods and droughts has already increased; many glaciers are melting; etc.). The point is, however, that continued emissions would most likely lead to further changes, most of which would be associated with negative impacts, and some of which would be practically irreversible on a millennia time scale.

Massive changes are indeed needed to achieve the required emission reductions –changes in energy sources, in energy efficiency, etc., as is well documented in the literature. However, those changes do not imply massive changes in the world's economy. The consensus among informed economists is that the cost would be of the order of one or two percent of global GNP, significantly smaller than the cost of inaction. Furthermore, delaying the required emission reduction measures makes it increasingly more difficult and more expensive to remain below the desired limit to the average surface temperature increase.

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

June 11, 2010

Dr. Santer:

Following your appearance in front of the Select Committee on Energy Independence and Global Warming, members of the committee submitted additional questions for your attention. I have attached the document with those questions to this email. Please respond at your earliest convenience, or within 3 weeks. Responses may be submitted in electronic form, at sarah.butler@mail.house.gov. Please call with any questions or concerns.

Sarah Butler
Chief Clerk
Select Committee on Energy Independence and Global Warming
(202)225-4012
sarah.butler@mail.house.gov

Questions from the Majority:

1. Some argue that because ice core data show that changes in carbon dioxide lag changes in temperature, carbon dioxide must be a feedback rather than a forcing for the climate system. What is your assessment of this argument?

Response: This argument is flawed. This is not an "either/or" proposition. CO_2 is part of a natural feedback mechanism on ice age timescales, but has been a non-natural forcing mechanism since the Industrial Revolution.

On long, ice age timescales, there is clear evidence that CO_2 (and other greenhouse gases) act as a feedback, amplifying the changes in the amount and distribution[1] of the solar radiation received at Earth's surface. Changes in solar radiation occur on timescales of tens to hundreds of thousands of years. These changes are the primary driver of ice ages. They are caused by slow variations in the tilt of Earth's axis, the precession (or gyroscopic "wobble") of the axis, and the eccentricity (or degree of ellipticity) of Earth's orbit around the Sun.

The ability of the ocean to absorb or "draw down" atmospheric CO_2 is temperature dependent. CO_2 absorption is more effective at lower temperatures. During ice age conditions, therefore, the oceans absorb more atmospheric CO_2, thus reducing the natural greenhouse effect of the planet and amplifying the cooling caused by the

[1]The changes in the distribution of solar radiation are a function of both season and latitude.

changes in solar radiation. Cooler ice age conditions also slow down vegetative decay, thereby reducing the release of CO_2 to the atmosphere, and further amplifying the orbitally-induced cooling.

Changes in Earth's orbital parameters are not important over the past 150 years. They do not operate on such short timescales. The rapid increase in atmospheric CO_2 since the Industrial Revolution is mostly due to the burning of fossil fuels. We know this because fossil fuel burning has a distinct signature in isotopes of carbon.

For the first time in the history of our planet, CO_2 and other greenhouse gases are primarily acting as forcings in the climate system, rather than as a feedback to orbital forcing. The lag between temperature and greenhouse gases in ice core records[2] does not cast doubt on the importance of CO_2 as a forcing of recent changes in Earth's climate.

A detailed discussion of this issue is given in Jansen *et al.* (2007). For an excellent non-technical treatment of the "CO_2: Forcing versus feedback?" question, please refer to a 2007 article by Zeke Hausfather in the Yale Forum on Climate Change and the Media[3].

Questions from the Minority:

2. As recently as March 2009, you responded to an e-mail from Phil Jones - where he complains about a dispute with the editor of a magazine published by the Royal Meteorological Society – by telling him that you will not submit any papers to a journal that requires you to make your raw data available. Why?

    i. *At 16:48 19/03/2009, you wrote:*
    Thanks, Phil. The stuff on the website is awful. I'm really sorry you have to deal with that kind of crap. If the RMS is going to require authors to make ALL data available - raw data PLUS results from all intermediate calculations - I will not submit any further papers to RMS journals. Cheers, Ben
    ii. *http://www.eastangliaemails.com/emails.php?eid=967&filename=1237496573.txt*

Response: My statement to Professor Jones in the purloined email was very clear. *"If the RMS[4] is going to require authors to make ALL data available – raw data PLUS*

[2]This lag is estimated to be of the order of several hundred years.

[3]http://www.yaleclimatemediaforum.org/2007/10/common-climate-misconceptions-co2-as-a-feedback-and-forcing-in-the-climate-system/

[4]RMS stands for "Royal Meteorological Society".

results from all intermediate calculations – I will not submit any further papers to RMS journals." Please note use of the phrase of *"ALL data – raw data PLUS results from all intermediate calculations."*

The questioner misunderstands the point of this exchange. The raw data used in our research were freely available.

The key issue raised by my email exchange with Professor Jones is reproducibility. When Scientist A publishes a paper in the peer-reviewed literature, Scientist B should have access to all of the raw ("primary") data necessary to evaluate the credibility of Scientist A's findings.

In October 2008, my colleagues and I published a paper in the *International Journal of Climatology* (Santer *et al.*, 2008). The paper compared observed estimates of atmospheric temperature change (from weather balloons and satellites) with temperature changes estimated from computer model simulations. The raw computer model data used in our paper *International Journal of Climatology* are publicly available to anyone in the world.[5] The satellite and weather balloon data employed in our research are also freely available to any researcher.

Scientists who were not involved with the 2008 Santer *et al. International Journal of Climatology* paper had access to the same raw computer model data we had analyzed. It was possible for other researchers to perform independent checks on all of our calculations; to test the reproducibility of our results; and to examine the appropriateness of our conclusions.

As noted in my email exchange with Professor Jones, I do not believe that it is necessary for scientists to provide journals with every single product generated during the course of work on a scientific paper. I do not believe that scientists must supply journals with results from all intermediate calculations performed with raw data, or with all computer codes used in completing such calculations.

My responsibility was to provide other scientists with the raw data required to independently reproduce the results of the 2008 Santer *et al. International Journal of Climatology* paper. I fulfilled this responsibility.

Should you require further information regarding this specific email exchange with Phil Jones, please refer to a recent posting on "Real Climate"[6].

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[5]This is the so-called CMIP-3 database (Coupled Model Intercomparison Project, version 3) of computer model results. Currently, over 3,500 climate scientists around the world make use of these computer model results.

[6]http://www.realclimate.org/index.php/archives/2010/02/close-encounters-of-the-absurd-kind/

The relevant section of this posting is entitled *"Climate auditing: Close encounters with Mr. Stephen McIntyre"*.

3. As a major player in the Climategate e-mails, have you ever manipulated any data or paper or study in order to fabricate a document that bolstered the argument for human influenced global warming, when in fact that was not true?

Response: No.

4. Your testimony notes that you were "privileged to work together with exceptional scientists...like Tom Wigley, Phil Jones, Keith Briffa and Sarah Raper."

Response: I stand by this statement. Tom Wigley, Phil Jones, Keith Briffa, and Sarah Raper are exceptional scientists. Their research has substantially improved our scientific understanding of the nature and causes of climate change.

5. Do you disagree with the conduct of any of these scientists exposed in the Climategate emails?

Response: Intense scrutiny has been devoted to the conduct of Phil Jones, Keith Briffa, and other scientists mentioned in the purloined "Climategate" emails (such as Professor Mike Mann of Penn State University). To date, three formal investigations into issues arising from "Climategate" have concluded their work and published final reports. These investigations were undertaken by: 1) The U.K.'s Parliamentary Science and Technology Committee; 2) Lord Ron Oxburgh; and 3) Penn State University. All three investigations have fully exonerated Phil Jones, Keith Briffa, and Mike Mann of baseless charges of data manipulation, research misconduct, unethical behavior, *etc.*

For example, the Oxburgh Report found: *"no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit and had it been there we believe that it is likely that we would have detected it. Rather we found a small group of dedicated if slightly disorganised researchers who were ill-prepared for being the focus of public attention."*

The Oxburgh report specifically highlights the importance of the research conducted at CRU:

"We believe that CRU did a public service of great value by carrying out much time-consuming meticulous work on temperature records at a time when it was unfashionable and attracted the interest of a rather small section of the scientific community. CRU has been among the leaders in international efforts to determining

the overall uncertainty in the derived temperature records and where work is best focussed to improve them."

6. What is the ideal level of atmospheric CO2? The current level of 385 ppm, the pre-industrial level of 280 ppm, the 1000 ppm used in many greenhouses to enhance plant vigor?

Response: This question is ill-posed.

Consider first the case of "plant vigor". In experiments conducted in enclosed greenhouses, elevated CO_2 levels can indeed promote the growth of certain types of plants. In the real world, however, plant productivity is controlled by a variety of factors, including nutrient and moisture availability. Plant growth is not controlled by atmospheric CO_2 alone. In order to understand the potential impacts of human-caused climate change on agricultural systems, analysts must examine projected changes in temperature, rainfall, soil moisture, and other climatic variables. They must consider many different aspects of these changes – not simply changes in average climatic conditions, but also changes in the seasonal timing and variability of climate, and in the frequency, duration, and intensity of extreme climatic events.[7]

The most recent international assessment of climate change impacts concluded that agricultural systems in some regions would experience a net benefit from human-caused climate change. Crop productivity was *"projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1-3°C depending on the crop, and then decrease beyond that in some regions"* (IPCC, 2007a).

At lower latitudes, however, particularly in seasonally dry and tropical regions, crop productivity was *"projected to decrease for even small local temperature increases (1-2°C), which would increase the risk of hunger"* (IPCC, 2007a).

These complex findings illustrate the difficulty of making statements about "ideal" atmospheric CO_2 levels based solely on plant growth experiments conducted in greenhouses.

A related point is that "ideal" conditions for "plant vigor" are not necessarily ideal conditions for the development of *Homo sapiens*.[8]

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[7]Such as floods and droughts.

[8]Note also that the increasing acidification of the world's oceans is one consequence of increasing levels of atmospheric CO_2. "Ideal" CO_2 levels for the "vigor" of terrestrial plants are highly likely to be less than ideal for a variety of marine organisms with calcareous shells.

Virtually all of human civilization developed over the past five thousand years. During most of this time, atmospheric CO_2 levels remained relatively stable, at values close to 275 ppm.[9] This period of stability in atmospheric CO_2 concentrations ended at the start of the Industrial Revolution. As noted in the IPCC's Fourth Assessment Report:

"Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years... The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture" (IPCC, 2007b).

We now know, beyond a shadow of a doubt, that human activities have changed the chemical composition of Earth's atmosphere, and that these human-caused changes in atmospheric chemistry have altered Earth's climate. This is immutable fact, not speculation. Humans are active agents of change in the climate system. We are no longer merely passive bystanders.

As discussed in my written testimony (dated May 20, 2010), we have observed large and coherent changes in many different aspects of Earth's climate. The oceans and land surface have warmed. The amount of water vapor in the atmosphere has increased. Glaciers have retreated over most of the globe. Global-mean sea level has risen. Snow and sea-ice extent have decreased in the Northern Hemisphere. The troposphere has warmed. 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.

Our best scientific understanding is that these changes in climate will become larger – and even more obvious – over the course of the current century. Over the coming decades, human-induced climate change will have profound effects on many aspects of our lives (IPCC, 2007a). It will have even larger impacts on the lives of our children and grand-children.

In summary, the ideal atmospheric CO_2 level for "plant vigor" is unlikely to be the ideal CO_2 level for the stability and peaceful development of human civilization. Current atmospheric CO_2 levels are now over 30% higher than they were prior to the Industrial Revolution. A doubling of the pre-industrial level of atmospheric CO_2

[9]See, for example, Figure 6.4 in Jansen *et al.* (2007).

would yield a climatic state very different from that under which human civilization developed. This is of concern to me. It should be of concern to all of us.

7. If CO2 levels could be stabilized by massive changes in the world's economy would this stop further climate change?

Response: This question is also ill-posed. I assume that the intention here is to ask whether "further climate change" could be completely halted by stabilizing atmospheric CO_2 levels at or close to current values (emphasis added).[10]

If this is indeed the intended question, the answer is "no". Stabilization of atmospheric CO_2 would not completely "stop" further climate change. Stabilization would, however, reduce the size of future changes in climate, and it would reduce the severity of deleterious impacts of climate change.

The key scientific issue here relates to the thermal inertia of the oceans. Because of the huge total heat capacity of the oceans, it takes many decades for the climate system to come into equilibrium with current levels of atmospheric CO_2. Even if we had some means of instantaneously stabilizing atmospheric CO_2 at present-day levels (we do not), the climate system would continue to warm, and global-average sea-level would continue to rise. This is frequently referred to as "unrealized" or "committed" warming.

In its Fourth Assessment Report, the IPCC analyzed computer model experiments designed to study this "unrealized" warming. In these experiments, levels of atmospheric CO_2 (and other greenhouse gases) were held fixed at levels observed in the year 2000. The primary result was that:

"*...even if all radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios*" (IPCC, 2007b)[11].

Because of the thermal inertia of the oceans, and because of the long timescales involved in "equilibration" of the climate system to current atmospheric levels of greenhouse gases (GHGs), the climatic effects of different GHG emissions scenarios

[10] Climate scientists frequently discuss a variety of different stabilization options – for example, how the climate system might respond if we were able to stabilize atmospheric CO_2 (at some future date) at a level two or three times higher than the pre-industrial level.

[11] SRES stands for IPCC Special Report on Emissions Scenarios. For a brief description of these scenarios, refer to IPCC, 2007b.

are less obvious in the near term (the next several decades), and become much more obvious during the second half of the 21st century.

As noted in the recent report of the U.S. Global Change Research Program (Karl *et al.*, 2009):

"Reducing emissions of carbon dioxide would lessen warming over this century and beyond. Sizable early cuts in emissions would significantly reduce the pace and overall amount of climate change."

The bottom line is that our choices matter. The decisions we reach over the next few years – in terms of when and by how much we reduce GHG emissions – will influence the climate inherited by future generations.

8. Your written testimony includes a little over 5 pages of text and some 3 pages of "References and notes" addressing what you call "The Microwave Sounding Unit Debate," which alleges that the University of Alabama at Huntsville (UAH) data are suspect and that there is no longer a fundamental discrepancy between modeled and observed estimates of tropospheric temperature changes.

Response: My written testimony on the subject of the "Microwave Sounding Unit Debate" is a factual account of the history of the debate. What aspect of that account is being challenged by the questioner?

The conclusion that there is no longer a fundamental discrepancy between modeled and observed estimates of tropospheric temperature changes is not simply an 'allegation' made in my testimony. Please note the following text from the abstract of the first Synthesis and Assessment Report of the U.S. Climate Change Science Program (Karl *et al.*, 2006):

"Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human-induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite and radiosonde data showed little or no warming above the surface. This significant discrepancy no longer exists because errors in the satellite and radiosonde data have been identified and corrected. New data sets have also been developed that do not show such discrepancies."

Two UAH scientists (Dr. John Christy and Dr. Roy Spencer) were part of the team of nearly two dozen Lead Authors who drafted the first Synthesis and Assessment Report.

9. I have listed below 8 papers that have been recently published in peer-reviewed scientific journals - in fact, 5 of them have appeared in 2009 and 2010 - and another in press that attest to the robustness of the UAH results and/or that there is still a fundamental discrepancy between modeled and observed estimates of tropospheric temperature changes. How would you respond?

<u>List</u>:

1. Christy, J.R. and W.B. Norris, 2006: Satellite and VIZ-Radiosonde intercomparisons for diagnosis on non-climatic influences. J. Atmos. Oc. Tech., 23, 1181 – 1194. — Demonstrates in two, independent methods a spurious warming in RSS data and that UAH data have lower error statistics than RSS.

2. Christy, J. R., W. B. Norris, R. W. Spencer, and J. J. Hnilo, 2007: Tropospheric temperature change since 1979 from tropical radiosonde and satellite measurements, J. Geophys. Res., 112, D06102, doi:10.1029/2005JD006881. — Demonstrates that in the tropics the tropospheric temperatures do not warm at a rate indicated by models using all radiosondes (both uncorrected and then corrected). Also, using balloon data and surface data, a clear spurious warming is indicated in RSS tropical tropospheric temperature data.

3. Sakamoto, M. and J.R. Christy, 2009: The influences of TOVS radiance assimilation on temperature and moisture tendencies in JRA-25 and ERA-40. J. Atmos. Oc. Tech., doi:10.1175/2009JTECHA1193.1. Shows that the reference dataset (ERA-40) utilized by one set of balloon adjustments contains a spurious warming due to contamination by the Mt. Pinatubo. This means this balloon dataset, used by Santer et al. 2008, is spuriously too warm. The European Centre has since corrected this reference dataset so that its trend is the same as that from UAH data in the tropics.

4. Randall, R.M. and B.M. Herman, 2008: Using limited time period trends as a means to determine attribution of discrepancies in microwave sounding unit-derived tropospheric temperature time series. J. Geophys. Res. 113, doi:10.1029/2007JD008864. Demonstrates by comparing the relationship between different satellite layers from the same sources that RSS data contain a spurious warming in the lower tropical troposphere while UAH data match the relationship determined by balloons — a relationship that remains stable through time.

5. Bengtsson, L. and K.I. Hodges, 2010: On the evaluation of temperature trends in the troposphere. Climatic Change. Demonstrates that the new European analysis agrees with UAH tropospheric trends and that

RSS data experienced a spurious warming in the tropics as found in papers above (but this is determined by an independent dataset.)

6. Christy, J.R. and W.B. Norris, 2009: Discontinuity issues with radiosondes and satellite temperatures in the Australian region 1979-2006. J. Atmos. Oc. Tech., 26, 508-522, DOI: 10.1175/2008JTECHA1126.1 Using Australian balloons, this study again shows low error characteristics for UAH data and higher error characteristics for RSS and NOAA-STAR satellite data.

7. Klotzbach, P. J., R. A. Pielke Sr., R. A. Pielke Jr., J. R. Christy, and R. T. McNider (2010), Correction to "An alternative explanation for differential temperature trends at the surface and in the lower troposphere", J. Geophys. Res., 115, D01107, doi:10.1029/2009JD013655.

8. Klotzbach, P. J., R. A. Pielke Sr., R. A. Pielke Jr., J. R. Christy, and R. T. McNider (2009), An alternative explanation for differential temperature trends at the surface and in the lower troposphere, J. Geophys. Res., 114, D21102, doi:10.1029/2009JD011841. Demonstrates using both UAH and RSS data that the relationship between the surface and tropospheric temperatures in observations is significantly different than that of climate models.

*9. Christy, J.R., R.W. Spencer and W.B. Norris, 2010: The role of remote sensing in monitoring global bulk tropospheric temperatures. Int. J. Remote Sensing, **(in press)**. Analysizes the three satellite datasets in an update of studies above and shows that UAH contains the lowest error characteristics with RSS and NOAA-STAR showing high error characteristics, including spurious warming in the 1990s. Also points out that the relationship between the surface and troposphere is significantly different between models and observations.*

Response: My response is as follows.

First, I note (as in response to question 8 above) that no specific aspect of my testimony has been challenged. I have simply been provided with a list of 8 papers (one of which is still unpublished) and am being asked to provide a general response.

Second, as my written testimony points out, there are significant technical difficulties in constructing homogeneous temperature datasets from the raw radiance measurements of well over a dozen (drifting) satellites. There are factors such as satellite orbital drift, and the effects of that drift on the sampling of Earth's daily temperature cycle. There are biases between the measurements made by

Microwave Sounding Units (MSUs) flown on different satellites.[12] There are changes in the temperature of MSU instruments (caused by changes in their exposure to sunlight), which can influence the measured microwave emissions.

All of these factors must be accounted for. If they are not, they can impart spurious, non-climatic effects to the temperatures estimated from MSU measurements.

Different groups make different choices in identifying and accounting for the effects of satellite orbital drift, inter-satellite biases, and the changing temperature of MSU instruments. To date, five groups have relied on MSU-based measurements to produce independent estimates of mid- to upper-tropospheric temperature change. The estimates produced by the UAH group are noticeably smaller than those obtained by the other four groups. These issues are discussed in detail in my testimony.

The key point here is that, despite persistent claims to the contrary by UAH scientists, there are very large "structural uncertainties"[13] in satellite estimates of tropospheric temperature change. This was one of the bottom-line findings of the first Synthetic and Assessment Product of the U.S. Global Change Research Program (Karl *et al.*, 2006). Other analysts of MSU measurements have been unable to replicate the tropospheric temperature change estimates produced by the UAH group.

To my knowledge, the UAH group has not publicly released the computer codes they use to process the raw microwave emissions measured by MSUs. It is therefore very difficult for our community to determine why the UAH estimates of tropospheric temperature change differ from the estimates produced by other groups.[14]

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[12]Because the overlap between satellites can be short, it is sometimes difficult to obtain reliable estimates of inter-satellite biases.

[13]These are uncertainties arising from the different choices analysts make in adjusting satellite measurements for non-climatic effects.

[14]In the aftermath of "Climategate", there has been intense scrutiny of the "HadCRUT" surface temperature dataset developed jointly at the U.K. Climatic Research Unit (CRU) and the U.K. Meteorological Office Hadley Centre, with calls for full disclosure of all raw data and data processing codes used by U.K. groups. The CRU/Hadley Centre estimates of surface temperature change have been independently replicated by at least two other research groups. Yet the UAH estimates of muted warming of the troposphere have <u>not</u> been independently replicated by other groups (at Remote Sensing Systems in Santa Rosa, at the University of Maryland, at the University of Washington, and at the NOAA/NESDIS Center for Satellite Applications and Research). Furthermore, the UAH group have <u>not</u> publicly released their data processing codes. This would be an excellent opportunity for them to do so.

Third, as documented in my testimony, the UAH group has a history of making incorrect claims. For many years, UAH scientists claimed that the tropical troposphere had cooled since 1979. This claim was incorrect. UAH data now show warming of the troposphere – yet the myth of a cooling troposphere still persists in the blogosphere.

The "cooling troposphere" claim arose because the UAH group made a sign error in adjusting for the effects of satellite orbital drift on the sampling of the daily temperature cycle. This error was identified in 2005 by scientists at Remote Sensing System (RSS) in Santa Rosa. RSS scientists had also discovered an earlier error (in 1998) in the UAH lower tropospheric temperature dataset, related to neglect of the effects of satellite orbital degradation.

Fourth, the list of papers appended to question 9 does not include a paper published in 2007 by Professor David Douglass and three co-authors (UAH's Dr. John Christy was one of the co-authors). The Douglass *et al.* paper claimed that *"models and observations disagree to a statistically significant extent"*. Douglass *et al.* interpreted their results as evidence that computer models are seriously flawed, and that the projections of future climate change made with such models are untrustworthy.

The *"robust statistical test"* which Douglass *et al.* used to arrive at this conclusion was seriously flawed. This was shown in a paper my colleagues and I published in 2008. We demonstrated that the Douglass *et al.* test produced incorrect results when it was applied to randomly-generated data. The test could not, therefore, perform reliably when used to compare computer model output with satellite-based estimates of atmospheric temperature change.

To date, none of the authors of the Douglass *et al.* paper have acknowledged the existence of errors in their work. This is disappointing, and provides context for new claims (see question 9) of a *"fundamental discrepancy between modeled and observed estimates of tropospheric temperature changes"*.

Fifth and finally, I note that the U.S. Department of Energy decided to establish the Program for Climate Model Diagnosis and Intercomparison (PCMDI), where I have worked for the past 19 years, in order to ensure that the evaluation of climate model quality was separated from the development of such computer models. A similar separation of "dataset development" and "dataset quality evaluation" would be highly desirable in the development and evaluation of satellite-based estimates of atmospheric temperature change. The current situation – where UAH scientists are both satellite dataset developers and arbiters of the quality of satellite datasets produced by different groups – is not optimal.

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Answers to the Additional Questions from Members of the Select Committee on Energy Independence and Global Warming, Following the 20 May 2010 Testimony of Stephen H. Schneider, Stanford University; SHS@stanford.edu.

June 11, 2010

Dr. Schneider:

Following your appearance in front of the Select Committee on Energy Independence and Global Warming, members of the committee submitted additional questions for your attention. I have attached the document with those questions to this email. Please respond at your earliest convenience, or within 3 weeks. Responses may be submitted in electronic form, at sarah.butler@mail.house.gov. Please call with any questions or concerns.

Sarah Butler
Chief Clerk
Select Committee on Energy Independence and Global Warming
(202)225-4012
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Questions from the Minority:

Question 1

1) **How comfortable are you with today's climate models being able to accurately predict future climate trends?**

   - **Have these models been successful at identifying the causes of previous historical warming and cooling trends?**
   - **How confident are you that today's models accurately simulate the role of water vapor and clouds, and their interaction with CO2?**

Response adapted in part from: Schneider, S.H. and M.D. Mastrandrea, 2009: "Climate Change Science Overview." In *Climate Change Science and Policy*, S.H Schneider, A. Rosencranz, M.D. Mastrandrea, and K. Kuntz-Duriseti, (eds.) Washington D.C.: Island Press.

Climate Models
Uncertainty in future greenhouse gas emissions and in scientific understanding of the response of the climate system to their influence makes projecting future climate change a complex task. The most sophisticated tools we have are global models of the climate

system. Not only can they reproduce global temperature records, as shown in Figure MQ1, but the best model results reproduce, although not completely, the detailed geographic patterns of temperature, precipitation, and other climatic variables seen on a regional scale, and can project changes in those patterns given scenarios for future greenhouse gas emissions.

A climate model is a set of mathematical statements describing physical, biological, and chemical processes that determine climate. What must go into a climate model depends on what one wants to learn from it. A few simple equations can give a reasonable range of estimates of the average global warming in response to specified greenhouse gas disturbances to the radiative balance of the atmosphere—so called "radiative forcings". These can include natural drivers like volcanic dust veils that screen out a percent or so of incoming sunlight for a few years post eruption, or human induced forcings like increases in methane or carbon dioxide. Simple climate models have for a half century now estimated that that Earth's global average temperature in the absence of the natural greenhouse effect would be about 33°C colder than it would without our habitable planet having a natural greenhouse effect from water vapor and carbon dioxide primarily. In that case, the Earth surface is treated as a single point, with a simple height-varying atmosphere and no distinction between land and oceans. Simple models have the advantage that their predictions are easily understood on the basis of well-known physical laws. Furthermore, they produce results quickly and can, therefore, be used to test a wide range of assumptions by changing parameters of the model. More advanced are "multibox" models that treat land, ocean, and atmosphere as separate "boxes," and include flows of energy and matter between these boxes. More sophisticated multi-box models may break the atmosphere and ocean into several layers or Earth into several latitude zones. As with the simpler models, models of differing complexity all simulate the natural greenhouse effect very well.

Most sophisticated are the complex computer models known as general circulation models (GCMs) —such detailed models can only be run effectively on a limited number of supercomputers around the world. These divide Earth's surface into a grid that can represent with reasonable accuracy the actual shape of Earth's land masses and to a lesser extent mountains. The atmosphere above and ocean below each surface grid cell are further divided into layers, making the basic unit of the model a small three-dimensional cell. Properties such as temperature, pressure, and humidity are averaged within each cell. Equations based in physics, chemistry, and biology regulate the various quantities within a cell, and other equations describe the transfer of energy and matter between adjacent cells. The newest models also include processes such as the cycling of carbon between the atmosphere, land, and ocean, the response of Earth's vegetation to changing conditions and its feedbacks to the climate system, atmospheric chemistry, and the functioning of the cryosphere. Figure MQ2, panel A displays the typical geographic resolution of the grid representing northern Europe at the time of each of the four IPCC Assessment Reports and the improvement in resolution (i.e., grid box size) over this period. Panel B displays the progression in climate models since the 1970s in terms of the processes and components of the climate system that GCMs incorporate. [See Intergovernmental Panel on Climate Change (IPCC), 2007(a)]

Even with the rapid expansion of computational power, the best global climate models are currently limited to a geographic grid-box resolution of roughly 100 km horizontally and a kilometer vertically. But climatically important phenomena occur on smaller scales, such as clouds, or the substantial thermal differences between cities and surrounding areas. Because all physical, chemical and biological properties are averaged over a single grid cell, it is impossible to represent these phenomena *explicitly* within a model. But they can be treated *implicitly* via what is called a parametric representation, or "parameterization." A parameterization connects small scale processes to grid box averages via semi-empirical rules designed to capture the major interactions between explicitly-modeled grid-scale variables and sub-grid-scale processes. For example, a grid cell half covered by scattered clouds might be parameterized as a uniform blockage of somewhat less than half the incoming sunlight. Such an approximation manages not to ignore clouds altogether but doesn't handle them explicitly. One can imagine that the effects of full sunlight penetrating to the ground in some parts of a grid box while other parts are in full shade might be different from those of a uniform light overcast, even with the same total energy reaching the ground averaged over the grid box. [See Schneider, S.H. and R.E. Dickinson, 1976] Thus the important question is how well these unavoidable approximations do in simulating climate change.

Model Validation

How can modelers be reasonably confident in at least the magnitude and direction of their model results? How do they know that they have taken into account sufficiently the climatologically significant processes and that they have satisfactorily parameterized processes whose scales are smaller than their models' grid cells? The answer lies in a variety of model validation techniques, most of which attempt to reproduce known climatic conditions in response to known forcings. This process is on-going and always being refined as model complexity increases and new data is obtained. That is one reason for updating assessments like those done at the US National Academy of Sciences or the IPCC every five years or so.

Major volcanic eruptions inject enough dust into the stratosphere to exert a global cooling influence that lasts several years. Such eruptions typically occur once a decade or so, and they constitute natural experiments that can be used to test climate models. The climatic effects of the largest recent major eruption, Mt. Pinatubo in 1991, were forecast by a number of climate modeling groups to cool the planet by several tenths of a degree Celsius for a few years. That is indeed what happened.

Seasonality provides another natural experiment for testing climate models. Winter predictably follows summer, averaging some 15°C colder than summer in the Northern Hemisphere and 5°C colder in the Southern Hemisphere (the Southern Hemisphere variation is smaller because a much larger portion of that hemisphere is water, with a high heat capacity that moderates seasonal temperature variations). Climate models do an excellent job of reproducing the timing and magnitude of the seasonal temperature variations, although the absolute temperatures themselves may not be completely accurate.

Again, these are all essential and necessary tests to which all credible models must be subjected, but are part of a hierarchy of tests over different time averages to provide sufficiency that more than short term time scales are tested. Problematically, though, although past performance of surface temperatures simulated at large scales of models forced by greenhouse gas increases are very skillful, projecting future amount of warming due to different forcings is more difficult since the unresolved scales in grid-box parameterizatons of clouds leaves uncertainties in long term future warming projections of some factor of two to three. It is a personal frustration for me, having published the first paper with the terms "cloudiness feedback" (Schneider, 1972, *Jnl Atmos Sci*) in it about 40 years ago, that our monitoring systems are still insufficient to pin down the cloud feedback effects precisely, and thus we still cannot resolve the future warming from a specific scenario of both natural and anthropogenic forcings to much better than a factor of two uncertainty. But it is very unlikely that our projected ranges of warming would be off by a very large amount, like greater than a factor of 3. Thus, overall magnitude and direction of future warming can be confidently assessed, but not precise amounts as just explained.

Still another way to gain confidence in a model's future climate projections is to model past climates. Starting in 1860 with known climatic conditions, for example, can the model reproduce a reasonable simulation of the temperatures observed over the 20th century? The "experiments" of Figure MQ1 discussed above provide clear evidence that the answer is " mostly yes", and also help modelers understand what physical processes are significant in determining past climate trends.

Climate models certainly have room for improvement. For example, models are less accurate in representing climatic variations involving precipitation and other aspects of the hydrologic cycle. While temperature changes are driven by large-scale forcing such as greenhouse gas heat-trapping or continental-scale aerosol cooling, precipitation is influenced by complex local/regional processes like the nature of the land surface, proximity to topographical features (e.g., mountains) and temperature differences across the region. All of those interacting smaller-scale processes and drivers are more difficult to include accurately in models. Nevertheless, today's climate models can reproduce recognizable simulations of regional patterns of temperature, precipitation, and other climatic variables. These pattern-based comparisons of models and reality provide further confirmation of the models' broad-scale validity. No one model validation experiment alone is enough to give us high confidence in future climate projections. But considered together, results from the wide range of experiments probing the validity of climate models give considerable confidence that these models are treating the essential climate-determining processes with reasonable accuracy—certainly for temperature trends at continental scales, and with some skills for regional trends and/or precipitation changes in certain regions like high latitude continents and Mediterranean climates of the sub-tropics. [See IPCC, 2007(a)] Furthermore, researchers have linked grid-box scale changes in temperature with observed changes in the lifecycles of plants and animals during the last fifty years [See Root et al. 2005 and Root and Goldsmith, 2009].

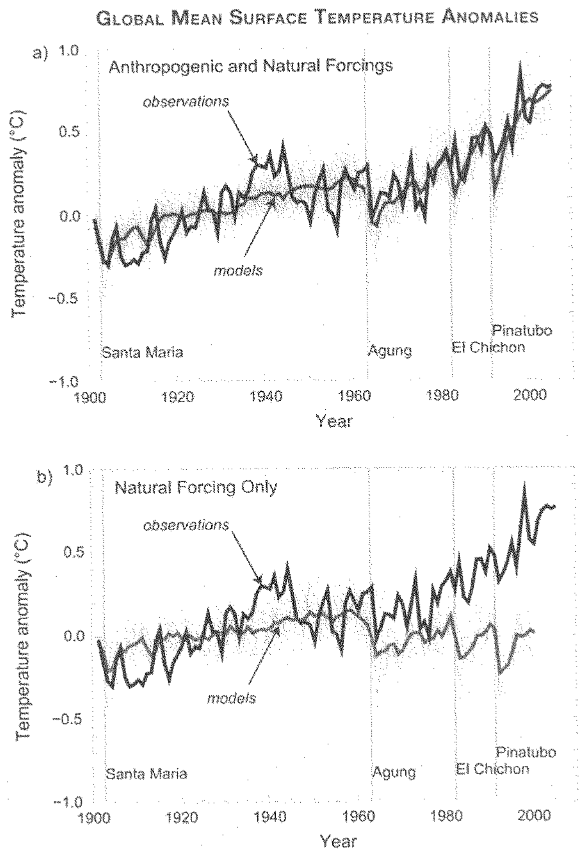

Figure MQ1: Observed changes in surface temperature compared with results simulated by climate models using natural and anthropogenic driving mechanisms (forcings). Decadal averages of observations are shown for the period 1906–2005 (black lines) relative to the corresponding average for 1901–1950. Colored lines depict model estimates; the ranges of estimates are a measure of model uncertainty. Blue lines use only natural forcings based on solar activity and volcanoes (dark blue line is multi-model average). Yellow lines use both natural and anthropogenic forcings (red line is multi-model average). Major volcanic eruptions are shown in both panels, corresponding to temporary cooling. Note the models well simulate this natural forcing of the climate system, an important and necessary test to check their validity in responding to radiative forcing, but not sufficient to test their capacity to simulate longer term climate changes. The hundred year record is a much better validation experiment to demonstrate century-long simulation skill, which is quite good at a global scale as the strong agreement between observations and simulation of surface temperature over the past century demonstrates. Source: IPCC, 2007a.

(A) (B)

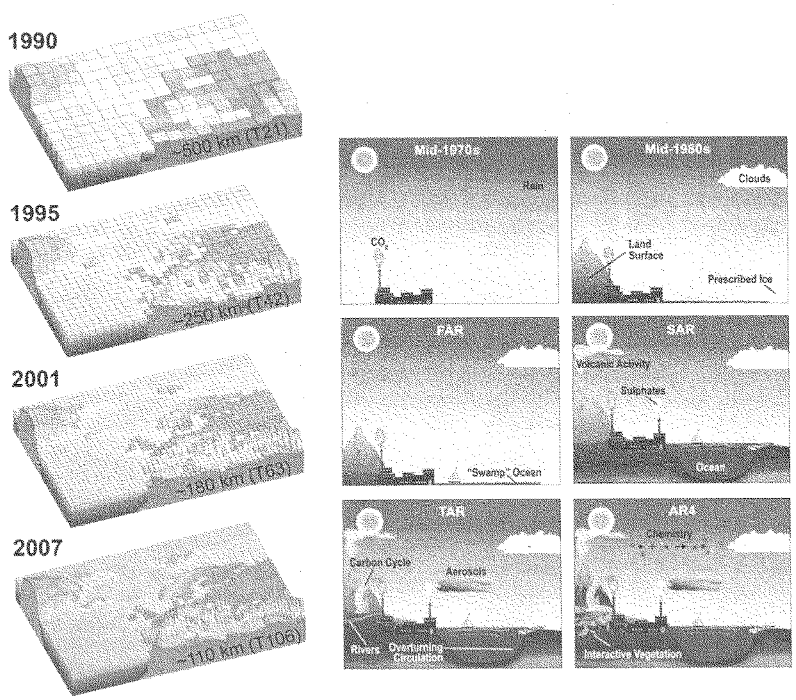

Figure MQ2: Panel A: Geographic resolutions of GCMs at the time of each of the IPCC assessments reports. Vertical resolution in both atmosphere and ocean models is not shown but has increased, as well, beginning typically with a single layer "slab" ocean and ten atmospheric layers in 1990 and progressing to about thirty levels in both atmosphere and ocean in 2007. Panel B: The complexity of the climate models has increased during the last few decades. The series of pictures displays different features of the modeled world, and when they were incorporated. Source: Intergovernmental Panel on Climate Change (IPCC), 2007(a), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon et al. (eds.), Cambridge University Press: Cambridge, United Kingdom

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Discernable Human Fingerprints

Response adapted in part from Mastrandrea, M.D. and S.H. Schneider, 2010: *Preparing for Climate Change*, Cambridge, Mass.: A Boston Review Book, MIT Press: in press

The Scientific Consensus: Pages 19-20

Since the second half of the nineteenth century, global temperatures have been on the rise. The increase in global average surface temperature, as estimated by the IPCC, is around 0.75°C (~1.4°F). Twelve of the thirteen years leading up to 2009 are the twelve warmest years on record, and the first half of 2010 is the warmest so far. There is now overwhelming scientific evidence of a human fingerprint on this global warming. No other plausible combination of known or currently imaginable factors that leaves out human influences can explain this set of observations well. This is a conclusion that has become successively confident as climate assessments have followed each other since the 1970s.

Many related impacts of warming can be—and have been—observed: the melting of mountain glaciers, the Greenland ice sheets and parts of the West Antarctic ice sheets, and northern polar sea ice; rising and increasingly acidic seas; increasing severity of droughts, heat waves, fires, and hurricanes (the intensity and/ or frequency of extreme events can change substantially with small changes in average conditions); and changing lifecycles and ranges of plants and animals. The primary driver, particularly of the rapid warming since the 1970s, is emissions of greenhouse gases, such as carbon dioxide and methane, generated by human activities. The burning of fossil fuels is the greatest contributor of greenhouse gases, but agricultural practices, deforestation, and cement production also play a role, as does the complicating factor of air pollution such as dust and smoke emissions, most of which restrain warming by blocking some sunlight, though black carbon aerosols can enhance warming.

Pages 27-29

Examining climates of the more distant past allows scientists to compare the current changes to earlier natural ones. Scientists use proxies that provide a window into those natural fluctuations. Proxies such as tree rings and pollen percentages in lake beds indicate that current temperatures are the warmest of the millennium and that the rate and magnitude of warming likely have been greater in the past 50 years than during the rest of this period. Ice cores bored in Greenland and Antarctica provide estimates of both temperature and atmospheric greenhouse gases going back hundreds of thousands of years, spanning several cycles of warmth (5,000-20,000 year "interglacials") separated by ice ages up to 100,000 years in duration. Not only do the samples indicate a strong correlation between temperature and atmospheric greenhouse- gas concentrations—particularly carbon dioxide and methane—the samples also indicate that current levels of carbon dioxide and other greenhouse gases in the atmosphere are far above any seen in at least the past 650,000 years. Ice cores also provide information about volcanic eruptions and variations in solar energy, furthering understanding of these natural forcing mechanisms described above.

There are many other lines of evidence of the human "fingerprint" on observed warming trends. To give one more example, the Earth's stratosphere has cooled while the surface has warmed, an indicator of increased concentrations of atmospheric greenhouse gases and stratospheric ozone-depleting substances rather than, for example, an increase in the energy output of the sun, which should warm all levels of the atmosphere. Combined, the present-day observations and the data provided by proxies have led the IPCC to conclude that it is very likely (there is at least a 90 percent chance) that human activities are responsible for most of the warming observed over the twentieth century, particularly that of the last 40 years. I still concur with that assessment.

- **Have these models been successful at identifying the causes of previous historical warming and cooling trends?**

Response adapted in part from Schneider, S.H., 2009: *Science as a Contact Sport.* Washington D.C.: National Geographic Press, 295 pp.

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Michael Mann, whose "hockey stick" graph of the reconstruction of temperatures over the past millennium showed in 1999 that the 1990s had been the warmest decade in a thousand years, led a team that calibrated "proxy" records like deep earth bore hole temperatures or tree ring widths against actual atmospheric temperatures during an overlap period when both were available, and then used these calibrations on a Northern Hemispheric scale to infer temperatures over a thousand years, well before the thermometer was invented or archived in sufficient numbers to achieve a meaningful hemispheric average. Before that, most longer-term estimates of temperature were not calibrated—like Hubert Lamb's famous record showing a large "mediaeval optimum" and "little ice age", was largely obtained from ship captains records of sea ice variations near Iceland and not a hemispherically broad estimate of calibrated records like the Mann et al effort. In that sense, the Mann *et al.* scientific advance was very important new science—thermometer data-proxy calibration. Of course calibrations of proxies involve approximations, and thus alternative ways to do it could and now have been done by nearly a dozen independent groups. Taken together, they make the "handle" of the hockey stick very wavy relative to Mann's early work, but the "blade" remains well warmer than the handle in all the recent dozen studies undertaken with alternative calibrations of proxy data or different statistical techniques over the past 500 years.

These proxy records up to 1900 are not typically modeled in detection and attribution studies that have been used to evaluate anthropogenic global warming—confidence in which was NOT based on the "hockey stick" in IPCC, but on fingerprint studies using real data since 1900 as mentioned earlier—since the forces creating the pre-constructed fluctuations of temperature before 1900 are not well constrained, as they are after 1900 when many more direct measurements became available.

It took a full review of the hockey stick study by a National Academy of Sciences committee to prove that although Mann and colleagues did make some minor errors—as is normal in creative, original science—the basic conclusion, that the past several decades were the warmest in at least 500 years, remained. In 2007 the IPCC Fourth Assessment Report SPM said about this controversy: "Average northern hemispheric temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in the past 1300 years."

Wikipedia:

http://en.wikipedia.org/wiki/Hockey_stick_controversy

A (perhaps surprisingly accurate) independent summary of the controversy on Wikipedia: "The **hockey stick controversy** refers to debates over the technical correctness and implications for global warming of graphs showing reconstructed estimates of the temperature record of the past 1000 years; at a political level, the debate is about the use of this graph to convey complex science to the public, and the question of the robustness of the assessment presented by the Intergovernmental Panel on Climate Change (IPCC).

By the late 1990s a number of competing teams were using proxy indicators to estimate the temperature record of past centuries, and finding suggestions that recent warming was exceptional.[1] In 1998 Michael E. Mann, Raymond S. Bradley and Malcolm K. Hughes produced the first quantitative hemispheric-scale reconstruction, from an analysis of a variety of measures, which they summarised in a graph going back to 1400 showing recent measured temperatures increasing sharply. Their 1999 paper extended this study back to 1000, and included a graph which was featured prominently in the 2001 United Nations Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) as supporting the mainstream view of climate scientists that there had been a relatively sharp rise in temperatures during the second half of the 20th century. It became a focus of attacks from those opposed to this scientific consensus.[2] The term *hockey stick* was coined by the National Oceanic and Atmospheric Administration climatologist Jerry Mahlman, to describe the pattern, envisaging a graph that is relatively flat to 1900 as forming the hockey stick's "shaft", followed by a sharp increase corresponding to the "blade".[3]

1. Spencer R. Weart. "The Modern Temperature Trend". *The Discovery of Global Warming*. http://www.aip.org/history/climate/20ctrend.htm. Retrieved 2010-03-08.

2. Fred Pearce (9 February 2010). "Part three: Hockey stick graph took pride of place in IPCC report, despite doubts | Environment". The Guardian. http://www.guardian.co.uk/environment/2010/feb/09/hockey-stick-graph-ipcc-report. Retrieved 2010-03-08.

3. "Climate legacy of 'hockey stick'". BBC. 2004-08-16. http://news.bbc.co.uk/1/hi/sci/tech/3569604.stm. Retrieved 2007-05-08.

National Research Council Report 2006 [summary of findings from Wikipedia]

At the request of the U.S. Congress, a special "Committee on Surface Temperature Reconstructions for the Past 2,000 Years" was assembled by the National Research Council's Board on Atmospheric Sciences and Climate. The Committee consisted of 12 scientists, chaired by Gerald North, from different disciplines and was tasked with explaining the current scientific information on the temperature record for the past two millennia, and identifying the main areas of uncertainty, the principal methodologies used, any problems with these approaches, and how central the debate is to the state of scientific knowledge on global climate change.

The panel published its report in 2006.[36] The report agreed that there were statistical shortcomings in the MBH analysis, but concluded that they were small in effect. The report summarizes its main findings as follows:[37]

* The instrumentally measured warming of about 0.6 °C (1.1 °F) during the 20th century is also reflected in borehole temperature measurements, the retreat of glaciers, and other observational evidence, and can be simulated with climate models.

* Large-scale surface temperature reconstructions yield a generally consistent picture of temperature trends during the preceding millennium, including relatively warm conditions centered around A.D. 1000 (identified by some as the "Medieval Warm Period") and a relatively cold period (or "Little Ice Age") centered around 1700. The existence and extent of a Little Ice Age from roughly 1500 to 1850 is supported by a wide variety of evidence including ice cores, tree rings, borehole temperatures, glacier length records, and historical documents. Evidence for regional warmth during medieval times can be found in a diverse but more limited set of records including ice cores, tree rings, marine sediments, and historical sources from Europe and Asia, but the exact timing and duration of warm periods may have varied from region to region, and the magnitude and geographic extent of the warmth are uncertain.

* It can be said with a high level of confidence that global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries. This statement is justified by the consistency of the evidence from a wide variety of geographically diverse proxies.

* Less confidence can be placed in large-scale surface temperature reconstructions for the period from A.D. 900 to 1600. Presently available proxy evidence indicates that temperatures at many, but not all, individual locations were higher during the past 25 years than during any period of comparable length since A.D. 900. The uncertainties associated with reconstructing hemispheric mean or global mean temperatures from these data increase substantially backward in time through this period and are not yet fully quantified.

* Very little confidence can be assigned to statements concerning the hemispheric mean or global mean surface temperature prior to about A.D. 900 because of sparse data coverage and because the uncertainties associated with proxy data and the methods used to analyze and combine them are larger than during more recent time periods.

36. Committee on Surface Temperature Reconstructions for the Past 2,000 Years. *Surface Temperature Reconstructions for the Past 2,000 Years*. The National Academies Press: Washington, D.C. 2006.

37. *Surface Temperature Reconstructions for the Last 2,000 Years*

Question 2

2) In the 1970s, you expressed concern about global cooling – what made you change your mind?

Answer adapted from Schneider, S.H., 2009: *Science as a Contact Sport*. Washington D.C.: National Geographic Press, 295 pp.

The first chapter of my recent book, Science as a Contact Sport, describes the process of moving from my earlier analysis based on available evidence that the earth might be entering a period of global cooling in 1970 to with new evidence concluding that the cumulative effect is that earth is warming. In 1970 when I began working with S. I. Rasool at NASA's Goddard Institute for Space Studies as part-time graduate student while finishing my thesis at Columbia for my Ph.D. in Mechanical Engineering, Plasma Physics, the field of climate modeling was in its infancy.

An open question centered on the effect of aerosols in the atmosphere. Any particles suspended in a gas are called aerosols. My work with Rasool focused on the aerosols caused by industrial pollution in the form of hazes and smoke that can blow high into the atmosphere and last for weeks. They can spread a thousand miles downwind of the source and affect the amount of sunlight that is absorbed and reflected in the atmosphere. Since most aerosols are lighter in color than the surfaces they float over, they reflect away sunlight—thus they cool the climate.

In our paper for which I was the second author: "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate" published in *Science* in 1971, the driving assumptions were that the aerosols were global and the greenhouse gases—CO2 only—were also global in extent [S. Ichtiaque Rasool and Stephen H. Schneider, "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate," *Science* 173 (1971): 138-141]. The model that I was given by Rasool had no stratosphere—the layer of the atmosphere above the turbulent troposphere, where all the water clouds are and the mixing takes place. The stratosphere is where high-flying jets cruise and where Earth's life-protecting ozone layer predominately exists. At that time I had no idea that leaving the stratosphere out of our greenhouse effect computer calculations was such a large error. I didn't learn until later that running the model without a stratosphere was going to cut in half the climate's sensitivity to CO2 increases. As a result, we only calculated about 0.7 or 0.8 degree Celsius (about 1.4 degrees Fahrenheit) warming if the amount of CO2 doubled. In contrast, when we ran the model with aerosols as if they were everywhere, our global CO2 effect was swamped by the global aerosol effect, and we predicted cooling of 3 to 5 degrees Celsius (5.4 to 9 degrees Fahrenheit) by the year 2100.

This paper was based on two incorrect assumptions that Rasool and I made and which, with new evidence, I proudly corrected myself before any critics. By 1973 I was convinced that the Rasool-Schneider calculation couldn't be right, because we now had found good measurements of the geographic distribution of aerosols, and they were not uniformly global in extent, but they were regionally significant. I immediately proceeded to read all the papers that had been done that estimated climate sensitivity, and then plotted them all out on the same figure. In my opinion then the best guess of climate sensitivity was between 1.5 and 3.5 degrees Celsius (2.7 to 6.3 degrees Fahrenheit), based upon the literature, which I published in 1975 in the *Journal of Atmospheric Sciences* in a paper called "On the Carbon Dioxide Climate Confusion." Thus, leaving out the stratosphere in first calculation halved the climate sensitivity, and assuming aerosols were globally distributed overestimated cooling by about a factor of four was documented by me in peer reviewed literature as early as my 1975 paper

I am very proud of the fact that I operated in the best tradition of science: You draw conclusions based on what you think at the time, making all your assumptions explicit; then you reexamine the assumptions in light of new evidence; you recalculate; and then you publish the revisions without any shame. That's how science proceeds. A model provides the logical consequences of explicit assumptions. The real science is in how good the assumptions are—and that is where empirical testing and peer debate comes in.

I was attacked decades later by George Will, Charles Krauthammer, and others about predicting cooling in the early 1970s as a grad student and now warming as a senior scientist. In a rebuttal in the Washington Post, I wrote, "Imagine the doctor who makes a preliminary diagnosis before the blood test and the x-rays are in, and then they are different from the preliminary diagnosis, but the doctor sticks with it to be politically consistent. This is not what we do in science . . . and we're not ever ashamed of getting the wrong answer for the right reason." [Stephen H. Schneider, "Hot About Global Warming," Washington Post, September 26, 1992.]

Question 3

3) You conclude your testimony with the point that had we begun mitigation and adaptation investments decades ago, we would be in a better position now. But a few decades ago, you argued that the earth was entering a cooling period. Were you making the same suggestions then as you are now?

Answer adapted in part from Schneider, S.H., 2009: *Science as a Contact Sport*. Washington D.C.: National Geographic Press, 295 pp.

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The open question centered on the effect of aerosols in the atmosphere. Any particles suspended in a gas are called aerosols. An aerosol spray can draws liquid from inside the can and with compressed gas inside, propels it out through a nozzle to aerosolize it—that is, make it into droplets suspended in a gas. Being liquid, they evaporate nearly immediately. But at a much grander scale the particles that make up the hazes and smoke from industrial pollution or agricultural or desert dust can blow high into the atmosphere and last for weeks. They can spread a thousand miles downwind of the source and affect the amount of sunlight that is absorbed and reflected in the atmosphere. Since most aerosols are lighter in color than the surfaces they float over, they reflect away sunlight—thus they cool the climate.

In science, we build our case on existing literature, explain what original findings or ideas you are adding, state your assumptions transparently, calculate the consequences as if those assumptions were true, and then redo your calculations after debating with your colleagues, learning more, and reading the latest literature. In science, we are proud of getting the wrong answer for the right reasons at the time as noted above, and we're especially proud if we ourselves are the first to correct it.[3] [For an independent assessment, see Thomas C. Peterson, William M. Connolley, and John Fleck, "The Myth of the 1970s Global Cooling Scientific Consensus," *Bulletin of the American Meteorological Society* (September 2008): 1325-1337, especially Table 1, 1332.]

The paper Rasool and I wrote, entitled "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate," was published in July 1971 in *Science* magazine.[4] [S. Ichtiaque Rasool and Stephen H. Schneider, "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate," *Science* 173 (1971): 138-141.] In a way, I don't deserve much credit for that paper even if I did all the calculations, because I did not make the key assumptions. I earned that credit later, when our paper became a cause célèbre. Rasool asked me to go out and give all the talks defending it, because people were really trying to shoot it down, a common practice for new claims, especially ones as controversial as that at the time.

As to policy advocacy in the early 1970s, I was not particularly policy-oriented then relative to later as the confidence in the underlying science grew, but I had always argued that impacts of climate changes were not dependent on whether it was warming or cooling deviations from the existing conditions but large and rapid changes away from what nature and society had become accustomed to as the "normal" climate. I believed then and still do that a few degrees warming would be harmful overall for the climate system including human and natural systems, and that a few degrees cooling in a century time scale would be even more harmful than warming. So for me the key then—and now that warming over cooling is essentially settled science—is to prevent large and rapid deviations from the status quo climate. Since some additional climate change is now unavoidable, we also need to adapt to it to minimize disruptions. In that sense, I still advocate the same solution—reduce the human fingerprint on the climate system from both aerosols and greenhouse gases as well as massive land use changes, since the interactions of all these is threatening to the viability of many natural and human systems.

By 1976 and the publication of my first book, *The Genesis Strategy: Climate and Global Survival*, I had increased my advocacy of solutions to include energy efficiency, renewable less polluting energy systems, and global development assistance to rapidly populating developing countries both to slow their potentially dangerous population growth rates and to build their economies on cleaner energy systems. I have no reason to change that assessment, in fact argue for it even more strongly now than 35 years as we have watched nature "cooperate with theory" and actually reveal many changes only theoretically predicted in the 1970s: reduced cooling extremes, increased heat waves, rising sea levels, melting glaciers, increasing wild fires and altered patterns of wild species.

Stephen H. Schneider with Lynne E. Mesirow, 1976: *The Genesis Strategy: Climate and Global Survival*. New York: Plenum Press.

Question 4

4) **What is the ideal level of atmospheric CO_2? The current level of 385 ppm, the pre-industrial level of 280 ppm, the 1000 ppm used in many greenhouses to enhance plant vigor?**

Answer adapted from Mastrandrea, M.D. and S.H. Schneider, 2010: *Preparing for climate Change*, Cambridge, Mass.: A Boston Review Book, MIT Press: in press

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All of these local [weather] conditions, however, are the products of an enormously complex global system in which myriad variables contribute to a diverse set of climates and ecosystems. That diversity has been relatively stable for the past several thousand years—until humans dramatically expanded their population size and economic activities. Now, major alterations to land surfaces, chemical composition of soils, air, and water and accelerating changes in global average temperature, even seemingly small changes, are upsetting that relative stability, affecting local conditions all over the planet.

The IPCC AR4 summarized many projected impacts of climate change for specific regions and highlighted "key vulnerabilities." These include the loss of glaciers, melting ice sheets, and other factors that produce rising seas, which could inundate low-lying coastal areas and small island nations around the world; escalating infectious disease transmission; increases in the severity of extreme events such as heat waves, storms, floods, and droughts; large drops in farming productivity, especially in hotter areas; the loss of cultural diversity as people are driven from their historical communities; and an escalating rate of species extinction.

Not Just Theoretical

Many of the types of problems discussed in the IPCC Report can be witnessed in their early stages today. As glaciers melt, sea level rises and water in turn becomes scarcer in regions that depend heavily on glacier water during their dry seasons. In South America a significant fraction of the population west of the Andes could be at risk due to shrinking glaciers. According to a 2005 study from researchers at the University of San Diego, glacier-covered areas in Peru have shrunk by 25 percent in the past three decades. The authors note, "at current rates some of the glaciers may disappear in a few decades, if not sooner" and warn that fossil water lost through glacial melting will not be replaced in the foreseeable future. China, India, and other parts of Asia are also vulnerable. The ice mass in the region's mountainous area is the third largest on Earth following Arctic-Greenland and Antarctica, and as its glaciers diminish in the coming decades, decreasing water supplies will affect vast populations. Precise dates of melt are, of course, beyond the state of the art to project with confidence, but rapid and serious changes are already documented at temperature rises way below "worst case" projections like 1000PPM CO_2 equivalent.

While some worry about their dwindling water supplies, others, particularly vulnerable populations and those with little capacity to adapt, have begun to experience the direct health impacts of climate change acutely. For example, the increased frequency and intensity of heat waves put small children and the elderly at risk, especially where air conditioning is unavailable or unaffordable. Devastating events such as the 2003 European heat wave—now linked to the premature deaths of some 50,000 people—illustrate the dangers that exist even such as the 2003 European heat wave—now linked to the premature deaths of some 50,000 people—illustrate the dangers that exist even in developed countries. Increases in the frequency and/or intensity of floods, hurricanes, fires, and other extreme events are also troubling. The immediate effects of, say, wildfires are obvious, but the indirect impacts can be more damaging to health: smoke degrades air quality, exacerbating respiratory illnesses of millions in downwind areas.

In some regions—particularly the Arctic, where surface air temperatures have warmed at approximately twice the global rate—changing climate patterns are threatening entire ways of life....

With regard to biodiversity, climate changes are having potentially irreversible effects on plant and animal habitats and lifecycles, forcing some species poleward or up mountain slopes, and hastening the arrival of certain biological events each spring. Depending on the severity of its impacts and the rates of response among different individual species, climate change could pull apart the natural functioning of existing plant and animal communities, making extinctions much more likely.

For example, over the past several decades, warming has led to the early arrival of some birds that migrate in the spring. If those arrivals are no longer in sync with the emergence of vegetation needed for nesting or hatching of bugs that are prey for these birds, then the interlocked life cycles of these co-dependent species can be disrupted. Such disruptions are not only a threat to biodiversity, but also ecosystem "goods"—seafood, fodder, fuel wood, timber, pharmaceutical products, etc.—and "services"—air and water purification, flood control, pollination, waste detoxification and decomposition, climate moderation, soil-fertility regeneration, etc.

In addition to these well-understood effects of climate change, climate change could trigger "surprises." These are fast, non-linear climate responses, thought to occur when environmental thresholds are crossed. Some of these surprises could be anticipated. "Imaginable surprises" include the collapse of the North Atlantic thermohaline circulation (ocean currents)—which could cause significant and potentially rapid cooling in parts of the North Atlantic (though this is considered still only a remote possibility in the next century)—and deglaciation of Greenland or the West Antarctic ice sheets, which would occur over many centuries (though would persist over many millennia), causing a considerable rise in sea level, threatening many coastal cities and low-lying coastal areas such as river deltas. But there is also the possibility of true surprises thanks to the enormous complexities of the climate system and the relationships, for example, between oceanic, atmospheric, and terrestrial systems.

Answer adapted from: Root, Terry L. and Stephen H. Schneider, 2006: "Conservation and Climate Change: The Challenges Ahead". *Conservation Biology* 20: 706 – 708.

Climate Change and Ecological Responses

The specific question from the committee focused on CO_2 fertilization of plants, but it would be an error to abstract that one bit from the overall question of ecological responses to climate change and CO_2 increases since all those go together, so I add this "tutorial section" for perspective on ecological responses, for which CO_2 enhancement is but one small part—hopefully this perspective is useful.

Climatic changes in the distant past were driven by natural causes, such as variations in the Earth's orbit or the carbon dioxide (CO_2) content of the atmosphere. Today, and even moreso in the future, climatic changes have another driver as well -- human activities (Intergovernmental Panel on Climate Change [IPCC] 1996). The natural greenhouse effect from clouds, water vapor and CO_2, primarily, is responsible for some 33°C (60°F) of surface warming. Human use of the atmosphere to dump our gaseous wastes adds to the natural greenhouse gases, and is typically projected to result in a global warming of about 1.5°C to 6°C in the next century (IPCC, 2001a). This range—especially if beyond 2^{o}C--could result in ecologically significant changes (Thomas et al, 2004), which is why climatic considerations are fundamental in the discussion of conservation strategies for the 21^{st} century.

The transition from extensive glaciations of the Ice Age to more hospitable landscapes of the Holocene took from 5,000 to 10,000 years, during which time the average global temperature increased 5-7°C and the sea level rose some 100 meters. Thus, we estimate that over the last 20,000 years, the natural rates of warming on a *sustained global* basis are about 0.5°C to 1.5°C per thousand years. There is, however, evidence amassing of regional, rapid, so-called "abrupt non-linear," changes as well (e.g., Schneider, 2004, provides an overview). Both the slower and more rapid changes radically influenced where species lived and extinction rates. Climate change was a potential contributor—along with hunting and other human activities--to the well-known extinctions of woolly mammoths, saber tooth cats, and enormous salamanders.

During the last Ice Age, most of Canada was under ice; pollen cores indicate that as the ice receded, boreal trees moved northward 'chasing' the ice cap (i.e., moving with the warming temperature). But did the species within the boreal tree community shift in lock-step with the trees? In historic times many thought that biological communities moved intact with a changing climate. In fact, Darwin (1859) asserted as much:

> As the arctic forms moved first southward and afterward backward to the north, in unison with the changing climate, they will not have been exposed during their long migrations to any great diversity of temperature; and as they all migrated in a body together, their mutual relations will not have been much disturbed. Hence, in accordance with the principles inculcated in this volume, these forms will not have been liable to much modification.

If this were true, the principal ecological concern over the prospect of future climate change would be that human land-use patterns might block what had previously been the free-ranging movement of natural communities in response to climate change. The Cooperative Holocene Mapping Project, however, discovered that during the transition from the last Ice Age to the present interglacial, nearly all Northern Hemisphere species moved generally north, as expected, but for a significant portion of the transition period different species moved at different rates and directions, not as groups (Cooperative Holocene Mapping Project, 1988; Wright et al., 1993; Overpeck *et al.*, 1992). The relevance of these "no-analog" habitats is that today and in the future ecosystems will probably not move as a unit as climate changes.

Furthermore, because the forecasted global average rate of temperature increase over the next century (~1-5°C per century) greatly exceeds those typical of the sustained average rates experienced during the last 20,000 years, it is unlikely that paleoclimatic conditions will provide analogs for a rapidly changing anthropogenically warmed world. Nevertheless, understanding past changes is important, not as a spatial analog to future conditions, but rather as means to construct or verify the behavior of models of climate and ecosystem dynamics. Tested models are needed to project the future conditions given the rapid time-evolving patterns of anthropogenic forcing (Crowley 1993; Schneider 1993).

<u>Meta-Analyses</u>. Meta-analyses provide methods for combining results from various studies, whether statistically significant or not. The results from the meta-analyses determine if there is a consistent "signal" or "fingerprint" among the studies. The balance of evidence from two such meta-analyses done on species from many different taxa examined at disparate locations around the globe (Root and Schneider 2002, Parmesan and Yohe, 2003 and Root *et al.*, 2003) suggests that a significant impact from recent climatic warming is discernible in the form of long-term, large-scale alteration of animal and plant populations. The latter conclusion was extended by IPCC (2001b) to include "environmental systems"—sea- and lake-ice cover and mountain glaciers. Clearly, if such climatic and ecological signals are now being detected above the background of climatic and ecological noise for a 20^{th} century warming of "only" 0.6°C, it is likely that the expected impacts on ecosystems of temperature increases up to an order of magnitude larger by 2100 AD will most probably be dramatic.

Joint Attribution. The meta-analyses have established that many plant and animal species are responding to regional climatic changes, but can the extent to which such regional warming is natural variation as opposed to attributable to human activities be teased apart? If there is a discernible impact of human activities on climate (IPCC 1996, 2001a) and a discernible impact of climate on plants and animals (e.g., IPCC 2001b), can it be asserted that there is a discernible impact of human-induced climate change on plants and animals, so-called "joint attribution"? Root *et al.* (2005) correlated the phenological responses of plants and animals reported to be changing over the past 50 years to spring temperature data produced by climatic models (HADCM3 general circulation model). These models were driven by three sets of observed potential causes: (1) only natural forcings (e.g., solar activity and volcanic dust veils, (2) only anthropogenic forcings (e.g., CO_2 and aerosol increases), and (3) combined forcings (i.e., natural and anthropogenic forcings together). Given the many uncertainties and missing factors, it is not expected that most of the variance of observed phonological changes in the past 50 years can be attributed to anthropogenic forcings. Thus, the key question is: Did the correlations between observed plant and animal phonological records improve when anthropogenic forcing was driving the models relative to the correlations when only natural forcings produced the climate model records? Root *et al.*'s (2005) results show a clear signal that, despite known uncertainties and missing factors, temperatures driven by anthropogenic forcing are much more highly correlated with observed phenological changes in plants and animals than natural forcing. This result provides strong support for the joint-attribution hypothesis.

Synergisms. One of the most potentially serious conservation problems is the synergistic effect of habitat fragmentation and climate change. As the climate warms, individual species of plants and animals will be forced to adjust if they can, as they have in the past. During the Ice Age transition many species survived by moving to appropriate habitats. Today such dispersal is more difficult because they need to travel across freeways, agricultural areas, industrial parks, and cities. An even further complication arises with the imposition of the direct effects of changes in CO_2, which can change terrestrial, aquatic and marine primary productivity, drop the pH of the oceans significantly, as well as alter the competitive relations among plants and animals.

In summary, conservation biologists not only need to anticipate the phenology and movements of individual species in response to climate change, but must also project potential changes to biological communities. Disruption of competitive or predator-prey interaction could jeopardize sustainability of ecosystem services on which we rely (e.g., Root and Schneider, 1993 and Millennium Assessment, 2005), and lead to numerous extinctions. This is one of the most important challenges for conservation biologists in the next several decades, as extensive land use and rapid climatic changes are likely to accelerate.

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As to the CO_2 fertilization of individual plants included in Question 4, indeed enhanced CO_2 chamber studies do suggest that plants subjected one at a time to CO_2 increases increase their yields. But this individual effect does not necessarily translate into an ecosystem effect for several reasons. First, some plants grow faster than others in enhanced CO_2 and thus crowd out or shade competitors thus altering ecosystems in unknown ways. Second, the co factors of soil water availability, nutrients in the soils and other species being present in the ecosystem, can dramatically alter the ecosystem productivity studies obtained with single species chamber studies. Furthermore, CO_2 fertilizes weeds and allergens as well as desirable food plants, and there is no way to escape the already observed enhancement in ocean acidification from increasing atmospheric CO_2.

Thus, the potential benefits of some photosynthetic enhancements in mono cultures of single species crops could well be offset or more by ecosystem effects, especially in the oceans. Thus there is no clear answer, and even more problematic is that benefits of CO_2 enhancement are overpowered by CO_2-enhanced warming in most regions of the world, especially those in the warmer parts where loss of yields would have the most human damage.

Question 5

5) If CO_2 levels could be stabilized by massive changes in the world's economy would this stop further climate change?

Yes, eventually, but not in the next several decades at least and the eventual warming would be likely to be much more than now unless ways to directly remove carbon from the atmosphere are found in the next 10 to 40 years. Given the inertia in the system, once GHGs are stabilized some further warming over at least a century will occur due to historical accumulated emissions and the slowness of the oceans to respond to radiative forcing. Stabilizing GHGs emissions will avoid further climate change beyond what is already in the pipeline.

Answer adopted from: SH Schneider, February 28, 2007: "Climate Change Risks and Control Strategies." Testimony to the Committee on Ways and Means U.S. House of Representatives

The Numbers Game.

But is there really a "massive change in the world's economy" implicit in redirecting energy systems away from more polluting ones? It is common for some opposed to climate policies to cite draconian absolute numbers: trillions of dollars of annual costs for climate mitigation policies; or a few percent of GDP lost. But let me report that there is a wide variance across economic models on how much mitigation might cost—and some estimates suggest that it could actually improve the economy at first by promoting the implementation of cost-effective efficiency actions sooner. But even if one accepts some of the seemingly staggering estimates like trillions of dollars of costs, let me add some perspective. Figure MQ3 shows the results that Christian Azar from Sweden and I (Azar and Schneider, 2002) produced based on conventional economic models that estimate the costs of climate policy. We found that a typical shadow price on carbon (a carbon fee or tax, for example) to prevent the concentrations of CO2 from more than doubling was around $200 per ton Carbon emitted. A fee twice that high could eventually keep concentrations near present values (though an overshoot of concentrations above present in the next half century seems unavoidable—see Schneider and Mastrandrea, 2005). Even though stabilizing CO2 levels at as low a level as possible will stop further climate change, some further warming will occur due to historical emissions. Stablizing GHGs emissions will avoid further climate change beyond what is already in the pipeline. Even with aggressive global efforts to reduce emissions, the earth's climate will continue to change significantly for many decades because of the magnitude of past emissions and the inertia of social and physical systems. Significant impacts resulting from climate change are already evident, and pose increasing risks for many vulnerable populations and regions. Azar and I used typical economic models estimates of the costs of such policies, although we believe them personally to be too pessimistic. These models estimate between a half a percent and several percent GDP lost annually by century's end.

Let us reframe this for perspective. If the annual costs in the future were indeed a few trillion dollars lost from climate policies, and one compared that to today's level of GDP, it would indeed seem astronomically high—equivalent to a depression—some tens of percent loss of economic production. But that comparison would be totally misleading, if not pernicious. We can't legitimately compare potential future costs of climate mitigation policies to the present size of the economy. Nearly all mainstream economic analyses typically project GDP growth rates of some 2% per year—barring pandemics, world wars or other unforeseeable catastrophes we all work so hard to prevent. A few numbers to illustrate this follow.

If the current economy of the world now were about $40 trillion and it grew at 2% per year, then in 100 years it would be about eight times bigger—about $320 trillion annually. So indeed, a 2% loss in 2100 from a century of shadow prices on carbon that reduced most of the climate change risks would be a seemingly very daunting figure: about $6.4 trillion—a major fraction of the economy today. But in 2100, that loss would be made up in only one year by economic growth! In other words, if our economy continues to grow as typically projected, that growth will swamp the costs of mitigation. In this simple demonstration, we would be about 500% per capita richer on average in 2101 with major climate policies to reduce risks versus being 500% per capita richer in 2100 having taken no climate policy action and thus faced with full risks of dangerous climate change. In the language of risk-management, such an investment in mitigation is a cheap insurance policy or hedging strategy to avoid significant threat to our planetary life support system. It is unacceptable to compare future costs to the present scale of the economy. Framing costs in terms of the delay time to be x% richer is much more understandable than frightening, but largely out of perspective, relative to the seemingly daunting absolute dollar costs.

But just because overall costs of climate mitigation may not be a large number relative to projected growth in the economy, there will still be, as mentioned earlier, individuals and groups with more than average difficulties. Thus, the critical challenge to governance is to both protect the planetary commons for our posterity and the conservation of Nature, while at the same time fashioning solutions to deal fairly with those particularly hard hit by both the impacts of climate change (via adaptation programs) or from climate policies (perhaps via job retraining, incentives for relocation of industries, side payments, etc.).

I am often asked if I am optimistic or pessimistic about addressing climate change. In a sentence: I am optimistic that we can affordably and effectively sequence a series of policy steps to deal with climate change via efficiency, learning, adaptation and mitigation, but I am also pessimistic that we will fail to prevent a considerable climate change risk while we debate and delay the implementation of such policies. When I testified on many occasions to this honorable body over the decades, I always was asked and offered the personal opinion that steps to anticipate and reduce risks via climate policies were already called for, as the sooner one starts, the lower the eventual risks and costs. Given that the scientific evidence now is overwhelming that global warming is a reality, that humans are responsible for a considerable chunk of it, and that in the decades ahead we will become the dominant factor in climate change and related impacts, a clear and effective portfolio of policies is now more urgently needed than ever.

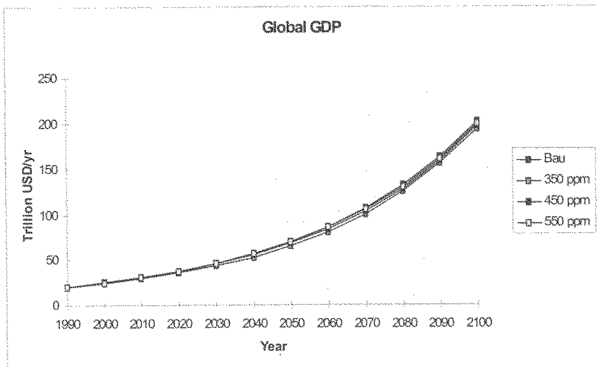

Figure MQ3. Global income trajectories under Business as usual (top curve) and for the case of stabilizing the atmosphere at 350 (bottom curve), 450 and 550 ppm. Note that we have assumed rather pessimistic estimates of the cost of atmospheric stabilization (average costs to the economy assumed here are \$200/tC for 550 ppm target, \$300/tC for 450 ppm and \$400/tC for 350 ppm) and that the environmental benefits (in terms of climate change avoidance and reduction of local air pollution) of meeting various stabilization targets have not been included. (Source: Azar and Schneider, 2002)

Finally, has there been any support in the literature for the Azar and Schneider (2002) claim that overall costs of mitigation by switching the energy basis of the economy to lower emitting technology and organizations are but a small fraction of the growth rate of the GDP typically projected in economic models? Here is what IPCC recently had to say about that point by surveying the literature and putting it in a table given below. The *bottom line in my view* is that claims made that climate policy applied to energy systems over decades would somehow "wreck the economy" are completely inconsistent with the economics literature or historic analysis, but rather are just assertions of those arguing for preservation of the status quo, and using absolute cost estimates rather than relative tiny fractions of GDP loss associated with such energy transformations. In short, the energy economy can be transformed to more sustainability at costs well below the typically projected growth rates of the GDP, if done gradually and side payments are considered to those who might be hurt in the transition.

AR4 WGIII Summary for Policy Makers page 12: Table SPM.4: Estimated global macro-economic costs in 2030[a)] for least-cost trajectories towards different long-term stabilization levels.[b), c)] Note that it reaches the essentially same conclusion as Azar and I did years earlier—controlling climate to avoid large damages and "worst cases" is not expensive relative to either the potential damages themselves or the growth rate of the GDP typically projected for the 21[st] century by most economic models http://www.ipcc.ch/publications_and_data/ar4/wg3/en/spmsspm-c.html#table-spm-4

Table SPM.4: *Estimated global macro-economic costs in 2030[a] for least-cost trajectories towards different long-term stabilization levels[b, c]*

Stabilization levels (ppm CO_2-eq)	Median GDP reduction[d] (%)	Range of GDP reduction[d, e] (%)	Reduction of average annual GDP growth rates[d, f] (percentage points)
590-710	0.2	-0.6-1.2	<0.06
535-590	0.6	0.2-2.5	<0.1
445-535[g]	not available	<3	<0.12

Notes:
a) For a given stabilization level, GDP reduction would increase over time in most models after 2030. Long-term costs also become more uncertain. [Figure 3.25]
b) Results based on studies using various baselines.
c) Studies vary in terms of the point in time stabilization is achieved; generally this is in 2100 or later.
d) This is global GDP based market exchange rates.
e) The median and the 10th and 90th percentile range of the analyzed data are given.
f) The calculation of the reduction of the annual growth rate is based on the average reduction during the period till 2030 that would result in the indicated GDP decrease in 2030.
g) The number of studies that report GDP results is relatively small and they generally use low baselines.

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June 22, 2010

Sarah Butler
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Select Committee on Energy Independence
and Global Warming
U.S. House of Representatives
Washington, DC 20515

Dear Ms. Butler:

Thank you for your letter of June 11 with questions from the Select Committee on Energy Independence and Global Warming. In my response below, I will first repeat the questions and then give my answer.

Question 1. In your testimony, you argue that increased concentrations of carbon dioxide and global warming will be "good for mankind." Is this a personal value judgment or a scientific determination? If it is scientifically based, please describe the methodology that you have employed and provide a list of any peer-reviewed papers that you have authored to support this determination.

Answer 1. That increased CO2 will be good for mankind is an assessment based on many scientific studies. One example is the book "The Greening of Planet Earth," which can be accessed at the website http://www.co2science.org/. This book contains many references to peer-reviewed scientific papers, and its contents are summarized as: "Evidence is presented to show how current CO2 levels, which are 30 percent higher than in the pre-industrial era, have greatly enhanced the growth of trees and other plants. Results from controlled studies show how a doubling of CO2 in the atmosphere, which is expected to occur over the next century, will increase crop yields by 30 to 40 percent, double the water-use efficiency of most of the earth's vegetation and possibly triple the productivity of forests."

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I am by no means alone in arguing for the benefits of increased CO2. Professor Freeman Dyson of the Princeton Institute for Advanced Study (Albert Einstein and John Von Neumann were among the first members of the Institute) says in a book review, http://www.vaclavsmil.com/wp-content/uploads/docs/smil-bookreview-earths-biosphere 20030515-the-new-york-review-of-books-what-a-world!.pdf , "Experiments in greenhouses with an atmosphere enriched in carbon dioxide show that the yields of many crop plants increase roughly with the square root of the carbon dioxide abundance. If this were true for the major crop plants grown in the open air, it would mean that the 30 percent increase in carbon dioxide produced by fossil fuel-burning over the last sixty years would have resulted in a 15 percent increase of the world's food supply. A similar increase might have occurred in the world production of biomass of all kinds."

Professor Dyson goes on to point out, "If the supply of water is limiting, as it often is in times of drought, then increased carbon dioxide can still be helpful. The little pores in the leaves of plants have to be kept open for the plant to acquire carbon dioxide from the air, but the plant loses a hundred molecules of water through the pores for every one molecule of carbon dioxide that it gains. This means that increased carbon dioxide in the air allows the plant to partially close the pores and reduce the loss of water. In dry conditions, increased carbon dioxide becomes a water-saver and gives the plant a better chance to keep on growing."

Concluding his review, Professor Dyson says, "The humanist ethic does not regard an increase of carbon dioxide in the atmosphere as evil, if the increase is associated with worldwide economic prosperity, and if the poorer half of humanity gets its fair share of the benefits."

Of course there is more to the issue of overall benefit than vegetation growth and crop yields. For example, as part of the campaign of fear, IPCC reports have told us of impending malaria epidemics in a warming world. However, Professor Paul Reiter, a medical entomologist at the prestigious Pasteur Institute in Paris, has pointed out in an open letter to a select committee of the British Parliament, "Malaria is not a tropical disease. The principle determinants of malaria transmission are politics, economics, and human activities," not climate change. Noting that not one of the IPCC lead authors has ever written a research paper on mosquito-borne diseases, he calls the IPCC treatment of malaria "ill-informed, biased, and scientifically unacceptable." Reiter says that mosquito-borne diseases are unlikely to spread to non-tropical regions of the world and become a problem there. Malaria, for example, was once prevalent in most of Europe and even Siberia but has been largely eliminated. The main reason is that modern farming methods and changes in human living conditions have reduced the number of disease-spreading mosquitoes and reduced their access to people.

One cannot help but observe that bursts of human development have tended to accompany warm periods in the past; the Holocene; the Roman, and Medieval Warmings all coincided with expansions of human civilization and culture.

Many similar studies conclude that increasing CO2 will benefit mankind. But unfortunately in IPCC, National Academy of Sciences, and media reporting, these beneficial effects of increased atmospheric CO2 are not discussed, nor is research on them recommended. Instead we continue to pour ever more funding dollars into climate models, which are known to have serious flaws. Therefore in the public mind, effects of CO2 are considered to be threatening, if not alarming. This is a good example of the unbalanced, indeed biased, approach to the issue by the institutions entrusted to understand and inform us dispassionately on the global-warming issue.

Question 2a. In your testimony, you argue that dangerous levels of warming require a large feedback from water vapor. What temperature change would you consider dangerous? What atmospheric water vapor content would produce such a temperature change?

Answer 2a. The geological history of the earth shows that when CO2 levels were several thousand parts per million (ppm) – many times the 390 ppm we have now, and much more than we can produce from burning fossil fuels – life flourished on the land and in the oceans. Neither the higher CO2 levels or higher water levels of the atmosphere were a problem, and both contributed to more abundant life.

Question 2b. Would that level of water content pose a threat to human health if directly inhaled?

Answer 2b. Humans experience no ill effects from breathing the water vapor in air of 100% relative humidity (the maximum water-vapor content) at any temperatures encountered on earth, from the tropics to the poles. Health problems often come from too little water in the air, which is why forced-air heating systems of homes normally include a humidifier.

Question 3. In the past, you have compared climate scientists to a "religious cult" and to Nazis as reported in Daily Princetonian. Do you believe that this sort of public characterization of climate scientists - comparing them to Nazis - benefits the science and the position of science in the public policy process?

Answer 3. Naturally, comparing climate scientists or climate advocates to Nazis would be extreme and undefendable, and I never did so. Puzzled by this false accusation, I went back and looked at the Daily Princetonian article that I presume you have in mind. I could not find the word Nazi mentioned once. At the beginning of the article, in the context of characterizing the wild claims, fear, and exaggerations being promulgated under the guise of climate science, I was quoted as saying "This is George Orwell. This is the Germans are the master race. The Jews are the scum of the earth. It's that kind of propaganda." I was referring to the demonization of CO2, which is very similar to the demonization and scapegoating of the Jews in Germany. German Jews were a huge benefit to their country, just as CO2 is a benefit to the planet.

As for extreme public statements, of course they don't help, and you may wish to ponder extreme statements from some climate scientists and their supporters which do little to advance a dispassionate dialogue on the issue: In the Congressional Record Dr. James Hansen stated that climate skeptics are guilty of "high crimes against humanity and nature."

Attacking any who question impending climate catastrophe at a "Live Earth" concert, Robert Kennedy, Jr. said: "Get rid of all these rotten politicians that we have in Washington, who are nothing more than corporate toadies for companies like Exxon and Southern Company; these villainous companies that consistently put their private financial interest ahead of American interest and ahead of the interest of all of humanity. This is treason. And we need to start treating them as traitors."

Commenting on those who question global-warming hysteria, Canadian environmentalist David Suzuki stated: "What I would challenge you to do is to put a lot of effort into trying to see whether there's a legal way of throwing our so-called leaders into jail because what they're doing is a criminal act. It's an intergenerational crime in the face of all the knowledge and science from over 20 years."

Speaking of those who question climate apocalypse, Vermont's Senator Sanders said "It reminds me in some ways of the debate taking place in this country and around the world in the late 1930s. During that period of Nazism and fascism's growth - a real danger to the United States and democratic countries around the world - there were people in this country and in the British parliament who said; 'don't worry! Hitler's not real! It'll disappear!' "

In spite of these and even more extreme attacks on any who dare question the dogmas of global warming, in testimony to the Senate on February 25, 2009, I stated: "Let me say again that we should provide adequate support to the many brilliant scientists, some at my own institution of Princeton University, who are trying to better understand the earth's climate, now, in the past, and what it may be in the future."

Question 4a. On Slide 8 of your presentation, you compare observed and predicted temperature trends. Which IPCC scenarios have you plotted?

Answer 4a. The central projection for each of the four reports. For example, we have from the Summary for Policy Makers, AR4 of 2007 (page 12): "For the next two decades a warming of about 0.2 C per decade is projected for a range of SRES emission scenarios." The value of 0.2 C is plotted in the figure from 2007, and similarly for the previous reports. Obviously, at longer timeframes, projected warming would become more dependent on future emissions scenarios, but the projections are not sensitive to those scenarios at the relatively short timeframes shown in the figure.

Question 4b. Do the model outputs begin in the year in which the IPCC reports were issued as indicated in your plot?

Answer 4b. Yes. There was no attempt to show correspondence or lack of correspondence for times before the respective IPCC reports. As is the norm in scientific hypothesis testing, the objective was to compare predicted vs. subsequently measured temperature.

Question 4c. What are the uncertainty bounds for the model projections that you have plotted?

Answer 4c. The "uncertainty bounds" in the models are quite large, and this is often reflected in IPCC summaries (see following paragraph). Not only are the spreads in results large, there is no evidence of the spreads decreasing during the existence of IPCC, which now exceeds twenty years. For most other scientific investigations, uncertainties diminish with time as observations and modelling improve. As an example of the spread, we find in the Summary for Policy Makers, TAR of 2001 (page 8), "For the periods 1990 to 2025 and 1990 to 2050, the projected increases are 0.4 to 1.1 C and 0.8 to 2.6 C, respectively." The value plotted in the graph corresponds to 0.7 C for 1990-2025, in the center of the range. No attempt has been made to perform a statistical analysis on the projections shown in the figure. Rather the objective of the graph is simply to compare visually what we have been told to expect with what has actually happened during the 20-year period covered by IPCC reports.

The large spread in model predictions has been used by some climate scientists to defend the models against the disagreement between the models as a whole and the actual temperature record. The disagreement increases with each passing year. Clearly the larger the spread, the better one is able to say that "the models still agree with the temperature record." This is a serious flaw in the IPCC approach, for it places a premium on maintaining a large spread by having more models that stray significantly from the central projections.

Instead of circling the wagons around all models, we should view different models as containing different physics, with some models agreeing better with the temperature record than others. For example, in the AR4 of 2007, models show a range of equilibrium climate sensitivity (the amount of warming for doubling of atmospheric CO2) ranging from close to 1 C to more than 4.5 C. This difference reflects different ways of treating the key feedbacks in the climate system. The lower end of the range of models is more consistent with the actual temperature record and with empirical studies that give low climate sensitivities, which are far from threatening catastrophe. Instead the IPCC disregards these low values of climate sensitivity; we have on page 12 of the Summary for Policy Makers, AR4: "It [the equilibrium climate sensitivity] is likely to be in the range 2 to 4.5 C with a best estimate of about 3 C, and is *very unlikely* to be less than 1.5 C [emphasis original]." We would all be better served if the IPCC were to study the physical basis for model disagreements, including comparisons with empirical research finding low climate sensitivities, rather than continuing to defend all models as the basis for its position supporting large climate sensitivity.

Question 5. What is the cause and effect relationship between increased levels of CO2 in the atmosphere and the earth's temperature changes?

Answer 5. CO2 levels have increased from about 280 ppm at the beginning of the industrial revolution to about 390 ppm today. From comparing this increase to the quantity of coal, oil and natural gas burned and changes in the ratio of the isotopes ^{12}C and ^{13}C in the atmosphere, it appears that most of this increase has come from fossil fuels. The CO2 of the atmosphere is readily exchanged with the biosphere, with the soil and with the upper layers of the oceans, which contain about 100 times as much CO2 per unit volume, mainly as the bicarbonate ion, as the air at sea level. Since the solubility of CO2 decreases with temperature, and since the surface layers of the ocean have warmed slightly since the industrial revolution, a small fraction of the increase of CO2 in the atmosphere has come from the oceans.

Question 6. To what extent does CO2 lead to global warming?

Answer 6. The current average surface temperature of the earth is about 34 C warmer than it would be if there were no greenhouse effect. Most of the current greenhouse warming is due to water vapor and clouds, with a relatively minor contribution from CO2. Doubling the concentration of CO2 from preindustrial levels, with no other changes to the atmosphere, would cause an additional warming of about 1 C. The IPCC maintains that water vapor and clouds will change in ways that greatly amplify the warming due to CO2 alone. Two recent studies, one led by Dr. Roy Spencer and one by Dr. Richard Lindzen have compared satellite observations of outgoing short-wave and long-wave radiation with changes in the sea-surface and air temperature. These observational studies indicate that the net effect of water vapor and clouds is to diminish the warming from a CO2 doubling to less than 1 C. Several other independent studies based on observations, not models, also point to a warming from doubling CO2 that will be no more than 1 C. This is far smaller than the IPCC "most likely" value of 3 C.

Question 7. Is EPA right to classify CO2 as a pollutant?

Answer 7. EPA is completely wrong to classify CO2 as a pollutant. Calling CO2 a pollutant is truly Orwellian newspeak. With each breath, humans exhale air with 40,000 ppm CO2, far above the current level of 390 ppm in the atmosphere or any level we can attain by burning all fossil fuels we can find. As I discussed in my answer to question 1, increased levels of CO2 in the atmosphere will very likely be a net benefit for mankind.

Question 8. What empirical data do we have to prove the human impact on climate warming?

Answer 8. We have no persuasive empirical data that the warming of about 0.8 C over the last 150 years – since the end of the little ice age – is mostly due to humans. There have been many similar warmings in the past, for example, the medieval warm period when Vikings farmed Greenland around the year 1000. As I mentioned in connection with Question 6, observational data indicates doubling of CO2 should produce a warming of no more than 1 C. Because of the "saturation" of the CO2 absorption band, most models predict that temperature increases will be proportional to the logarithm of the CO2 increases. This would imply that the increase from 280 to 390 ppm of CO2 has produced half or less of the observed warming. The remaining warming has been due to natural causes that are still poorly understood, but presumably similar to the causes of the medieval warming and earlier warmings. These natural causes, which may be the result of solar variability or spontaneous, unforced changes in the oceans, have been neglected by the IPCC in its relentless focus on ascribing nearly all climate change to human activities. Nevertheless, natural causes are operating today and will continue to operate in the future.

Question 9. Does the climate science record support the implementation of economically expensive proposals like cap and trade as a solution to global warming?

Answer 9. Cap and trade will have no beneficial effect on climate.

Question 10a. Have you ever been discriminated against or felt pressure because of your scientific opinion on global warming?

Answer 10a. Support for the dogma of climate apocalypse due to increased levels of CO2 is a fervidly-held belief in most academic communities and in some other parts of society. I have experienced hostility from time to time, but so far my own institution, Princeton University, has upheld the tradition of academic freedom. However, I know of individuals who are aware of the real state of the science, as I have described it, but who are reluctant to step forward because of concerns about their careers or continued research funding.

Question 10b. Do you believe that grant money favors scientists who exaggerate the effects of global warming?

Answer 10b. One need only survey the research groups working on climate science and related fields and count the few researchers who are brave enough to challenge the alarmist dogma with scientific findings. I estimate that at least ten times more money goes to researchers who exaggerate the effects of global warming than those who question the alarm. There is a concern that funding for climate science will dry up if anthropogenic global warming is widely understood to be a nonthreat.

I believe that the huge amount of funding directed toward this issue is not good for climate science. It may attract researchers who are more motivated by the prospect of readily available funding, prizes, election to honorific learned societies, favorable media attention, and other rewards than a commitment to the science itself and the pursuit of scientific truth.

Best wishes,

William Happer

William Happer
Cyrus Fogg Brackett
Professor of Physics