S. HRG. 106–1115

THE SCIENCE BEHIND GLOBAL WARMING

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SIXTH CONGRESS

SECOND SESSION

MAY 17, 2000

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

81–375 PDF WASHINGTON : 2003

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2250 Mail: Stop SSOP, Washington, DC 20402–0001

CONTENTS

THE SCIENCE BEHIND GLOBAL WARMING

WEDNESDAY, MAY 17, 2000

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

The Committee met, pursuant to notice, at 9:31 a.m., in room SR–253, Russell Senate Office Building, Hon. John McCain, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOHN McCAIN, U.S. SENATOR FROM ARIZONA

The CHAIRMAN. Good morning. We meet today to examine the issues surrounding global warming. This subject continues to be an issue of great importance to the environment and the economic future of the country.

To better prepare ourselves to objectively evaluate future legislative policy, the Committee will explore three issues: One, the underlying science behind global warming; two, exactly where we are in our research efforts; and, three, what does it all mean.

For many years, scientists have been warning us about the greenhouse effect caused by man-made emissions of carbon dioxide and other gases, and the far reaching environmental consequences which could result if the problem is not properly addressed.

A large amount of evidence has been presented to suggest that this phenomena is real and is due to the activity of man. However, there also has been evidence presented to contradict this conclusion.

Earlier this year, the National Research Council concluded that the warming trend during the past 20 years is real, and is substantially greater than the average temperature of warming during the 20th Century. The report also identified a substantial disparity between satellite data trends and surface temperature trends as well.

The Intergovernmental Panel on Climate Change also has issued a draft of its third assessment report which will, in all likelihood, suggests a warming trend when its final version is released early next year. These two reports, in addition to hundreds of other studies, outline the need for a more firm understanding of and scientific consensus on global warming.

I would like to offer one brief example of global warming's potential harm. According to the United Nations Environment Program, the global average sea level has risen by 10 to 25 centimeters over the past 100 years. It is likely that much of the rise is related to an increase in the lower atmosphere's global average temperature since 1860.

Scientific models further project a rise in sea levels of a foot and a half by the year 2100. This projected rise is two to five times faster than the rise experienced over the past century. The impact of such movement on our coastal communities and businesses, such as fisheries, agriculture, and tourism, is unknown, but the consequences could be serious considering that half of the U.S. population lives in the coastal communities.

We look forward to hearing more about the outlined reports and potential scenarios from our witnesses today, along with the new findings from the government's research efforts.

Most importantly, any actions the United States takes in response to claims of global warming must be based on the best science available and not on rhetoric or political expedience. We must continue to invest in our research capabilities to fully understand the scientific interactions between humans, the land, the ocean, and the atmosphere.

Testimony presented here today will serve as a valuable insight for this Committee. We hope to establish a baseline for the Committee on the current state of knowledge on the subject of global warming. And I welcome all of our witnesses who are here today.

Before I ask Dr. Neal Lane, who is the Assistant to the President for Science and Technology of the Office of Science and Technology Policy, to begin his statement, I would like to make one additional comment.

One of the great things about the requirements of the electoral process is extensive interaction with the citizenry. I just finished an unsuccessful, but very enlightening, adventure in that area.

In town hall meeting after town hall meeting after town hall meeting, of which I had hundreds, young Americans stood up and said, "Senator McCain, what is your position on global warming?" There is a group of Americans who now come to political rallies with signs that say, "What is your plan?" "What is your plan," is the question that is asked.

I do not have a plan. I am sorry to say that I do not have a plan because I do not have, nor do the American people have, sufficient information and knowledge. But I do believe that Americans and we who are policymakers in all branches of government, should be concerned about mounting evidence that indicates that something is happening.

I do not pretend to have the expertise and knowledge on this very important and very controversial issue, but I do intend, beginning with this hearing and follow-on hearings, to become informed, to reach some conclusions, and make some recommendations, or make some non-recommendations depending on the information that I receive.

I believe that it is of the utmost importance that we examine this issue thoroughly, and I am dedicated to that proposition. And I am very grateful that we have such a very well informed group of Americans who will appear before us today.

[The prepared statement of Senator Hollings follows:]

PREPARED STATEMENT OF HON. ERNEST F. HOLLINGS, U.S. SENATOR FROM SOUTH CAROLINA

Mr. Chairman, thank you for holding this hearing today on global climate change, which I hope will be only one of many. It's been about 3 years since our last full Committee hearing on climate change, so I welcome this opportunity to hear what the science can now tell us about this important topic. This Committee has worked hard to ensure that the federal government has the best research and information possible about global warming, as well as other types of climate changes. I'm glad to see our investments are bearing fruit and that we are identifying ways to focus our research to help us make decisions now and in the decades ahead.

During the 1980s, a number of us here on the Committee became increasingly concerned about the potential threat of global warming and loss of the ozone layer. In 1989, I sponsored the National Global Change Research Act, which attracted support from many Members still serving on this Committee including Chairman McCain, as well as Senators Stevens, Inouye, and Gorton. In 1990, after numerous hearings and roundtable discussions, Congress enacted the legislation, thereby creating the U.S. Global Climate Research Program.

When we passed the Global Change Research Act, we knew it was the first step in investigating a very complex problem. We placed a lot of responsibility in NOAA, the scientific agency best suited to monitor and predict ocean and atmospheric processes. We need to renew this ocean research commitment to ensure we better understand the oceans, the engines of climate. The so-called "wild card" of the climate system, the oceans, are capable of dramatic climate surprises we should strive to comprehend. In addition, the oceans are critical to our continued well-being. I am particularly interested that we pursue the questions covered by the recent NRC report, *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health.* This excellent report tells everyone here—even those who don't live on the coast—that understanding our oceans is of the utmost national importance. The Oceans Act this Committee approved only a few weeks ago would go a long way to ensuring that we give priority to these important ocean research questions.

I am glad to report that the research accomplished under the National Global Change Research Act has led to increased understanding of global climate changes, as well as regional climate phenomena like El Niño/Southern Oscillation (ENSO). We now have a better understanding of how the Earth's oceans, atmosphere, and land surface function together as a dynamic system, but we cannot stop there. Only recently, NOAA measured an important increase in temperature in all the world's oceans over a 40 year period. We need to understand the causes and how that will affect us. All this research ensures that federal and state decisionmakers get better information and tools to cope with such climate related problems as food supply, energy allocation, and water resources.

While we have learned an astonishing amount about climate and other earth/ocean interactions in only a decade, we have other critical questions that require further research to answer. Many of these questions are relevant not only to improving our scientific understanding, but also to contributing to our future social and economic well-being. For example, climate anomalies during the past two years—most directly related to the 1997–1998 El Niño event—have accounted for over $30 billion in impacts worldwide. When impacts from the recent floods in China are included, these direct losses could rise to $60 billion. This most recent El Niño claimed 21,000 lives, displaced 4.5 million people, and affected 82 million acres of land through severe flood, drought, and fire. When we better understand the global climate system, and its relationship to regional climate events like El Niño, we may be able to find ways—such as improved forecasting and early warning—to avoid some of the severe impacts.

Under current global warming scenarios, scientists predict a 6 to 37 inch rise in sea level by the year 2100 that will put our coastal areas at an increased risk of flooding. This could have severe consequences for coastal states, such as mine, particularly if climate change has any bearing on the frequency or severity of hurricanes. While we have been in a pattern of infrequent hurricane landfalls along the East Coast, it is possible that recent severe storms signal a return to conditions similar to those of the 1930s, 1940s, and 1950s when huge storms were frequently making landfall. If so, and particularly if global warming increases our vulnerability to flooding, we must develop the science to better understand and respond to any environmental changes in weather patterns.

I welcome our witnesses to discuss the current state of science on global climate change. I am anxious to hear about the progress we've made towards better understanding the complex temperature and precipitation pattern changes, and where our research efforts are going in the upcoming decade. I hope today's hearing will reinvigorate this Committee's leadership in promoting sound research on these important scientific questions.

[The prepared statement of Senator Snowe follows:]

PREPARED STATEMENT OF HON. OLYMPIA J. SNOWE, U.S. SENATOR FROM MAINE

Thank you, Mr. Chairman, for holding this timely hearing so that we can further understand the underlying science behind global climate variability from a distinguished group of internationally renowned scientists.

Mr. Chairman, last spring, Maine had a first-of-its-kind conference specifically to debate and discuss the impact of potential environmental climate change with state, national and international experts. For two days, over 150 people explored many questions. Are we leaving a human fingerprint on the Earth's climate? Why has the average temperature in Lewiston—where the conference was held—increased 3.4 degrees F. over the last century? Are we in a race against an uncertainty that none of us on this planet can afford to lose? And, if so, what do we need to do to establish a sound scientific basis for making state, regional, national, and international resource management and economic and policy decisions when considering global environmental change issues? The answers to these questions are complex, and our approach to them must continue to be through research and thorough analysis of the research results.

It is important to continue to develop more accurate models led by common scientific research and thought so we might better predict what the impacts will be on plants and animals—including ourselves—under any changing climatic conditions. Concurrently, we must also evaluate the mitigation and adaptation strategies under consideration by policy makers in response to increasing amounts of atmospheric carbon dioxide and other greenhouse gases and possible environmental changes.

The U.S. Forest Service has predicted that climate and pollution stresses from wild pests, humans, and other environmental changes are likely to cause unprecedented cumulative effects on our northern forest ecosystems and, by extension, on our economy and our culture. Our forests can largely adapt to environmental changes. But, over time, these forests could very well change in their composition, range, health, and productivity. Oak and conifers, for instance, could prevail over the maple dominated hardwood forests—diminishing the brilliant fall foliage for which New England is so famous.

The fact is, the vast majority of international scientists say that something appears to be happening because of the excess of greenhouse gases in the atmosphere, and there is general agreement that human activities are affecting the global climate and thus affecting both land and sea.

As Chair of the Oceans and Fisheries Subcommittee, I have introduced the Coral Reef Conservation Act, along with you, Mr. Chairman, in an effort to protect, sustain, and restore the health of coral reef ecosystems. In 1998, coral reefs around the world appeared to have suffered the most extensive and severe bleaching damage and subsequent mortality in modern times. Reefs in at least 60 countries were affected, and in some areas, more than 70 percent of the corals died off. These impacts have been attributed to, among other factors, the warmest ocean temperatures in 600 years. We must increase our efforts to protect these coral reefs, which are among the world's most biologically diverse and productive ecosystems.

Again, Mr. Chairman, I thank you for holding this hearing on the science of global warming, and thank you for assembling such a distinguished panel today to share their vast expertise with us.

The CHAIRMAN. Dr. Lane, thank you and welcome, and thank you for all the outstanding work you have done in the past and are presently doing.

STATEMENT OF DR. NEAL LANE, ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Dr. LANE. Thank you very much, Mr. Chairman.

And I want to thank you, Senator Hollings, members of the Committee, for holding this hearing, and for giving me and also my colleagues, who are the experts in this matter, a chance to talk to you today about the state of knowledge of climate change, and about our Federal agency research program.

The U.S. Global Change Research Program continues a strong bipartisan tradition of support for this scientific endeavor. And it began with President Reagan, continued through President Bush's Administration, and on to the Clinton/Gore Administration.

I would ask that my written testimony be included for the record.

The CHAIRMAN. Without objection, the entire statement of you and the other witnesses will be included in the record.

Dr. LANE. Thank you. I will summarize three issues in my oral statement very briefly: First, what we know about the Earth's climate and how it is changing; second, the remaining difficult scientific questions that we must address; and finally, how our research program is going after these issues.

Let me start with the area of scientific consensus. First, human activities has significantly increased atmospheric carbon dioxide. In the past century, atmospheric CO_2 has risen 30 percent. The concentration of carbon dioxide is now higher than at any time over the past 420,000 years.

Second, the surface of the Earth is warming. The Earth's surface has warmed significantly over the last century. The oceans are warming as well, and evidence is strong that the temperatures of the late 20th Century are without precedent in the last several centuries, the 1990's are the warmest decade on record, and 1998 was the warmest year in 1,000 years.

Third, the Earth's global average surface temperature will continue to rise during the next century. Greenhouse gases in the atmosphere will increase the surface temperature of the Earth. Global temperatures are projected to increase two to six and a half degrees Fahrenheit over the next 100 years.

Rising temperatures will increase rates of evaporation and lead to more total precipitation. Sea level will rise as warming expands the ocean water. Finally, these changes in temperature, precipitation, and sea level will affect the natural environment and human society.

The ideal ranges for plants and animals will change, and in some cases the effects of other environmental stresses and urban and rural areas will be amplified.

Let me now move to the areas of remaining uncertainty. The key questions I think are: How fast will temperatures change over the next century, and how will the impacts of this change vary across different regions of the world?

Differences in future climate projections largely stem from disagreements over so-called feedback effects. For example, will more water in the atmosphere increase warming by acting as a greenhouse gas, or result in more low clouds that will reflect sunlight away from the Earth? Will aerosols, small particles, reflect incoming sunlight, or will they absorb heat and contribute to warming effects?

We do not know the exact answers to these questions, but our estimates of future average temperature increases in the range of two to six and a half degrees Fahrenheit include all of these uncertainties.

We know the amount of carbon dioxide the global biosphere takes up and releases each year varies widely, but we do not know why. And although evidence suggests that plants and vegetation in the northern hemisphere are currently taking up substantial amounts of carbon dioxide, we do not know whether this capacity can be maintained or even increased over the long term.

And though we often discuss global climate change, many important policy questions will have a regional focus. For instance, how will climate change affect rainfall in the southwest, fisheries in the northwest, or the distribution of maple trees in the northeast? We need to know how these changes will affect agriculture, tourism, and local economies.

Finally, Mr. Chairman, I would like to comment on our efforts to answer these questions. Federal agencies that participate in the U.S. Global Change Research Program conduct research on the mechanisms of the Earth's climate system, on the future course of climate change, and the potential impacts of climate change on the environment and human society.

The research agenda for the Global Change Research Program has been developed in cooperation with the scientific community, including the National Academy of Sciences.

Over the last decade, the Global Change Research Program has had a strong focus on the physics and chemistry of the atmosphere and the oceans, including reducing uncertainties about the rule of aerosols and water in the atmosphere.

Recently, the Global Change Research Program has broadened its scope, and I would like to highlight three new priorities. First, we are completing the first U.S. national assessment of the potential consequences of climate variability and change.

This assessment is examining the potential ecological and socioeconomic impacts of climate variation and change in the United States and the ways we might prepare for them.

Second, our new carbon cycle science initiative will evaluate the potential for the Earth's forests, the agriculture regions, and wetlands, to take up and store carbon.

And finally, new research under the Global Change Research Program umbrella will focus on how water moves through the land, the atmosphere, and the ocean, and how climate change may increase or decrease regional availability of this critical global resource.

Mr. Chairman, I thank you again for the opportunity to testify today. Your sponsorship of the Global Change Research Seminar Series clearly shows your interest in climate science. And I am confident that together we can continue to increase our understanding of these important issues that will help us make sound policy decisions for our nation.

I will be happy to answer any questions you have.

The CHAIRMAN. I thank you, Dr. Lane, and I did read your entire statement which I think is very illuminating.

[The prepared statement of Dr. Lane follows:]

PREPARED STATEMENT OF DR. NEAL LANE, ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Thank you for this opportunity to discuss with you the Administration's science and technology programs that are relevant to the understanding of climate change. I know the Members of this Committee share my strong belief that America's world-leading science and technology enterprise must be sustained and nurtured. While we sometimes differ on precisely how and where to invest our taxpayers' funds, we share a bipartisan understanding that the future prosperity of this country depends on continued strong federal support for all areas of scientific inquiry.

Today I come before you to suggest that we can bring that same common appreciation for science to an area of considerable policy disagreement—the issue of climate change. Whatever your policy views may be on the wisdom of the Kyoto Protocol, I respectfully suggest that supporting scientific research on climate change and its potential impacts is in our national interest. The President's FY2001 budget requests substantial funding for the U.S. Global Change Research Program, as has every budget submitted by this Administration and those of President Reagan and President Bush. I hope that Congress sees fit to continue the bipartisan tradition of strong support for this scientific endeavor, which is providing the sound, objective information we need to support decision-making in the public and private sectors.

The Science of Climate Change

I would now like to summarize what we know about the Earth's climate and how it is changing. In 1995, the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reviewed all of the science then available. Through the IPCC process, leading scientists from more than 150 countries periodically review and assess scientific information about climate change and its environmental and economic effects. The report documented a series of changes that had already occurred, including increases in greenhouse gas concentrations, an unusually rapid increase in temperatures, and rising sea levels. It explained that the magnitude, timing, and geographic pattern of observed temperature changes closely matches the changes that models project from human activities, and does not match well with model simulations of natural change or changes seen in the natural record. The Report famously concluded: "The balance of evidence suggests that there is a discernible human influence on global climate."

The qualified nature of the IPCC attribution statement reflected the existence of alternative interpretations of parts of the data and known shortcomings in models of how the climate system works.

Recently, however, important scientific evidence has emerged that has substantially undercut many of potential dissenting arguments, thereby fundamentally changing the debate over global warming. Basically, the debate has changed from "Are we warming the Earth?" to "How much are we warming the Earth?" To understand the current state of climate change science, let me first start with a series of statements that virtually all credible atmospheric scientists agree with.

1. *The atmospheric concentration of CO_2 has been significantly increased by human activities*. In the past century or so the CO_2 concentration has risen from less than 280 parts per million by volume (ppmv) to about 365 ppmv, an increase of about 30 percent. At 365 ppmv, CO_2 is now higher than at any time over the past 420,000 years. It is universally recognized that human activity is responsible for this increase, mainly through fossil fuel combustion and deforestation. Our best estimates show that unless action is taken to reduce CO_2 emissions, atmospheric carbon dioxide levels will likely reach about 700 ppmv by the end of the 21st century, about double current levels. Other greenhouse gases, such as nitrous oxide, methane, and halocarbons (CFCs and HFCs), have also increased due to human activities and further increases over the 21st century will add to the tendency for global warming.

2. *The surface of the Earth is warming*. There is now near unanimous agreement, including most of the climate skeptics, that the Earth's surface has warmed significantly over the last century.

- A recent National Research Council report ("Reconciling Observations of Global Temperature Change") carefully examined direct measurements of surface temperature. The report concluded that "The warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the twentieth century." These data show that the surface of the Earth has warmed by 0.4–0.7 degrees C (0.7–1.4 degrees F) over the last 100 years, with 0.2–0.4 degrees C (0.4–0.8 degrees F) of that coming in just the last 20 years.

- Borehole measurements of temperature at various depths below the Earth's surface show that the average surface temperature of the late 20th century is without precedent in the last 500 years.
- Using tree rings, lake sediment records, ice cores, and other paleoclimate indicators, a global temperature record extending back 1000 years has been constructed. This record is in broad agreement with the other data sets, and it shows that the 1990s were the Earth's warmest decade in the last 1000 years, and that 1998 was the warmest year in this entire period.
- Measurements made over the last few decades have shown a precipitous decrease in both the areal extent and thickness of Arctic Sea ice. Model simulations of the data suggest that this decline is unlikely to be an entirely natural phenomenon. Mountain glaciers have retreated worldwide during the last century.
- Over the last century, global mean sea level has risen 4 to 8 inches, and further rise is inevitable because of the thermal inertia of the ocean and melting glaciers.
- During the past 45 years the upper 300 meters of world Ocean has warmed by approximately 0.56 degrees F. This warming is consistent with predictions from general circulation models that simulate the effect of greenhouse gas increases since the beginning of the industrial revolution.

3. *The Earth's surface temperature will continue to rise during the next century*. Elementary physics shows that increasing greenhouse gases in the atmosphere must exert a strong warming tendency on the surface temperature of the Earth. This is not a controversial concept. Indeed, the greenhouse effect is responsible for providing a hospitable climate on Earth. It is generally agreed that the Earth's surface temperature will rise over the next century as the atmospheric concentrations of CO_2 and other greenhouse gases increase. The questions are: "How much and how fast will temperature increase, and with what regional impact?" The 1995 IPCC Second Assessment Report, representing the broad consensus of the scientific community, projected a temperature increase of 1.0 to 3.5 degrees C (2 to 6.5 degrees F) over the next 100 years. The more sophisticated analyses conducted since that time, which will form the basis of the IPCC Third Assessment Report, due out in early 2001, continue to show that such an increase is likely. This rate of warming would be greater than any seen during the past 10,000 years.

4. *There is mounting scientific evidence that climate change is already affecting ecosystems.* Data from many sites in Europe and North America show that the observed warming has been accompanied by earlier plant growth and flowering. For example, here in Washington, D.C., cherry trees, along with 89 of 99 other plants examined, are blooming a week or more earlier than they did 30 years ago. Satellite data for high latitudes in the Northern Hemisphere show that plants are leafing eight days earlier in 1991 than in 1982. Observed changes are not confined to vegetation:

- The ranges of some animals appear to be shifting. Birds are going further north to breed and the range of many European and North American butterflies are shifting north as well.
- Some species are disappearing when a habitat changes. Warmer and drier conditions have caused the high elevation "cloud forest" of Costa Rica to rise and 20 frog species to disappear.
- Observations in several sites along the Pacific coast of North America indicate that the distribution of fish and phytoplankton has changed as waters warm. There is also evidence that warming waters increase the amount of coral bleaching.

We have discovered much about the way the climate system works, and about how the climate system is likely to evolve in response to increases in greenhouse gases. As I noted above, the debate has changed from "Are we warming the Earth?" to "How much are we warming the Earth?" It leads directly to the question of "So what?" Right now, science only provides a partial answer. As temperatures rise evaporation will increase, leading to more moisture in the atmosphere. Hence, worldwide, an increase in total rainfall is likely, with much coming in heavier downpours. But increased evaporation will also lead to more drought in some regions. Rising temperatures will also bring sea-level rise. These changes in temperature, precipitation and sea level will likely change the ideal ranges for plant and animals, and will also affect human society. Our understanding of how the life support systems on Earth will respond to these changes remains quite uncertain. This uncertainty is no reason to be complacent about the future.

Emerging Questions

Let me now move past points of agreement, and talk about the cutting edge of climate science.

To a large extent, the disagreements between future estimates of the climate are disagreements about effects of the "feedbacks" of the climate system. While increasing CO_2 will, by itself, tend to increase the surface temperature of the Earth, it will also change other parameters, such as the amount of water vapor or the extent of clouds, which also affect the climate system. For example, if the climate warms due to increased CO_2, then this will evaporate more water vapor into the atmosphere. Water vapor is a powerful greenhouse gas, so this will amplify the warming. This is an example of a positive feedback. On the other hand, the increase in CO_2 might also increase low clouds. These clouds reflect sunlight, so if they increase it would cool the Earth, moderating somewhat the warming effects of the CO_2 increase. These feedbacks are only roughly understood, and improving our understanding of them would significantly improve our ability to predict the future climate.

Changes in the amount of solar radiation would definitely affect the climate, and there are indications that changes in solar radiation may have been an important contributor to climate change over the past few centuries. However, changes in output of the sun cannot, by themselves, entirely explain the observed warming over the last century. Our best estimates are that changes in solar output could explain about 25 percent of the surface temperature increase observed in the last 100 years. The rapidly increasing concentrations of greenhouse gases also mean that solar variability will be an ever-smaller component of climate change in the future.

There are also important questions about the relationship of temperature change to other changes in the physical climate system. One of the expected consequences of warming is acceleration of the Earth's hydrological cycle. The increased evaporation of water described above will transfer water more rapidly from the land and oceans to the atmosphere, and could result in an increased incidence of both droughts and the extreme rainfall events that lead to flooding. There is already evidence that such change has begun in the U.S., where the incidence of heavy downpours (where more than 2 inches of rain falls in a 24-hour period) has increased by about 10% over the last century. We know that there will be significant regional variation in these changes, but our ability to project regional-scale precipitation change is very limited, and we do not have a good understanding of how precipitation change will interact with other stresses on managed and natural ecosystems.

We also need to quantify the relative contributions of the oceans and terrestrial plants to removing carbon from the atmosphere. Human activities add about 7 billion tons of carbon to the atmosphere every year. About 3 billion tons remain in the atmosphere, while 4 billion are absorbed by terrestrial and ocean "sinks." We know that land ecosystems play an important role in carbon sequestration, but important questions remain about the magnitude and geographic distribution of terrestrial sinks. For example, there is consensus that more carbon is being taken up than is released by land ecosystems in the Northern Hemisphere, but we don't know if the amount is on the order of tens of millions or hundreds of millions of tons. And where in the Northern Hemisphere is carbon is being sequestered? It could be mostly in North America, or it might be in Siberia.

More importantly, we don't know whether it is the above ground vegetation or the soils that are responsible for the apparent increase in sequestration. We also don't know what is causing this and whether it will persist. Is it from nitrogen fertilization, an effect that will disappear when soils become nitrogen-saturated, or as industrial and automobile pollution is decreased? Is it from carbon fertilization, an effect that could slowly decline with increasing atmospheric concentrations? Is it from plants growing on abandoned farmland, or from increased use of "low-till" agricultural practices? Is it from growth of many young forests created recently under revised logging laws, an effect that will decline as the forests mature? Or is it simply from forest trees growing better in warmer, moister conditions, an effect that may continue indefinitely? Finally, we know that the amount of carbon the global biosphere stores and releases each year can vary widely. However, we don't know how much of that sequestered CO_2 in the terrestrial biosphere is transitory, being returned to the atmosphere in a year or two to continue contributing to atmospheric CO_2 increases. We also don't know how much carbon is retained in soils for the decades or centuries required to ameliorate atmospheric increases. Different answers to these questions will determine very different trajectories of future atmospheric CO_2 change.

We also know that local plant and animal species are being mixed into ecosystems all over the world at increasing rates. Climate change may exacerbate this problem. We also know that when these exotic species spread aggressively, they can reduce and displace current species, disrupt ecosystem functioning, and do enormous economic damage. The National Academy of Sciences estimates that pubic and private-sector spending on Zebra Mussel control, a problem we did not even anticipate in the 1980s, will total $5 billion in 2000. Given that expected rates of change over the next century will alter the ideal ranges of plant and animal species faster than they can migrate, ecosystem disruption is likely.

New Directions in the U.S. Global Change Research Program (USGCRP)

One of the consequences of increased understanding is the definition of new research questions. The process of revising and updating research strategies in response to new findings and new questions goes on every year. It is a regular part of managing large research programs, and the USGCRP is no exception. But periodically, it is also valuable to step back and take a longer-term view of what has been accomplished and what new research challenges are arising. One of the most important contributions of the National Research Council to the USGCRP is precisely this kind of taking stock. In 1996, the USGCRP requested the NRC to undertake a major study of emerging issues in global change science. The result was Global Environmental Change: Research Pathways for the Next Decade, which consists of a summary issued in mid 1998 and a full report published in 1999. The "Pathways" report identified a comprehensive set of science questions, and identified several cross-cutting areas of special concern, including carbon cycle science, water cycle science, and climate change research "on temporal and spatial scales relevant to human activities." These recommendations played an important part in the definition and initiation of a series of new activities in the USGCRP: the Carbon Cycle Initiative, an increased emphasis on water cycle research, and the initiation of the first National Assessment of the Potential Consequences of Climate Variability and Change for the US.

The USGCRP Carbon Cycle Science Initiative was established in the FY2000 budget. The focus of this activity is on improving our understanding of how carbon moves through the Earth's terrestrial ecosystems, soils, ocean, and atmosphere, with $229 million proposed in the FY2001 budget (a $25 million increase over FY2000). This on-going effort will provide critical scientific information on the fate of carbon in the environment, the sources and sinks of carbon on continental and regional scales, and how sinks might change naturally over time or be modified by agricultural or forestry practices. USDA, DOE, DOI/USGS, NASA, NSF, DOC/NOAA, and the Smithsonian Institution will all play important roles in this effort, guided by a science plan that has been drafted with participation by many of the leading scientists in this field.

The Carbon Cycle Science Initiative will employ a wide variety of research activities in a comprehensive examination of the carbon cycle as an integrated system, with an initial emphasis on North America. Comparison of North America to other regions will also be important for understanding the relative importance of our region in the global context. Atmospheric and oceanographic field sampling campaigns over the continent and adjacent ocean basins will be combined with atmospheric transport models to develop more robust estimates of the continental distribution and subcontinental-scale magnitude of North American carbon sinks. Local-scale experiments conducted in various regions will begin to identify the mechanisms involved in the operation of carbon sinks on land and in the ocean; the quantities of carbon assimilated by ecosystems, and how quantities might change to be enhanced in the future.

The initiative will also include evaluation of information from past and current land-use changes, both from remotely sensed and historical records, to assess how human activity has affected carbon storage on land. Potential management strategies for maximizing carbon storage will be studied, including evaluation of the variability, sustainability, lifetime, and related uncertainties of different managed sequestration approaches. Finally, enhanced long-term monitoring of the atmosphere, ocean, forests, agricultural lands, and range lands, using improved inventory techniques and new remote sensing, will be used to determine long-term changes in carbon stocks. Integration of new observations and understanding of carbon cycle processes in regional and global carbon system models will enable us to more accurately project future atmospheric concentrations of carbon dioxide and other greenhouse gases.

The highest priority for FY2001 will continue to be on understanding and quantifying North American carbon sources and sinks, and on filling critical gaps in our understanding of the causes of carbon sinks on land as well as processes controlling the uptake and storage of carbon in the ocean. Research advances on these questions will provide information needed as a basis for sound policymaking, as well as valuable information about potential management strategies to land and forest managers in both the public and private sectors.

Research on the **Global Water Cycle** is receiving increased attention in the USGCRP, with $308 million proposed in the FY2001 budget (a $35 million increase over FY2000). This has been an important research area since the inception of the USGCRP, but the increasing evidence that changes in the water cycle are already occurring, and that changes in the water cycle and climate are closely coupled, are leading to a new emphasis on water cycle science. The USGCRP has established a Water Cycle Study Panel that is focused on improving our understanding of how water moves through the land, atmosphere, and ocean, and how global change may increase or decrease regional water availability. This group, which includes government and academic scientists, is developing comprehensive research and applications strategies that will take advantage of existing and future observing systems to address the major issues concerning the global water cycle and global and national water resources.

The primary goal is to achieve a greater understanding of the seasonal, annual, and interannual mean state and variability of water and energy cycles at continental-to-global scales, and thus a greater understanding of the hydrological interactions in the Earth's climate system. The study of the global water cycle is a unifying theme that bridges the gap between the spatial scales involved in global atmospheric (and atmosphere-ocean interaction) processes, and land surface hydrological processes, which determine the availability of water resources.

Finally, the **U.S. National Assessment of the Potential Consequences of Climate Variability and Change** is now nearing completion. The National Assessment effort, which began in 1997, is examining the degree to which particular regions and sectors of the U.S. are vulnerable to climate variations and change. The National Assessment is examining the potential ecological and socioeconomic impacts of climate variations and change, and ways we might prepare for both the next few decades and the next century, including identification of possible adaptation measures. It is also identifying key information gaps and research needs (i.e., information that is still required to answer questions of interest to resource managers and decision-makers).

The assessment effort has included a series of regional workshops with participation from a broad range of public and private stakeholders in the identification of issues of interest and a series of regional and sectoral analyses, most of which are not yet complete. The major product of the assessment process is a National Assessment Synthesis Report that should be completed this year. The National Assessment Synthesis Report is undergoing a rigorous peer-review that includes several rounds of technical review, full agency review, and a 60-day public comment period before it is submitted to the President and the Congress. The U.S. Global Change Research Act calls for this type of assessment of the potential consequences of global changes on a periodic basis.

The first National Assessment will soon be completed, but we expect many of the lessons learned during this process to play a significant role in the definition of future USGCRP research activities. There were important issues that it was not possible to fully address in this initial effort, such as the potential indirect effects on the U.S. of changes in other parts of the world. Many additional questions of interest have been identified. Farmers and ranchers are curious about what might change for their competitors in other nations. People all around the country are interested in how climate change might alter the incidence of extreme climate conditions that affect the quality of life and livelihoods, such as drought, heat waves, and severe storms.

This first assessment is part of a larger evolution of the USGCRP. During much of the first decade of its existence, the program concentrated on observing and documenting change in the Earth's physical systems and understanding why these changes are occurring. It is now appropriately shifting from this predominant focus on physical systems to a much broader effort to understand how global change will affect the Earth's biological systems and the human societies that are dependent upon them, and make useful scientific data and information more broadly available for public and private planning and decision making.

To accomplish this, we must greatly improve our capabilities for conducting regional-scale assessment of global change and its potential consequences around the country. Our current level of understanding tells us that climate change and its effects will vary by region, but our ability to project specific regional effects remains limited. We also need to learn more about the interactions of natural and human-induced climate change and variability and other human-induced stresses on the environment, such as pollution, land-use change, resource extraction, and invasive species, many of which are regional in scale. Additionally, we need to achieve an integrated understanding not only of the nature and extent of physical and biological effects of climate change, but also of their ramifications for our social and economic systems.

The Organization of the U.S. Global Change Research Program

Our current understanding of climate change, as well as our understanding of many other important global change issues, is the result of the significant progress that has occurred over the last several decades through scientific research. U.S. climate change research is largely supported through the USGCRP. The Administration is committed to continued strong support for the research needed to improve our understanding of the mechanisms of the Earth's climate system, the likely future course of climate change, and the potential impacts of such change on the environment and human society.

The USGCRP, a program planned during the Reagan Administration and elevated to a Presidential Initiative under President Bush in 1989, was codified by the Global Change Research Act of 1990. The program has been strongly backed by every Administration and Congress since its inception. The FY2001 Budget Request demonstrates President Clinton's ongoing commitment to the program, with an overall request for the USGCRP of approximately $1.74 billion dollars, about 2 percent (or $39 million) higher than last year's enacted level (tables showing the budget by agency and by program element area are attached).

Within the total, support for scientific research is up about $53 million (7%), including a $31 million increase for carbon cycle studies at USDA as part of the carbon cycle research initiative begun last year. Surface-based observations at NOAA are receiving a substantial increase ($26 million, or about 39%) that will help provide new information on changing patterns of temperature and rainfall in the US. The total increase for surface-based observations and science together is about $79 million, or 10%. The space-based observation component of the budget is reduced by about $40 million, to a total of $897 million. This decrease is mainly a consequence of decreases in NASA development costs as some of the first series of Earth Observing System (EOS) satellites are completed and launched.

The fact that the increase in science funding more than offsets the decrease in funding for space-based observations is important. Increasing the proportion of program funding for science has been one of the most consistent recommendations from the National Research Council and various agency advisory committees over the last few years. The National Research Council (NRC) report, Global Environmental Change: Research Pathways for the Next Decade, noted that 65 percent of the total USGCRP were devoted to space-based observations and data systems in the 1996 budget proposal. In this year's budget proposal, the equivalent number is about 52 percent, demonstrating the progress that has been made over the last 5 years in increasing the proportion of USGCRP funding for scientific research and analysis.

Since its inception, the USGCRP has been directed toward strengthening research on key scientific issues, and has fostered much improved insight into the processes and interactions of the Earth system. The results of research supported by the USGCRP play an important role in international scientific assessments, including assessments of climate change and stratospheric ozone depletion. The USGCRP research results provide the scientific information base that underpins consideration of possible response strategies. The USGCRP does not recommend specific government policies responsive to global change, nor does it include support for research and development of energy technologies or development of mitigation strategies.

Participants and Organization

The Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources (CENR), a component of the National Science and Technology Council (NSTC), provides overall direction and executive oversight of the USGCRP. In addition, the National Research Council within the National Academy of Sciences provides external oversight and review of USGCRP programs. Agencies manage and coordinate Federally supported scientific research on global change within this framework. In addition to USGCRP review of the overall set of agency research programs, each agency is responsible for the review of individual projects within its programs. These reviews are almost exclusively based on an external peer-review process, which is deemed an important means of ensuring continued program quality.

The agencies that actively participate in the USGCRP are USDA, DOC/NOAA, DOE, HHS/NIH, DOI/USGS, EPA, NASA, NSF, and the Smithsonian Institution. OMB and OSTP are the Executive Office of the President liaisons to the SGCR. The

Department of State does not fund research but is part of the SGCR because of the extensive international cooperation necessary in all aspects of global change research. The Department of Defense does not fund research focused on global change, but participates in the SGCR because it performs related research, such as how changing ocean conditions may affect their ability to ensure the nation's security. Some of these agencies support research on a broad range of issues, while others have a more specialized focus. Programmatic contributions are closely matched to agency missions and areas of expertise. The crosscutting research that takes place in the USGCRP program element areas takes advantage of the unique capabilities of different agencies and applies them to science problems that are beyond the scope of any single agency's mission or the ability of any one agency's programs to address.

The scientific community contributes to the planning, definition, and implementation of USGCRP research activities. An important aspect of this is scientific oversight and review of the USGCRP that is provided by the National Academy of Sciences. This function includes review of various program activities and examination of scientific issues in response to requests from the USGCRP and participating agencies. Over the past several years, the USGCRP has commissioned a series of reports, including "Pathways" and smaller reports on climate observations and climate modeling. These reports have provided important input to the ongoing planning and program implementation decisions of the USGCRP agencies, including the initiation of the carbon cycle and water cycle research efforts described above, and the current organization of the USGCRP as a series of other interrelated program elements.

- **Understanding the Earth's Climate System,** with a focus on improving our understanding of the climate system as a whole, rather than its individual components, and thus improving our ability to predict climate change and variability. The FY2001 budget proposes $487 million for this program element (a decrease of $16 million), which is largely focused on the physical climate system. Improving our understanding of climate change, including its potential impacts on ecosystems and human society, requires support of research and integration of results across the entire USGCRP. Climate is a naturally varying and dynamic system with important implications for the social and economic well being of our societies. Understanding and predicting climate changes across multiple time scales (ranging from seasonal to interannual, to decadal and longer) offers valuable information for decision making in those sectors sensitive to rainfall and temperature fluctuations, including agriculture, water management, energy, transportation, and human health.
- **Biology and Biogeochemistry of Ecosystems,** with a focus on improving understanding of the relationship between a changing biosphere and a changing climate and the impacts of global change on managed and natural ecosystems, including forests, coastal areas, and agriculture. The budget proposes $224 million in FY2001 (an increase of $19 million) for the study of changes in managed and unmanaged ecosystems. The biosphere consists of diverse ecosystems that vary widely in complexity and productivity, in the extent to which they are managed, and in their economic value to society. Better scientific understanding of the processes that regulate ecosystems and the capability to predict ecosystem changes and evaluate the potential consequences of management strategies will improve our ability to manage for sustainability.
- **Composition and Chemistry of the Atmosphere,** with a focus on improving our understanding of the impacts of natural and human processes on the chemical composition of the atmosphere at global and regional scales, and determining the effect of such changes on air quality and human health. The budget proposes $368 million for programs studying the composition and chemistry of the atmosphere (a decrease of $21 million from FY2000). Changes in the global atmosphere can have important implications for life on Earth, including such factors as the exposure to biologically damaging ultraviolet (UV) radiation, the abundance of greenhouse gases and aerosols (which in turn affect climate), and regional air pollution.
- **Paleoenvironment and Paleoclimate,** with a focus on providing a quantitative understanding of the patterns of natural environmental variability, on timescales from centuries to millennia, upon which are superimposed the effects of human activities on the planet's biosphere, geosphere, and atmosphere. The budget proposes $27 million in FY2001 (a decrease of $2 million) for the study of the Earth's environmental past. Reconstructing the historical climate record offers an enhanced understanding of the mechanisms controlling the Earth's cli-

mate system and, together with insight obtained from numerical modeling exercises, provides a foundation for anticipating how the planet might respond to future environmental perturbations.

- **Human Dimensions of Global Change,** with a focus on explaining how humans affect the Earth system and are affected by it, and on investigating how humans respond to global change. The budget proposes $93 million in FY2001 (level with FY2000) for the study of the human dimensions of global change. Scientific uncertainties about the role of human socioeconomic and institutional factors in global change are as significant as uncertainties about the physical, chemical, and biological aspects of the Earth system. Improving our scientific understanding of how humans cause changes in the Earth system, and how society, in turn, is affected by the interactions between natural and social processes, is an important priority for the USGCRP.

Conclusion

This brief description of climate change science and U.S. climate change research efforts should be seen as a summary rather than a comprehensive overview. Nevertheless, it highlights several very important points. The USGCRP is a broad and successful program of research on global change that is resulting in increases in our understanding of how the Earth system is changing, and of the human role in such change. In particular, it has made a major contribution to our understanding of climate change. USGCRP-supported research has played a key role in demonstrating that climate change is occurring, and that human activities are playing a role in causing such change. It has helped explain the relationships between climate change and other significant global-scale environmental changes, such as land cover change, ozone depletion, and loss of biodiversity.

We expect a much fuller understanding of the processes of change to emerge from this effort in the future. The sustained bipartisan support for global change research over the last decade has enabled steady scientific progress and resulted in the development of a new generation of tools that offer the promise of more rapid progress in the years ahead. We will benefit from unprecedented amounts of data about the Earth, and these data will be of higher quality than ever before. We will develop more complex and accurate models that permit more realistic simulation of the Earth system. Most importantly, we can expect to learn much more about the potential consequences of change for ecosystems and for human society.

U.S. Global Change Research Program
By Agency/Appropriation Account
FY 2001 Budget

(Discretionary budget authority; in millions of dollars)

	FY 1999 Actual	FY 2000 Estimate	FY 2001 Proposed	Change 2000–2001
Department of Health and Human Services				
National Institutes of Health	40	46	48	+2
National Aeronautics and Space Administration				
Science, Aeronautics, and Technology	1,155	1,173	1,149	–24
Department of Energy				
Science (Biological & Environmental Research)	114	120	123	+3
National Science Foundation				
Research and Related Activities	182	187	187	0
Department of Agriculture				
Agricultural Research Service	26	27	36	+9
Cooperative State Research, Education and Extension Services				
Research and Education	7	7	14	+7
Economic Research Service	1	1	2	+1
Natural Resources Conservation Service				
Conservation Operations	1	1	14	+13
Forest Service				
Forest and Rangeland Research	17	17	20	+3
Subtotal—USDA	52	53	85	+32
Department of Commerce				
National Oceanic and Atmospheric Administration				
Operations, Research, and Facilities	63	67	93	+26
Department of the Interior				
U.S. Geological Survey				
Surveys, Investigations, and Research	27	25	25	0
Environmental Protection Agency				
Science and Technology	17	23	23	0
Smithsonian Institution				
Salaries and Expenses	7	7	7	0
TOTAL [1]	1,657	1,701	1,740	+39

[1] Note: Total may not add due to rounding.

U.S. Global Change Research Program
Details by Program Element/By Agency
FY 2001 Budget
(Discretionary budget authority; in millions of dollars)

	FY 1999 Actual	FY 2000 Estimate	FY 2001 Proposed	Change 2000–2001
Understanding the Earth's Climate System				
National Aeronautics and Space Administration	324	310	271	–39
National Science Foundation	82	84	84	0
Department of Energy	64	68	73	+5
Department of Commerce/NOAA	38	41	59	+18
Department of the Interior	7	0	0	0
Smithsonian	*	*	*	*
Subtotal	515	503	487	–16
Composition and Chemistry of the Atmosphere				
National Aeronautics and Space Administration	310	330	306	–24
National Science Foundation	18	19	19	0
Department of Energy	16	16	15	–1
Department of Agriculture	16	15	18	+3
Department of Commerce/NOAA	8	9	10	+1
Smithsonian	*	*	*	*
Subtotal	368	389	368	–21
Global Water Cycle				
National Aeronautics and Space Administration	238	255	288	+33
National Science Foundation	10	10	10	0
Department of Commerce/NOAA	5	5	7	+2
Department of Energy	0	4	3	–1
Department of Agriculture	0	*	*	*
Subtotal	253	274	308	+34
Carbon Cycle Science				
National Aeronautics and Space Administration	154	154	150	–4
National Science Foundation	13	13	13	0
Department of Energy	14	14	15	+1
Department of Agriculture	7	15	37	+22
Department of Commerce/NOAA	4	5	10	+5
Department of the Interior	3	3	4	+1
Smithsonian	*	*	*	*
Subtotal	195	204	229	+25
Biology and Biochemistry of Ecosystems				
National Aeronautics and Space Administration	129	124	134	+10
Department of Agriculture	32	22	29	+7
National Science Foundation	27	29	29	0
Department of Energy	13	11	11	0
Department of the Interior	13	13	14	+1
Smithsonian	4	4	4	0
Environmental Protection Agency	0	2	3	+1
Subtotal	218	205	224	+19
Human Dimensions of Climate Change				
Health and Human Services	40	46	48	+2
Environmental Protection Agency	17	19	20	+1
National Science Foundation	14	14	14	0
Department of Energy	5	8	5	–3
Department of Commerce/NOAA	5	5	5	0
Smithsonian	1	1	1	0
Subtotal	82	93	93	0
Paleoenvironment/Paleoclimate				
National Science Foundation	18	19	19	0
Department of Commerce/NOAA	2	2	2	0
Smithsonian	2	2	2	0
Department of the Interior	0	6	4	–2
Subtotal	22	29	27	–2
Total [1,2,3]	1,653	1,697	1,736	+39

* less than $500,000.
[1] Total may not add due to rounding.
[2] FY 1999 does not include $3 million in DOE Small Business Innovative Research funding.
[3] FY 2000 and FY 2001 does not include $4 million in DOI Data Management funding.

The CHAIRMAN. We will proceed during this hearing, at least as far as this member is concerned, on the premise that there is no such thing as a dumb question. This is an area where I admitted in my opening statement that I have a very steep learning curve. And as I also mentioned, this will be the first, of what I hope to be a number of hearings, that we can have on this issue.

First of all, what changed between the 1995 IPCC report and today that has shifted the debate from "Are we warming the Earth?" to "How much are we warming the Earth?"

Dr. LANE. Senator, I think the simple answer is just that more science got done, and became available, and then could be analyzed by this international peer review process.

The CHAIRMAN. That is an important change, do you not think?

Dr. LANE. I think the change is important. It is—particularly in the Academy report that was referred to—very clear that there really is not any remaining debate about whether the Earth is warming or not. It is quite clear that the Earth is warming, and there is significant consensus that the human activity is a part of that warming.

So I think it is time to focus on what that means in terms of lives of people and nations. And that also involves significant research questions, and that in part, what the Global Change Research Program is all about.

It does not mean there are not still important questions about the physics and the chemistry of climate change. And we will continue to support those research activities to further deepen our knowledge in those areas, but I think it is quite clear that the larger questions have shifted. And it is important the research program respond.

The CHAIRMAN. Do you believe that the upcoming report will alter the current debate among scientists?

Dr. LANE. Senator, I think that many of these questions have been subject to scientific debate, and that is how the scientific process works. I would expect that increasingly researchers will turn their attention to some of these more complex questions, and we will see more attention in the scientific arena to this research.

The CHAIRMAN. Are other nations devoting anywhere near the time and assets and scientific effort that the United States is?

Dr. LANE. I can submit budget numbers to the Committee for the record. I do not have them fresh in my mind.

The CHAIRMAN. Just your overall impression about that.

Dr. LANE. I would emphasize that, yes, the Global Change Research Program, the U.S. program, is part of a much larger international effort. And it, in my view, is one of the best examples among several very good ones, of international cooperation and science. The IPCC process involves hundreds of experts in all aspects of climate change, the social sciences, the economic sciences, as well as the physics——

The CHAIRMAN. Well, I do not mean to interrupt, but my question is: Are other nations devoting the time and assets—I understand we have a budget request for $1.74 billion. Are other nations involving themselves with the degree of commitment that we are?

Dr. LANE. My sense is that the degree of commitment on the part of many nations of the world is very substantial, and in the research area, which I think is what you would like for me to address, the area of climate modeling is one in which, in some sense, other countries are ahead of us. And that is an issue for us to be concerned about.

We asked the Academy to study this question, give us a report. And the Academy concluded that in the case of climate modeling, the United States may be losing leadership to researchers in other countries. So I would say in a case like that, it is very clear that the commitment is quite strong.

The CHAIRMAN. A lot of our concerns here are anecdotal obviously. We read where a huge piece of ice broke off from the Antarctic. Does that mean anything to you?

Dr. LANE. I found that an extremely interesting story, as well, and it is a true story. And I have been to the Antarctic several times in my role as Director of the National Science Foundation since National Science Foundation runs the U.S. program down there. That was an extraordinary event.

One cannot really connect single events of that kind with the larger issue of global climate change, and I think it would be a mistake to do that. But there are many other examples such as the receding of the glaciers and high country around the world over the last several decades.

There is the fairly recent observation that the ice in the Arctic region is less in extent and also thinner than we anticipated. All those are very significant research questions that do have a relationship with the Global Change Research Program.

The CHAIRMAN. What about the disappearance of species of fish?

Dr. LANE. We do have evidence that all kinds of life, animal life and plant life, is responding to a global change. Fish appear to be moving. There is much evidence of early blooming of plants. In fact, even in Washington, the cherry blossoms are blooming an average of a week earlier, I think the number would be, than they were a decade or so ago.

So ecosystems all over the world are showing some unusual movement that might be connected with climate change.

The CHAIRMAN. A lot of this is in the oceans, right?

Dr. LANE. Define——

The CHAIRMAN. A lot of these changes, we have seen in the oceans. What about the death of coral reefs?

Dr. LANE. Coral reefs are dying all over the world. It is a serious problem. Some would predict that without finding the cause and doing something about it, we could lose essentially all of our coral reefs in the next 100 years.

We have a significant research effort trying to understand the problem with coral reefs. Scientific opinion is that there may be several causes, including global warming, which sort of chases the algae out of the coral.

The CHAIRMAN. What are some of the other reasons?

Dr. LANE. Some of the others are pollution, some damage just from the human interaction directly with the coral, coral disease from causes we do not entirely understand. But there is a pretty strong opinion that the warming of the oceans may very well be responsible for loss of coral.

A recent example of that is with the El Niño event which may or may not be connected with overall global climate change, but which is a very significant climate feature. During the last severe El Niño, there was considerable coral bleaching and loss of coral due to the increased temperatures.

So we know that if you increase the temperature of the ocean over the coral, you will lose coral. We simply do not know how large that effect is versus other possible problems that we have with our coral reefs.

The CHAIRMAN. It seems to me that it is almost like connecting the dots here. We see example after example ranging from ice breaking up in the Antarctic to the death of coral reefs to the inexorable increase in water levels, oceanic levels. Does that make any sense, or is it just that we are being a little bit hysterical?

Dr. LANE. I think—picking up on your earlier statement, Mr. Chairman, I think the public understands something is going on, something is happening.

Scientifically, the experts, who you will hear from shortly, have the data, and the analysis, and the modeling to show just what we know in detail scientifically and where the questions remain. But there are things going on that point to potential problems that perhaps we do not have what we would consider reliable scientific data on yet, but in time, we will better understand how the various dots connect. And maybe there is a dot that does not connect.

Maybe there is some phenomenon out there that looks like it might connect with climate change, but in the end, we find it has nothing to do with it. We cannot know that for sure right now.

That is why I think having the discussion about the science and helping the public understand—as you emphasized, Mr. Chairman, we need to do—what the science is and how the science consensus is formed, and why there will be debate and differences of opinion among experts, that is all good.

That is the way science advances, and I think this potential for harm to the people of our country and our world due to global climate change is so great that it behooves us to have this discussion, and have it as early as we can, and make the necessary investment to try to get the answers to some of these remaining questions.

The CHAIRMAN. By intent, our next panel has experts of contrasting views. And I think that that is the most important and only fair way to address this issue.

When do you think—if we did everything in a perfect scenario, when do you think we could have some definitive answers to these largely unanswered questions, or some of them?

In other words, what can we as Americans expect out of the scientific community and out of the $1.74 billion investment in the U.S. Global Change Research Program?

Dr. LANE. Senator, I think that we can expect significant progress in answering some of these questions. What the experts sort of need to help the Committee understand is "Which are we most likely to be able to pin down first, and which are we going to pin down next?"

For example, one reason we are felt by the Academy to be falling a bit behind in our climate modeling has a lot to do with computer capability. I mean, our modelers are among the top experts in the world in this area, but for a variety of reasons, they really do not have access to the kind of computer capability that they need to run these big models.

So, as we address that, and we are doing so in the President's information technology initiatives that have received bi-partisan support, we will provide that capability. Then we will be able to run these models, get the error bars down, and answer the questions most directly.

So I hesitate to speculate on a particular question that "I think we are going to answer in 1 or 2 years," but the progress has been very good since the last IPCC report. And I would anticipate just as great progress answering the remaining questions in the next period.

The CHAIRMAN. Will we have some definitive answers within the next couple of years?

Dr. LANE. I would expect we will have some definitive answers in the next several years. For example, places where we have made significant progress is in understanding the role—I emphasized the importance of clouds—understanding the role of clouds.

One of the big uncertainties in the model is how clouds behave and how most appropriately to put them in the model.

The second one is the effect of aerosols. Generally, the view is that aerosols, which can be anything from ice to crystals of other kinds and soot—just tiny little particles that are suspended in the atmosphere—the thought has been that those would generally have a cooling effect. They would reflect the sunlight before it gets down and has a chance to heat the earth and contribute to global warming.

By and large, my own view is that still is probably true, but there was a recent report from our international research activity in the Indian Ocean where the aerosols turn out to be quite dark and pollution is very heavy. It looks as if those aerosols are actually not reflecting light very well.

They are heating up. They themselves then, in their interaction with the clouds, are causing the clouds to dissipate, and that is having a warming effect. We need to understand that—my guess is that those are areas: clouds, ice, which I did not mention, and aerosols, in which we would be able to make significant progress in the next few years, but I would concede to my experts on the subject for their estimate.

The CHAIRMAN. Senator Kerry, thank you for being here.

STATEMENT OF HON. JOHN F. KERRY, U.S. SENATOR FROM MASSACHUSETTS

Senator KERRY. Thank you, Mr. Chairman, and thank you very much for having this hearing and for your willingness to open up the dialogue with respect to this issue. I have been interested in and have been involved in this issue for a long period of time now.

In my responsibilities as a Senator I had the privilege of joining Vice President Gore, Tim Wirth, John Chafee, and others as a member of the delegation down in Rio for the first Earth Summit when President Bush embraced the early findings of scientists regarding global warming.

I subsequently have been at the Buenos Aires followup meeting, and I was working with Stu Eisenstat and others in Kyoto where the negotiations took place. Stu, I think, did a very brilliant job in helping develop the Kyoto Treaty.

And I must say, Mr. Chairman, I have been a little bit dumbfounded and somewhat disturbed by the level of skepticism that exists, and has existed over a long period of time, in the U.S. Congress with respect to this issue.

We may not have definitive answers for every model, as to exactly what forest may move, or precisely how much the sea may rise in a particular area over what period of time, but we have—correct me if I am wrong, Dr. Lane—absolutely definitive science to tell us that the ocean is rising, and that there are a number of pollutants that we emit.

I mean, there is a health issue here, not just a question of the effect of global warming. Over the last years, the science just keeps getting stronger, and stronger, and stronger, reinforcing the theories. The world has, frankly, moved more rapidly than the United States.

And in answer to your question—a couple of weeks ago, we had a dinner with the Deputy Prime Minister John Prescott, who heads up negotiations for Great Britain, and with the Dutch, and others here in Washington, talking about the next meeting that will take place in Berlin. There are great concerns about the United States' lack of response.

Frankly, the lack of response by the United States is significantly impeding our capacity to bring less developed countries into the equation. I am all for the Senate Resolution passed in the 105th Congress, which supports this goal of the Kyoto Protocol. If we let Mexico, and Korea, and India, and China proceed to develop without being participants, they can negate every gain that we take in the United States. So, this is a global problem.

But right now, there is such antipathy directed at the United States for our lack of seriousness about this, that few people are willing to join us in a serious dialogue until we demonstrate a little bit of leadership.

Let me just say, Mr. Chairman, that the science—and we will hear this from two of our witnesses this morning—on a scale of virtual certainty from one to ten, it is ten out of ten. It is virtually certain that some changes indicative of climate change are now happening.

And, Dr. Lane, you will confirm, as every scientist here will, that the half life of carbon dioxide and of the other greenhouse gas emissions is such that if we just went cold turkey today and brought our levels down to the 1990 baseline where we are supposed to be according to the Rio voluntary agreements, we would still have 70 years of global warming effects that are going to occur because the gases have long half lives. Therefore, the danger of global warming is going to continue no matter what we do today even if we are successful at reducing emissions.

The complexity of global warming can be so daunting that it partly is a turn-off to people. They do not want to cope with it or try to grapple with it because the problem is quite enormous.

Now again, I say, I know we do not have certainty in the model, and, to a degree, people fight about the trivial matters. Do we know whether or not Florida is by year such and such absolutely going to lose the Miami beaches? No, we cannot say exactly what year or when, but we have absolute certainty as to the rise in sea level, a range that is disastrous. Take even the bottom line of the range—we know it is disastrous.

Now, we know the worldwide rise in temperatures at the earth's surface is real. We know it has accelerated in recent decades. The independent scientific panel organized by the National Academy of Sciences concluded in a major report issued this February that they now have that sort of certainty. They estimate the increase in temperatures in the past century between .7 and 1.4 degrees Fahrenheit. That is a 30-percent increase from earlier projections that reflect record shattering high temperatures in the late 1990's.

We now have learned how to deal with the disparity between the satellite findings of the upper atmosphere versus what we have on earth, and it sort of makes sense that it is going to be warmer down here than it is up there in terms of the ratio of impact.

And I might say, Mr. Chairman, this sounds sort of fundamental, but it really goes to the bottom of this. The theory about this was found by a fellow named Arhenius in 1898, and it has progressed since then.

And every prognostication of the early scientific data on this has been eclipsed by the subsequent findings of fact. Each time it has blown away the theory in terms of being more serious than people thought.

But the fact is that life exists on earth because we have a greenhouse effect. Were it not for the existence of the greenhouse effect, we would not have plant life and human life.

And it is common sense that if you are emitting gases into that atmosphere that are trapped, it will have a long-term impact on weather and other things.

Well, we now find that for the third year in a row we have set a record for winter warmth. The 3-month period of December 1999 through February of 2000 was the warmest winter season in the contiguous 48 states in the entire 105 years that we have recorded the data.

That slightly surpassed the record set just one year ago, and that slightly surpassed the record set the prior year. So we have the three warmest years in the last 3 years. And that fits in completely with the detected trend about later freezes in the fall, and earlier temperatures of the frost.

I remember as a kid in Massachusetts, we always looked forward to October/November because the ponds froze over and we were going to have thick ice, and go play hockey. Today, you are lucky if the ponds freeze in Northern New Hampshire.

And unlike the days when we used to have snow on the ground from October to April when we were campaigning as recently as 20 years ago, I used to freeze and wear a coat in the morning. I do not wear a coat until after November now.

Anybody who does not see the impact of these changes is putting their head in the sand. Now, can we say that every bit of this is due to global warming? The answer is no. I cannot sit here and tell you that. No scientist is going to tell you that every bit of it is. Some of it may be normal changes that are taking place in terms of the climate process, but we do know with absolute certainty, incontrovertible scientific fact, we are contributing to it.

And we ought to adopt the prudent person theory with respect to those things that you do not quite know what the final consequences are going to be but you know they might be disastrous.

It is like smoking, Mr. Chairman. You and others have adopted a very tough policy on the odds about contracting cancer from smoking. Does everybody get cancer who smokes? The answer is no. But do we know what the probabilities are? The answer is yes. The probabilities of this are greater than some of what we know about the linkages of cancer in certain kinds of disease. We take far more steps to deal with that than we do with this.

Final comment I would make is, and this is of enormous concern I think to everybody, is the great ice cover that stretches across the top of the globe is about 40 percent thinner than it was just 2 to 4 decades ago. We know this through our data from nuclear submarines that have been plying the Arctic Ocean.

Scientists from the University of Washington found in a new study that the average thickness of the Arctic ice was about ten feet from 1958 to 1976. From 1993 to 1997, it is about six feet, and in the 1990's, the thinning has been continuing at a rate of about four inches a year.

The area covered by sea ice has diminished and the duration of the cover has shortened. Mountain glaciers in Alaska have shrunk as has the Greenland ice cap. And the consequences of this, according to many experts now, is huge concern about what happens with sea levels because if the big ice sheets melt even partly, sea levels will rise around the world.

And there are serious questions—I do not have the answers again—about the potential disruption of certain ocean currents, but those ocean currents modulate the earth's climate. We do not know the answer of what happens to the Gulf Stream, but I am concerned about the potential of what might happen to it.

So this hearing and the further science is critical, but we should not confuse ourselves by not having answers to every single question that common sense drives us to try to mitigate at this point in time. And I think that is really the critical issue that this Committee, the Congress, and the entire country faces.

Unless the United States is more serious about this effort, we are going to have a difficult time getting less developed countries and others to join in a more cooperative effort. So there is a huge amount at stake and I think this hearing is very important in that regard.

In each of the past 2 years, the House of Representatives has included riders in appropriations bills on the Kyoto Protocol. And this year, a new bill has language that is included in the Agricultural Appropriations Bill that will limit the Administration's activities on an international level to even continue the dialogue and process of building a consensus about Kyoto.

Do you share a concern that this provision could impede our understanding of climate change and the ways we might mitigate it, Doctor?

Dr. LANE. Yes, Senator, I am very concerned about this rider. The rider seems, on the face of it, extreme. It tries to block the United States from even trying to reach an agreement with other countries on action to combat global warming, which is very difficult to explain to our international partners around the world.

It undermines the ability of the executive branch to conduct international negotiations, which seems to me to raise serious constitutional questions. It may stifle U.S. efforts to achieve bi-partisan goals with a cost effective treaty and meaningful participation of developing countries which, Senator, you have emphasized.

It is extremely important that we are able to sit down with developing countries and address their participation in dealing with this problem of global warming.

The amendment is bad for American industry. It is bad for the farmers. It is bad for consumers. It tries to stop work on the most important tools for holding down costs as we combat global warming. And depending on how you interpret the language itself, it could also have a serious chilling effect on our international research activities. So it is difficult to understand the rationale here, and we certainly have great difficulties with the rider.

Senator KERRY. I do not want to abuse the time too much, but there is another problem I'd like to focus on. You go to a place like North Dakota, or you go to some northern place, they like the fact that it is warmer. Their heating bills are less. They figure that their gardens are going to last longer; they get a longer summer.

I mean, there is a psychological difficulty here to get people to focus on what may happen to your water tables, to your crops, to the movement of whole forests. Do you agree that there are very significant down sides that have not yet been properly quantified to people so that you can create a consensus on this?

Dr. LANE. Indeed I do agree, Senator. I think this national assessment I spoke about, which attempts, for the first time, to provide some wisdom on what the regional effects of global climate change might be, will help us understand better the answer to your question.

There appear to be some positive benefits to increasing temperature in certain parts of the country, certain parts of the world. People might like a little warmer evenings, little warmer winters, but that is kind of taking an isolationist's view. You know, if you put a big wall up around your state or your community, if that is the view of the world, then you might like it a little warmer.

On the other hand, there are some very real questions. How fast can the ecology keep up with the climate change? So suppose the forests that need to move in response to climate change cannot move fast enough, and so then they are gone. That opens the way for all kinds of invasive species, plant and animal, that might be very harmful. So we simply do not know the answers to those kinds of questions.

I would also say that if we think we might be comfy in our part of the country because it is getting a little warmer, and maybe we can grow crops a little more easily, there are other parts of the world are becoming destabilized, people are dying from the spread of disease that could well be caused by climate change, or significant coastal regions that are increasingly densely populated around the world are going under water, if we think that is a world in which we all could live comfortably, then I think we need to look much more carefully at the implications for climate change.

Senator KERRY. Thank you, Doctor.

Thank you, Mr. Chairman.

The CHAIRMAN. I just want to say, Senator Kerry, I thank you for your involvement and many years on this issue. I am a relative newcomer. I appreciate what you have done for many years and your participation on this issue, and these hearings are very important.

And I would like to add again, that I think we have tried to find a balanced second panel that represent a variety of views on this issue, and I think that is the best way we can be educated on this issue.

Senator Brownback.

STATEMENT OF HON. SAM BROWNBACK, U.S. SENATOR FROM KANSAS

Senator BROWNBACK. Thank you very much, Mr. Chairman, and I want to congratulate you for once again taking leadership on an important and tough topic in typical McCain fashion, grabbing a hold and saying, "Here is something that is tough to do, and let us get after it." And I applaud you very much and hope you hold a series of hearings on this.

And I also thank Senator Kerry for his leadership for a long time on this topic as well.

Dr. Lane, you have made comments on a number of issues here. I have got your testimony and caught the end of it, but I want to focus on specifically the issue of CO_2 in the air, carbon dioxide in the air. And apparently, there are some scientific questions that remain out here. There are a number of them that are resolved and understood, and I think there is unanimity on agreement that there is too much CO_2 in the air. Is there anybody that disagrees with that point?

Dr. LANE. You could probably find somebody, but I think that the consensus is precisely as you stated it.

Senator BROWNBACK. And that you have in your statements the factual—the loading of CO_2 that is in the air and what has occurred there. And I am a relative newcomer to this topic as well, but as I have looked at it, I thought, we can disagree on a lot of things, but here is one that I think everybody agrees.

You may disagree about how it all got there, or how you pull it out of the air, or some things like that, but there is too much CO_2, and it would be better if we had less in the air. And everybody would agree to that, or I guess, most would, although as Senator Kerry was talking about how he looked forward to the winter and playing ice hockey, I was sitting here thinking I was out cutting holes in the ice to water cattle, and I did not like that, as thick as it got.

It is not that I am saying we should have global warming. I do not agree with that. I am not for global warming, but we just did not play the ice hockey. I had to cut ice holes.

[Laughter.]

Senator BROWNBACK. I put forward a bill along with Senator Kerrey from Nebraska that tries to get more carbon sequestration taking place in agriculture in this country, a domestic component. And we have got an international component we are putting forward of trying to have more carbon sequestration taking place internationally; the international component by tax credits, the domestic component by carbon payments to farmers along the model of the CRP, the Conservation Reserve Program style.

It seems to me that if we all agree that we have too much CO_2 in the air—and you can kind of disagree about "Here is the impact, or this is how it got there." If you just step past that one and say, "We have got too much CO_2 in the air. How do we get it out," here are a couple of ways of doing that.

And the research is coming along pretty well on no till farming, different biomass cropping practices of their ability to sequester carbon in the soil. The research is pretty good on the amount of carbon that has been released from U.S. soil over the years of our agricultural practices so that—we know it has the capacity to fix it back, because at one time it had a higher degree of carbon in the soil. And we know that as well internationally from a number of the forests that have been uprooted, that if you started or re-instilled those forests, or did not take them down in the first place, you would be releasing less carbon into the atmosphere.

I would like your thoughts about those two approaches on addressing the issue of carbon sequestration and taking carbon out of the atmosphere.

Dr. LANE. Senator, this is clearly a very important issue on which a great deal of progress has been made in understanding the science, but there is much more to do.

There is, in the Fiscal Year 2001 budget, a significant initiative this year and last, for the part of the U.S. Global Change Research Program focused on carbon sequestration. It is one of the ways that we expect that we will be able to remove carbon from the atmosphere.

The second thing I might say here is that the recent IPCC report on land use and land use change and forestry, addresses this issue and provides important international consensus on what the issues are here, and the remaining scientific questions, but also what we know.

Our understanding of the matter so far is that there is significant potential for removal of carbon dioxide through changes in land use. Just exactly how much is still quite widely debated. The error bars, we say, in the science community are rather large on that.

I think most would feel at this point that even with all kinds of reasonable land use changes, and accounting for that, it would not be enough to deal with the enormous increases that we project in carbon dioxide, but it is very important.

And I think the only issue then is: How do you deal with that in terms of our international discussions? So there are some important research questions to continue to get at.

There are also some serious policy issues in any kind of international agreement on dealing with the greenhouse emission problem. It is important to have the right agreement on how you account for land use in each country's participation in reducing greenhouse emissions, or removing carbon dioxide from the air. And that is an issue that needs to get sorted out. It is clearly going to be very important for both developed and developing countries.

And then I know we have got panelists that can address that more precisely. So there are policy issues that are big ones, and have to do with how reforestation, and biomass, and no till farming, how all that would get counted in any kind of international agreement of removal and reduction of greenhouse gases.

Also, even if we knew all we need to know about this, actually getting it in practice in our country and in other countries is challenging also. And that has major policy implications.

But the issue is important. There is no doubt that this is a place we must look to to help with the carbon dioxide problem.

Senator BROWNBACK. So you support doing it, but your reservation is that you want it done in a global context.

Dr. LANE. It must be done in a global context.

Senator BROWNBACK. I mean, if I could challenge you for a minute on that. It seems to me that it would be useful for us to start moving that way now, and learning from wide scale implementation of those practices, and that that is a benefit.

I do not see that you do any harm, and you actually do a great deal of good, and you probably learn a lot by scaling up and doing those things, and doing it now.

Dr. LANE. Without question, I think the—first of all, the science is something we are doing now, and should continue to increase our investments in this particular area of carbon sequestration. There is no reason the United States should not play a leadership role here as it does in so many other areas. And so nothing says that if one sees a good thing to do, one should not proceed to do it.

Senator BROWNBACK. Because, I mean, it seems like to me, that that almost gets us to Senator Kerry's point about the United States showing some leadership on this, whereas there has been great concern about the Kyoto Treaty for the reasons that you articulated of a number of countries being allowed out of it that could offset any sort of gain that the United States would do.

And that you almost could get past that issue as well, and in doing something here that is a good and right thing to do, that would show strong and aggressive U.S. leadership. And it would be a positive thing to do.

Dr. LANE. But I do want to emphasize that our current assessment is that even under ideal land use, it is not expected to take care of the whole problem.

Senator BROWNBACK. No, I understand you on that. And I would not submit that it would, although I will submit that the research I have looked at, looks like it is very promising and will take care of a good portion of the problem. It does not do it all, but it has got a chance to really help us out in a very significant way. I will look forward to pursuing that with the Administration.

We have the one bill that is out there that will be considered. I think as we re-write the farm bill, there will be a lot of looks at the issue of carbon sequestration, and I would hope that we could do an aggressive support internationally to other places that are looking to do the right thing. We can help in supporting that as well as keeping the carbon from either, first, ever being released, and increase the amount that is sequestered into the ground.

Dr. LANE. Senator, we applaud your efforts here with the bill, and look forward to working with you on these matters that I just addressed.

Senator BROWNBACK. I look forward to working with you.

Mr. Chairman, I have an opening statement I want to submit for the record, too, if I could.

The CHAIRMAN. Without objection.

[The prepared statement of Senator Brownback follows:]

PREPARED STATEMENT OF HON. SAM BROWNBACK, U.S. SENATOR FROM KANSAS

Thank you Mr. Chairman. I commend you for holding a hearing on a topic as important and as controversial as climate change.

Scientists generally agree that atmospheric concentrations of carbon dioxide are now projected to double by the middle of the next century—and continue to rise. This additional carbon in the atmosphere could lead to a number of disastrous consequences including significantly higher temperatures—which could have a detrimental affect on certain forms of agriculture, disruption of ocean currents—leading to an increase in natural disasters, and coastland destruction. The potential effects from global warming are serious and warrant our close attention and study.

The issue of climate change has been most closely linked to the international treaty on climate change—the Kyoto Treaty. This treaty had several flawed components and is highly unlikely to become policy—nor should it. However, the issue of climate change should not be linked solely to any one treaty. Instead, it is vital that we continue our research and look for pro-active measures which can be taken to reduce carbon dioxide in the atmosphere without sacrificing our economy or our standard of living. Voluntary, incentive-based measures to improve the environment should be pursued regardless of the Kyoto Treaty. In the debate on climate change, there is a middle ground—it doesn't have to be an all or nothing proposition.

Recently, I have introduced legislation which would provide financial incentives to landowners who increase conservation practices which help pull carbon dioxide out of the atmosphere and store it as carbon in the soil. The Domestic Carbon Storage Incentives Act of 2000—seeks to encourage the positive contributions to the environment made by the agriculture industry.

My bill focuses on offsetting greenhouse gases through improved land management and conservation. As a result, these practices will also lead to better water quality, less runoff pollution, better wildlife habitat and an additional revenue source for farmers. It is a win-win proposition for agriculture and the environment. We must look for more of these opportunities if we are to avoid the often discussed negative economic impacts that a global climate treaty could bring—and research is vital to that goal.

There are currently efforts to prevent the agencies (USDA in particular) and the administration from even researching this issue. I understand the complex and controversial nature of climate change. That is all the more reason to encourage voluntary efforts to mitigate the problem and carefully study the science—not to avoid the issue.

Again, I commend my colleague for holding this hearing and I look forward to the testimony and debate it may inspire.

The CHAIRMAN. Thank you, Dr. Lane. Thank you very much for your great work and for appearing before the Committee.

Dr. LANE. Thank you very much, Mr. Chairman, Senator Kerry.

The CHAIRMAN. Our next panel will be Dr. Ray Bradley, Department Chair, Department of Geosciences, University of Massachusetts; Dr. John R. Christy, Director of the Earth System Science Center, University of Alabama; Dr. Jerry Mahlman, Director of Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration; Dr. Kevin Trenberth, Director of the Climate Analysis Section of the National Center for Atmospheric Research; Dr. Robert Watson, Chairman of the Intergovernmental Panel on Climate Changes here in Washington, D.C. Thank you.

Dr. Bradley, please, we will begin with you.

STATEMENT OF DR. RAY BRADLEY, DEPARTMENT CHAIR, DEPARTMENT OF GEOSCIENCES, UNIVERSITY OF MASSACHUSETTS

Dr. BRADLEY. Thank you, Senator. I would like to thank you for holding this hearing on a very important issue.

Studies of instrumental temperature measurements from around the world show that the climate of the 20th Century was dominated by universal warming. At the end of the 20th Century, almost all parts of the Earth had temperatures that were higher than when the century began.

This conclusion is supported by numerous lines of environmental evidence, melting of glaciers, retreat of sea ice, changes in vegetation, rising of sea level, et cetera. At the same time, concentration of greenhouse gases in the atmosphere increased to levels that were higher than at any time in the last 420,000 years. Carbon dioxide levels are now 35 to 40 percent higher than they were in the middle of the 19th Century. This change is largely the result of fossil fuel combustion.

I do not believe that the evidence for 20th Century warming, or for these extraordinarily high levels of greenhouse gases can be seriously challenged. However, the big question as you mentioned is: What has caused the warming? Is it just a natural change in climate, and does it have anything to do with these increased levels of greenhouse gases?

With only 100 or 150 years of globally extensive instrumentally recorded climate data, we have quite a limited perspective on natural climate variability and its relation to the phenomena that might have caused climate to change such things as we call our forcing factors.

To obtain a longer perspective requires that we examine climate dependant natural phenomena that in some way have preserved a record of past climate. The most important of these are tree rings, ice cores, banded corals, these laminated lake and marine sediments, as well as historical records of past weather conditions.

In recent studies, we have assembled the best of these records to produce a global picture of how temperatures changed over the last 1,000 years as shown in this figure.

[Slide.]

Dr. BRADLEY. In spite of the uncertainties that such a reconstruction entails—and that is—the uncertainty is demonstrated here by the yellow shading.

[Indicating]

The record shown here of mean annual temperature for the Northern Hemisphere, shows the temperature slowly decline over the millennium. However, this downward trend changed abruptly to a strong warming trend in the—early in the 20th Century.

And this rate of warming was unprecedented in the last 1,000 years. The warming continued through the 1990's making that decade the warmest in at least 1,000 years. Indeed, 1998 was arguably the warmest year of the millennium, and 1999 was only slightly cooler.

What can this one perspective on temperature tells us about natural climate warming? By comparing it with the records of various factors that may have affected the temperature.

It is a pattern of variations in the amount of energy emitted by the sun, major explosive volcanic eruptions, and perhaps slight changes in the position of the earth in relation to the sun, were responsible for much of the variability of temperatures leading up to the 20th Century.

However, these natural effects were completely overwhelmed in the 20th Century by the increasing effective greenhouse gases.

[Slide.]

Dr. BRADLEY. Human effects on the climate system variations now appear to dominate over natural factors. If the variations of these natural factors continue into the future and are similar to those of the last 1,000 years, it is unlikely that they will be of great importance since the climatic changes will be mainly affected by human-induced changes in greenhouse gases.

Earlier I noted that the levels of two important greenhouse gases, carbon dioxide and methane, were now higher than at any time in the last 420,000 years.

[Slide.]

Dr. BRADLEY. Carbon dioxide levels have risen from fairly steady background levels to present day levels in a little over a century; on this time scale, almost instantaneously.

This rate of change has no parallel in historical past, just as temperatures recorded in the late 20th Century were unprecedented.

Most of the change in carbon dioxide and the greenhouse gases resulted from the growth of world population and the insatiable demand for fossil-fuel based energy.

Given that the world population will almost certainly double from the present level of 6 billion within the lifetime of those who are currently in kindergarten, unless something is done to curb the use of fossil fuel consumption, it seems very likely that significant change in climate will occur in the near future.

Consider again the record of temperature over the last 1,000 years.

[Slide.]

Dr. BRADLEY. An important conclusion of my long term climate studies is that until the second half of the 20th Century, temperatures generally remained within a half degree Celsius, one degree Fahrenheit of the average for the baseline which we use, which is 1902 to 1980.

The latest IPCC long phased projection of future climate point to a temperature a temperature rise of .6 to 2.2 Celsius, 1 to 4 Fahrenheit above 1990 levels by 2050. I think this graph puts it all into perspective.

[Slide.]

Dr. BRADLEY. Clearly, these estimates have pretty large uncertainties. This shaded area to the right is the model based estimates of future change.

But it is important to know that even the lowest would be far beyond the range of temperatures in the last 1,000 years. If these estimates are even close to being correct, we are heading into uncharted waters relative to the climate over the last 1,000 years.

Should we be concerned that the climate may change significantly in the future? I have focused exclusively here in the changes of temperature. The temperature change is only one component of our overall climate system.

Changes in temperature are associated with variations in rainfall, the amount of snow, frequency of floods and droughts, El Niño, or El Niños events, shifts in storm tracks and hurricanes, et cetera.

Our economy and way of life has become highly dependent on certain expectations regarding climate. Much of our infrastructure for water supply, for agriculture, and transportation, was built on the assumption that climate would operate in the future pretty much as it has in the past.

A relatively small shift in average global or hemispheric temperature when it is associated with the atmospheric circulation, rainfall patterns, et cetera, can be highly disruptive to society. We have seen many examples of such in recent decades, yet temperatures that were warm were nowhere near the levels that may be reached later on in this century.

Now, these include extremes of rainfall leading to catastrophic flooding in some areas, droughts, exceptional wildfires, historically low lake levels elsewhere, as well as an increase in windstorms and other weather related disasters. Unusual weather events are becoming less uncommon, in fact with agriculture, transportation, and commercial activity, a fact noted with concern by major international property insurance agencies.

Can we be certain that future climate will involve unprecedented risks? Can we be certain? Some argue the processes within the climate system will act to compensate for the effects of high greenhouse gas levels, some call negative feedback events.

According to this scenario, these feedbacks will help maintain the climatic status quo, enabling us to continue to contaminate the atmosphere with greenhouse gases.

There is a small chance that such critics are right in which case it would be safe to do nothing. But they may be completely wrong and, indeed, the scientific consensus is that they are wrong.

Political decisions, as you well know, inevitably involve assessing risk and weighing the consequences of action versus inaction. Congress must decide and must weigh the potentially catastrophic environmental and commercial consequences of future global warming against the costs of limiting fossil fuel consumption to reduce these risks.

Given that it will take many decades to stabilize greenhouse gas levels in the atmosphere, even if strong action was taken today, as Senator Kerry pointed out, to limit fossil fuel consumption, the issue is urgent and demands our attention.

Scientists cannot provide Congress with a certain forecast of the future. As our research on global warming continues, our understanding will undoubtedly change. But the picture at present, is that we are indeed living in climatically unusual times, and that the future is likely to be even more unusual. And I believe we ignore this prospect at our peril.

Thank you.

The CHAIRMAN. Thank you very much.
[The prepared statement of Dr. Bradley follows:]

PREPARED STATEMENT OF DR. RAY BRADLEY, DEPARTMENT CHAIR, DEPARTMENT OF GEOSCIENCES, UNIVERSITY OF MASSACHUSETTS

CLIMATE IN PERSPECTIVE:
HOW DOES PRESENT DAY CLIMATE DIFFER FROM CLIMATES IN THE PAST?

Introduction

My name is Raymond Bradley. I am the Head of the Department of Geosciences, and Director of the Climate System Research Center, at the University of Massachusetts, Amherst. My research interests are in climate variations during the last century and how these compare with variations over longer periods. This involves studying both instrumental records of climate, and paleo-records—natural phenomena that have in some way registered past changes of climate in their structure (for example, tree rings, ice cores, lake sediments, banded corals etc). Using such "proxies" of climate enables the short instrumental record to be extended back in time, so it can be placed in a longer-term perspective. Like other witnesses here, I have served on many national and international committees related to climate variability. Most recently I was Chairman of the Past Global Changes Project of the International Geosphere Biosphere Programme (IGBP–PAGES), a member of the National Research Council Panel on Climate Variability on Decade-to-Century Time Scales, and I have been contributing author to all of the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activities. I have written or edited 8 books and numerous articles on climatic change.

We are living in unusual times. The climate of the twentieth century climate was dominated by universal warming; almost all parts of the earth had temperatures at the end of the century that were higher than when it began. At the same time, the concentration of greenhouse gases in the atmosphere increased to levels that were higher than at any time in *at least* the last 420,000 years. **These observations are incontrovertible.** Global warming is real and the levels of greenhouse gases (such as carbon dioxide) are now 35–40% higher than they were in the middle of the 19th century. This change in greenhouse gas concentration is largely the result of fossil fuel combustion. What is less certain is whether the observed global warming is due entirely to the build-up of greenhouse gases, or to other "natural" factors, or to a combination of both. Here I provide a longer-term perspective on the issue by focusing on the evolution of climate in the centuries and millennia leading up to the 20th century. Such a perspective encompasses the period before large-scale contamination of the global atmosphere and global-scale changes in land-surface conditions. By studying both the record of past climate variability and factors that may have caused climate to change ("forcing factors"), we can establish how the climate system varied under "natural" conditions, *before* human effects became significant on a global scale. Although there is considerable uncertainty about the rate and magnitude of any future warming which may occur as a result of human activities, one thing is not in dispute: any human-induced changes in climate will be superimposed on a background of natural climatic variations. Hence, in order to understand future climatic changes, it is necessary to have an understanding of how and why climates have varied in the past. Of particular relevance are climatic variations of the last few centuries leading up to the recent warming trends observed in instrumental records.

For most parts of the world, instrumental records of climate rarely span more than a century. We thus have a very limited perspective on climate variability and its relationship to potentially important forcing factors. To obtain a longer perspective requires reliance on climate-dependent natural phenomena that have preserved, in some way, a record of past climate. The most important of these are tree rings, ice cores, banded corals, varved lake and marine sediments, as well as historical records of past weather conditions (see Appendix 1). In recent studies we have assembled the best of these records to produce a global picture of how temperature has changed over the last 1000 years (Figure 1). It is worth noting that it is not sufficient to select one or two records; an extensive network is needed to obtain a global assessment. Just as listening to one instrument would not capture the full beauty of a symphony, so one can not hope to say anything meaningful about global climatic change by using data from only one site.

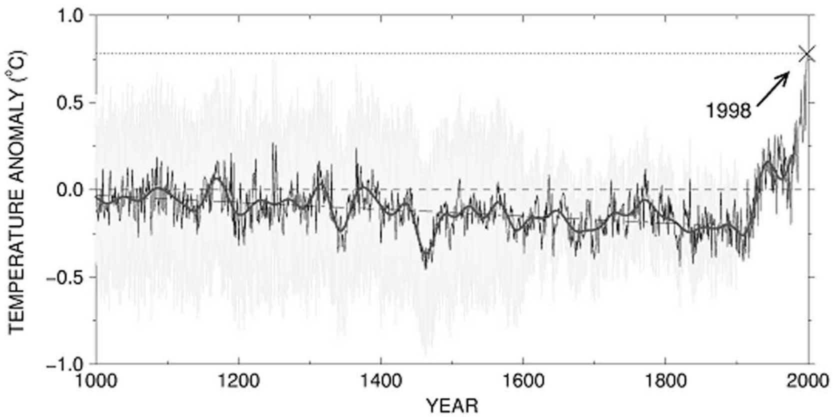


Figure 1. Mean annual temperatures for the northern hemisphere since A.D. 1000. Values are shown as anomalies from the average for 1902–1980 (from M.E. Mann, R.S. Bradley and M.K. Hughes, 1999: *Geophysical Research Letters,* v.26, p.759–762).

In spite of the uncertainties that such a global reconstruction entails, the reconstructed record (of mean annual temperature for the northern hemisphere) shows that temperatures slowly declined over the millennium, with especially cold conditions in the 15th, 17th and 19th centuries. This colder period is generally referred to as the "Little Ice Age," when glaciers advanced in most mountainous regions of the world. However, the downward trend changed abruptly to a strong warming trend early in the 20th century and *this rate of warming was unprecedented in the last 1000 years.* The warming continued through the 1990s making that decade the warmest in at *least* 1000 years; indeed, 1998 was arguably the warmest year of the millennium, and 1999 was only slightly cooler.

What can this longer perspective on temperature tell us about natural climate variability? By comparing it with the records of factors that may have affected temperature, it is apparent that variations of solar irradiance (the total energy emitted by the sun), major explosive eruptions and perhaps changes in the position of the earth in relation to the sun (slight orbital variations) were responsible for much of the variability of temperatures leading up to the 20th century. However, these "natural" effects were completely overwhelmed in the 20th century by the increasing effect of greenhouse gases. Human effects on climate system variability now appear to dominate over natural factors. If variations in "natural" forcings in the future are similar to those of the last millennium, it is unlikely that they will be of great importance since climatic changes will be mainly affected by anthropogenic (human-induced) increases in greenhouse gases.

What significance does the paleo-record of temperature have for future climate? An important conclusion from our long-term climate studies is that until the second half of the 20th century, temperatures generally remained within 0.5°C (~1°F) of the average for 1902–1980 (the arbitrary baseline we used in our studies). The latest IPCC model-based projections of future climate point to a temperature increase of 0.6 to 2.2°C (~1 to 4°F) above 1990 levels by 2050. Clearly, these estimates have large uncertainties, but it is important to note that even the lowest value would be far beyond the range of temperatures in the last millennium. If these estimates are even close to being correct, we are heading into uncharted waters relative to the climate of the last 1000 years.

Why should we be concerned about global contamination of the atmosphere and future changes in climate? Earlier, I noted that the levels of two important greenhouse gases (carbon dioxide and methane) were now higher than at any time in the last 420,000 years (Figure 2). In fact, this conclusion is based on measurements from the longest ice core record available (from the Russian Vostok station in Antarctica) but it is likely that current levels are higher than at any time for several million years. To put this in perspective, recall that it was only 10,000 years ago that human society first developed agriculture, and 120,000 years ago sabre-toothed tigers roamed what is now Trafalgar Square. Yet carbon dioxide levels have risen from fairly steady background levels (~270ppmv) to present day levels (370ppmv) in a little over a century. This rate of change has no parallel in the historical past, just as temperatures recorded in the late 20th century were unprecedented. Most of the change in CO_2 and other greenhouse gases resulted from the growth of world population and the insatiable demand for fossil fuel-based energy. Given that world population will almost certainly double within the lifetime of those currently in kindergarten, unless something is done to curb the use of fossil fuel consumption, it seems very likely that significant changes in climate will occur in the near future.

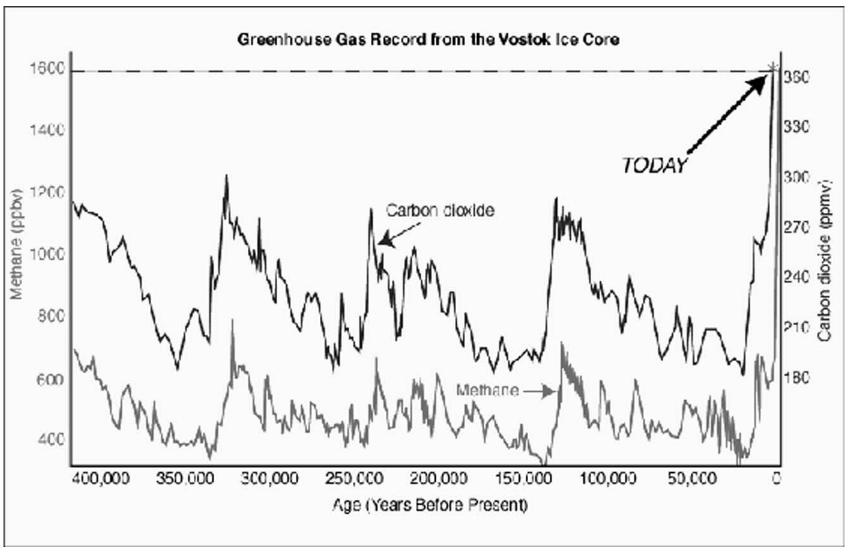


Figure 2. Changes in atmospheric carbon dioxide and methane levels in the atmosphere over the last 420,000 years (from gas bubbles trapped in an ice core, from Vostok, Antarctica).

Should we be concerned that the climate may change significantly in the future? Here I have focused exclusively on changes in temperature, but temperature change is only one component of our overall climate system. Changes in temperature are associated with variations in rainfall and the amounts of snow, shifts in storm tracks and hurricanes etc. From the record of past climate, we know that a relatively small overall change in global temperature can have significant environmental effects. The “Little Ice Age” was characterized by dramatic changes in ice cover in mountain regions throughout the world. But historical records from lowland areas of Europe also document more extensive snow cover, longer periods when rivers and lakes were frozen over and frequent cold, wet summers, with disastrous consequences for agriculture, leading to social disruption and political upheavals. Such changes all occurred with an overall change in average hemispheric temperature of less than 1°F. Of course, in trying to anticipate the effects of future climate change, we are looking at the consequences of warmer, not colder conditions but the implication is the same—even a small shift in average global or hemispheric temperature, with its associated changes in atmospheric circulation, rainfall patterns etc., can be highly disruptive to society. We have seen many examples of such anomalies in recent decades, yet temperatures, though warm, were nowhere near the levels that may be reached later in this century. These include extremes in rainfall, leading to catastrophic flooding in some areas, and droughts, exceptional wildfires and historically low lake levels elsewhere, as well as an increase in windstorms and other weather-related disasters. Unusual weather events are becoming less uncommon, impacting agriculture, transportation and commercial activity. Of course, such disasters have always occurred to some extent, but the frequency of extremes has increased in recent years throughout the world, leading major insurance companies to express grave concerns about their exposure to these unprecedented risks (note that these risks are in addition to the costs due to increased development). Munich Re, one of the world's largest re-insurance firms recently reported:

> *"1999 fits exactly into the long-term pattern of increasing losses from natural catastrophes . . . insured losses came to $22bn. This is the second highest figure ever recorded . . . windstorms were responsible for 80% of the insured losses while earthquakes accounted for 10%, floods 6%, and other events like forest fires, frost, and heat waves around 4% . . . In view of the fact that the signs of climate change and all its related effects are becoming more and more discernible . . . if . . . meteorological extremes like torrential rain, windstorms, and heat waves continue to increase and the rise in sea level accelerates, many regions of the world will be in immediate danger . . ."*

Can we be certain that future climate will involve unprecedented risks? Some argue that processes within the climate system will act to compensate for the effects of higher greenhouse gas levels (so-called negative feedback effects). According to this scenario, these feedbacks will help maintain the climatic *status quo* enabling us to continue to contaminate the atmosphere *ad infinitum.* There is a small chance that such critics are right, in which case it would be safe to do nothing. But they may be completely wrong, and indeed the scientific consensus is that they are wrong. Political decisions inevitably involve assessing risk and weighing the consequences of action versus inaction. Just as Congress must decide if the (perhaps small) risk of a rogue nation launching a nuclear missile at the United States (resulting in a catastrophe) is worth avoiding by spending large sums of money on a space defense system, so it must weigh the potentially catastrophic environmental and commercial consequences of future global warming against the costs of curbing fossil fuel consumption to reduce these risks. Scientists cannot provide Congress with a *certain* forecast of the future and as research on global warming continues, our understanding will undoubtedly change. But the picture at present is that we are indeed living in climatically unusual times, and that the future is likely to be even more unusual.

Appendix 1.

Tree ring data include both ring width and ring density variations. Records are available from all continental areas (except Antarctica) though most series are from outside the tropical regions. High latitude and high altitude trees generally provide estimates of past temperature; trees in dry regions generally provide estimates of past precipitation, though even in wetter areas, records of rainfall changes can sometimes be obtained.

Ice cores provide many records of past climate but changes in oxygen isotopes in the ice, accumulation rate and (summer) melt conditions are of primary interest in examining recent centuries. In polar regions oxygen isotopes are generally considered to be an indicator of annual temperature. Other useful climate indicators include the fraction of a core containing 'melt features' (produced by the re-freezing of percolating surface melt water) which provides a useful index of summer temperature conditions, and accumulation rate changes, which indicate past snowfall amounts.

Corals provide uniquely detailed records of sea-surface temperatures, from changes in the (temperature-dependent) oxygen isotopes in the carbonate skeletons of the corals. In some cases, salinity variation is the most important factor influencing isotope content, in which case the changes reflect precipitation and runoff from adjacent continental regions.

Varved sediments, from both lake and marine environments, are annual layers that record past environmental conditions in the lake or oceanic region. There are few ocean areas where varved sediments are known to occur (generally upwelling coastal regions where there is little oxygen in the deep waters) but varved lake sediments are found on all continents. Providing the records are clearly annual and a strong climatic signal can be demonstrated, these records can provide useful data from many regions of the world.

Historical records can, potentially, provide seasonal estimates of past climate over wide geographic regions, though at present only European and East Asian sources have been adequately studied.

Details of how these and other paleoclimate proxies are used to reconstruct past climates can be found in the book "Paleoclimatology" by R.S. Bradley (1999, Academic Press).

The CHAIRMAN. Dr. Christy, welcome.

STATEMENT OF DR. JOHN R. CHRISTY, DIRECTOR, EARTH SYSTEM SCIENCE CENTER, UNIVERSITY OF ALABAMA

Dr. CHRISTY. Thank you, Mr. Chairman. I am pleased to be here testifying before this Committee.

By the way, I am from the University of Alabama in Huntsville. We do not have football team. Ice hockey, in fact, is our favorite sport.

[Laughter.]

Dr. CHRISTY. Considering the varying levels of skepticism represented on this panel, it would be apparent that I am very likely the witness that is most skeptical, but not agnostic, regarding our ability to predict future climate. And I hope to demonstrate why this is so.

The universal feature of climate model projections of global temperature changes due to greenhouse gas increases is a rise in the temperature of the atmosphere from the surface to about 30,000 feet.

This temperature rise itself is projected to be significant at the surface, with increasing magnitude as one rises in the atmosphere, which we call the troposphere.

Over the past 21-years various calculations of surface temperature, indeed, show a rise between .45 and .65 of a degree. This represents about half of the total rise since the end of the 19th Century.

In the troposphere, however, various estimates, which include satellite data that Dr. Roy Spencer of NASA and I produced, show only a very slight warming between .09 and .18 of a degree, a rate less than one-third that observed at the surface.

So rather than seeing a rise in temperature that increases with altitude as climate models project, we see that in the real world since 1979, the rise decreases substantially with altitude.

The most recent modeling efforts which attempt to explain this disparity suggest that when some of the actual climate processes are factored in, and I emphasize "some," such as the Mount Pinatubo eruption, the models looked like they came close to reality.

On closer inspection of these studies, however, one finds that the apparent agreement was achieved only by comparing apples with oranges. The model experiments included some major processes, but not all major processes.

When those additional processes were included, like real El Niños, the climate models did not produce the observed global average vertical temperature changes. In other words, 60 percent of the atmosphere is going in a direction not predicted by models.

And that, in my view, is a significant missing piece of the climate puzzle that introduces considerable uncertainty of the models' utility regarding predicting temperatures.

Now, it is certainly possible that the inability of the climate models to predict what happened over the past 21 years may only indicate that the climate experiences large natural fluctuations in the vertical temperature structure.

However, this means that any attention drawn to the surface temperature rise for the past two decades must, I repeat must, also acknowledge the fact that 60 percent of the atmospheric mass that was projected to warm did not.

This vertical temperature situation is a curious and unexplained issue regarding global average temperatures. But we do not live 30,000 feet in the atmosphere, and we do not live in a global average. We live in a specific place, city, state, and so on.

Local and regional projections of climate are very difficult and challenging. An example from North Alabama that I wanted to use here, only illustrates the difficulty in providing regional estimates of what might happen.

A few climate models have attempted to reproduce the temperature changes over the last 150 years, since the 19th century. These are complex models with solar changes, carbon dioxide increases, sulfate pollution, oceans, and so on.

They indicate that since the 1890's we in North Alabama should have experienced a warming of about two degrees.

Observations show we have actually experienced a cooling of over two degrees. The models may have done fairly well at the global average surface temperature, and may have done acceptably well in several geographic locations, but my opinion in the southeast, is that there was false information there. I am not hitting climate models in a critical way. I am showing the challenge that is there on reproducing climate results on a regional basis.

If in trying to reproduce the past we see such model errors, one must assume that predicting the future would produce similar opportunity for regional errors. I want to encourage the Committee to be suspicious of media reports in which weather extremes are given as proof of human-induced climate change.

Weather extremes occur somewhere all the time. For example, you have seen recent reports perhaps about the U.S. surface temperature data showing January through March the highest ever in one surface temperature data set of the United States, not others.

The satellite data provides information for the entire globe and show that, yes, indeed, the tropospheric temperatures were well above average for the 48 contiguous states. However, most of the globe experienced below average temperatures in that massive bulk of the atmosphere.

It was our turn to be warm while in places such as the equatorial oceans and the Sahara Desert, it was their turn to be cool. Other climate data give us similar information. Hurricanes have not increased. Tornadoes have not increased. Droughts and wet spells have not statistically increased, or decreased.

Let me quickly add, there are many more people and much more wealth in the paths of these destructive events, so losses have increased but that is not due to climate change. Deaths in U.S. cities are no longer correlated with high temperatures, though deaths still increase during cold temperatures.

When looking at data such as these, especially on a regional basis, climate change, and in particular, the human factor of climate change, is very difficult to detect at all.

I will close with three questions and a plea. Is the climate changing? Yes, it always has and it always will, but it is very difficult to detect on decadal time scales.

Are climate models useful? Yes, and improving. At this point, their utility is mostly in global average scale, yet there are still some significant shortcomings even there.

Is that portion of climate change due to human factors good, bad, or inconsequential? And that, no one knows, although we do know that the plant world thrives on additional CO_2 in the atmosphere.

What I do know is that we depend on data to answer these questions. The global data network is decaying at the very time we need it most.

If the richest country in the world could do anything, it would be to step up efforts to monitor the present global climate, reconstruct the past climate, assure easy and timely access to data, and to support scientists to study the data on which to depend such important answers.

Thank you.

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

[The prepared statement of Dr. Christy follows:]

PREPARED STATEMENT OF DR. JOHN R. CHRISTY, DIRECTOR, EARTH SYSTEM SCIENCE CENTER, UNIVERSITY OF ALABAMA

Mr. Chairman and Committee Members, I am pleased to accept your invitation to offer information on climate change along with my own assessment. I am John Christy, Professor of Atmospheric Science and Director of the Earth System Science Center at the University of Alabama in Huntsville.

Carbon Dioxide

The concentration of carbon dioxide (CO_2) is increasing in the atmosphere due primarily to the combustion of fossil fuels. It is our great fortune (because we produce so much of it) that CO_2 is not a pollutant. In simple terms, CO_2 is plant food. The green world we see around us would disappear if not for atmospheric CO_2. These plants largely evolved at a time when the atmospheric CO_2 concentration was many times what it is today. Indeed, numerous studies indicate the present biosphere is being invigorated by the human-induced rise of CO_2. In and of itself, therefore, the increasing concentration of CO_2 does not pose a toxic risk to the planet. It is the secondary impact of CO_2 that may present challenges to human life in the future. It has been proposed that CO_2 increases could cause climate change of a magnitude beyond what naturally occurs that would force costly adaptation or significant ecological stress. For example, sea level rise and/or reduced rainfall would be two possible effects likely to be costly to those regions so affected. Data from the past and projections from climate models are employed to provide insight on these concerns.

Climate Models

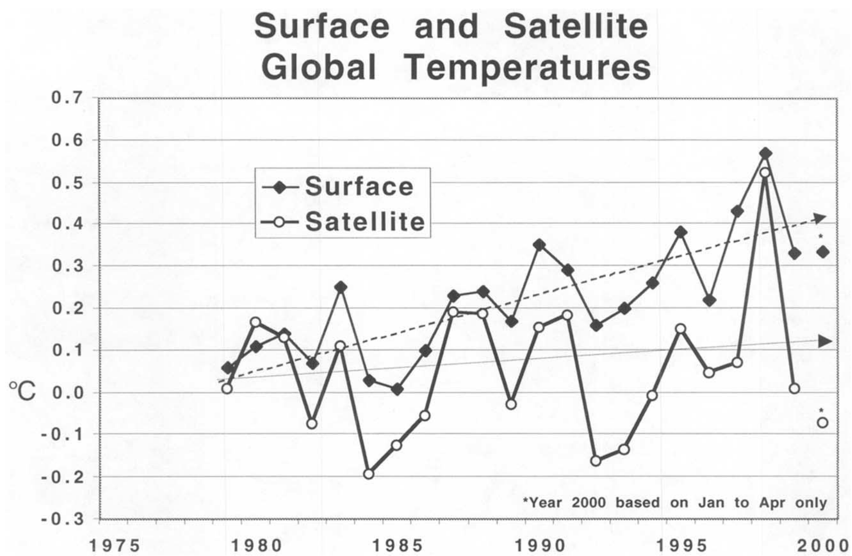
Climate models attempt to describe the ocean/atmospheric system with equations which approximate the processes of nature. No model is perfect because the system is incredibly complex. One modest goal of model simulations is to describe and predict the evolution of the ocean/atmospheric system in a way that is useful to discover possible environmental hazards which lie ahead. The goal is not to achieve a perfect forecast for every type of weather in every unique geographic region, but to provide information on changes in large-scale features. If in testing models for current large-scale features one finds conflict with observations, this suggests that at least some fundamental process, for example heat transfer, are not adequately described in the models.

Global Averages

A universal feature of climate model projections of global average temperature changes due to enhanced greenhouse gasses is a rise in the temperature of the atmosphere from the surface to 30,000 feet. This temperature rise itself is projected to be significant at the surface, with increasing magnitude as one rises through this layer called the troposphere. Most people use the term Global Warming to describe this temperature rise.

Over the past 21-years various calculations of surface temperature do indeed show a rise between +0.45 and +0.65°F (0.25 and 0.36°C depending on which estimate is used.) This represents about half of the total surface warming since the 19th century. In the troposphere, however, the values, which include the satellite data Dr. Roy Spencer of NASA and I produce, show only a very slight warming between +0.09 and +0.18°F (+0.05 and +0.10°C)—a rate less than a third that observed at the surface. So, rather than seeing a warming that increases with altitude as climate models project, we see that in the real world the warming substantially decreases with altitude.

It is critically important in my view to correctly model tropospheric temperature changes because this is where much of the global atmospheric heat is moved about and eventually expelled to space. This layer also has a strong influence on surface temperature through radiation processes. It is conceivable that a model which retains too much heat in the troposphere, may also retain too much at the surface.



The most recent modeling attempts which seek to reconcile this disparity suggest that when *some* of the actual climate processes are factored in, the models come very close to reality. These processes are events such as the Mt. Pinatubo eruption and slow changes such as ozone depletion.

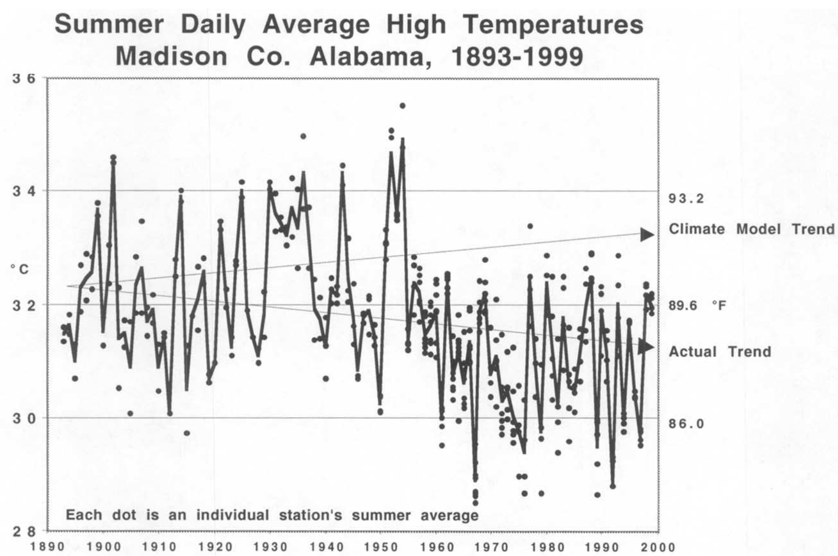
On closer inspection of these studies, however, one finds that the apparent agreement was achieved only by comparing apples with oranges. The model experiments included *some* major processes, but not *all* major processes. When those additional processes are also factored in, such as real El Niños, the climate models do not produce the observed global average vertical temperature changes observed since 1979. In other words, the temperature of 60% of the atmosphere appears to be going in a direction not predicted by models. That, in my view, is a significant missing piece of the climate puzzle which introduces considerable uncertainty about a model's predictive utility.

It is certainly possible that the inability of the present generation of climate models to reproduce the reality of the past 21 years may only reflect the fact that the climate experiences large natural variations in the vertical temperature structure over such time periods. By recognizing this however, the implication is that any attention drawn to the surface temperature rise over the past two decades must also acknowledge the fact that 60% of the atmospheric mass has not similarly warmed.

Regional Averages

This disparity between observations and model results is a curious and unexplained issue regarding the global average vertical temperature structure. But we do not live 30,000 feet in the atmosphere, and we do not live in a global average surface temperature. We live in specific places, cities, states and regions. Local and regional projections of surface climate are very difficult and challenging. An example from Alabama's past is useful here only to illustrate the difficulty of providing local predictions with a high level of confidence.

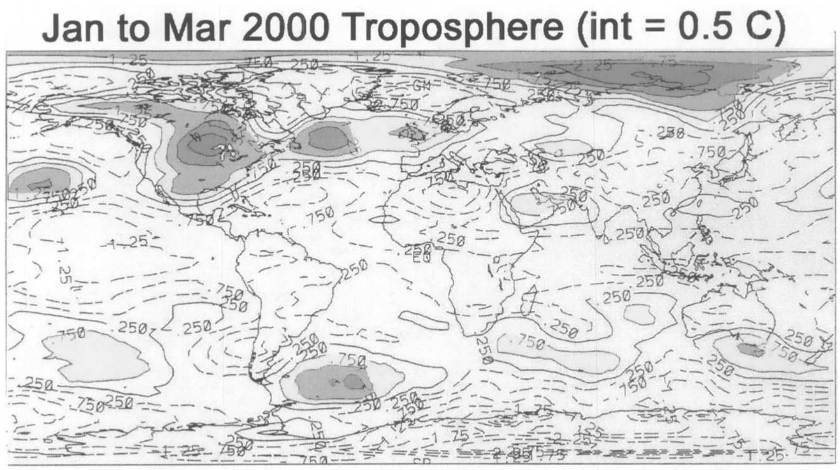
A few of the present set of climate models have attempted to reproduce the distribution of actual surface temperatures since the 19th century. These complex models incorporate solar changes, increasing carbon dioxide, sulfate pollution and so on. They indicate that since the 1890's we in North Alabama should have experienced a warming of about 2°F (1°C). The truth is that we have actually experienced a cooling of over 2°F (1°C).[1] The model may have done fairly well in the global average, and may have done acceptably well in many geographic locations, but in my opinion it provided false information for those of us in the Southeast. If in trying to reproduce the past we see such model errors, one must assume that predicting the future would produce similar opportunities for errors on a regional basis.



Weather Extremes and Climate Change

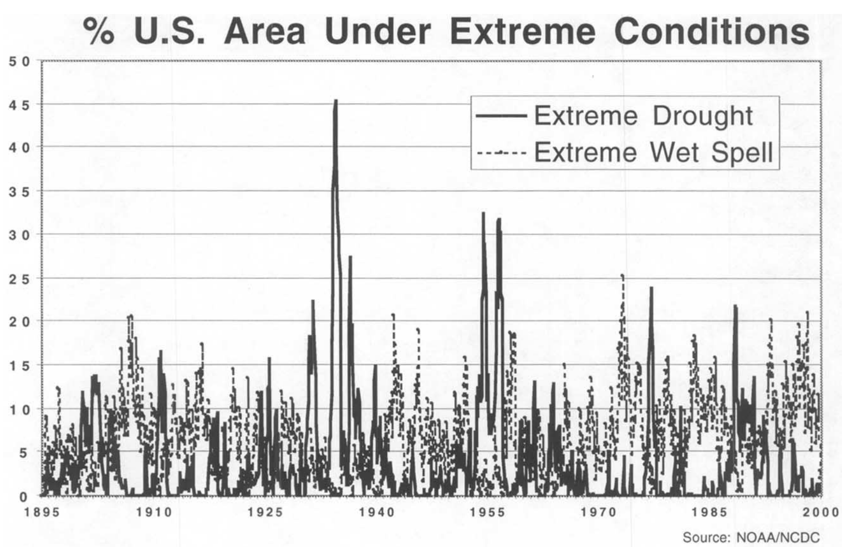
I want to encourage the Committee to be suspicious of media reports in which weather extremes are given as proof of human-induced climate change. Weather extremes occur somewhere all the time. For example, you may have seen a recent report based on one version of the U.S. surface temperature data stating that January through March of this year was the hottest ever recorded. The satellite data provide information for the entire globe and show that indeed tropospheric temperatures were much above average over the lower 48 states. However, most of the globe experienced below average temperatures in that massive bulk of the troposphere. It was our turn to be warm while in places such as the equatorial oceans and the Sahara Desert it was their turn to be cold.

[1] Data have been adjusted for all station moves, time of observation biases and instrument changes.



Above: Departure from a 20-year average for January to March 2000 of tropospheric temperature measurements. Colored areas are those with departures greater than 0.75 (yellow), 1.25 (light orange), 1.75 (dark orange) and 2.25 (red) °C. Note that most of the globe is covered with negative departures (dashed lines).

Has hot weather occurred before in the US? All time record high temperatures by states begin in 1888. Only eleven of the states have uniquely seen record highs since 1950 (35 occurred prior to 1950, 4 states had records occurring both before and after 1950.) Hot weather happens. Similar findings appear from an examination of destructive weather events. The intensity and frequency of hurricanes have not increased. The intensity and frequency of tornadoes have not increased. (Let me quickly add that we now have more people and much more wealth in the paths of these destructive events so that the losses have certainly risen, but that is not due to climate change.) Droughts and wet spells have not statistically increased or decreased. Last summer's drought in the Northeast was remarkable in the sense that for the country as a whole, the typical percentage area covered by drought was below average. Deaths in U.S. cities are no longer correlated with high temperatures, though deaths still increase during cold temperatures.



When considering information such as indicated above, one finds it difficult to conclude the climate change is occurring in the U.S. and that it is exceedingly difficult to conclude that part of that change might have been caused by human factors.

In the past 100 years, sea level has risen 6 in. ± 4 in. (15 cm ± 10 cm) and is apparently not accelerating. Sea level also rose in the 17th and 18th centuries, obviously due to natural causes, but not as much. One of my duties in the office of the State Climatologist is to inform developers and industries of the potential climate risks and rewards in Alabama. I am very frank in pointing out the dangers of beach front property along the Gulf Coast. A sea level rise of 6 in. over 100 years, or even 50 years is minuscule compared with the storm surge of a powerful hurricane like Fredrick or Camille. Coastal areas threatened today will be threatened in the future. The sea level rise, if it continues, will be very slow and thus give decades of opportunity for adaptation, if one is able to survive the storms.

Summary

I will close with three questions and a plea.

Is the climate changing? Yes, it always has and it always will, but it is very difficult to detect on decadal time scales or on regional spatial scales.

Are climate models useful? Yes, and improving. At this point, their utility is mostly related to global averages, though shortcomings are still apparent.

Is that portion of climate change due to human factors good, bad or inconsequential? No one knows (although the plant world thrives on increases in carbon dioxide because CO_2 is plant food.)

What we do know is that we depend on data to answer these questions. The global data network is decaying at the very time we need it most. If the richest country in the world could do something, it would be to lead out in monitoring the present climate, in reconstructing the past climate, in assuring easy and timely access to the data . . . and in supporting scientists to study the data on which depend such important answers.

The CHAIRMAN. Dr. Mahlman, is that the proper pronunciation?

Dr. MAHLMAN. Yes, it is.

The CHAIRMAN. Welcome, Doctor. Would you pull the microphone over? Thank you.

STATEMENT OF DR. JERRY MAHLMAN, DIRECTOR, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. MAHLMAN. Thank you, Mr. Chairman. We have long known that buildups of atmospheric carbon dioxide and other gases have the potential to warm earth's climate, through the so-called greenhouse effect.

Today, I will discuss the modeling of projections of climate changes due to these increases in greenhouse gases for the time around the middle of this 21st Century. Because I speak with credentials as a physical scientist, I do not offer personal opinions on what society should do about these projected climate changes.

Societal actions to greenhouse warming involve value and policy judgments that are beyond the realm of climate science. At the onset, please recognize that a major international effort to assess climate warming was completed in 1996. This is the IPCC assessment that Dr. Lane referred to earlier.

This was the most widely accepted assessment ever on climate change. The 2001 climate assessment will be completed soon. I expect only small changes in its major conclusions, mainly concerning some very important increases in scientific confidence over the last 5 years.

I strongly recommend your use of these IPCC assessments as a foundation for your own evaluations. I also recommend their use as a point of departure for evaluating the credibility of opinions that disagree with the IPCC assessments. IPCC is not an infallible system, in that sciences is always self corrective, but opinions that disagree with them have the burden to make sense.

My information I present today is derived from the strengths and weaknesses of climate models, the strengths and weaknesses of climate theory, and the strengths and weaknesses of widespread observations of the climate system.

Climate models have improved in their ability to simulate the climate and its natural variations. Unfortunately, important uncertainties due to deficiencies in our scientific understanding and in our computing power still remain. Nevertheless, significant progress is expected over the next decade.

However, let me say at the onset, none of the uncertainties that I discuss today can make current concerns about greenhouse warming go away. This problem is very real, and is guaranteed to be with us for a very long time.

I will give my evaluation of current model projections of climate change for the middle of the next century by my setting of simple betting odds. By "virtually certain," a phrase used earlier by Senator Kerry, I mean, that there is no plausible alternative that we know of. In effect, the bet would be off the books.

"Very probable" means that I estimate a nine out of ten chance that this will happen within the range projected. "Probable" implies that I am setting the odds at about a two out of three chance, while uncertain means a plausible effect, but which lacks appropriate evidence. I will give examples of all of these. So essentially, I set the betting odds; you choose your bet.

My analysis is presented in decreasing levels of scientific confidence. Human-caused increasing greenhouse gases in the atmosphere is virtually certain. There is no remaining real doubt that increasing greenhouse gases are due to human activities.

Radiative effects of increased greenhouse gases is virtually certain. Greenhouse gases absorb and reradiate infrared radiation, the heat radiation that leaves the planet all the time, that makes it cool off at night. Independent of other factors, this acts to produce an increased heating on the planet.

A doubling of atmospheric carbon dioxide expected, virtually certain. Atmospheric carbon dioxide amounts are now expected to at least double over pre-industrial levels in this century. Currently, emission growth is on track to quadruple carbon dioxide levels.

Long time to draw down excess carbon dioxide, virtually certain. We know that it takes decades to centuries to produce a large buildup of greenhouse gases. Much less appreciated is that a return to normal from high carbon dioxide levels in the atmosphere would require many additional centuries, perhaps more than 1,000 years.

Global surface warming over the past century, virtually certain. The measured 20th century warming in the surface temperature records of over one degree Fahrenheit is undoubtedly real. Its cause is very probably due mostly to added greenhouse gases. No other hypothesis today is nearly as creditable.

Future global-mean surface warming, very probable. Assuming business as usual for the middle of the next century, global-mean surface warming is estimated to be in the range of two to six degrees Fahrenheit, with continued increases for the rest of the century. The largest uncertainty is due to the effects of clouds.

Increased summertime heat index, very probable. In warm moist subtropical climates, such as Washington, D.C., the summertime heat index effect is expected to magnify the warming impact felt by humans by an additional 50 percent.

Rise in global sea level, very probable. A further rise of four to twelve inches in global mean sea level by the year 2050 is estimated due simply to the thermal expansion of warmer sea water. As the water warms, it occupies more volume. This does not include the effects of possible melting of Greenland ice. Continued sea level rise is expected for many centuries, probably to much higher levels.

Disappearance over the last 50 years of Arctic sea ice, very probably, due to human activities. There is some uncertainty about how much humans have had to do with that, but it is pretty well conceded that the models are now calculating that properly.

Summer mid-continental dryness, probable. Model studies project a marked decrease in soil moisture over summer mid-latitude continents. This projection remains sensitive to model assumptions, thus, I give it a two out of three bet.

Increased tropical storm intensities, probable. A warmer, wetter atmosphere will likely lead to increased intensities of tropical storms such as hurricanes, and substantial increases in their precipitation rates.

We still know little about changes in the number of hurricanes. When people tell you there will be more hurricanes, we do not know where those kind of statements come from. So, when people say we are not finding increased numbers of hurricanes, I do not understand that either.

Increased numbers of weather disturbances, uncertain. Although many speak of more large-scale storms, such as northeasters, and so forth, there is no solid evidence for this, in either models or theory.

Global and regional details for the next 25 years, uncertain. The predicted warming, up to now, is not yet large compared to natural climate fluctuations. We can find it in the data, but it does not yet fully dominate. On these shorter time scales, the natural fluctuations can artificially reduce or enhance apparent measured greenhouse warming signals, especially so on regional scales.

Endorsing Dr. Christy's point, but raising the bet, variations on decadal scales at a particular region can be due to completely natural effects, California and Southwest United States are particularly vulnerable to these natural fluctuations.

Even though these uncertainties are daunting, important advances have already been achieved in observing, understanding, and modeling the climate. Today's models can simulate many aspects of climate and its changes.

Although major progress has been made, much more needs to be learned. More efforts are needed worldwide to provide a long-term climate measuring system that is really designed to do the job.

Focused research into climate processes must be continued. Theories must be formulated and re-evaluated in the light of newer data. Climate modeling efforts must receive resources that are in balance with the broader scientific programs.

In my view, the U.S. Global Change Research Program has already made important progress on these fronts. However, patient and sustained efforts will be required in the years ahead.

I endorse Dr. Lane's balanced presentation of this vital interagency effort under the U.S. Global Change Research Program. Through long-term research and measurements, uncertainties will decrease, and confidence for projections of climate change will increase.

In summary, the greenhouse warming effect is quite real. The state of the science is strong, but important uncertainties do remain. Finally, it is a virtually certain bet that this problem will refuse to go away no matter what is said or done about it over the next 5 to 10 years.

Thank you, Mr. Chairman.

PREPARED STATEMENT OF DR. JERRY MAHLMAN, DIRECTOR, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Mr. Chairman:

My name is Jerry Mahlman. I am the Director of the Geophysical Fluid Dynamics Laboratory of NOAA. For over thirty years our Laboratory has been a world leader in modeling the earth's climate. I will evaluate scientific projections of climate change as well as their current uncertainties.

We have long known that buildups of atmospheric carbon dioxide and other gases have the potential to warm earth's climate, through the so-called "greenhouse" effect. Today, I will discuss modeling the projections of climate changes due to these increasing greenhouse gases for a time around the middle of the century.

Because I speak with credentials as a physical scientist, I do not offer personal opinions on what society should do about these projected climate changes. Societal actions in response to greenhouse warming involve value and policy judgements that are beyond the realm of climate science.

At the onset, please recognize that a major international effort to assess climate warming was completed in 1996. This is "The Intergovernmental Panel on Climate Change Assessment" (IPCC). The IPCC was established in 1988 by the United Nations Environment Programme and the World Meteorological Organization to assess the available information on climate change and its environmental and economic impacts. This was the most widely accepted assessment ever on climate change. The 2001 IPCC Assessment will be completed soon. I expect only small changes in its major conclusions, mainly concerning some important increases in scientific confidence.

I strongly recommend your use of the IPCC assessments as a foundation for your own evaluations. I also recommend their use as a point of departure for evaluating the credibility of opinions that disagree with them.

My information is derived from the strengths and weaknesses of climate models, climate theory, and widespread observations of the climate system. Climate models have improved in their ability to simulate the climate and its natural variability. Unfortunately, important uncertainties remain due to deficiencies in our scientific understanding and in computer power. However, significant progress is expected over the next 10 years.

However, let me say at the outset: None of the uncertainties I will discuss can make current concerns about greenhouse warming go away. This problem is very real and will be with us for a very long time.

I will give my evaluation of current model predictions of climate change in the middle of the next century by setting simple "betting odds." By "Virtually Certain," I mean that there is no plausible alternative; in effect, the bet is off the books. "Very Probable" means I estimate about a 9 out of 10 chance that this will happen within the range projected; "Probable" implies about a 2 out of 3 chance. "Uncertain" means a plausible effect, but which lacks appropriate evidence. Essentially, I set the odds; you choose your bet. My analysis is presented in decreasing levels of confidence.

Human-Caused Increasing Greenhouse Gases (virtually certain)

There is no remaining doubt that increasing greenhouse gases are due to human activities.

Radiative Effect of Increased Greenhouse Gases (virtually certain)

Greenhouse gases absorb and reradiate infrared radiation. Independent of other factors, this property acts to produce an increased heating effect on the planet.

A Doubling of Carbon Dioxide Expected (virtually certain)

Atmospheric carbon dioxide amounts are expected to double over pre-industrial levels in this century. Current emissions growth is on track to quadruple atmospheric carbon dioxide.

Long Time to Draw Down Excess Carbon Dioxide (virtually certain)

We know that it takes decades to centuries to produce a large buildup of greenhouse gases. Much less appreciated is that a "return to normal" from high carbon dioxide levels would require many additional centuries.

Global Surface Warming Over the Past Century (virtually certain)

The measured 20th century warming in the surface temperature records of over one degree fahrenheit is undoubtedly real. Its cause is very probably due mostly to added greenhouse gases. No other hypothesis is nearly as credible.

Future Global-Mean Surface Warming (very probable)

For the middle of the next century, global-mean surface warming is estimated to be in the range of 2 to 6° fahrenheit, with continued increases for the rest of the century. The largest uncertainty is due to the effects of clouds.

Increased Summertime Heat Index (very probable)

In warm, moist subtropical climates the summertime heat index effect is expected to magnify the warming impact felt by humans by an additional 50%.

Rise in Global Mean Sea Level (very probable)

A further rise of 4–12 inches in mean sea level by the year 2050 is estimated due to thermal expansion of warmer sea water. Continued sea level rise is expected for many centuries, probably to much higher levels.

Summer Mid-Continental Dryness and Warming (probable)

Model studies predict a marked decrease of soil moisture over summer mid-latitude continents. This projection remains sensitive to model assumptions.

Increased Tropical Storm Intensities (probable)

A warmer, wetter atmosphere will likely lead to increased intensities of tropical storms, such as hurricanes. We still know little about changes in the number of hurricanes.

Increased Numbers of Weather Disturbances (uncertain)

Although many speak of more large-scale storms, there is still no solid evidence for this.

Global and Regional Details of the Next 25 Years (uncertain)

The predicted warming up to now is not yet large compared to natural climate fluctuations. On these shorter time scales, the natural fluctuations can artificially reduce or enhance apparent measured greenhouse warming signals, especially so on regional scales.

Even though these uncertainties are daunting, important advances have already been achieved in observing, understanding, and modeling the climate. Today's models can simulate many aspects of climate and its changes. Although major progress has been made, much more needs to be learned. More efforts are needed world-wide to provide a long-term climate measuring system. Focussed research into climate processes must be continued. Theories must be formulated and re-evaluated in the light of newer data. Climate modeling efforts must receive resources that are in balance with the broader scientific programs.

The U.S. Global Change Research Program has already made important progress on these fronts. However, patient, sustained efforts will be required in the years ahead.

Through long-term research and measurements, uncertainties will decrease and confidence for predicting climate changes will increase.

In summary, the greenhouse warming effect is quite real. The state of the science is strong, but important uncertainties remain. Finally, it is a "virtually certain" bet that this problem will refuse to go away, no matter what is said or done about it over the next five years.

Thank you, Mr. Chairman. That concludes my testimony.

The CHAIRMAN. Thank you, Dr. Mahlman.

Dr. Trenberth, welcome.

STATEMENT OF DR. KEVIN E. TRENBERTH, DIRECTOR, CLIMATE ANALYSIS SECTION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. TRENBERTH. Thank you, Senator.

I recently served on the National Research Council Panel that produced the report that has been referred to, this report here on reconciling observations of global temperature change. And I was asked in my comments to especially address the findings of this particular Committee.

The first thing I would say is that the mere need for this report highlights the fact that we do not have a global climate observing system. Most of the observations that are used for climate purposes are made for weather or aviation purposes. The observations are made for purposes other than for climate.

Heroic efforts are, therefore, needed, it turns out, to reconstruct exactly what has happened even in the instrumental period, let alone what has happened in the last 1,000 years.

What we do conclude in this report is that in the past 20 years, global mean surface temperatures have been rising at a rate as large as any that has been observed within the historical record.

The surface temperatures have increased. A central number I would put on it is about 1.3 degrees Fahrenheit over the past century. 1998 is the warmest year, as has been mentioned several times, and the 1990's is the warmest decade. And melting glaciers and rising sea level provides additional support that these effects are real.

Now this rapid warming at the earth's surface is in contrast, as John Christy has mentioned, to the trend in the satellite record, which only began though in 1979. Now the satellite record measures the temperature of about the lowest five miles of the atmosphere. It is not measuring the same thing as the temperature of the surface. It is an indirect measurement, and it is inferred from radiation that is emitted by oxygen molecules and it is sampled by a microwave sound unit.

So these are measurements in the microwave frequencies, and these measurements are made aboard polar orbiting satellites.

Before I go on to summarize some aspects of the temperature record, I would emphasize a point which has been made by others: Temperature changes are only part of the total picture, and that the global mean temperature, I think of more as an indicator that something extraordinary is happening now. It is a little bit like the canary in a cage in a coal mine. It shows that something extraordinary is happening, but it has very little practical significance locally. And other changes such as rainfall and droughts, and fires such as in your own state, Senator, are probably of much more practical significance.

Now in my written testimony, I summarize firstly, the surface temperature record; second, the radiosonde balloon-borne temperature record which measures the temperatures above the surface of the earth; and third, the satellite record. And for each of these, I discuss the nature of the measurements, their coverage in space and time, their biases, their advantages and disadvantages, and they all have some, and a brief overall assessment of them. And I then deal with the issues of reconciling them, and I do not have time to go through all of those things here.

What I will say is that all three records have been improved and developed in recent years, in particular several corrections have been made to the satellite record, for example, through the effects of the systematic orbital decay of each satellite—and this has improved the level of agreement among the records.

Now using the radiosonde record, we can estimate the temperatures of the layer seen by the satellite. And this shows quite good agreement during the overlap period after 1979. And therefore, we can use the radiosonde record to extend that record back in time to about 1964 quite reliably.

And when we do that, although we find that the temperature trends in the satellite record from 1979 to 1999 are quite small, the longer term trends are somewhat more in agreement with what we see at the surface.

I would emphasize that the trends in the satellite record, after 1979, are less than those at the surface, primarily because they are measuring different things. A reasonable interpretation, I think, of the overall record is that global warming increases——

The CHAIRMAN. What different things are they measuring?

Dr. TRENBERTH. The satellite record is measuring the layer in the lowest five miles or so of the atmosphere, and it is influenced by a number of things that have much less influence at the surface. I was just coming to that point, in fact.

The CHAIRMAN. I am sorry.

Dr. TRENBERTH. I think a reasonable interpretation of the overall record is that the global warming from increased greenhouse gases is producing the rising temperatures that we are seeing at the surface, and now those rises are above and beyond those arising from natural variability.

The main reasons the tropospheric temperatures are not keeping pace are because of stratospheric ozone depletion which has a much greater effect on what is happening, especially in the lower stratosphere and the upper part of the troposphere than it does on the surface. And also, changes in cloud cover, which have an effect on maximum versus minimum temperatures. We know that minimum temperatures are rising much faster than maximum temperatures, for instance. So changes in cloud coverage which may or may not be associated with other pollution in the atmosphere (effects other than climate change), may also be due to climate change itself. These are probably the two biggest effects that are causing the disparity.

Therefore, what we do see is that the larger surface temperature increases are occurring over land and at night time, somewhat less during the day, and somewhat less over the oceans.

The panel concluded that the records are probably reasonably consistent with each other once all of the forcing factors are taken into account. Now this goes beyond the models themselves, as it also is the forcing factors such as the depletion of the ozone layer and its vertical profile which are not known very well. And that is one of the uncertainties that exists.

Once all of those factors are taken into account, we believe the records are consistent with one another. In other words, the bigger increase at the surface than in the troposphere is real. And accordingly, the recent warming at the surface is undoubtedly real. It is substantially greater than the average rate during the 20th century, and it is in no way invalidated by the satellite record.

In my closing remarks, I would like to make a comment about global warming in general. I think the term itself is often misused, and it really should refer to the increased heating that is occurring because of the changes in composition of the atmosphere.

Some of that heat goes into raising temperature, but in actual fact, most of it goes into evaporating moisture at the surface of the earth. Most of the earth is covered by ocean, 70 percent of the surface, and most of the heat is, in fact, going into evaporating moisture.

Over land that is true also as long as there is moisture around, but when things dry out, as happens in a drought, then all of the heat tends to go into raising temperature, and that is when we get the greatest heat waves.

In the United States, there has been a general increase in precipitation and this tends to mute any changes in temperature because more heat is going then into evaporating moisture. As an example of this, if it has been raining and the sun comes out, the first thing that happens is that all of the puddles dry up. The heat goes into evaporating the moisture, not raising temperature.

So it is very important to consider changes in temperature along with changes in rainfall, and just focusing on temperature does not give you a complete picture or an adequate understanding of what exactly is going on.

So I would emphasize that it is much more than changes in temperature. Changes in precipitation, changes in moisture can act as a swamp cooler to air condition the planet, and in fact, do so. And we should also be concerned about changes in storms and changes in severe weather events.

Thank you for the opportunity to testify.

The CHAIRMAN. Thank you very much.

[The prepared statement of Dr. Trenberth follows:]

PREPARED STATEMENT OF DR. KEVIN E. TRENBERTH, DIRECTOR, CLIMATE ANALYSIS SECTION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

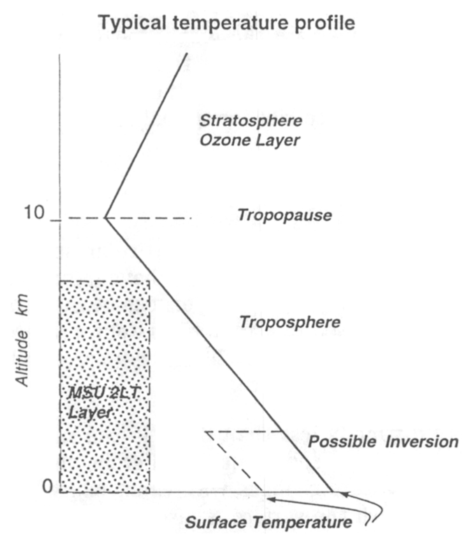
CLIMATE CHANGE AND TEMPERATURES

Introduction

My name is Kevin Trenberth. I am the Head of the Climate Analysis Section at NCAR, the National Center for Atmospheric Research. I am especially interested in global-scale climate dynamics; the observations, processes and modeling of climate changes from interannual to centennial time scales. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I recently served on the National Research Council Panel on "Reconciling observations of global temperature change," whose report was published in January 2000. I co-chaired the international CLIVAR Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I remain a member of that group as well as the Joint Scientific Committee that oversees the WCRP as a whole. CLIVAR is short for Climate Variability and Predictability and it deals with variability from El Niño to global warming. I have been involved in the global warming debate and I am extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary and Policy Makers Summary of Working Group I.

During the past 20 years, global mean surface temperatures have been rising at a rate as large as any that has been observed within the historical record. Such rapid warming at the Earth's surface is in contrast to the trend in the global-mean temperature of the lowest 8 kilometers of the atmosphere (within that portion of the atmosphere referred to as the troposphere) as inferred from measurements of radiation emitted by oxygen molecules (a proxy for tropospheric temperature) sampled by the microwave sounding unit (MSU) carried aboard the NOAA polar-orbiting satellites; see Fig. 1 for the vertical structure of the atmosphere. I will summarize here the state of knowledge with regard to observed climate change, and especially the issues of the changes in temperatures as seen by the synthesis of observations taken at the Earth's surface versus those measured by satellite.

Fig. 1. The typical structure of temperature with height is shown. The lower atmosphere is the troposphere and the lowest 8 km or so of that is the region measured by the MSU–LT. The stratosphere contains the ozone layer and is separated from the troposphere by the tropopause which varies in height from about 10 km in the extratropics to 16 km in the tropics.



Observed climate change

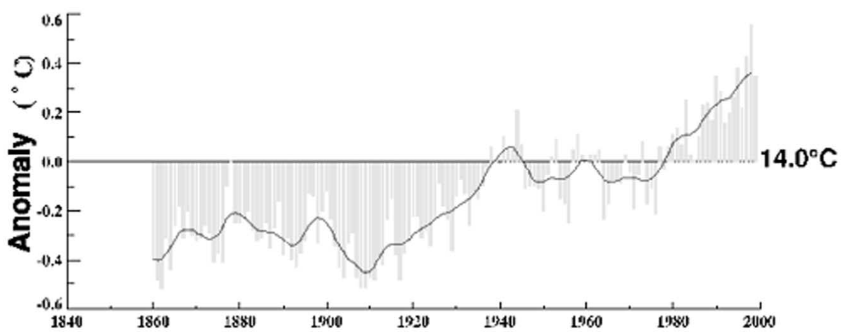
It is important to appreciate that temperature changes are only a part of the total picture. Global warming refers to the increased heating of the Earth arising from well documented increases in greenhouse gases such as Carbon Dioxide. At the surface, some of that heat goes into raising temperatures, but most of it goes into evaporating moisture. This is especially true as long as the surface is wet, as it always is over the 70% of the globe covered by oceans. After rainfalls, in bright sunshine, it is only following the drying up of surface puddles that temperatures are apt to rise. Accordingly, the strongest heat waves occur in association with droughts because then there is no surface moisture to act as a "swamp cooler," and droughts are apt to become more intense with global warming. Meanwhile the increases in atmospheric moisture fuel more vigorous storms. Changes in extremes of climate will be much greater than changes in the mean. It also means that temperature increases are likely to be muted in places where precipitation has increased, as is generally the case for most of the United States. Changes in cloud cover, storm tracks, winds, and so forth further complicate the picture. The very nature of the atmospheric circulation, in which large-scale waves occur, also guarantees that some regions will warm more than others and some regions may cool even as the planet as a whole warms. These comments highlight the need to examine several factors, including precipitation, when developing an understanding of temperature changes.

Surface temperatures

The surface temperature record is made up mostly from measurements by thermometers that track surface air temperature over land and ocean, as well as sea surface temperatures (SSTs) over the oceans. In recent years satellite infrared measurements have helped determine patterns of SSTs. The coverage increases over time after about 1850; it was quite poor in the 1800s and is best after the 1950s. It is only truly global after 1982 with the help of satellite measurements. It is generally poor over the southern oceans and there were almost no data over Antarctica prior to the IGY (1957). Changing biases confound the climate record. These arise from changes in observing practices (thermometer types, their exposure, the time of measurement etc.), and changes in land use practices. The urban heat island is the best known latter effect and arises because of the concrete jungle in cities which retains heat at night and causes rapid runoff of rain.

The advantages of the surface record are its length, well over 100 years, the many independent measurements, several independent analyses, and its robustness to the many cross checks, such as Northern versus Southern Hemisphere, urban versus rural, and land-based versus marine measurements. The disadvantages are the mostly less than global coverage, and coverage changes with time. An overall assessment is that the trends are robust, but may be slightly over-estimated owing to under-representation of the southern oceans and Antarctica.

Fig. 2. The average annual mean global temperature expressed as the departure from the 1961–90 average of 14C, called anomalies. From U.K. Met. Office and University of East Anglia.



Surface temperatures (Fig. 2) have increased by 0.7°C (1.3°F) over the past century. The increase is not steady but occurs mainly from the 1910s to 1940 and the 1970s to the present. 1998 is the warmest year on record and the 1990s are the warmest decade in both hemispheres, on land and on the ocean. Melting glaciers and rising sea level provide strong supporting evidence. However, over land nighttime temperatures are rising faster then daytime temperatures, by almost 0.1°C per decade since 1950, apparently largely because of increases in low cloud cover.

The surface temperature record has been extended back in time by use of proxy indicators that are known to be sensitive to temperatures, such as from tree rings, corals, and ice cores. A recent synthesis of these provides further context for the recent trends and shows that the last decade is likely to have been the warmest in the past 1000 years.

Radiosonde temperatures

Measurements of temperatures in the atmosphere above the surface became routine beginning in the mid-1940s through use of balloon-borne instrument packages (radiosondes) that transmit thermister-measured temperatures back to ground along with pressure and humidity. Their purpose has been mainly for aviation use and weather forecasting. The observations are at best twice daily and while spatial coverage improved in the IGY, it is marginal for large-scale estimates before about 1964. The biases are the many changes in instrumentation and observing methods, often with poor documentation of these changes. There are known biases in some brands, and a common problem has been improper shading from the sun and adequate ventilation. [Recall the temperature is that of the air, which must therefore be circulated past the sensor, and the sensor must be protected from direct solar radiation.] The advantages are the very high vertical resolution of the measurements, the use of new independent instruments for each sounding and the diversity of instruments. Also, there have been a few independent analyses. The disadvantages are the diversity of instruments that are inadequately calibrated for climate purposes, their often unknown changes with time, and the spotty non-global coverage. An assessment suggests that the tropospheric record is reasonably well known after 1964 in the Northern Hemisphere extratropics, but that coverage is inadequate elsewhere.

Satellite temperature measurements

The satellite record is made up of MSU measurements of microwave radiation emitted by the atmosphere which are proportional to temperature. The coverage began in December 1978 twice or four times a day from one or two satellites, and is global. The emissions represent a very broad layer in the vertical, and so a retrieval is used to obtain the temperature closer to the surface. This is the commonly used satellite record but it still represents the lowest 8 km or so of the atmosphere, so it is physically a very different quantity than the surface temperature.

The observation times vary with satellite and orbit drift. Biases arise from the use of 9 different satellites and instruments, orbital decay affects the retrieval, east-west drift of the satellite affects the time of day of observation, and there are instrument calibration and solar heating of the platform effects. Another significant factor is that the retrieval amplifies the noise by a factor of 3 to 5. Other disadvantages are some contaminating effects from the surface, especially over land, contamination by precipitation-sized ice, the difficulty of obtaining continuity across satellites, the shortness of the record, and one group has processed the data. The advantages are the global fairly uniform coverage, the long-term stability of microwave radiation emissions from oxygen, the biases may be well determined if there is adequate satellite overlap, and there are many observations which can be used to reduce random noise. The assessment is that this record is excellent for spatial coverage and determining interannual variations but suspect for trends.

Reconciling temperature records

All three records have been improved and developed in recent years. In particular several corrections have been made to the satellite record (e.g., for orbital decay), and these have improved the agreement. Using the radiosonde record to estimate the temperatures of the layer seen by satellite shows very good agreement, so that the radiosonde record can be used to extend the satellite record back to about 1964 (Fig. 3). While tropospheric temperature trends from 1979 to 1999 are small, longer term trends are more clearly positive and closer to those at the surface.

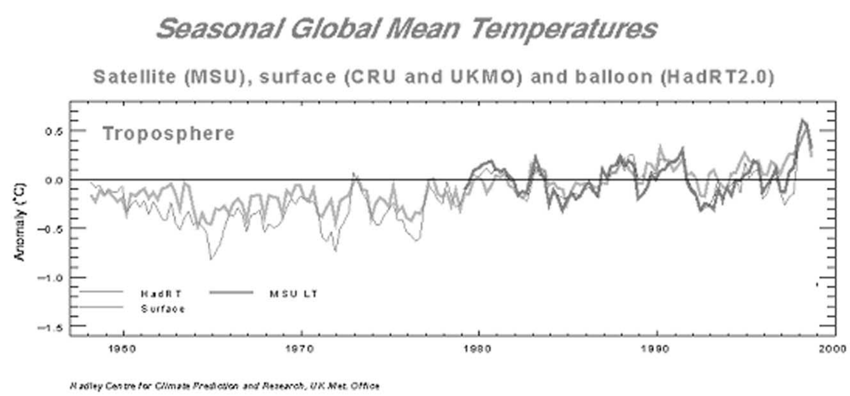
It is evident that the trends in the satellite record are distinctly less than those in the surface record after 1979, and this arises primarily because they are measuring quite different things. The differences come from the vertical structure of the temperature changes with time, which are complicated by features, such as temperature inversions, in which the surface is disconnected from the atmosphere aloft. Low level inversions trap pollutants near the surface and are common over extratropical continents in winter, as well as throughout much of the tropics and subtropics. The physical forcing factors believed to be involved in causing differences in trends include (1) stratospheric ozone depletion which preferentially cools the satellite record; (2) episodic volcanic eruptions which cool the MSU more; (3) increases in greenhouse gases which warms MSU more; (4) changes in visible pollution (aerosols) which have complex regional effects that are not well known in vertical structure; (5) solar variations which are fairly small in this interval.

Other physical factors include (1) El Niño and other natural variability which seems to produce a larger MSU response than at the surface by about 30 to 40%; (2) day-night differences which relate to maximum versus minimum temperature trends; and (3) land-ocean differences. The much greater increases in minimum temperature, related to increasing cloud cover, occur through a shallow layer and are not seen as much by satellite as maximum temperature changes which are distributed throughout the atmosphere by convection. The extent to which the changes in cloud cover arise from changes in atmospheric pollution or are a response to climate change is quite uncertain. Also ocean surface temperatures are muted, land temperature changes are much larger, and these differences are paramount at the surface but less evident in the troposphere where winds are much stronger.

Not all of these effects have been included in models that deal with global warming or future climate change projections, but more sophisticated climate model simulations are expected in which best estimates of all the forcings will be included. Further improvements are also likely in the observational records of all three types. However, it is believed that the records are reasonably physically consistent with each other once all the forcing factors are taken into account. Accordingly, the recent warming at the surface is undoubtedly real, substantially greater than the average rate during the 20th century, and is in no way invalidated by the satellite record.

A reasonable interpretation of the observational record is that global warming from increased greenhouse gases is resulting in global temperatures that are now above and beyond those arising from natural variability. The main reasons tropospheric temperatures are not keeping pace are because of stratospheric ozone depletion and increases in cloud cover. Consequently larger surface temperature increases occur over land and at nighttime. While observationally uncertain globally, although with strong evidence over the United States, increases in surface drying, atmospheric moisture amounts and precipitation rates are expected as part of an increase in the hydrological cycle. This increases risk of floods, droughts and associated fires; these are all extremes which are very costly to the environment and to society.

Fig. 3. Global mean seasonal temperature anomalies from the MSU–LT after 1979, the equivalent from radiosondes, and the surface from 1958 on.



The CHAIRMAN. Dr. Watson.

STATEMENT OF DR. ROBERT WATSON, CHAIRMAN, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Dr. WATSON. Thank you, Senator. It is a pleasure to be here today to testify on the issue of climate change. I am testifying in my capacity as the Chairman of the Intergovernmental Panel on Climate Change.

The IPCC conducts peer reviewed, comprehensive assessments of the climate system every 5 years, and periodic technical papers, special reports, and methodological studies as needed.

These assessments provide the scientific and technical basis for the international negotiations. The IPCC assessments involve experts from all relevant disciplines, all stakeholder groups and from around the world.

The second IPCC assessment report was prepared and peer-reviewed by over 2,000 experts from over 100 countries.

During the last year, the IPCC has published four special reports, one on aviation and the global atmosphere; one on technology transfer; one on emissions scenarios; and the one that I personally chaired and finished last week on land-use, land-use change and forestry.

We are in the middle of preparing and peer-reviewing the third assessment report, which will be finished early next year.

There is no doubt that human-induced climate change is one of the most important environmental issues facing society worldwide. Climate change is inevitable. It is only a question of how much, when and where.

Human activities have significantly changed the composition of the Earth's atmosphere during the last 150 years. The atmospheric abundance of carbon dioxides increased about 30 percent, largely due to the combustion of fossil fuels and changes in land-use, primarily—primarily deforestation in the tropics.

The Earth's surface temperature warmed 0.4 to 0.8 degrees centigrade over the last 100 years. The last two decades are the warmest of the last century. And the 12 warmest years of the last century have all occurred since 1983. And this century is clearly the warmest century in the last 1,000 years.

The spacial and temporal patterns of precipitation are changing. There have been observed increases in precipitation in the mid- and high-latitude and decreases in the sub-tropics.

And there has been an increase in heavy precipitation events and a decrease in light precipitation events, at least in the United States.

Many parts of the world have suffered major heat waves, floods and droughts during the last few years, leading to significant economic losses and loss of life.

While individual events cannot be directly linked to human-induced climate change, the frequency and magnitude of these types of events are expected to increase in a warmer world.

Glaciers are retreating worldwide. Sea level has increased 10 to 20 centimeters in the last 100 years. And Arctic ice is thinning. The observed changes in the Earth's climate cannot be explained by natural phenomena alone. And the scientific evidence, observations and models suggest a discernible human influence.

The recent projections of future emissions of greenhouse gases and sulfur dioxide suggest that in the absence of global climate policies, the atmospheric concentrations of greenhouse gases will increase substantially over the next 100 years, while the emissions of sulfur dioxide will increase initially for a decade or two, and then decrease significantly because of the concern of acid deposition.

Temperatures are projected to increase from about one to five degrees Centigrade, two to nine degrees Fahrenheit, between now and 2100. Why is this number that I am showing larger than the previous witnesses? And that is because the new emissions scenarios from the IPCC suggest very low sulfur dioxide emissions over the next 100 years and, hence, there is little or no offsetting/cooling effect due to aerosols on the greenhouse gas warming.

So the projections for climate change are now larger than what they were a few years ago under the second assessment report. Precipitation is projected to increase globally. But many arid and semi-arid areas of the Earth are projected to become drier. The sea level is projected to increase between 10 and 90 centimeters by 2100.

So why do we, society, care? Water resources, managed and unmanaged ecological systems, human health and human settlements are all predicted to be impacted by climate change.

The arid and semi-arid areas of Africa, the Middle East and Southern Europe will become even more water-stressed than they are today.

Agricultural production in Africa and Latin America could decrease ten to thirty percent. The incidence of vector-borne diseases, such as malaria and dengue, will increase significantly in tropical countries.

Tens of millions of people will be displaced by rising sea levels in small island states and low-lying deltaic areas. And major changes are expected in the boundaries and the structure and functioning of critical ecological systems, especially in forests and coral reefs.

The social costs of inaction are quite uncertain, but they are likely to be in the range of a few percent of world GDP annually in a doubled carbon dioxide world, with the cost being substantially greater in developing countries.

However, the good news is that if we go beyond political ideology, there are numerous cost-effective ways to mitigate climate change using the extensive array of technologies and policy measures in both the energy supply and demand sectors.

In addition, a significant potential to increase the uptake or decrease the emissions of carbon dioxide and other greenhouse gases through cost-effective changes in land use, land-use practices and forestry, slowing deforestation, and improve forest, crop land and range land management.

Policy reform such as the elimination of fossil fuel subsidies and the internalization of the social costs of environmental damage will be essential to reduce the emissions of greenhouse gases.

The flexibility mechanisms of the Kyoto Protocol, emissions trading, and project-based carbon-offset activities, offer the possibility of reducing greenhouse gas emissions at a lower cost than domestic actions alone, and can lead to the transfer of environmentally sound technologies to countries with economies in transition and developing countries.

What we also note, however, is that the current efforts and processes will not be sufficient to facilitate the efficient transfer of environmentally sound technologies from developed to developing countries, but opportunities do exist to enhance the transfer of these technologies, but it will require all stakeholders to play their role, i.e., governments, industry, and NGO's.

We should note that the atmospheric lifetime of carbon dioxide, which is the major anthropogenic greenhouse gas, is more than a century. This means that if policy formulation waits until all scientific uncertainties are resolved and carbon dioxide and other greenhouse gases are responsible for changing the earth's climate as projected by all climate models, the time to reverse human induced changes in climate and the resulting environmental damages will not be years or decades, but centuries to millennia.

I note that enhanced R&D, research and development, policy reform and promoting market mechanisms will be essential to address the climate change issue, both domestically and globally.

Last, while scientific uncertainties clearly exist, governments from around the world have recognized that we know enough to take the first steps to mitigate climate change.

And, let me leave you with one simple observation. Many of the global warming skeptics today are the same skeptics who questioned whether human activities were destroying the earth's fragile ozone layer and increasing the level of damaging ultraviolet radiation reaching the Earth's surface. These skeptics argued against national and global action to protect the ozone layer.

We now know that human activities were destroying the ozone layer and thankfully governments from around the world, working with industry, ignored the skeptics and cost-effective solutions were developed, thus protecting all life on Earth from the damaging—damaging ultraviolet radiation.

Thank you.

The CHAIRMAN. Thank you, Dr. Watson.

[The prepared statement of Dr. Watson follows:]

PREPARED STATEMENT OF DR. ROBERT WATSON, CHAIRMAN, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

It is a pleasure to appear before you today to discuss an issue of critical importance to this and future generations: global climate change. My name is Robert T. Watson and I am testifying in my capacity as the chairman of the Intergovernmental Panel on Climate Change (IPCC).

I would like to first describe the work of the IPCC (Part I) and then briefly review the current state of knowledge concerning the climate system (Part II).

PART I: The Intergovernmental Panel on Climate Change

The IPCC is an intergovernmental panel established by the United Nations in 1988 under the auspices of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the current state of scientific, technical and economic knowledge regarding climate change. While the IPCC is an independent scientific panel, it rides itself on being responsive to addressing the needs of the UNFCCC and the Kyoto Protocol. Indeed, the current IPCC work program has been designed to provide the scientific, technical and economic information that is needed to implement the Convention and the Kyoto Protocol.

The IPCC provides comprehensive assessments of the state of knowledge every five years, complemented by technical papers, special reports, and methodological work.

The IPCC is in the midst of the preparation and peer-review of the Third Assessment Report, including the Synthesis Report, and has, during the last year, completed work on four special reports: (i) Aviation and the Global Atmosphere; (ii) Methodological and Technological Aspects of Technology Transfer: Opportunities for Technology Cooperation; (iii) Emissions Scenarios of Greenhouse Gases and Aerosol Precursors; and (iv) Land-Use, Land-Use Change and Forestry. The Summaries for Policymakers for each of these special reports is included in a series of Annexes * to this testimony. The three Working Group Reports of the TAR will be completed between January 2001 and March 2001, while the Synthesis Report will be completed in September/October 2001.

The Third Assessment Report will be a comprehensive assessment and build upon the findings of the Second assessment Report, which was completed in 1995. The Third assessment Report will: (i) emphasize cross-sectoral issues, adaptation and the regional dimensions of climate change; (ii) place the issue of climate change more centrally within the concept of sustainable development; and (iii) identify the synergies and trade-offs between local, regional and global environmental issues, in particular the inter-linkages between climate change, biodiversity, water resources and land degradation.

All IPCC assessments are prepared and peer-reviewed, according to an approved set of principles and procedures, by experts from all relevant disciplines (natural scientists, social Scientists, and technologists), from all stakeholder groups (universities, government agencies, industry, business and environmental organizations) and from all around the world. Over two thousand experts, from over one hundred countries, participated in the preparation and peer-review of the Second Assessment Report. The reports emphasize what is known and what is uncertain. Areas of controversy are discussed and alternate viewpoints presented.

The IPCC is currently structured into three Working Groups:

Working Group I

The climate system: Sources and sinks of greenhouse gases and aerosols; observed changes in atmospheric composition, climate variables, cryosphere, and sea level; climate variability; physical and biogeochemical processes; evaluation of approaches for developing regional climate information; evaluation of models; model simulations of past and current regional and global climate; model simulations of future regional and global changes in atmospheric composition, radiative forcing, climate, cryosphere, and sea level, using agreed and proposed policies to mitigate climate change, different stabilization levels of greenhouse gases, and the emissions scenarios from the ongoing special report; and detection and attribution of climate change.

Working Group II

Regional, sectoral and cross-sectoral impacts of and adaptation to, climate change, including the social dimensions (e.g., equity) and economic costs and benefits: Primers on how terrestrial and marine ecological and hydrological processes respond to changes in climatic conditions and atmospheric composition, e.g., increased carbon dioxide concentrations; primer on human health mechanisms; methodological approaches to the impact of, and adaptation to, climate change, for ecological systems, human health and socio-economic sectors; issues in integrating ecological and economic assessments of impacts and adaptation potential; evaluation of the sensitivity of ecological systems, human health and socio-economic sectors to climatic variables; regional evaluations of the sectoral and cross-sectoral impacts of climate change, including the social dimensions and economic costs and benefits; regional sectoral and cross-sectoral adaptation strategies (technological, institutional, and policy aspects) in the context of meeting human needs; and global sectoral assessments (e.g., movements in ecosystem boundaries, and changes in agricultural and fisheries productivity at the global level). Impact studies will: (i) use a range of transient GCM pro-

* Annex 1—Summary for Policymakers: Aviation and the Global Atmosphere; Annex 2—Summary for Policymakers: Special Report on Methodological and Technological Issues in Technology Transfer; Annex 3—Summary for Policymakers: Special Report on Emissions Scenarios; and Annex 4—Summary for Policymakers: Special Report on Land Use, Land-Use Change and Forestry, have been retained in the Committee files and are available on the web at http://www.ipcc.ch/pub/reports.htm.

jections of climate change, be placed in the context of other changes in socio-economic and environmental conditions, and assess to what degree climate change affects the ability to meet human needs (adequate food, clean water, a healthy environment, safe shelter, etc.); and (ii) be performed for a range of climates associated with different greenhouse gas stabilization levels.

Working Group III

Mitigation of climate change, including the social aspects and economic costs and benefits, and methodological aspects of cross-cutting issues: Methodological issues associated with mitigation, equity, discount rates, decision-making framework, uncertainties, and integrated assessment modeling; evaluation of the technical, economic and market potential of energy supply and demand and land-use technologies, regional assessments of the mitigation potential of different technologies, including the social dimensions and economic costs and benefits, with and integrated energy-related and land-related mitigation options, including "distributional" costs for different stabilization levels and different emissions profiles; and evaluation of policy options (including carbon and energy taxes, subsidy elimination, internalization of local and regional environmental externalities, emissions trading and joint implementation).

In addition to the three Working Group Reports, the Third Assessment Report will contain a Synthesis Report, which is based on previously approved IPCC reports and will address the following ten key policy-relevant questions (abbreviated):

- What can scientific, technical and socio-economic analyses contribute to the determination of what constitutes dangerous anthropogenic interference with the climate system as referred to in Article 2 of the Framework Convention on Climate Change?
- What is the evidence for, causes of, and consequences of changes in the Earth's climate since the pre-industrial era?
- What is known about the influence of the increasing atmospheric concentrations of greenhouse gases and aerosols, and the projected human-induced change in climate regionally and globally?
- What is known about the inertia and time-scales associated with the changes in the climate system, ecological systems, and socio-economic sectors and their interactions?
- What is known about the regional and global climatic, environmental, and socio-economic consequences in the next 25, 50 and 100 years associated with a range of greenhouse gas emissions arising from scenarios used in the TAR (projections which involve no climate policy interventions)?
- How does the extent and timing of the introduction of a range of emissions reduction actions determine and affect the rate, magnitude, and impacts of climate change, and affect the global and regional economy, taking into account the historical and current emissions?
- What is known from sensitivity studies about the regional and global climatic, environmental and socio-economic consequences of stabilizing the atmospheric concentrations of greenhouse gases (in carbon dioxide equivalents), at a range of levels from today's to double that or more, taking into account to the extent possible the effects of aerosols. For each stabilization scenario, including different pathways to stabilization, evaluate the range of costs and benefits, relative to the range of scenarios considered in question 5.
- What is known about the interactions between projected human-induced changes in climate and other environmental issues, e.g., urban air pollution, regional acid deposition, loss of biological diversity, stratospheric ozone depletion, and desertification and land degradation? What is known about the environmental, social and economic costs and benefits and implications of these interactions for integrating climate response strategies in an equitable manner into broad sustainable development strategies at the local, regional and global levels?
- What is known about the potential for, and costs and benefits of, and timeframe for reducing greenhouse gas emissions?
- What are the most robust findings and key uncertainties regarding attribution of climate change and regarding model projections of: (i) future emissions of greenhouse gases and aerosols; (ii) future concentrations of greenhouse gases and aerosols; (iii) future changes in regional and global climate; (iv) regional

and global impacts of climate change; and (v) costs and benefits of mitigation and adaptation options?

I would like to briefly summarize the current state of scientific knowledge concerning climate change.

PART II: Present State of Knowledge

Overview

The overwhelming majority of scientific experts recognize that scientific uncertainties exist, but still believe that human-induced climate change is inevitable. Indeed, during the last few years, many parts of the world have suffered major heatwaves, floods, droughts and extreme weather events leading to significant economic losses and loss of life. While individual events cannot be directly linked to human-induced climate change, the frequency and magnitude of these types of events are expected to increase in a warmer world.

The question is not whether climate will change in response to human activities, but rather *where* (regional patterns), *when* (the rate of change) and by *how much* (magnitude). It is also clear that climate change will adversely effect human health (particularly vector-borne diseases), ecological systems (particularly forests and coral reefs), and socio-economic sectors, including agriculture, forestry, fisheries, water resources, and human settlements, with developing countries being the most vulnerable. These are the fundamental conclusions of a careful and objective analysis of all relevant scientific, technical and economic information by thousands of experts from the appropriate fields of science from academia, governments, industry and environmental organizations from around the world under the auspices of the United Nations International Panel on Climate Change. The good news is, however, that the majority of energy experts believe that significant reductions in greenhouse gas emissions are technically feasible due to an extensive array of technologies and policy measures in the energy supply and energy demand sectors at little or no cost to society. In addition, changes in land-use practices can also reduce net carbon emissions cost-effectively.

However, decision-makers should realize that the atmospheric residence/adjustment time of carbon dioxide, the major anthropogenic greenhouse gas, is more than a century, which means that if policy formulation waits until all scientific uncertainties are resolved, and carbon dioxide and other greenhouse gases are responsible for changing the Earth's climate as projected by all climate models, the time to reverse the human-induced changes in climate and the resulting environmental damages, would not be years or decades, but centuries to millennia, even if all emissions of greenhouse gases were terminated, which is clearly not practical.

This testimony briefly describes the current state of understanding of the Earth's climate system and the influence of human activities; the vulnerability of human health, ecological systems, and socio-economic sectors to climate change; and approaches to reduce emissions and enhance sinks.

The Earth's Climate System: The Influence of Human Activities

The Earth's climate has been relatively stable (global temperature changes of less than 1°C over a century) during the present interglacial (i.e., the past 10,000 years). During this time modem society has evolved, and, in many cases, successfully adapted to the prevailing local climate and its natural variability. However, the Earth's climate is now changing. The Earth's surface temperature this century is as warm or warmer than any other century during the last thousand years; the Earth's surface temperature has increased by between 0.4 and 0.8 degree centigrade over the last century, with land areas warming more than the oceans; and the last few decades have been the hottest this century. Indeed, the three warmest years during the last one hundred years all occurred in the 1990s and the twelve warmest years during the last one hundred years all occurred since 1983. In addition, there is evidence of changes in sea level, that glaciers are retreating world-wide, that Arctic sea ice is thinning, precipitation patterns are changing, and that the incidence of extreme weather events is increasing in some parts of the world. Not only is there evidence of a change in climate at the global level, but there is observational evidence that the climate of the U.S. is changing in a manner consistent with that predicted by climate models (I have specifically mentioned the U.S. because it has a large geographic area and a long accurate set of weather observations against which model simulations can be evaluated): increased temperatures (day and night), more intense rainfall events (defined as two inches within a 24 hour period), increased precipitation in winter, and less day-day variability in temperature.

The atmospheric concentrations of greenhouse gases have increased because of human activities, primarily due to the combustion of fossil fuels (coal, oil and gas), deforestation and agricultural practices, since the beginning of the pre-industrial era around 1750: carbon dioxide by nearly 30%, methane by more than a factor of two, and nitrous oxide by about 15%. Their concentrations are higher now than at any time during the last 160,000 years, the period for which there are reliable ice-core data, and probably significantly longer. In addition, the atmospheric concentrations of sulfate aerosols have also increased. Greenhouse gases tend to warm the atmosphere and, in some regions, primarily in the Northern hemisphere, aerosols tend to cool the atmosphere.

Theoretical models that take into account the observed increases in the atmospheric concentrations of greenhouse gases and sulfate aerosols simulate the observed changes in surface temperature and the vertical distribution of temperature quite well. This, and other information, suggests that human activities are implicated in the observed changes in the Earth's climate. In fact, the observed changes in climate cannot be explained by natural phenomena alone (e.g., changes in solar output and volcanic emissions).

Future emissions of greenhouse gases and the sulfate aerosol precursor, sulfur dioxide, are sensitive to the evolution of governance structures world-wide, whether the current inequitable distribution of wealth continues or decreases, changes in population and gross domestic product, the rate of diffusion of new technologies into the market place, production and consumption patterns, land-use practices, energy intensity, and the price and availability of energy. Most projections suggest that greenhouse gas concentrations will increase significantly during the next century in the absence of policies specifically designed to address the issue of climate change. Indeed, the recent IPCC special report on emissions scenarios reported, for example, carbon dioxide emissions from the combustion of fossil fuels are projected to range from bout 5 to 35 GtC per year in the year 2100: compared to current emissions of about 6.3 GtC per year. Such a range of emissions would mean that the atmospheric concentration of carbon dioxide would increase from today's level of 360 ppmv (parts per million by volume) to between 500 and 900 ppmmv by 2100. It should be noted that two major oil companies, Shell and British Petroleum, have suggested that the mix of energy sources could change radically, with renewable energy sources (solar, wind and modern biomass) accounting for as much as half of all energy produced by the middle of the next century. Such a future would be consistent with the lower projections of greenhouse gas emissions and would clearly eliminate the highest projections of greenhouse gases from being realized, but this vision of a future world will not occur without policy reform and significantly enhanced public and private sector energy R&D programs.

While the recent IPCC special report on emissions scenarios (SRES 00) reported similar projected emissions for carbon dioxide to the 1992 projections, it differed in one important aspect from the 1992 projections, in-so-far-as the projected emissions of sulfur dioxide are much lower. This has important implications for future projections of temperature changes, because sulfur dioxide emissions lead to the formation of sulfate aerosols in the atmosphere, which as stated earlier can partially offset the warming effect of the greenhouse gases.

Based on the range of climate sensitivities (an increase in the equilibrium global mean surface temperature of 1.5–4.5°C for a doubling of atmospheric carbon dioxide concentrations) and plausible ranges of greenhouse gas and sulfur dioxide emissions (SRES 00), climate models project that the global mean surface temperature could increase by 1 to 5°C by 2100. These projected global-average temperature changes would be greater than recent natural fluctuations and would also occur at a rate significantly faster than observed changes over the last 10,000 years. These long-term, large-scale, human-induced changes are likely to interact with natural climate variability on time-scales of days to decades (e.g., the El Niño-Southern Oscillation (ENSO) phenomena). Temperature changes are expected to differ by region with high latitudes projected to warm more than the global average. However, the reliability of regional scale predictions is still low. Associated with these estimated changes in temperature, sea level is projected to increase by 10–90 cm by 2100, caused primarily by thermal expansion of the oceans and the melting of glaciers. However, it should be noted that even when the atmospheric concentrations of greenhouse gases are stabilized, temperatures will continue to increase for several decades because of the thermal inertia of the climate system (temperature by another 30–50%), and sea level for an even longer period of time (centuries to millennia).

Model calculations show that evaporation will be enhanced as the climate warms, and that there will be an increase in global mean precipitation and an increase in the frequency of intense rainfall. However, not all land-regions will experience an increase in precipitation, and even those land regions with increased precipitation may experience decreases in soil moisture, because of enhanced evaporation. Seasonal shifts in precipitation are also projected. In general, precipitation is projected to increase at high latitudes in winter, and soil moisture is projected to decrease in some mid-latitude continental regions during summer. The arid and semi-arid areas in Southern and Northern Africa, Southern Europe and the Middle East are expected to become drier.

While the incidence of extreme temperature events, floods, droughts, soil moisture deficits, fires and pest outbreaks is expected to increase in some regions, it is unclear whether there will be changes in the frequency and intensity of extreme weather events such as tropical storms, cyclones, and tornadoes.

The Vulnerability of Human Health, Ecological Systems, and Socio-economic Sectors to Climate Change

The IPCC has assessed the potential consequences of changes in climate for human health, ecological systems and socio-economic sectors for ten continental- or subcontinental-scale regions: Africa, Australasia, Europe, Latin America, Middle East and Arid Asia, North America, Polar regions, Small Island States, Temperate Asia, and Tropical Asia. Because of uncertainties associated with regional projections of climate change, the IPCC assessed the vulnerability of these natural and social systems to changes in climate, rather than attempting to provide quantitative predictions of the impacts of climate change at the regional level. Vulnerability is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the sensitivity of a system to changes in climate and the ability to adapt the system to changes in climate. Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained.

Most impact studies have assessed how systems would respond to a climate change resulting from an arbitrary doubling of atmospheric carbon dioxide concentrations. Very few have considered the dynamic responses to steadily increasing greenhouse gas concentrations; fewer yet have been able to examine the consequences of increases beyond a doubling of greenhouse gas concentrations or to assess the implications of multiple stress factors.

The IPCC concluded that human health, terrestrial and aquatic ecological systems, and socioeconomic systems (e.g., agriculture, forestry, fisheries, water resources, and human settlements), which are all vital to human development and well-being, are all vulnerable to changes in climate, including the magnitude and rate of climate change, as well as to changes in climate variability. Whereas many regions are likely to experience the adverse effects of climate change—some of which are potentially irreversible—some effects of climate change are likely to be beneficial. Hence, different segments of society can expect to confront a variety of changes and the need to adapt to them.

There are a number of general conclusions that can be easily drawn: (i) human-induced climate change is an important new stress, particularly on ecological and socio-economic systems that are already affected by pollution, increasing resource demands, and non-sustainable management practices; (ii) the most vulnerable systems are those with the greatest sensitivity to climate change and the least adaptability; (iii) most systems are sensitive to both the magnitude and rate of climate change; (iv) many of the impacts are difficult to quantify because existing studies are limited in scope; and (v) successful adaptation depends upon technological advances, institutional arrangements, availability of financing and information exchange, and that vulnerability increases as adaptation capacity decreases. Therefore, developing countries are more vulnerable to climate change than developed countries.

The range of adaptation options for managed systems such as agriculture and water supply is generally increasing because of technological advances. However, some regions of the world, i.e., developing countries, have limited access to these technologies and appropriate information. The efficacy and cost-effectiveness of adaptation strategies will depend upon cultural, educational, managerial, institutional, legal and regulatory practices that are both domestic and international in scope. Incorporation of climate change concerns into resource-use and development decisions and plans for regularly scheduled investments in infrastructure will facilitate adaptation.

Let me now briefly discuss the implications of climate change for a representative number of systems: natural ecosystems (forests and coral reefs), food security, water resources, sea level rise, and human health.

Natural Ecosystems—Forests

The composition and geographic distribution of many ecosystems will shift as individual species respond to changes in climate, and there will likely be reductions in biological diversity (particularly species diversity) and in the goods and services ecosystems provide society, e.g., sources of food, fiber, medicines, recreation and tourism, and ecological services such as controlling nutrient cycling, Waste quality, water run-off, and soil erosion. Models project that as a consequence of possible changes in temperature and water availability under doubled carbon dioxide equilibrium conditions, a substantial fraction (a global average of one-third, varying by region from one-seventh in tropical forests to two-thirds in Boreal forests) of the existing forested area of the world will undergo major changes in broad vegetation types. Climate change is expected to occur at a rapid rate relative to the speed at which forest species grow, reproduce and re-establish themselves. For mid-latitude regions a global average warming of 1–3.5°C over the next 100 years would be equivalent to a poleward shift of isotherms of approximately 150–550 km or an altitude shift of 150–550 meters. This compares to past tree species migration rates that are believed to be on the order of 4–200 km per century. Therefore, species composition of impacted forests is likely to change, entire forest types may disappear, while new assemblages of species and hence new forest ecosystems may be established. Large amounts of carbon could be released into the atmosphere during times of high forest mortality prior to regrowth of a mature forest.

Natural Ecosystems—Coral Reefs

Coral reefs, the most biologically diverse marine ecosystems, are important for fisheries, tourism, coastal protection, and erosion control. Coral reef systems, which are already being threatened by pollution, unsustainable tourism and fishing practices, are very vulnerable to changes in climate. While these systems may be able to adapt to the projected increases in sea level, sustained increases in water temperatures of 3–4°C above long-term average seasonal maxima over a 6-month period can cause significant coral mortality; short-term increases on the order of only 1–2°C can cause "bleaching," leading to reef destruction. Indications are that the full restoration of coral communities could require several centuries.

Food Security

Currently, 800 million people are malnourished; as the world's population increases and incomes in some countries rise, food consumption is expected to double over the next three to four decades. Studies show that on the whole, global agricultural production could be maintained relative to baseline production in the face of climate change under doubled carbon dioxide equilibrium conditions. However, crop yields and changes in productivity due to climate change will vary considerably across regions and among localities, thus changing the patterns of production. In general, productivity is projected to increase in middle to high latitudes, depending on crop type, growing season, changes in temperature regime, and seasonality of precipitation, whereas in the tropics and subtropics, where some crops are near their maximum temperature tolerance and where dryland, non-irrigated agriculture dominates, yields are likely to decrease, especially in Africa and Latin America, where decreases in overall agricultural productivity of 30% are projected under doubled carbon dioxide conditions. Therefore, there may be increased risk of hunger in some locations in the tropics and subtropics where many of the world's poorest people live.

Water Resources

Currently 1.3 billion people do not have access to adequate supplies of safe water, and 2 billion people do not have access to adequate sanitation. Today, some nineteen countries, primarily in the Middle East and Africa, are classified as water-scarce or water-stressed. Even in the absence of climate change, this number is expected to double by 2025, in large part because of increases in demand from economic and population growth. Climate change will further exacerbate the frequency and magnitude of droughts in some places, in particular Northern and Southern Africa and the Middle East where droughts are already a recurrent feature. Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid areas.

Sea Level Rise

Sea-level rise can have negative impacts on tourism, freshwater supplies, fisheries, exposed infrastructure, agricultural and dry lands, and wetlands. It is currently estimated that about half of the world's population lives in coastal zones, although there is a large variation among countries. Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards, and possible changes in the frequency and/or intensity of extreme events. Impacts may vary across regions, and societal costs will greatly depend upon the vulnerability of the coastal system and the economic situation of the country. Sea-level rise will increase the vulnerability of coastal populations to flooding. An average of about 46 million people per year currently experience flooding due to storm surges; a 50 cm sea-level rise would increase this number to about 92 million; a 1 meter sea-level rise would increase this number to 118 million. The estimates will be substantially higher if one incorporates population growth projections. A number of studies have shown that small islands and deltaic areas are particularly vulnerable to a one-meter sea-level rise. In the absence of mitigation actions (e.g., building sea walls), land losses are projected to range from 1.0% for Egypt, 6% for Netherlands, 17.5% for Bangladesh, to about 80% of the Marshall Islands, displacing tens of millions of people, and in the case of low-lying Small Island States, the possible loss of whole cultures. Many nations face lost capital value in excess of 10% of GDP. While annual adaptation/protection costs for most of these nations are relatively modest (about 0.1% GDP), average annual costs to many small island states are much higher, several percent of GDP, assuming adaptation is possible.

Human Health

Human health is sensitive to changes in climate because of changes in food security, water supply and quality, and the distribution of ecological systems. These impacts would be mostly adverse, and in many cases would cause some loss of life. Direct health effects would include increases in heat-related mortality and illness resulting from an anticipated increase in heatwaves. Indirect effects would include extensions of the range and season for vector organisms, thus increasing the transmission of vector-borne infectious diseases (e.g., malaria, dengue, yellow fever and encephalitis). Projected changes in climate under doubled carbon dioxide equilibrium conditions could lead to potential increases in malaria incidence of the order of 50–80 million additional cases annually, primarily in tropical, subtropical, and less well-protected temperate-zone populations. Some increases in non-vector-borne infectious diseases such as salmonellosis, cholera and other food- and water-related infections could also occur, particularly in tropical and subtropical regions, because of climatic impacts on water distribution and temperature, and on micro-organism proliferation.

Social Costs of Climate Change

The range of estimates of economic damages caused by changes in climate are quite uncertain. Taking into account both market and non-market costs, IPCC reported a reduction in world GDP of 1.5–2.0% for a doubled carbon dioxide environment. This value was obtained by summing widely varying estimates of damages by sector, including socio-economic sectors (e.g., agriculture, forestry, fisheries), ecological systems, and human health. Nordhaus, conducted an "expert" survey which resulted in a range from 0 to 21% for loss of world GDP, with a mean value of 3.6% and a median value of 1.9%.

Losses in developing countries are estimated to be much higher than the world average, ranging from 5% to 9%. Alternate assumptions about the value of a statistical life could increase the estimate of economic damages in developing countries.

IPCC reported values for the marginal damage of one extra ton of carbon emitted ranging from $5 to $125. A value of $5 to $12 per ton of carbon is obtained using a 5% social rate of time preference (discount rate). Lower discount rates increase this estimate, e.g. a 2% discount rate would increase this estimate by an order of magnitude.

Approaches to Reduce Emissions and Enhance Sinks

Significant reductions in net greenhouse gas emissions are technically, and often economically, feasible and can be achieved by utilizing an extensive array of technologies and policy measures that accelerate technology diffusion in the *energy supply* (more efficient conversion of fossil fuels; switching from high to low carbon fossil fuels; decarbonization of flue gases and fuels, coupled with carbon dioxide storage; increasing the use of nuclear energy; and increased use of modem renewable sources of energy (e.g., plantation biomass, micro-hydro, and solar), *energy demand* (industry, transportation, and residential/commercial buildings) and *agricultural/foresty sectors* (altered management of agricultural soils and rangelands, restoration of degraded agricultural lands and rangelands, slowing deforestation, natural forest generation, establishment of tree plantations, promoting agroforestry, and improving the quality of the diet of ruminants). By the year 2100, the world's commercial energy system will be replaced at least twice offering opportunities to change the energy system without premature retirement of capital stock. However, full technical potential is rarely achieved because of a lack of information and cultural, institutional, legal and economic barriers.

Policy instruments can be used to facilitate the penetration of lower carbon intensive technologies and modified consumption patterns. These policies include: energy pricing strategies (e.g., carbon taxes and reduced energy subsidies); reducing or removing other subsidies that increase greenhouse gas emissions (e.g., agricultural and transport subsidies); incentives such as provisions for accelerated depreciation and reduced costs for the consumer; tradable emissions permits (and joint implementation); voluntary programs and negotiated agreements with industry; utility demand-side management programs; regulatory programs including minimum energy efficiency standards; market pull and demonstration programs that stimulate the development and application of advanced technologies; and product labeling. The optimum mix of policies will vary from country to country; policies need to be tailored for local situations and developed through consultation with stakeholders.

Estimates of the costs of mitigating climate change should take into account secondary benefits of switching from a fossil fuel based economy to a lower-carbon intensity energy system. Secondary benefits include lower levels of local and regional pollution, including particulates, ozone and acid rain.

A key issue recognized by all Parties to the UNFCCC and the Kyoto Protocol is that of technology transfer. The recent IPCC special report on technology transfer examined the flows of knowledge, experience and equipment among governments, private sector entities, financial institutions, NGOs, and research and education institutions, and the different roles that each of these stakeholders can play in facilitating the transfer of technologies to address climate change in the context of sustainable development. The report concluded that the current efforts and established processes will not be sufficient to meet this challenge. It is clear that enhanced capacity is required in developing countries and that additional government actions can create the enabling environment for private sector technology transfers within and across national boundaries.

Summary

Policymakers are faced with responding to the risks posed by anthropogenic emissions of greenhouse gases in the face of significant scientific uncertainties. They should consider these uncertainties in the context that climate-induced environmental changes cannot be reversed quickly, if at all, due to the long time scales (decades to millennia) associated with the climate system. Decisions taken during the next few years may limit the range of possible policy options in the future because high near-term emissions would require deeper reductions in the future to meet any given target concentration. Delaying action might reduce the overall costs of mitigation because of potential technological advances but could increase both the rate and the eventual magnitude of climate change, and hence the adaptation and damage costs.

Policymakers will have to decide to what degree they want to take precautionary measures by mitigating greenhouse gas emissions and enhancing the resilience of vulnerable systems by means of adaptation. Uncertainty does not mean that a nation or the world community cannot position itself better to cope with the broad range of possible climate changes or protect against potentially costly future outcomes. Delaying such measures may leave a nation or the world poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences. Options for adapting to change or mitigating change that can be justified for other reasons today (e.g., abatement of air and water pollution) and make society more flexible or resilient to anticipated adverse effects of climate change appear particularly desirable.

If, actions are not taken to reduce the projected increase in greenhouse gas emissions, the Earth's climate is projected to change at an unprecedented rate with adverse consequences for society, undermining the very foundation of sustainable development. Adaptive strategies to deal with this issue need to be developed, recognizing issues of equity and cost-effectiveness.

While there is no debate that protection of the climate system will eventually need all countries to limit their greenhouse gas emissions, the Framework Convention on Climate Change recognizes the principle of differentiated responsibilities, and also recognizes that developed countries and countries with economies in transition should take the lead in limiting their greenhouse gas emissions given the historical and current emissions of greenhouse gases, and their financial, technical and institutional capabilities. Current and historical emissions of greenhouse gases arise mainly from developed countries and countries with economies in transition, i.e., emissions in developing countries are much lower, both in absolute and per capita terms. Even though it is well recognized that emissions from developing countries are increasing rapidly due to increases in population and economic growth, and are likely to surpass those from developed countries within a few decades (absolute terms, not per-capita), their contribution to global warming will not equal that of developed countries until nearly 2100 because the climate system responds to the cumulative emissions of greenhouse gases not the annual emissions. It is also quite clear that increased energy services in developing countries are critical in order to alleviate poverty and underdevelopment, where 1.3 billion people live on less than $1 per day, 3 billion people live on less than $2 per day, and 2 billion people are without electricity. Hence the challenge is to assist developing countries expand their production and consumption of energy in the most efficient and environmentally benign manner. Financial instruments such as the Global Environment Facility and promoting market mechanisms such as emissions trading and joint implementation can assist in this endeavor. In addition, an increased commitment to energy R&D for energy efficient technologies and low-carbon technologies would not only allow the U.S. to meet it's energy needs in a more climate friendly manner, but it would also provide a large market in developing countries for U.S. exports.

Mr. Chairman, members of the Committee, I appreciate the opportunity you have provided me to be able to discuss these important issues with you today. Thank-you.

The CHAIRMAN. Dr. Christy, can you further discuss the reasons why we are not experiencing the rate of temperature increase in the upper altitudes that computer models may be predicting?

Dr. CHRISTY. OK. You are asking for the "why" of this issue, and I do not have an answer for why, here. I would like to say that the disparity is greatest in the tropical regions, and this lower tropospheric layer of the atmosphere is far below what ozone depletion would impact. In fact, I have checked specifically to make sure that—that the temperature rise at 100 millebars—what would that be? About—about ten miles or so.

The temperature even in the upper troposphere at 100 millebars is actually slightly warmer than it is in this bulk of the atmosphere below that we are measuring in terms of trends. So I do not have an answer for "why." I am skeptical about ozone depletion as part of the cooling effect on that particular layer (i.e., the lower troposphere.

The CHAIRMAN. Well, do you disagree with Dr. Mahlman's assertion that the increasing greenhouse gas effect is due to human activities?

Dr. CHRISTY. Oh, no. I do not disagree with that at all.

The CHAIRMAN. Thank you.

Dr. Mahlman, Dr. Trenberth's statement says that the main reason tropospheric temperatures are not keeping pace are because of stratospheric ozone depletion and increases in cloud cover. Do your models confirm those events?

Dr. MAHLMAN. We have done independent calculations of the effect of the reduced ozone levels in the lower stratosphere, both in the tropical regions and in higher latitudes.

And we calculate a double effect from that. One is that the reduced ozone produces a reduced downward welling of infrared radiation, therefore cooling the troposphere.

But we also see that that depleted ozone in the lower stratosphere is transported downward and making lower ozone levels in the upper troposphere. Both of these effects produce cooling as counterbalance to the warming effect. So it is a real effect.

Part of the problem is that we do not have really good ozone profile data, because some of the best measurements of ozone profiles have literally disappeared over the last 20 years and not to be replaced. And so it is hard to really pin that down.

There are also the uncertain effects, in my view, of this 21-year time series of the quantitative effects of the El Chichon and

Pinatubo volcanoes, whether these would also lead to a cooling effect in the upper troposphere that would add to the ozone effect.

There is also the issue of "What are the errors in the repaired satellite data and the repaired radiosonde data?" Both Dr. Christy and Dr. Trenberth can comment on that as well.

But as Dr. Trenberth quite properly pointed out, neither of these are well-posed measuring systems that are designed to produce accurate monitoring of the climate in three dimensions in the atmosphere.

So we are really suffering from significant data problems whether that residual difference is physically robust or not. If I were forced to put it on Jerry's betting odds scale, so to speak, I would guess that it is a two out of three chance that there is a robust difference. But I think there is a significant uncertainty in how big that difference is.

The CHAIRMAN. If other panel members wish to make comments on the questions that I direct to the witnesses, please feel free to do so.

Dr. Trenberth, you heard me say at the beginning of this hearing that there is no such thing as a dumb question, right? If evaporation is taking place as the result of this and that evaporation, as you mentioned, is taking place in the oceans, why is the sea level rising? Is it simply because of the melting of the icecaps?

Dr. TRENBERTH. The sea level is rising because of two things. About—one of the estimates is that about maybe 20 percent of the heat from the global warming overall is going into the ocean. That causes expansion of the ocean and the evidence suggests now that, indeed, the oceans are warming up.

The second thing is the melting of glaciers. Glaciers are melting almost everywhere around the world. The only places where they are not melting is because of increases in precipitation; increases in snow. And that is mainly in Scandinavia. And so these are the main reasons for the rise in sea level.

The amount of moisture in the atmosphere is really very small compared with that in the oceans. And so anything that is stored in the atmosphere has a minuscule effect on sea level changes.

But over the United States where we have the best measurements and—unfortunately, these measurements are really only reliable for about the past 25 years or so—there is good evidence that the amount of moisture in the atmosphere has increased by about 10 percent.

That is a large amount. It is more than we would expect from just the greenhouse effect alone of global warming, but it is one of the effects, which means that there is more moisture that is hanging around to get caught up in storms. And it makes the storms more severe than they otherwise would be, rainfall rates heavier than they otherwise would be, such as we have just seen, for instance, in eastern Oklahoma and—and Missouri with the flooding that occurred there. And drying, of course, occurs somewhere else in the system. In this case, there has been a lot of drying over the Southwest.

The CHAIRMAN. Dr. Watson, what has caused scientific confidence to increase between the IPCC's 1996 assessment and now?

Dr. WATSON. Well, even in the 1995 assessment, we could not explain the observed changes in the Earth's climate on natural phenomena alone. And that led to the very famous phrase, and that is, "There is now—the scientific evidence now shows a discernible human influence on the earth's climate system."

And as Dr. Mahlman said, the likely conclusions from the third assessment report, which is currently undergoing very careful peer review, are likely to confirm the findings of the second assessment report.

We have got improved models. We have continuing data sets. Obviously, the research done by the U.S. Global Change Research Program has helped us get a slightly better understanding of some of these phenomena.

But I do not believe that there has been a radical change, in my opinion, of thinking over the last few years. I think there has been a consolidation of the thinking that we had in 1995, which, of course, as you know, led most governments in the world to negotiate the Kyoto Protocol.

The CHAIRMAN. Go ahead, Doctor.

Dr. MAHLMAN. If I might just add to that. The observational record is very important here. The warmest years on record have occurred since the 1995 report, 1998 being the warmest year on record. And that is not something to be neglected.

The other thing is the reconstruction, which Dr. Bradley showed, of the pulling together of all of the paleoclimatic data and synthesizing that to give us a better picture as to what the natural variability has been like in the past. That this puts the current warming in a much better historical context has been a significant factor, as well.

And the third thing, in addition to the improvements in modeling, I would point to is improved statistical analysis and detection methods that have been applied to this problem.

The CHAIRMAN. Dr. Christy, would you like to respond to that? I do not—I am not sure you—I do not believe you share exactly those views according to your testimony.

Dr. CHRISTY. The—all of us that work on the IPCC—and my chapter is the observations chapter—we will document in the IPCC indications of rapid climate changes that have occurred in the past under natural conditions, most of which can be explained by unusual situations in the earth.

I would like to comment, though, on what we affectionately call the hockey stick diagram that Dr. Bradley showed, because it has this steady decline and then this rapid increase. I want to describe a feature of that diagram, which is not a criticism.

The information that went into the first half of that record is very limited and as you go to the end of the record to the year 2000, a considerably larger amount of data went into that part, so that there could be a—a refinement of what the temperature record looks like at the end.

If you just took the information that was available at the beginning and kept only that to the end, you would not see this dramatic spike at the end. And so it is different information that allows you to see what has happened in the last 100 years than what is shown at the beginning.

The CHAIRMAN. But you do not disagree with the fundamental premise that the other witnesses have asserted that there is an increase in global warming. It is attributed to human activity.

Dr. CHRISTY. The Earth's temperature has risen. I do not disagree with that. And I agree that a portion of that is due to human effects, but I would not say all of it is due to human effects. I do not think anyone here might either.

The CHAIRMAN. Dr. Mahlman, I know you want to speak.

And then, Dr. Bradley, maybe you would like to respond to the hockey stick issue.

Dr. MAHLMAN. Yes. If I were to have answered the question first, I would have raised the same two points that Dr. Trenberth raised, namely the fact that it is getting warmer, and noticeably so since the last IPCC assessment; and then also the amazing 1,000-year record from Drs. Mann and Bradley.

And the other thing I would add to that is that, post-IPCC 1995, the IPCC process made their best guess as to what the forcing agents for climate were over the past 150 years, and asked the leading model groups to make independent calculations of a retrospective run-through from 1760 to 2000. Effectively, all of the models pretty much nailed this increase in temperature. And models with different physics, different constructions still get essentially the same kind of answer.

Now, in each one of these cases, you can make the counter-argument and say, "Well, that's certainly not definitive evidence." And that would be a valid point.

But on the other hand, the fact that there are three new and essentially totally independent pieces of information that came since the last IPCC, in my mind, that shrinks the betting odds, shrinks the range of uncertainty. It does not make uncertainty go away.

And so ultimately, it will boil down to the level of proof that people require in order to take meaningful action.

The CHAIRMAN. Dr. Bradley.

Dr. BRADLEY. With reference to this hockey stick issue, there may not be too many hockey sticks needed in the future, in Massachusetts anyway.

[Laughter.]

Dr. BRADLEY. We initially began this analysis originally by assembling as much data as we could and push the record back to, I think it was, maybe 1400. And on the basis of that data set, we demonstrated that we could reproduce the instrumental data completely independent from this—this network of paleo data. We then attempted to push it back a little bit further with a much sparser network of data. As you go through back in time, you lose more data.

[Slide.]

Dr. BRADLEY. But you can see from this record and we—we tried to be as honest as possible, by putting this yellow envelope of uncertainty. You can see the envelope of uncertainty gets bigger as you go back in time.

But in the context of what the model projections are for the next century, the changes we have seen in the last 1,000 years are fairly trivial.

And so I think that is the important value of this perspective. You step back beyond the period of our own experience, the last century or so. You look at it in the longer term, when clearly before 1800, it was all due to natural variability. It was not due to greenhouse gases—a pre-industrial level of greenhouse gases.

So what you see in that graph is just the earth doing its thing, solar variations, volcanic eruptions, whatever. Those are the amplitudes of change that we believe are real.

And then you compare that with what are projected to—to take place in the future. And you can see that it is just off the scale.

The CHAIRMAN. My final question—I appreciate the indulgence of my colleagues.

If the blade part of the hockey stick here in your graph is largely accepted as valid, why is it that you think that there is not greater concern than that exists today about that blade of the hockey stick?

Dr. BRADLEY. You know, this diagram is patched together from two pieces of information. I do not think it has been seen before, in fact.

The left-hand side, the red and the yellow represent—the red is the instrumental element; the yellow is the reconstruction; and the gray area represents the projected. So that brings it all together and puts it in perspective.

I think this diagram is compelling. And if it is seen more widely people will be forced to face the fact that these are very large changes. I think as we develop our science and we make these kinds of figures available to people, they will begin to realize the magnitude of change.

Now, why do we not take it more seriously? Because the problem is incredibly difficult to resolve, as you no doubt, grapple with within yourself.

How do—how are we going to deal with the fundamental use of fossil fuel in our society and around the world? How are we going to deal with the fact that the population growth is going to double this century? That is the fundamental driver of this change in temperature.

Unless we can come to grips, we obviously are not going to do much about changing population growths. We have got to do something about the carbon-based fuel economy of the world. We have got to come up with more efficient ways of managing our society.

And in the long run, it obviously must be more beneficial to our economy to use less fossil fuel. It has got to be more sensible to run an engine on less energy, to run a factory on less energy, and use less energy to heat or cool our homes. The short-term costs may be profound. But the long-term has got to be a boost for our overall commerce, I would think.

The CHAIRMAN. Any other panelists wish to—go ahead, Dr. Mahlman. We will go right down the list. Dr. Christy, you are included in this assessment.

Dr. MAHLMAN. Oh, I think this is an extremely important question, and if I could repeat the question to know I understand it. Given all this, why are people not more concerned than—than they are——

The CHAIRMAN. Than they—yes.

Dr. MAHLMAN [continuing]. Governments and everybody? I have had the good fortune to have spoken face to face to the order of 10,000 people on this—on this subject. And this comes up all the time.

And it is a universal issue. And I would submit on the basis of my encounters with all these people that it boils down to a couple of things.

One is that it is a hard problem to immediately associate with—with a really scary issue, until you start doing what we have been doing today, which is looking at each thing and finding out what sectors are—are affected and how they might be affected. And then suddenly, the potential for serious harm begins to creep out of that. And the second part——

The CHAIRMAN. By the way, including a new European—a group recently discovered a greenhouse gas with frightful characteristics, SF—SCF3, I think.

Dr. MAHLMAN. Yes.

The CHAIRMAN. You are familiar with that?

Dr. MAHLMAN. Yes. Dr. Watson and I will probably both quickly say that this is part of a class of extraordinarily long-lived greenhouse gases, most of them human produced, that have tremendous global warming potential. It is in the IPCC and the ozone assessment reports.

And there is nothing, to me, particularly new about that. It is part of a whole class of fluorocarbons and other very long-lived greenhouse gases that exist in a few parts per trillion, that probably will be removed quickly from manufacturing processes. So I do not see this as a new issue.

The second thing I would like to say about why people are not acting and concerned so much is, in my view, this problem has an extraordinarily high degree of difficulty factor. It is very easy to demagogue it from all sorts of viewpoints, because it is not just a matter of what the U.S. does or what this Committee does. It is what the whole planet does.

And, in that sense, it seems so overwhelming that we, therefore, do not have to do very much. And, of course, in this problem, like many other problems, a non-decision is a decision in the sense that we all are implicitly agreeing to keep increasing emissions of CO_2 into the atmosphere.

The CHAIRMAN. Dr. Trenberth.

Dr. TRENBERTH. Yes. Thank you. Climate change is not necessarily bad. When you deplete the ozone layer, the consensus was that this was a universally bad thing and, therefore, a coordinated activity could occur. But warming in wintertime can be beneficial for some things, for instance.

The real problem, which I do not think is adequately appreciated, is that change by its very nature can be disruptive and tends to be disruptive. And even though we may be changing in some areas to a climate that is better in some sense, it is not going to stay there. It is going to continue to change.

In fact, we are entering a period of instability in our climate, and we are not going to know just what the climate is going to be next year or for the next 30 years, and actually this puts an imperative on making better climate predictions so that we will have those predictions to be able to base decisions upon, because we will not be able to use the climate of the past to make those decisions.

And this applies in so many parts of society and activities that we have, such as planning of dams and especially water resources. And I personally think the main pressure points on society will be changes in precipitation, changes in extremes, managing water and water resources, portable water in particular, and the effects of changes in the extremes on society and on the environment.

Unfortunately, our data bases for those are not as good as they are for mean global temperature. As I mentioned before, a one-degree change in global mean temperature translated locally does not mean much. But, in fact, this record has included things like the Little Ice Age, which caused major disruptions in Europe.

And so regionally, the manifestations of this can, indeed, be very great and profound. And so getting these aspects across to the general public and to policymakers is not an easy thing to do.

The CHAIRMAN. Dr. Christy.

Dr. CHRISTY. I agree with Dr. Trenberth, who actually is my former advisor when I was back in graduate school. And I usually have a difficult time to be more skeptical than he is, but sometimes I can.

In Alabama, the temperature has fallen over the last 105 years, so people right there are not going to be very concerned about global warming when the temperature in their local region has not warmed at all. The second thing——

The CHAIRMAN. If the Gulf shores is inundated, at least in the southern part of the state there remains some concern.

Dr. CHRISTY. I repeatedly advise people who are interested in beach-front property that I do not care about six inches of rise relative to hurricanes. It is the next hurricane that is going to visit the area that is the problem, and they should stay away from the beach for that reason.

Cheap energy means longer and better lives. And I have seen that. I was a missionary in Africa, and I saw people who literally died when energy costs increased because they just lived right on the edge of existence. So I would be very concerned about increasing the cost of energy for the poor people of Alabama, and those around the world.

And in agreement with everyone here, if there is some way to keep energy cheap and not produce CO_2, I am all for it. That is fine, if we can do that.

Now, lastly, fortunately in this business, CO_2 itself is plant food. It is not toxic. CO_2 does not bother us, and it invigorates the plant world. The plant world you see around you evolved at a time when there was ten times as much CO_2 as there is now. So that is one thing that we can be thankful for, at least in terms of the toxicity that CO_2 is harmless.

It is the climate change issue, the secondary effect of CO_2 that is of concern to us all.

The CHAIRMAN. Dr. Watson.

Dr. WATSON. My comment would be, simply, most scientists are concerned about climate change. Most governments are concerned about climate change, which is why most of them signed the Kyoto Protocol.

Some businesses are becoming more concerned about climate change. Shell and B.P. in Europe, others in the U.S. have all now got internal trading systems, and they have got their own targets, and they are very similar to Kyoto.

One of the big problems, however, is what differentiates this from the ozone issue. In both cases ozone depletion and global warming is largely being caused by emissions from the rich countries, the U.S. and Europe, Japan.

With ozone depletion, the impact is skin cancer on light-skinned people. Americans cared about it. So did the Europeans.

The major impact of global warming will be on developing countries and especially the poor in developing countries. The U.S. will be hit, but the biggest impact is on developing countries. So it does not hit home in quite the way skin cancer did with the ozone issue.

But the basic point is—and that is why Shell and others are starting to act—there are cost effective solutions, especially when we use the so-called flexibility mechanisms, emissions trading internationally and project-based joint implementation.

There are distributionable issues. The coal industry is not going to be a winner. The renewable energy industry will be a winner, and even the gas industry. So there are distributionable issues and political forces at play, especially in the U.S. and in, say, Australia, where there is a lot of cheap coal reserves.

There is no question we can de-carbonize the energy system in the next 50 years. We do not need to do it in 5 years. We have to have a long-term strategy to de-carbonize our energy system.

And the population issue is also a manageable issue. If we follow the Cairo principles of culturally acceptable forms of contraception, education especially of girls and empowerment of women, we can actually start to lower the projections of population.

And the latest projections suggest that there could well be a stabilization around 9 billion people, only 50 percent more than now and starting to decrease by the end of the next century.

So these are indeed solvable issues, but it takes political will and it takes partnership between government, the private sector and civil society.

The CHAIRMAN. Dr. Christy, you will have the last word from me.

Dr. CHRISTY. OK. I just want to say "Amen" to something Dr. Watson said. In my experience as an educator in Africa, the educational component was the key ingredient to seeing those societies bring about a better situation in the lives of the people, and I just wanted to echo the need for education of women in those countries.

The CHAIRMAN. Thank you very much.

Senator Kerry.

Senator KERRY. Thank you, Mr. Chairman.

[Pause.]

Senator KERRY [presiding]: It seems to me that there is pretty broad agreement among you, not withstanding the differences, Dr. Christy, in your assessment of what you are willing to conclude from the satellite observations.

You have a differing of opinion about what the consequences of global warming may be, but you do accept the fundamental premise of the human impact and the basic findings of the increase of warming taking place.

And I take it that these circumstances have serious implications for us involved in policymaking. You do not think we should do nothing, do you?

Dr. CHRISTY. In terms of policy, I am not an expert, but——

Senator KERRY. Well do you think we should let CO_2 double? Should we just sit around and watch this happen? Is that your policy recommendation?

Dr. CHRISTY. If I were to predict, I would say it was going to double no matter what policy is adopted.

Senator KERRY. Realizing it is, would you simply sit back and accept that, or would you now begin to do greater research and see what——

Dr. CHRISTY. I would certainly support, especially in terms of energy use, research on the alternatives that can be used to produce energy, and keep it cheap and affordable, because cheap energy means longer and better lives.

Senator KERRY. So are you saying, about this process—I mean, here are four distinguished peers of yours——

Dr. CHRISTY. And I feel surrounded sitting here.

[Laughter.]

Senator KERRY. Well, it is hard to find a whole lot of contrarians now. There are a few more but it is hard to find it is hard to fill a room with them. How many people are on the IPCC? 2,500, is it?

Dr. TRENBERTH. There are several hundred as authors. There are several thousand, indeed, involved as reviewers. And indeed John is one of them, and so is Richard Lindsen, who is also a notable skeptic.

Senator KERRY. Is there a great difference of opinion between those 200?

Dr. Watson?

Dr. WATSON. I think the majority see the climate issue the same way. They all recognize what is known. They all recognize what is unknown.

I would say there are a half a dozen key contrarians, which include Dick Lindsen, Fred Singer and Pat Michaels, but I would say the large majority of the scientists clearly fall on one side.

And in the IPCC, we are trying desperately to make sure the full range of views is fully exposed. And so we can actually say what is known with certainty, what is less known, why do the majority think one way, and the minority think another. So we can actually explain what the implications of uncertainties are for policy formulation.

Senator KERRY. Dr. Trenberth, what is your sense of the schools of thought here, and how we should come up? What is the difference between these four or five that have been mentioned as the key contrarians and the vast majority who believe otherwise?

Dr. TRENBERTH. I think we need to take into account some of the ideologies that come into play and recognize that there are different views of the world.

In the IPCC process, particularly in working group one, what we try to do is to make the best statement as to what can be said about this problem of global climate change and leave to the politicians what should actually be done about it. And often, I think, those things do get mixed up. And they often, I think, get mixed up by some of those people.

We need to recognize that there are many value systems in the world today, from the extreme environmental position, which says we should stop the increases in greenhouse gases absolutely and mitigate the problem; to people who say technology will solve the problem, and we can just adapt to it as it goes along; to people who advocate sustainable development; to people who have vested interests.

And we have seen this in the tobacco industry, for instance, where often the strategy is to denigrate the science and to say that there is not a problem and recognize that they do have a vested interest. I do not think it is so much what you do about the problem, but how you do it and doing it over an appropriate time scale, that would help to assuage some of the projections that you see.

Senator KERRY. Well, it is completely fair and, I think, accurate to say, that some of the denigration of science has emanated from specific industries highly vested in fossil fuel. Is that accurate?

Dr. TRENBERTH. That is, I believe, accurate.

Senator KERRY. Is that accurate, Dr. Mahlman?

Dr. MAHLMAN. I think it is accurate, but I would answer a little bit differently, in that if you look at this problem worldwide, there are people who are trying to frame-out the science the best that we know.

Some of the issues we have just discussed here are ones where we can sit around at a table and discuss in a civil way and say, "Well, I disagree with you here or there," and we would all go out to lunch together, and there would be no yelling, or screaming or slugging going on.

[Laughter.]

Dr. MAHLMAN. But on the other hand, I think it is important for all of us to recognize that there are contrarians and there are also exaggerators. OK? And both are essentially, in my view, making points because of agendas that are somewhat independent of scientific analysis, and you can say, "Well, I do not see that as necessarily a new phenomenon on Capitol Hill." But it——

[Laughter.]

Dr. MAHLMAN [continuing]. Is part of human nature to have people torque the facts a little bit to hustle whatever their position is. And, as you know, they say, "That is part of the policy debate," but it is also part of the values conflicts and everything else.

I have gotten so that I do not get all that concerned about it, because I think it is part of the process of dealing with a problem that is extraordinarily difficult. Lots of folks see that a very special thing is going to get hurt by mitigation or is going to get hurt by climate change. I thus consider this to be the real greenhouse warming controversy.

Senator KERRY. Governments came together in Kyoto to adopt a policy, a response, and hopefully this policy does not represent grinding of a particular axe, but represents a reasonable approach in the middle. I do not think the Chairman or I or others want to adopt a policy we do not need to adopt.

I do not have any industry axe to grind on one side or the other. I mean, I am trying to respond to what I see is a problem caused by human beings, which is increasing because of our unwillingness to reduce what we are doing that is causing it. Now, we have got to make a decision, because there is some money involved here. Do we need to reduce the level of emissions or do we not? Countries signed on in Kyoto to the notion that we do; that reducing emissions is a worthwhile goal. Does anybody disagree with that? Is it a worthwhile goal?

Dr. MAHLMAN. I would like to comment. I was quoted in the *New York Times* before the Kyoto Conference. And I have written a paper in *Science Magazine*, you know, prior to Kyoto.

At that time, I said that the best Kyoto could do would be to set up a small, but significant decrease in the rate of increase of carbon dioxide in the atmosphere. And, this statement was somewhat controversial at the time. But the whole point was, that even Kyoto itself, if it were fully implemented, would still be nipping around the edges.

Senator KERRY. Absolutely.

Dr. MAHLMAN. And I said this not to demean the Kyoto process, but more or less to educate people that are probably going to be whittling away at this problem for the rest of the century. And Kyoto is kind of ground-zero, or maybe Rio was, of the process of what the world is going to do about it and how all of the hard issues can get worked out.

And so, therefore, Kyoto, from the point of view of the problem, was a very small step; not a radical, the world is going off the edge if we implement the Kyoto Protocol. And so, the next question is, what will happen in the next round?

Senator KERRY. Does anybody else want to add to that? Dr. Bradley, and then Dr. Watson.

Dr. BRADLEY. I think it is clearly—there is a long ladder we have to climb. And Kyoto is, perhaps, just the first rung on that ladder, but it is an important step, because it forces governments throughout the world to recognize the problem and to take steps to address the problem.

It is not going to solve the problem, but it—but just like the Montreal protocol, which began small and gradually made stronger and stronger steps, I think that is what is necessary in Kyoto.

Senator KERRY. Dr. Trenberth.

Dr. TRENBERTH. Well, the Kyoto Protocol is flawed, at least in some respects, especially insofar that it is not truly global, in terms of the agreements that exist.

The important thing about it is that it would buy time. The estimate is that doubling of carbon dioxide would be delayed by about 10 years. And people then ask, “Is it worth buying that time?”

And I think it, very strongly, is, because the climate is going to change, and every step we can take to buy that time provides us with better capabilities of planning for what is going to happen and for planning the adaptation that will be necessary to occur in the future.

And so, I think it is a desirable first step, even if a flawed first step.

Dr. WATSON. Yes. I think it is quite clear that governments from around the world recognize that human induced climate change is a threat to society. And what we need is some first steps toward meeting the ultimate objective of the convention, which is Article Two, which calls for the stabilization of greenhouse gas concentrations in the atmosphere.

They also recognize, and I agree, that it is very important to differentiate the responsibility between developing and developed countries. Energy is needed to alleviate poverty in developing countries and for having economic development.

But why is the Kyoto Protocol such an important first step? It will stimulate the development of new energy technologies. It will stimulate policy reform, both in developed and developing countries. We will find better mechanisms, which will involve all sectors and an appropriate enabling government framework for technology transfer. And it will give us the chance to put these flexibility mechanisms in place.

So, even though it is not a global convention, it does recognize, just like the Montreal Protocol did, that the developed world has the institutional, financial, and technical capability to take the first steps.

As they take those first steps, we will see a flow of technology transfer, such that it will be in the best interest of China and India to also reduce their greenhouse gas emissions, and simultaneously to reduce their local air pollution and regional air pollution.

So, I believe it is a very well founded first step, but clearly, at the end of the day, all countries will have to reduce their greenhouse gas emissions, if we are going to meet the ultimate objective of Article Two. There is no question.

Senator KERRY. Well, I agree with that. I accept that. I think that the difficulty is that the current political formulation in the United States makes it difficult for us to embrace that first step, absent at least an acknowledgment by the developing countries that they are willing to adopt some measures. Tackling the problem is going to be very complicated.

You know, I was involved and I led the fight on the floor to try to create some sort of rational approach in the Herd-Engle Amendment. And I am sympathetic to the notion that people in the United States are going to be hard-pressed to buy into something they do not see other people also buying into.

The fact is, though, that China and other developing countries are currently embracing significant steps to achieve clean air. And they are moving forward. In China, for instance, they are restricting certain kinds of vehicles, and are beginning to get conscious of these environmental issues. And they could actually qualify for participation very easily, based on many of the things they are doing now.

What we have is a dividing line between us—the traditional view of the developed (and developing) world. We have gotten stuck in cement for lack of people's willingness to really look at the long-run here. And I think we need to have some significant diplomacy exerted in order to try to pull us together now. We should not be that far off.

But let met just touch on a couple of other quick points. I know Senator Brownback wants to ask questions.

Just for the record, the 400,000 year basis that you are drawing conclusions on CO_2 increase from is based on the ice core, correct.

Dr. BRADLEY. These are little bubbles of gas; essentially samples of the atmosphere that have been trapped in the ice and buried for years.

Senator KERRY. I just want the record to reflect that I have read it and I am familiar with it. I want the record to reflect the accuracy of that judgment showing that it is not some kind of hypothesis.

You are able to take trapped CO_2 through the ice cores, through the ice that has been there through these millennia, and measure precisely the level of CO_2 increases over that period of time, correct?

Dr. BRADLEY. That is correct.

Senator KERRY. And that is how we know to a certain degree the demarcation point of the Industrial Revolution and the introduction of CO_2 by human industrial efforts that has made this marked increase.

Dr. BRADLEY. That is correct.

Senator KERRY. We can track precisely the level of weather changes, heat changes over the last 105 years, at least, by measuring the CO_2 gas in these cores.

Dr. BRADLEY. That is right. I might also add that this 420,000 year limit is only because that is as long an ice core record as we have. I am sure if we had a 2 million year ice core record—I feel confident that if we had a 2 million year ice core record, we would still be heading toward uncharted waters in the future.

Senator KERRY. Now, they also know that these things called "sinks" or entities that sequester carbon dioxide are ineffective on a constant basis. But the ocean is also a primary sink, correct? It is a huge sink.

And the ocean, in fact, is warming. And the ocean contains very significant amounts of CO_2 that it holds onto for long periods of time. It is my understanding that the ocean could conceivably have some limit as to how much CO_2 it, in fact, can sequester.

And at some point, if we were to continue to pour it in, we could have overload, so that all of a sudden the ocean is no longer available as a major sequesterer of CO_2, correct?

Dr. BRADLEY. That is correct.

Senator KERRY. And that could then have a profound impact, in terms of all of a sudden releasing this CO_2 The benefits of this once extraordinary sink are then negated. And where do we go from there, is a legitimate question, is it not?

Dr. BRADLEY. Yes. There are a number of these kind of thresholds in the climate system that we do not have a good handle on. And that is one, for sure. And changes in the ocean circulation, in general, are a great uncertainty.

Senator KERRY. And our weather in the northeast is significantly dependent on the ocean, on the Gulf Stream and on its relationship.

Dr. BRADLEY. That is right.

Senator KERRY. So, if that were to simply be altered in a major way, we could have—who knows what—perhaps some catastrophe.

Dr. BRADLEY. Yes. That is true in most parts of the world, wherein you have the economy and society has developed based on what they are used to.

Senator KERRY. Given that reality, we make judgments here everyday about flood plain settlement, about AIDS—the rate of spread of AIDS, about tobacco. We have spent $60 billion in the last few years, based on judgments we make about potential threats from North Korea or Iraq or Iran.

Here is a far more realistic, in my judgment, and definable quantifiable threat. And we are not even doing an adequate level of climate change research.

Dr. BRADLEY. Exactly. In fact, I would say, that we can carry on doing research. It is a trivial amount of money in the context of what we spend on other things, but what is really needed is a massive national effort to develop alternative energy sources to find non-carbon based fuels that will allow us to continue our economic progress without continuing to increase the level of CO_2 in the atmosphere.

Senator KERRY. But is it not true that, in fact, we are much further down that road than most Americans know, with respect to hydrogen, engine fuels or other alternatives?

Dr. BRADLEY. I am not sure where we are, but wherever we are, we are not far enough along. Certainly, on the global scale, this is a critical issue.

Senator KERRY. My point is, simply, that in 1980, before President Reagan arrived in Washington, we were the world's leader in alternatives and renewables. And we had created an energy institute out in Colorado, I believe. And professors left their universities and gave up tenure to go out there, and research the American future in renewable and alternative energy.

In 1981 the funding was cut completely. And we gave up our leadership to the Japanese and Europeans in those sectors, so that when the Communist block countries fell and they started searching for people who had the technology, they looked elsewhere than the United States.

Dr. BRADLEY. That is exactly right.

Senator KERRY. Now, I do not think this is as complicated as we make it. The threat may be enormous, but the truth is, if we were to unleash the technological capacity of this country to truly face this problem—we have an extraordinary capacity to develop jobs and economy and a future that is sustainable. But it seems to me that we need to face the difficulties of educating the public and drawing the people into the potential solutions here.

Problems are real, but solutions are there. We can certainly work through this, I think, providing we show some leadership.

Does anybody else want to make a comment?

Dr. WATSON. Yes. I would like to make one comment on it. Technology is very important and R&D is important, but the policy framework is crucial.

We are never going to get renewable energies to penetrate the marketplace unless we internalize the social costs of pollution, for example air pollution and acid deposition, and eliminate fossil fuel subsidies. It is worse in other countries than the U.S.A. But it has to be a combination of research and development into new energy technologies and policy reform.

There is no way that one is ever going to get renewable energies in most countries, because of the subsidies on fossil fuels and they subsidize the railways to transport coal, and they do not internalize the social costs of environmental pollution.

So, we do not have a level playing field. It does not matter how well you do on technology. So, it must be the combination of technological development and policy reform.

And the comment that should be made is, unfortunately, both public sector and private sector research in energy has decreased in every country in the world, except for Japan. And 90 percent of their research is on nuclear power, not on renewable energy.

In most of the European Union, energy research has dropped by a factor of five to ten. And in the U.S., in real terms, it has also dropped. And most of the U.S. money goes into, again, fossil fuels and nuclear power. Only 20 percent of the energy R&D budget goes into either renewable energies or energy efficiency.

And the other problem that compounds this, is that not only has public sector research dropped off, but because of deregulation of industries and liberalization, private sector research has dropped even further. And so, we have the unfortunate situation of both public and private research dropping precipitously.

We do not have the associated policy reform. And so, while we have been debating climate change at the convention and the Kyoto Protocol, the very instruments we need to enact a decarbonization of the energy system have actually been taken away from us.

Senator KERRY. Well, with respect to that policy, let me just add, I am a passionate and deeply committed advocate of a much more thoughtful foreign policy, where we, in fact, have a much more significant component of technology transfer and technical assistance.

And a year ago, I managed to get Jim Wilbinson, to his enormous credit, to commit the World Bank to holding the conference in, of all places, Hanoi, Vietnam. It is about precisely this kind of development.

And all the donor countries came, including Japan, to think about how, as they need to put in a power plant, we could provide them with an alternative to simply burning high-sulphur coal. We could even provide them with direct grant transfer of some of our technological abilities to be able to do these things, so that they can develop without repeating the mistakes that we have made, and learn, at the same time, that this is not a Western conspiracy to keep them from sharing in the abundance and wealth of the world, which is the way they view it today.

I concur with you that we desperately need to have a change in policy and a much more thoughtful approach to this. I thank you for your comments today. And I thank my colleague for his forbearance, and look forward to continuing this dialogue with you.

Senator BROWNBACK [presiding]. I want to thank the panel for the presentation. It was excellent. I thought it was very illuminating.

And it reminded me just—in looking at how much everything is interconnected. When you do one thing, and it just moves 100 different things, different places. I guess the philosopher says that you pull on one place in the universe and everything else moves. And it just really is interconnected.

Let me ask you—Dr. Bradley, you have already started to articulate some of this, about what you think the policy moves are that we should do today. Renewable energy sources, I think, is what your primary focus is.

Are there other specific policy recommendations outside of implementation of the Kyoto Treaty or the renewables that you—some of you would like to put on the table that we should start to discuss now in the U.S. Congress?

Dr. BRADLEY. I'm not convinced that renewable energy is going to be the solution, but I think one of the simplest things is conservation. And by that I mean using more energy-efficient processes, whether that process is heating a house or keeping the heat from going out of the roof; heating water; obviously, more efficient automobiles, and that goes for trucks and public transportation, too.

Those issues can be—can be encouraged with tax credits. As I recall, the Carter Administration there were—they introduced tax credits for energy conservation measures. And that was a boost to a whole emerging economic sector, which was the development of these products.

And it seems to me that would be a fairly painless way of encouraging energy conservation, by providing significant tax credits for people who buy cars that get more miles per gallon, people who introduce energy-efficient measures to their homes, et cetera. And that, in turn, would generate economic activity that could be transferred to other countries. And so, it would be a boost to our economy.

Senator BROWNBACK. Dr. Trenberth.

Dr. TRENBERTH. I mentioned before that it is not so much what you do, as how you do it. One of things which was mentioned by Dr. Watson was the importance of taking into account the lifetimes of the infrastructure that exists and planning appropriately. And I think that is very important.

A good example might be, for instance, automobiles. If we were to increase the cost of gasoline by a dollar tomorrow—well, firstly, that would not be politically viable. And secondly, it would cause major problems in the whole of the economy; very disruptive. But if we increased the cost of gasoline by a penny, it would be lost completely in the noise.

So, what would happen if we increased the cost of gasoline by a penny every month? After 10 years, we would have $1.20 increase in the cost of gasoline. In fact, even then, the cost of gasoline in the United States would be much less than it is in Europe and in most other places around the world.

But if we did that and it was a certainty that it was going to happen, then because the lifetime of a car is less than 10 years, the next time people went to buy a car, they would think twice about the energy-efficiency of the car that they are buying.

And it is this kind of thing that would enable people to plan ahead in a reasonable fashion and adapt to the changes in tax policy. And of course, you can use the increases in taxes to offset other taxes, so that it is tax-neutral. This kind of activity is the kind of thing which I think emphasizes the point I make in my comment that it is not what you do, it is how you do it.

Dr. WATSON. Yes. I think one needs to look at all facts of this. There is no simple home run here. One needs to look at the technology on both energy supply and energy demand. So, efficient vehicles, efficient housing, and more efficient industry can help.

On energy supply, you can have more efficient use of fossil fuels. It does not mean the elimination of fossil fuels—more efficient production of energy from fossil fuels.

You can have fuel switching, from coal to gas. One should think renewable energy.

The policy issues are very, very important policy reform. There is no question. And Kevin is absolutely right. We must do this in the economically least disruptive manner, which means we need a long-time perspective.

Just like the sulphur market, when there was a decision by Congress to reduce sulphur emissions in the U.S. The most important thing they did, did not actually involve new technologies, but it was the emissions training system that was put in place.

So, one could actually stimulate a market—in this case, on carbon—so that both domestically and internationally, you can buy and sell carbon as a commodity. That will absolutely drive down the price.

So, one needs to look at both the technology, but also the policy framework. And I think that one should—and of course, as you, yourself, have mentioned, I think there is a significant opportunity through better forest management, better agricultural management, better rangeland management.

And so, again, thinking through the policies that might stimulate the farmer to move toward no-till agriculture. What do we do with some of the degraded lands? It could actually be very useful land for either afforestation or reforestation or just simply to improve soil carbon. We must not lose the potential in soil carbon.

My view would be, do not move for one simple home run solution, but look right across the wide variety of options, both in technologies and in policies.

Senator BROWNBACK. Dr. Watson, when you look internationally on the issues of carbon sequestration in the construction of the—some of the forests in areas, do you think that that is a key component of—as well as to look at this issue, or is it not a major issue?

You have mentioned the complexity of this and the multifaceted solution that is going to be required, if we are going to try to pull more carbon out of the atmosphere. Regardless of how it got there, regardless of what may be some of its impact in the future, we want to get some of this CO_2 out of the atmosphere. And we could, I think, most would agree on that.

What do you see, as that component of it on the international scale?

Dr. WATSON. Today we put about 6.3 billion tons of carbon per year into the atmosphere from using energy. And from tropical deforestation, we put somewhere around 1.8 billion tons of carbon per year. So, from a total of 8.1, 25 percent comes from tropical deforestation.

Therefore, slowing tropical deforestation is a major component to acting to protect the earth's climate system. It would also have incredible benefits to the biodiversity and water resources in those regions. But it is unbelievably political.

I chaired the recent IPCC report and part of my testimony is on land use, land use change in forestry. And what we see from many developing countries—and this is a political, not a scientific issue—is that they are willing to think through issues of afforestation and reforestation, and issues such as no-till agriculture.

But Brazil, in particular, is absolutely opposed to including avoided deforestation into the Kyoto Protocol through the Clean Development Mechanism Article 12. It is a political issue. It has to do with the Federal/state government relationships, that is to say the interplay between the Federal Government and the state governments in Brazil. It is a question of whether or not, if you avoid deforestation in one part of Brazil, it will accelerate it in another part of Brazil.

So, you have to understand the drivers behind deforestation, in order to say that you can actually stop deforestation. You need to know all the underlying political and technical and industrial factors that drive it.

But there is no question in my mind that if we can slow deforestation in the tropics, and if we can accelerate afforestation and reforestation, both in the tropics and high latitudes, it would be a major contribution to climate change and to save the world's biological diversity.

Senator BROWNBACK. On the afforestation and reforestation, would we not actually affix or sequester more carbon if we—if our policies actually focused in that direction, avoiding some of the political issues that you have identified?

Dr. WATSON. Yes. On afforestation or reforestation—forests grow slowly, but surely, over the next 20, 50, 100 years, depending on the lifetime of the forest, you would sequester carbon. And there is no question it is a very good thing. But if you can avoid deforestation, it stops a big slug of carbon going into the atmosphere.

And of course, if one is trying to avoid deforestation in the tropics, one could argue there are national sovereignty issues at stake, as well.

I think we need the dialogue right across the world on all of these issues simultaneously. We have got to recognize political sensitivity, but we also need to recognize that avoiding deforestation is a powerful tool to keep the carbon where it is.

Afforestation and reforestation will draw additional carbon from the atmosphere, but avoiding deforestation stops it going in, in the first place.

Senator BROWNBACK. Dr. Trenberth.

Dr. TRENBERTH. Senator, you were asking especially about the sequestration of carbon dioxide, and there is also new technology, and I believe Norway is the leader in this area, where they are taking carbon dioxide out of the atmosphere as it is generated, essentially, and then the technology is to sequester it in the oceans or elsewhere.

I am not an expert in that area, but I did want to get on the record that there are, indeed, other technologies, but of course there is a cost attached to doing that.

Senator BROWNBACK. Other policy suggestions, or particularly in the carbon sequestration is a—I think that is—that is a key point of political reality. And one needs to recognize political reality, you know, here, as well.

We can probably spend a great deal of time arguing about how global warming is occurring. We could probably spend and probably will spend a lot of political time discussing, OK, whether Kyoto is a good or bad treaty for us to enter into. And then you are going to have the political forces that will line up both ways on that. And those are legitimate debates and discussions, and which you are going to have them in.

You could also start to do something right now. And you could recognize what the market will bear here and what we can start to do, which is, in my way of thinking, probably what we ought to be—perhaps we can, first and foremost, starting with now, because it starts to eat away, as one of you said—I think it was Dr. Mahlman.

He pointed out that even Kyoto just kind of nips around the edges of this. "And we will probably be doing that for the next century," was the quote of one of you.

I think there are ways that we can get started on this. I think we will need to have the dispassionate dialogue and recognize people's concerns and political realities, and then say there are ways that we can actually—we can move forward and start to address the problem now, rather than just having the issues back around.

Recognizing that that is probably the start of a lengthy process of how do we deal with issues like this in ways that are least disruptive.

Dr. WATSON. If one simply makes carbon a commodity, just like maize or wheat is, then there is real value in carbon. And that is how you can then trade carbon either within a company as British Petroleum is doing now. You can trade it nationally within the U.S. or any other country, like we trade sulphur at the moment. And it can be traded internationally.

As soon as you make carbon a commodity and it has value, then it will be a real incentive to farmers, it will be a real incentive to foresters, to improve agricultural practices, forestry practices, essentially be paid for those better management practices, and then also get the multiple benefits of increased soil fertility, et cetera.

So, one of the challenges is putting a policy framework together, where one has real value in carbon and will also stimulate research and development and will also stimulate energy-efficient technologies. There is no question, that the challenge is putting the framework together.

Dr. BRADLEY. If I could just pick up on a point there, and that is that many of these strategies do have multiple benefits. Bob talked about the preservation of biodiversity in—clearly, it will be more beneficial to the economy if we use less fuel to power our automobiles, power our plants and so on.

It is going to be better, ultimately, if we can do things more efficiently like that. So, we ought to develop sort of a table of strategies that have the least political disagreement and the maximum collateral benefits that we can imagine, so that we can start chipping away at this very large issue by taking some of these measures.

Senator BROWNBACK. It is picking the low lying fruit as best you can.

Thank you very much. You have been an excellent panel and an excellent discussion. I know the Chairman would like to hold additional hearings on this. And I think it certainly is warranted.

The record will remain open for the requisite number of days, if you choose to submit additional things for the record.

The hearing is adjourned.

[Whereupon, at 12:15 p.m., the hearing was adjourned.]

APPENDIX

ARTICLE WRITTEN BY DR. JERRY MAHLMAN, DIRECTOR, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Science Magazine, November 21, 1997

Uncertainties in Projections of Human-Caused Climate Warming

Mankind's activities have increased carbon dioxide (CO_2) in the atmosphere. This increase has the potential to warm the earth's climate by the "greenhouse effect"[1] in which CO_2 absorbs infrared radiation and then re-radiates it back toward the surface of the planet. Other gases also act as greenhouse gases and may warm the climate even further,[2] although human-produced airborne sulfate particles can cause cooling that offsets some of the warming.[3] Computational models that include these factors predict that the climate will warm significantly over the next century.

These forecasts of likely climate changes have forced a realization that it is necessary to reduce human-caused emissions of greenhouse gases. But because of the potential social disruptions and high economic costs of such reductions, vigorous debate has arisen about the size and nature of the projected climate changes and whether they will actually lead to serious impacts.

A key element of these spirited—and often acrimonious—debates is the credibility (or lack thereof) of the mathematically and physically based climate models[4] that are used to project the climate changes resulting from a sustained buildup of atmospheric CO_2. Some skeptics ask, to put it bluntly, why should we believe such models' attempts to describe changes in such a dauntingly complex system as Earth's climate? The cheap answer is that there are no credible alternatives. But the real answer is that the climate models do a reasonably good job of capturing the essence of the large-scale aspects of the current climate and its considerable natural variability on time scales ranging from 1 day to decades.[4] In spite of these considerable successes, the models contain weaknesses that add important uncertainty to the very best model projections of human-induced climate changes.

I express here a "policy-independent" evaluation of the levels of current scientific confidence in predictions emanating from climate models. This climate model uncertainty is distinct from the high social uncertainty associated with future scenarios of greenhouse gas and airborne particle concentrations. I assume that detailed future greenhouse and airborne particle scenarios are part of the policy question and thus do not discuss them further.

A fair-minded and exhaustive attempt to find a broad consensus on what science can say about this problem is contained in the most recent 1996 IPCC Working Group I Assessment.[3] Some of my evaluations differ in detail from those of IPCC 1996, mostly because of the addition of new research insights and information since 1994. A good guideline for evaluating contrary "expert" opinions is whether they use the IPCC science as a point of departure for their own analysis. In effect, if we disagree scientifically with IPCC, we should explain why. Without such discipline, contrary arguments are not likely to be scientifically sound.

---

[1] The greenhouse effect for CO_2 was first calculated over 100 years ago by S. Arrhenius, *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 41, 237 (1896).

[2] Intergovernmental Panel on Climate Change, *Climate Change, the IPCC Scientific Assessment,* J. T. Houghton et al., Eds. (Cambridge Univ. Press, Cambridge, 1990).

[3] Intergovernmental Panel on Climate Change, *Climate Change 1995, The Science of Climate Change,* J. T. Houghton et al., Eds. (Cambridge Univ. Press, Cambridge, 1996).

[4] Climate models are mathematically based models that attempt to calculate the climate, its variability, and its systematic changes on a first-principles basis. The fundamental equations solved are the conservation of mass, momentum, and energy. The interactions among the atmosphere, ocean, ice, and land surface systems are calculated on rather widely separated computational points on Earth (typical spacings are 200 to 400 km in the horizontal and 1 to 3 km in the vertical).

Virtually Certain "Facts"

These key aspects of our knowledge of the climate system do not depend directly on the skill of climate model simulations and projections:

- Atmospheric abundances of greenhouse gases are increasing because of human activities.
- Greenhouse gases absorb and re-radiate infrared radiation efficiently. This property acts directly to heat the planet.
- Altered amounts of greenhouse gases affect the climate for many centuries. The major greenhouse gases remain in the atmosphere for periods ranging from a decade to centuries. Also, the climate itself has considerable inertia, mainly because of the high heat capacity of the world ocean.
- Changes in other radiatively active substances offset somewhat the warming effect of increased greenhouse gases. Observed decreases in lower stratospheric ozone and increases in sulfate particles both produce cooling effects. The cooling effect of sulfate particles remains insufficiently quantified.
- Human-caused CO_2 increases and ozone decreases in the stratosphere have already produced more than a 1°C global average cooling there. This stratospheric cooling is generally consistent with model predictions.
- Over the past century, Earth's surface has warmed by about 0.5°C (±0.2°C).
- The natural variability of climate adds confusion to the effort to diagnose human-induced climate changes. Apparent long-term trends can be artificially amplified or damped by the contaminating effects of undiagnosed natural variations.
- Significant reduction of key uncertainties will require a decade or more. The uncertainties concerning the responses of clouds, water vapor, ice, ocean currents, and specific regions to increased greenhouse gases remain formidable.

I further illustrate these climate uncertainties using two extrapolations of the IPCC idealized scenarios of increases of 1% equivalent atmospheric CO_2 concentration per year.[5] The first case levels off at a CO_2 doubling after 70 years; the second levels off at a CO_2 quadrupling after 140 years. Both correspond to simple extrapolations of current trends in greenhouse gas emissions. Considering the long residence time of CO_2 at such large concentrations, these leveled-off scenarios are physically plausible but are presented as illustrations, not as social predictions.

Virtually Certain Projections

These projections have a greater than 99 out of 100 chance of being true within the predicted range:[6]

- The stratosphere will continue to cool significantly as CO_2 increases. If ozone continues to decrease, the cooling will be magnified. There is no known mechanism to prevent the global mean cooling of the stratosphere under these scenarios.
- Global mean amounts of water vapor will increase in the lower troposphere (0 to 3 km) in approximately exponential proportion (roughly 6% per 1°C of warming) to the global mean temperature change. The typical relative humidities would probably change substantially less, in percentage terms, than would water vapor concentrations.

Very Probable Projections

These projections have a greater than 9 out of 10 chance of being true within the predicted range:

- The global warming observed over the past century is generally consistent with a *posteriori* model projections of expected greenhouse warming, if a reasonable sulfate particle offset is included. It is difficult, but not impossible, to construct conceivable alternate hypotheses to explain this observed warming. Using vari-

[5] S. Manabe and R. J. Stouffer, *Nature* 364, 215 (1993); *J. Clim.* 7, 5 (1994).

[6] The approach used here was tested and challenged in E. Barron, *Forum on Global Change Modeling, U.S. Global Change Research Program Report 95–02* (U.S. Global Change Research Program, Washington, DC, 1995). Earlier evaluations were published in J. D. Mahlman, *Climate Change and Energy Policy,* L. Rosen and R. Glasser, Eds. (American Institute of Physics, Los Alamos National Laboratory LA–UR–92–502, New York, 1992) and in J. D. Mahlman, U.S. Congressional Record, 16 November 1995, House Science Committee Hearing on Climate Models and Projections of Potential Impacts on Global Climate Change (1995).

ations in solar output or in natural climate to explain the observed warming can be appealing, but both have serious logical inconsistencies.

- A doubling of atmospheric CO_2 over preindustrial levels is projected to lead to an equilibrium global warming in the range of 1.5° to 4.5°C. These generous uncertainty brackets reflect remaining limitations in modeling the radiative feedbacks of clouds, details of the changed amounts of water vapor in the upper troposphere (5 to 10 km), and responses of sea ice. In effect, this means that there is roughly a 10% chance that the actual equilibrium warming caused by doubled atmospheric CO_2 levels could be lower than 1.5°C or higher than 4.5°C. For the answer to lie outside these bounds, we would have to discover a substantial surprise beyond our current understanding.
- Essentially all climate models predict equilibrium global temperature increases that are nearly linear in the logarithm of CO_2 changes. This effect is mainly due to increasing saturation of many of the infrared absorption bands of CO_2. That is, a quadrupling of CO_2 levels generally produces projected warmings that are about twice as large as those for doubled CO_2.
- Models predict that by the year 2100, global mean surface temperature changes under these two idealized scenarios would be 1.5° to 5°C.
- Sea level rise could be substantial. The projections of 50 ± 25 cm by the year 2100, caused mainly by the thermal expansion of sea water, are below the equilibrium sea level rise that would ultimately be expected. After 500 years at quadrupled CO_2 levels, the sea level rise expected due to thermal expansion alone is roughly 2 ± 1 m. Long-term melting of landlocked ice carries the potential for considerably higher values but with less certainty.
- As the climate warms, the rate of evaporation must increase, leading to an increase in global mean precipitation of about 2 ± 0.5% per 1°C of global warming.
- By 2050 or so, the higher latitudes of the Northern Hemisphere are also expected to experience temperature increases well in excess of the global average increase. In addition, substantial reductions of northern sea ice are expected. Precipitation is expected to increase significantly in higher northern latitudes. This effect mainly occurs because of the higher moisture content of the warmer air as it moves poleward, cools, and releases its moisture.

Probable Projections

The following have a greater than two out of three chance of being true:

- Model studies project eventual marked decreases in soil moisture in response to increases in summer temperatures over northern mid-latitude continents. This result remains somewhat sensitive to the details of predicted spring and summer precipitation, as well as to model assumptions about land surface processes and the offsetting effects of airborne sulfate particles in those regions.
- Climate models imply that the circum-Antarctic ocean region is substantially resistant to warming, and thus little change in sea-ice cover is predicted to occur there, at least over the next century or two.
- The projected precipitation increases at higher latitudes act to reduce the ocean's salinity and thus its density. This effect inhibits the tendency of the water to sink, thus suppressing the overturning circulation.
- Very recent research [7] suggests that tropical storms, once formed, might tend to become more intense in the warmer ocean, at least in circumstances where weather and geographical (for example, no landfall) conditions permit.
- Model studies project that the standard deviations of the natural temperature fluctuations of the climate system would not change significantly. This indicates an increased probability of warm weather events and a decreased probability of cold events, simply because of the higher mean temperature.

Incorrect Projections and Policy Implications

There are a number of statements in informal writings that are not supported by climate science or projections with high-quality climate models. Some of these statements may appear to be physically plausible, but the evidence for their validity is weak, and some are just wrong.

There are assertions that the number of tropical storms, hurricanes, and typhoons per year will increase. That is possible, but there appears to be no credible evidence to substantiate such assertions.

---

[7] T. R. Knutson, R. E. Tuleya, Y. Kurihara, in preparation.

Assertions that winds in midlatitude (versus tropical) cyclones will become more intense do not appear to have credible scientific support. It is theoretically plausible that smaller-scale storms such as thunderstorms or squall lines could become stronger under locally favorable conditions, but the direct evidence remains weak.

There is a large demand for specific climate change predictions at the regional and local scales where life and life support systems are actually affected. Unfortunately, our confidence in predictions on these smaller scales will likely remain relatively low. Much greater fidelity of calculated local climate impacts will require large improvements in computational power and in the physical and biological sophistication of the models. For example, the large uncertainty in modeling the all-important responses of clouds could become even harder at regional and local levels. Major sustained efforts will be required to reduce these uncertainties substantially.

Characterizations of the state of the science of greenhouse warming are often warped in differing ways by people or groups with widely varying sociopolitical agendas and biases. This is unfortunate because such distortions grossly exaggerate the public's sense of controversy about the value of the scientific knowledge base as guidance for the policy deliberation process.

It is clear that much is known about the climate system and about how that knowledge is expressed through the use of physically based coupled models of the atmosphere, ocean, ice, and land surface systems. This knowledge makes it obvious that human-caused greenhouse warming is not a problem that can rationally be dismissed or ignored. However, the remaining uncertainties in modeling important aspects of the problem make it evident that we cannot yet produce a sharp picture of how the warmed climate will proceed, either globally or locally.

None of these recognized uncertainties can make the problem go away. It is virtually certain that human-caused greenhouse warming is going to continue to unfold, slowly but inexorably, for a long time into the future. The severity of the impacts can be modest or large, depending on how some of the remaining key uncertainties are resolved through the eventual changes in the real climate system, and on our success in reducing emissions of long-lived greenhouse gases.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. JOHN R. CHRISTY

Question 1. You mentioned in your statement that 60 percent of the atmospheric mass that was projected by computer models to warm significantly has not. How significant is this 60 percent? Are you saying that the claims of global warming are based on less than half of the affected mass?

Answer. To the layman, global warming is something that happens at the surface of the Earth, i.e. the surface temperature. Much has been made about the fact the surface temperature has increased in the past 21 years. At the same time, the bulk of the atmosphere, from the surface to 5 miles up, has experienced little change in that time. The significance here is that all climate models show that with enhanced greenhouse gasses, the surface temperature will rise and that the deeper layer will rise even more. The fact this bulk-layer has not risen indicates that the surface warming of the past 21 years is not human-induced warming (if models are correct) or that the climate system is not well-represented in the present models. I believe there are significant shortcomings in the present models with regard to distributing heat throughout the bulk of the atmosphere, and that this may lead to predictions of surface warming that are too high.

Question 2. Your written statement has suggested that no model is perfect because the weather system is incredibly complex. Furthermore, you stated that the goal of models is to provide information on changes in large-scale features. Given the increases in computing power, can we ever expect to have models provide information on smaller scale features?

Answer. I do not see, with either improved computing power or with improved models, the ability to predict with confidence what the climate will be in specific regions. At this point we are unable to do so for the next ten days, much less for the next ten years or next ten decades. Since local precipitation is more critical than temperature for human and other biological systems, predictions of changes in rainfall would be of great value if we could have confidence in them. However, the present set of climate models predicts a range of precipitation changes in any given region so wide (e.g. much more, more, same, less, much less) as to be of no use for policy decisions. Thus, establishing regulations that increase the cost of energy to people (with a greater impact on poorer people) will be done so to deal with a "global average," for which the local impacts are essentially unpredictable. Even so, reductions in CO_2 through regulation will be so tiny as to have microscopic effect on the global average temperature. A global economic depression (with associated loss of living standards, health, security etc.) would most likely do more to reduce CO_2 increases than regulation. Even this would have relatively no impact on the path of the present global average climate.

Question 3. Your written testimony referred to a recent report which stated that January through March of this year was the hottest ever recorded. The satellite data showed that the atmospheric temperature above the U.S. mainland was indeed higher than average. However, most of the globe experienced lower than average temperatures. Does this suggest that what we may be experiencing is not global warming, but a shifting of the temperature patterns?

Answer. The key point here is that the news media broadcast widely the report of "warmest ever" surface temperatures over the lower-48 states. This was then linked as evidence to human-induced global warming. The global picture, however, indicated the warm temperatures over the U.S. were only part of a typical weather pattern that has alternating regions of warm and cold. The U.S. was in a very warm spot, but most regions experienced cooler than average tropospheric temperatures (see map in written testimony). Thus, the lower-48 (2 percent of the globe) was not representative of global temperatures, and the global temperatures were not showing global warmth.

Question 4. Your written statement acknowledged that in the past 100 years, sea level has risen 6 inches (plus or minus 4 inches) and is not accelerating. You further stated that for the Gulf Coast, a rise of 6 inches over 100 years is minuscule. Can you elaborate on how minuscule this impact would be?

Answer. For this question, we actually have a good source of information—the real world. The sea level has risen 6 inches in the past 100 years, and the ecosystems along the Gulf Coast have not changed appreciably because of it. When sea level rises less than an inch per decade, ecosystems can naturally adapt. It is important to note that relative sea level is always changing as natural geologic forces uplift some coasts and subsidence lowers other coasts. At the sea level rates we are discussing for the global average, the change in the volume of water in the ocean is often a smaller effect than the other natural forces for a given location.

The stresses these coastal ecosystems do endure come not from sea level rise, but from human development and human-generated pollutants in river runoff. And, these developments are more and more in harms way of the next hurricane which could have a storm surge (i.e. sudden sea level rise) of 10 to 30 feet. This is the real danger for coastal dwellers and economic infrastructure. Natural ecosystems have ways to bounce back from hurricanes, but buildings and roads don't. What I tell developers and other potential beach front property owners is "If a 6 inch rise in sea level is a problem for you, you are too close to the water."

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. NEAL LANE

Question 1. Are there any areas within climate change research which you would characterize as deficient? Is the federal government making the right choices regarding which programs it should fund?

Answer. Our current understanding of climate change is the result of significant successes in research over the last several decades, and, as is often the case in science, that success has led to many new questions. I would not characterize any aspect of our current climate research effort as deficient, but it is certainly true that we need to modify and enhance various aspects of our research effort in response to new developments in science and new needs for information. As noted in my testimony, the climate change debate has evolved from "Are we warming the Earth?" to How much are we warming the Earth? and "What impacts will that warming have?" The U.S. Global Change Research Program (USGCRP) is benefiting from the advice in a number of recent National Research Council reports, including, "Global Environmental Change: Research Pathways for the Next Decade" as it addresses these questions. A number of priorities have emerged from USGCRP consideration of recommendations from the NRC and from other scientific advisory bodies. The program is enhancing its efforts and revising its strategies in a number of key areas, including carbon cycle research, water cycle research, research on the impacts of climate change, long-term climate observations, and high-end climate modeling.

The USGCRP established a Carbon Cycle Science initiative in the FY2000 budget, focused on improving our understanding of carbon dynamics in the environment, and we have continued strong support for this in the FY2001 budget request. The FY2001 request also proposes increases for water cycle research, long-term surface based climate observations, and research to understand the ecological impacts of climate change and other global changes. All of these topics will be important areas in the new overall long-term research strategy that is now being developed. We anticipate that a plan will be ready for review later this year. My view is that the federal government is making the right choices and that the programs we support are necessarily evolving and changing as we learn more about the problems and phenomena we are attempting to understand.

Question 2. Do you believe that the upcoming IPCC report will alter the current debate among scientists or Congress? Will the report confirm what we already believe to be true?

Answer. The Intergovernmental Panel on Climate Change (IPCC) produces a comprehensive assessment of global climate change approximately every five years. I do not think the work of the IPCC really alters or changes the views of the scientific community on climate change. It is more accurate to say that it describes these views, because the scientific community produces IPCC reports. This is one of the reasons they are so valuable. The process of creating IPCC assessment reports certainly influences scientific debate and discussion over many aspects of climate change, but I think it is important to note that the current scientific debate on climate change is not over whether climate change is occurring. It is rather over detailed projection of how much change will occur, exactly how much of this change is due to various forcing factors, and precisely what impacts change will have.

The upcoming Third Assessment Report, which is currently under government and technical review, will be completed in early 2001. I expect this report to confirm and reinforce the broad scientific consensus that atmospheric CO_2 has been significantly increased by human activities, that the surface of the earth is warming, and that the earth's surface temperature will continue to rise during the next century. It will document the increase in understanding that has occurred since the SAR was completed in 1995, and I believe it will also confirm the assertion in my testimony that the research and policy communities can now appropriately shift from a primary focus on the physical systems of climate change to a broader effort to understand how global change will affect the Earth's biological systems and the human societies that are dependent on them.

Question 3. Do you believe that the U.S. Global Change Research Program is achieving its full potential? What are the weaknesses of this multi-agency program? Are they currently being addressed?

Answer. The USGCRP has been and is a successful program that can serve as a model for broad multi-agency cooperation in addressing a crosscutting research theme. Coordinating a complex research agenda across a dozen diverse agencies of the federal government is difficult, and it is critical that the Program evolves in response to changing research priorities. With input from the NRC and the participating federal agencies, a new long-term strategic research plan is being developed for the Program.

Question 4. What are our national objectives for the modeling program?

Answer. Most global climate modeling research and application in the United States is sponsored by NSF, DOE, NASA, and NOAA. These agencies each have their own individual planning processes, but they have also worked together to establish well-defined priorities consistent with goals and objectives of the USGCRP.

As noted in numerous versions of "Our Changing Planet," the USGCRP modeling strategy calls for the use of the most powerful supercomputers to accommodate evolutionary development and revision of the climate models. An interagency group has established the Common Infrastructure Initiative and has made progress in development of a flexible national modeling infrastructure that will facilitate the exchange of scientific advances and technology between climate modeling and research and operational weather modeling groups. A USGCRP Integrated Modeling and Prediction Working Group formally coordinates the agencies' climate modeling research. This Working Group, which reports to the SGCR, has reviewed and endorsed the various plans for climate modeling activities and, in particular, the proposal for the Climate Simulation Laboratory at the National Center for Atmospheric Research (NCAR). In addition, the Advisory Board for the NSF-sponsored Climate System Model at NCAR has been reconstituted to include scientists and managers from DOE, NASA, and NOAA to reflect their growing participation in the nation's only community climate model.

Two specific efforts are underway to develop a national strategy for climate modeling, one by the National Research Council, and one by the agencies. These are complementary efforts with overlapping membership. Both are responsive to the recent Modeling report produced by the National Research Council that identified problems in high-end U.S. climate modeling capabilities. An important aspect of the USGCRP agency effort is to determine how the climate modeling community should focus its efforts and investments to best leverage the new capabilities that will be developed through the Administration's Information Technology Research (ITR) initiative to create more advanced supercomputers and software.

Finally, an implicit requirement for an effective modeling program is a robust observation system that can provide consistent, long-term data on the many parameters of the climate system. Thus, a diverse approach that supports modeling, observations, research and analysis, and assessment is needed. Each of these activities relies upon and informs the others.

Question 5. What are some of the lessons learned from the first National Assessment?

Answer. The "U.S. National Assessment of the Potential Consequences of Climate Variability and Change" is now nearing completion. We have learned a number of lessons related to process, research needs, and potential impacts. Related to process, I want to be on record in expressing sincere appreciation for the overwhelming support received in this effort. Stakeholders were very forthcoming in sharing their insights and concerns, which were critical in providing direction. Individuals from academia, industry, and non-governmental organizations demonstrated exceptional willingness to serve by volunteering their time to be chapter authors, technical reviewers, and advisors to the process.

In terms of research needs, work on the Assessment revealed a number of key priorities for further work. It became clear that we need more basic knowledge about how natural ecosystems and managed ecosystems such as agriculture and managed forests will respond to changes in climate and in atmospheric CO_2 concentration. Since many of the resources and ecosystems that will be affected by climate change, such as water and forests, are intensely managed, it is crucial that we understand better how present and potential future management practices could either compound or mitigate the effects of climate change and other environmental stresses. Finally, since the degree of impacts will inevitably depend on the actual rate and character of climate change, it is important to continue working to reduce uncertainties in our knowledge and projections of climate. This will require further improvement in climate models and our understanding of past climate variation, further development of methods to refine regional-scale projections, and crucially, better understanding of the socioeconomic drivers of potential climate change, such as population, demographics, income levels, and energy use patterns.

Question 6. The National Research Council report entitled "Global Environmental Change: Research Pathways for the Next Decade" stated that the USGCRP must be revitalized, focusing its use of funds more effectively on the principally unanswered scientific questions about global environmental change. What has been the USGCRP reaction to this point?

Answer. As noted in my testimony and in the answer to question 1, the USGCRP relies on input from both participating federal agencies and the broader scientific community to set research priorities and devise appropriate strategies for addressing critical issues. With guidance from the "Pathways" report, USGCRP research has been organized into a set of "program elements," including a Carbon Cycle Science initiative established in FY2000, and a Global Water Cycle initiative included in the FY2001 budget request:

- Understanding the Earth's Climate System
- Biology and Biogeochemistry of Ecosystems
- Composition and Chemistry of the Atmosphere
- Paleoenvironment/Paleoclimate
- Human Dimensions of Global Change
- Carbon Cycle Science
- The Global Water Cycle

The "Pathways" report is also a basis for current efforts to develop a new 10-year strategic plan for the USGCRP.

Question 7. Can you summarize how USGCRP has been meeting the requirements of Section 104 of the Global Change Research Act of 1990 (P.L. 101–606)?

Answer. The creation of a comprehensive research plan was one of the most important early tasks of the USGCRP. The 1991 edition of Our Changing Planet had two volumes, one of which was titled Our Changing Planet. The FY1991 Research Plan. This 250-page document was a detailed and comprehensive scientific strategy for the USGCRP. The ongoing consideration and revision of the plans set forth in this document has been an important topic for the USGCRP agencies as they engage in their yearly program planning and budget processes, and updates to these plans have been included in the subsequent editions of Our Changing Planet.

The progress that has been made in many areas of global change science, and the advice received in a number of major studies from the National Academy of Sciences, including the Pathways report, has resulted in a major effort to define a new long-term strategy for the USGCRP. This process has been underway for several years, and we anticipate that a draft will be submitted for public comment and NRC review later this fall. The draft will cover all the areas outlined in Section 104 of the U.S. Global Change Research Act.

Question 8. Given that USGCRP is ten years old, do you believe it's an appropriate time for a new ten-year plan?

Answer. Absolutely. The process of review and program improvement is continuous. The next important step in this process will be the completion of a new long-term plan later this year. This plan will be submitted to the National Research Council for review. The NRC Committee on Global Change Research, the follow-on committee to the "Pathways" report, is working with the USGCRP agencies to construct a reasonable schedule for review of progress in responding to the recommendations of the Pathways report and the new long-term plan.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. JERRY MAHLMAN

Question 1. You mentioned in your statement that important uncertainties remain due to deficiencies in our scientific understanding and in computer power. Can you explain how an increase in computing power will enable you to reduce some of the uncertainty in your models?

Answer. Increases in computer power and increases in ability to process very large volumes of data play an important role in reducing the scientific uncertainty in understanding human-caused climate warming.

First, increased computational power allows the climate models to resolve regional details far better. For example, today's long-running atmosphere-ocean-climate models represent the entire state of Arizona with one or two computational points. A factor of 10 increase in computer power allows Arizona and its complex topography and climate zones to have 20 or so points.

Second, it has been found advantageous to increase understanding of computer model experiments by running multiple versions, each under somewhat different circumstances. This allows a clearer view of what we do and do not understand well.

Third, much of the remaining scientific uncertainty in this problem arises from incomplete information about key physical processes, such as clouds, turbulence, severe storms, complex land-surface biosphere/climate interactions, etc. Greater computational power allows inclusion of considerably more complete physical processes and their possible roles in either decreasing or increasing our best estimates as to how much or how soon significant warming will occur, and how specific regions will be affected.

Fourth, greater computational power allows the major national climate modeling centers to interact more productively with colleagues in government, academia, and private industry, simply because more experiments can be run at greater fidelity, with more talented scientists evaluating the results from a wider range of perspectives.

Question 2. You mentioned that climate modeling efforts must receive resources that are in balance with broader scientific programs. What are your current funding levels and what level would you recommend?

Answer. The current total funding for NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) is about $22M in Fiscal Year 2000, of which $13M is in base funds, and most of the remainder in HPCC/IT2 interagency program funds. I believe it is fair to say that, thanks to a genuine FY2000 and 2001 commitment from Congress, OMB, and the Department of Commerce, GFDL's current supercomputer budget is in comparatively good shape. A number of our respected U.S. colleagues have not been as fortunate.

For example, in NOAA it has been much easier to obtain funding for large hardware ventures (e.g., satellites, ground-based measurement systems, and supercomputers) than for funding the scientific talent required to achieve optimal value from these critical investments. Even a 5% "tax" on these large "hardware" commitments would have produced a very highly leveraged enhancement of these "big ticket" items. Also, the recent National Research Council's "Pathways" report has made a similar point about the under funding of NASA's research base necessary to optimize the value of its large satellite programs.

In the case of my own lab, GFDL, the stresses created have been daunting. Over the past 15 years, GFDL's base funds for science have diminished by more than half in purchasing power due to unfunded inflationary losses, to increased administrative costs, and to Congressionally authorized pay raises, so conspicuously unaccompanied by the funds necessary to pay for them.

In my strong opinion, this seemingly oblivious diminution of the federal research talent base has produced a serious reduction from the expected return on NOAA's and NASA's substantial investments in large environmental data and computing systems. Moreover, I see no evidence of any observable reversal of this destructive trend. In fact, the current budget initiative processes in place for FY2001 and 2002 appear to perpetuate this seemingly oblivious shortfall in the return from our big ticket "hardware" investments, including supercomputers.

Many of us in the scientific community find it inexplicably baffling that something so obvious and so amenable to repair can remain so conspicuously unaddressed for so long.

Question 3. Can you discuss the validation process used to authenticate your models?

Answer. Let me begin by asserting that there is no such thing as a "validated climate model." We do find that the models perform very well for certain processes under certain circumstances. These same models exhibit important deficiencies under other circumstances. Interestingly, the same dilemma is present in the futile quest for "validated" data sets. There is a surprisingly small number of the scientists who analyze observational data and output data from model experiments who are focused on sharpening our understanding by careful evaluation of the strengths, weaknesses, and information content of these "real-world" and model-based data sets.

Given the above constraints, models are *evaluated* (not validated) through careful assessment of their agreement (or lack thereof) with carefully analyzed data sets. For example, are the model's simulated desert regions in the right location with the right climate and the right level of natural variability on time scales of years to decades? Are the characteristics of the modeled Arctic region, including sea ice, in agreement with available data? Does the model simulate credible El Niño and La Niña events? Are the characteristics of the moist subtropics, such as the southeast U.S., properly simulated? Is the seasonal cycle of climate correctly simulated in all of these regions? Generally speaking, the answers to these kinds of questions is *yes*. However, a closer look often reveals significant discrepancies between observations and model simulations.

Does a correct simulation of the present guarantee that we can simulate future climate well, assuming that we know how carbon dioxide, sulfate particles, and other greenhouse gases will change in the future? Not necessarily. Such agreements do add confidence to our use of the models as a tool, but do not supply the desired guarantee.

A very important international effort is currently underway to use the observed, roughly 1.3°F, warming of the global-mean surface-air temperature over the 20th century as a critical test of the models' abilities to project future climate changes. This international collaborative effort, which includes GFDL and the National Center for Atmospheric Research, is showing that the models capture the essence of the observed 20th century warming rather well, although the models differ in their details. These studies do indicate, however, that imperfections in the observations, in the "exotic" forcings operative in the past century (such as solar changes, and indirect effects of sulfate and carbon particles), and in the models themselves, still prohibit us from tightly constraining the levels of uncertainty in the model-based projections. That is why my official testimony gives a 2–6 °F range of warming for "business as usual" in the middle of this century. In spite of this genuine uncertainty, there is still no viable hypothesis that makes a credible case that the global warming problem will be substantially less than our best current estimates.

Question 4. Why is the largest uncertainty regarding global-mean surface warming due to clouds? Can you explain this further.

Answer. Many aspects of calculating the key effects of global warming are rather simple; many of its basic features are rather well understood. For the past three decades, for example, the clear-sky trapping of outgoing heat radiation from the earth by CO_2 and other greenhouse gases are well documented, as are many aspects of the role of water vapor increases in amplifying this "greenhouse" trapping effect.

As we all know, cloudy skies have a dramatic effect in suppressing the overnight cooling that is so evident when skies are clear. Clouds thus absorb outgoing heat radiation and radiate energy back to the earth's surface, producing a warming effect. They also reflect incoming radiation from the sun, producing a cooling effect. Increasing clouds near the ground produce a net cooling effect on the climate, while increasing clouds at 6 miles altitude tend to warm the climate.

Each of these separate cloud effects are difficult to calculate with accuracy. The combined effects in the context of climate change tend to be small differences between large opposing effects, of which all carry significant uncertainty. Moreover, the effects vary differently in different geographic regions, and all of these effects depend upon the details of very small-scale phenomena on the scale of the water droplets and/or ice crystals in the clouds. Furthermore, satellite-based measurements do not neatly diagnose the net role of clouds very well, even in today's climate.

Thus, clouds have legitimately earned their place as the leading source of the uncertainty in our projections of climate change.

Question 5. What is your current accuracy rate of climate models for projecting tropical storms, earthquakes, and floods? How has your understanding of global warming changed your models?

Answer. I am rather confident, better than 2 out of 3, that hurricanes and similar tropical storms, once formed, will tend to have stronger winds and considerably greater rainfall as the climate and the oceans continue to warm. The warmer and moister atmosphere and the warmer ocean below, simply put, makes the potential energy of a hurricane significantly stronger. Today, those hurricanes that stay over warm water for sufficient time do tend to approach their maximum potential power. We expect that to be also true in the future, only at higher intensities. Some have argued that we also should expect more hurricanes in the future warmer earth. That may be so, but I see no convincing scientific evidence that says that. For now, we simply do not know.

All models of which I am aware do tend to produce more floods- in those regions where floods already tend to be prevalent today. At the simplest level, this effect is mainly due to the expected higher water vapor amounts in the atmosphere due to increased evaporation efficiency over the warmer oceans. In effect, wet weather systems become even wetter because the atmosphere will carry more water. Conversely, drought prone regions, such as the southwest U.S., are likely to be even drier due to increased evaporation of soil moisture in the warmer climate.

Earthquakes have no known or suspected connection to a warming climate. Even speculated effects would be expected to be very weak.

Our models have evolved significantly in response to improvements in our understanding of very complex phenomena. For example, the mathematical modeling of clouds has become significantly more sophisticated in the treatment of radiative, convective, and cloud microphysical processes. Unfortunately, these improvements have yet to produce dramatic breakthroughs in this dauntingly difficult problem. However, the problem is now being attacked with increasingly focused tools from specialized observations, better theories, and models more firmly rooted in fundamentals of atmospheric physics and dynamics.

Question 6. You stated in your testimony that you are "virtually certain" that increasing greenhouse gases are due to human activities. What erased the doubt in your mind?

Answer. Actually, there has not been much doubt about this in the scientific community for over a decade. For the dominant greenhouse gas, carbon dioxide, we can directly calculate the changes in atmospheric fossil fuel carbon from year to year by measuring the amount of the isotope, carbon-14. This isotope is produced in the atmosphere by bombardment from high energy solar cosmic rays. Once created in the atmosphere, carbon-14 decays with a half life of about 5500 years. Because of this, fossil carbon in the form of coal, oil, and natural gas that has been buried for a hundred million years is devoid of the carbon-14 isotope. As more fossil carbon is injected into the atmosphere, the carbon-14 isotope has become progressively more deficient relative to the non-radioactive carbon-12 form.

Thus, we are not debating whether humans have substantially modified the carbon dioxide amounts in the atmosphere. They have. The real science issue is focused on how much climate change will occur. Beyond the science, people are concerned about who or what would be the most impacted, and who will "pay" the near-term costs of mitigating carbon dioxide emissions, or the delayed costs of dealing with the impacts of climate change upon essentially all life forms on earth.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. KEVIN E. TRENBERTH

Question 1. The national Research Council's report mentioned a substantial disparity between satellite data and surface temperature trends. Can you summarize the extent of the disparity?

Answer. Over the 20 years 1979 to 1998, the linear temperature trend for the surface is estimated to be 0.25 to 0.4°C in contrast to 0.0 to 0.2°C for the satellite data. While uncertainty exists in the exact trend number at about the 0.1°C/decade level (owing to how the spatial coverage of data is handled, how global averages are computed, treatment of missing data, begin and end points, etc.), the difference is large enough that it is significant. It was labeled a "disparity" by the report as opposed to a "discrepancy" as the latter implies something amiss, whereas the report assesses that it is likely mostly real and arises because the two measurements are of different physical quantities.

Question 2. The National Research Council report noted that at the outset none of the temperature measurements systems were specifically designed for long-term climate monitoring. Can you discuss the design life for these instruments and how it compares to the actual life? Also, what are the implications of this extended use on the accuracy of the measurements?

Answer. At the surface, measurements are made with individual thermometers at many sites around the world. As well as calibration of the thermometers, the siting and exposure to the atmosphere must be standardized and should not change in time if climate trends are to be correctly monitored. Changing thermometers is not an issue, as they are quite accurate. Of more concern are changes in the way and time of day they are read, and changes in exposure (such as trees or buildings changing nearby, or building a city around the site; this latter point is the "urban heat island effect"). Movements of sites for convenience, such as from city sites to the airport, are a substantial problem and this and other changes in practice, can be overcome as long as parallel measurements are maintained for at least a year, but often this has not been done.

For the atmosphere above the surface, radiosonde packages of instruments are used. The package is flown on a balloon and is regarded as expendable and only used once. As a result the package must be as inexpensive as possible, which has led to compromises in quality. Changes to new improved technology can appear as a spurious change in climate unless such changes are measured and adjusted for. Mostly this has not been the case.

For satellites and their platform of instruments, the typical design life is about 4 or 5 years. Problems arise with occasional loss of a satellite upon launch or premature failure of one or more instrument components. As the design for the NOAA series of satellites is to have two satellites in orbit at all times (one in the morning and one in the afternoon), there is some overlap expected from one satellite to the next. There have been times, however, notably in 1985 and 1986 when NOAA–9 was the only satellite flying, that the overlap at both ends was too short to reliably splice the record from one satellite to the next. Normally this is done by matching records between overlapping satellites. The difficulty of doing this is compounded by the fact that the orbits of the satellites are not stable. Instead they tend to drift, both through orbital decay and in local crossing time. This latter effect means that measurements are made at slightly different times each day. For instance, NOAA–11 drifted from an equator crossing time of 2 p.m. to after 5 p.m. from 1989 to 1994. The difference in temperature between these times of day is considerable and appears as a climate change over time unless corrected for. Corrections are indeed made for this but they are likely to be imperfect and leave residual effects that may be significant over land where the diurnal temperature changes are large. Orbital decay also has effects by altering the geometry of any measurements that are not directed in the vertical (which is most of them), and this alters the interpretation of the measurements, which is recently being allowed for. On-board calibration of the instrument itself helps to minimize effects of instrumental drift and changes in exposure of the instrument to the sun as the orbit changes and with time of year, which otherwise would also be considerable. Attempting to allow for such effects has been fully tried only recently but the adjustments are empirical, so again residual errors are probable, although these are believed to be small.

Question 3. Dr John Wallace, who served as Chairman of the National Research Council's Panel on Reconciling Temperature Observations, is quoted as saying that "There really is a difference between temperatures at the two levels that we don't fully understand." Do you agree with that statement and, if so, can you comment on the level that we don't understand?

Answer. I agree with the statement, although I also think it does warrant clarification. We have hypotheses about the nature of the differences but proving them or narrowing the possibilities down is difficult. Firstly, there are many differing influences on the temperatures at different levels in the atmosphere. At the surface it matters a great deal whether the surface is land or ocean, and over land whether the surface is wet or dry and how much vegetation is present. These influences are much less further aloft. Direct radiative heating within the atmosphere matters a great deal in the troposphere, and so it is important to known the spatial distribution and vertical profiles of greenhouse gases (water vapor, carbon dioxide, methane, etc., and especially ozone), aerosols and clouds. The radiative properties of the aerosols (how absorbing versus reflecting/scattering) are affected by the relative humidity and are poorly known and highly heterogenous in space and time. Similarly for clouds, the water content and size of droplets in clouds are needed to characterize their radiative effects. Secondly, the models we have that translate the forcings just mentioned into a vertical temperature profile also contain uncertainties and imperfections. Some of the processes believed to be important, such as convection, are either not well enough understood or are very difficult to model accurately because, for instance, of horizontal and vertical resolution of the model. Thirdly, there are likely to be some remnant errors in the observations that also add to uncertainties.

Climate models need to be further improved (especially in how they handle convection and clouds), the changes in distributions of greenhouse gases, aerosols, and clouds, and their radiative properties need to be much better known to narrow the uncertainties, and further improvements are desirable in the observational record.

Question 4. The National Research Council report stated that increases in the number of small particles called aerosols often mask the greenhouse effect, and that stratospheric depletion contributes to cooling of the upper troposphere and stratosphere. How much cooling is taking place as a result of these aerosols?

Answer. Aerosols vary enormously in space and time because they are washed out of the atmosphere by rain, and so their lifetime is typically 5 to 10 days. This is the reason they vary so much spatially and they tend to be greatest in concentration near their source. The sources vary greatly around the world. Some aerosols (containing soot for instance) absorb solar radiation and produce heating, but the most pervasive ones in the Northern Hemisphere make up the milky white haze that you see from airplane windows crossing North America and these sulfate aerosols cause cooling by reflecting the sun's rays back to space. The cooling from sulfates is believe to be about –0.5 W m^{-2} (plus or minus 50%) which converts to about a cooling of roughly 0.3°C over the past century. A bigger effect may come from the changes in clouds from aerosols. Aerosol particles encourage more cloud droplets to form, which makes a cloud brighter and more reflective. Low cloud is known from observations to have increased but how much of this increase is due to aerosols is unknown. The cooling is estimated to range from 0 to perhaps as much as –2 W m^{-2} and so the cooling could be as much as 1.2°C. Over land since 1950, the maximum temperature is rising at a rate of about 0.1°C/decade less than the minimum temperature and this has been shown to be mainly due to the increase in cloudiness. So there is huge uncertainty to this answer.

[Please note, the numbers in this answer are in the context of the IPCC estimates of radiative forcing. These include 2.3 W m^{-2} for the sum of the main well mixed greenhouse gases (not including ozone) to date and perhaps a total of about 1.5 W m^{-2} for all radiative forcings. I use a translation into a temperature change of 4 W m^{-2} (the value for doubling carbon dioxide alone) corresponding to 2.5°C. This total would then correspond to over 0.9°C increase in temperature versus 0.7°C observed; the difference being due to delays in the system response.]

Question 5. You mentioned in your written statement that changes in extremes changes in climate will be much greater than changes in the mean as a result of global warming and the increased amount of moisture in the air. Can you elaborate on the types of extremes we may be experiencing?

Answer. A relatively small change in the mean of any quantity can alter the frequency of extremes by 100% or more. By their very nature, extremes occur rarely, and so observationally based statistics on them and their changes are hard to come by. The databases to determine their changes are less available and the demands on accuracy are much greater, and so actual measured changes in extremes are often uncertain.

Changes in some extremes have been documented in the United States and to a much lesser extent elsewhere. In the United States, precipitation is increasing, and most of that increase is in the heaviest (top 10%) rainfall rates. Extremes of daily rainfall of over 2 inches per day have increased about 10% over the past century. (Because it typically rains 10% or less of the time, hourly rather than daily rainfall data should be used for this analysis, but are much less readily available). Much below normal temperatures (lowest 10%) are decreasing and much above normal temperatures (top 10%) are increasing for the U.S. (although some record high temperatures still hark from the 1930s in the Dust Bowl era). In general, extremes are observed to be increasing.

What we expect, but have little documentation of, is that rainfall rates are increasing, so that when it rains, it rains harder, and there is thus more runoff and a greater risk of flooding. Whether flooding occurs or not depends on whether it is mitigated by building drainage ditches, levees, culverts, etc. through planning by the Corp of Engineers and local councils in the U.S. In many developing countries, however, the risk of flooding has been exacerbated by deforestation that greatly increases runoff. In most places, increased building in coastal areas and flood plains has increased vulnerability to flooding. It is also suspected that droughts set in more quickly through increased drying. Plant therefore wilt faster and droughts become more severe and are apt to last a bit longer with global warming. The result is greatly increased risk of wild fire and for "control burn" fires to get out of control. Heat waves are also more likely. The "heat index," which combines humidity and temperature effects, is likely to venture into the uncomfortable range more often and over much greater areas.

Question 6. Figure 2 of your statement indicates a decrease in the average mean global temperature in the year 1940. Can you explain the decrease?

Answer. The global mean temperature had a peak in the early 1940s and there was a decline or leveling off until about the 1970s. Firstly, observations during World War II were less abundant than before or after but also occurred in new areas (like the Pacific atolls) and so some of the temperature peak might not be real (e.g., one can not stand on the deck of a ship and read a thermometer at night with a light during war, and so the thermometer is taken inside where it may be warmer.) However, a massive long-lived El Niño from 1939 to 1942 no doubt contributed to the warmth. Secondly, following the war there was great industrial development that is known to have increased the amount of aerosol in the atmosphere sharply, and so this contributes a cooling effect. Thirdly, the warming from about 1920 to 1940 was probably in part caused by increases in solar radiation, which leveled off in the 1940s. Climate models run with reasonable estimates of the changes in aerosols and sun plus greenhouse gas increases are able to reproduce this feature.

Question 7. One of the recommendations of the NRC report (page 25) states that the scientific community should explore the possibility of exploiting the sophisticated protocols that are now routinely used to ensure the quality control and consistency of the data ingested into operational numerical weather prediction models, to improve the reliability of the data sets used to monitor global climate change.

Would you explain this recommendation and discuss how it should be implemented?

Answer. During the ingestion of data into four dimensional data assimilation systems, extensive quality control of the observations occurs: 1) through comparison of observations with estimates of the observed values from the previous forecast, and 2) comparison with adjacent observations of all kinds in a consistent physical (model) framework. Sometimes this enables correction for some kinds of errors and it allows systematic errors to be estimated. The result is that a quality control flag can be assigned to each observation and information exists on whether the observation was used or rejected, and how accurate it appears to be. This information should be retained and archived. In the case of rejected or missing data, an accurate estimate of what the observation should have been can be made, and this estimate can be utilized to improve the data set. Similarly, more intelligent decisions can be made to quality control the whole data set and make it more reliable.

My recommendation is to have the numerical weather prediction centers, in collaboration with climate scientists, select a subset of observations (in particular a subset of radiosonde observations) and generate an enhanced data set that includes, with the original observation, the quality control output and estimates of correct values in cases of missing or erroneous data. This could feasibly be done for temperature, and perhaps humidity and wind measurements during a reanalysis of past data. In particular, monthly summaries of estimates of offset bias should prove very valuable. Then independent analysis of the more comprehensive data set should enable more reliable trend estimates from the radiosondes.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO ROBERT WATSON

Question 1. If you consider all of the peer-reviewed assessments that the IPCC has made over the years, have there been any distinctive trends in the findings? Have any of the studies contradicted each other?

Answer. There has clearly been a longer observational record and an evolution in our understanding of the Earth's climate system and the potential influence of human activities. Our understanding of the fundamental process that control the Earth's climate have clearly improved, although significant uncertainties still remain. This, improved understanding of the processes that control the Earth's climate system, combined with more powerful computers, has led to significantly more sophisticated theoretical models that include a more realistic simulation of land, oceanic and atmospheric processes with increased spatial resolution.

There have been no major changes in the conclusions of successive IPCC reports. In most cases, based on new research findings, there have been small changes in understanding but few, if any, substantial changes in our fundamental understanding.

Let me summarize how our understanding has evolved since the First IPCC assessment in 1990 using just a few key issues to illustrate trends in findings. I have focussed my answer on the climate system rather than on the projected impacts of climate change on human health, socio-economic sectors and ecological systems or the projected approaches to mitigate climate change:

1. Past changes in atmospheric composition, climate and climate-related parameters:

- *atmospheric composition:* the atmospheric concentrations of the major greenhouse gases, i.e., carbon dioxide, methane and nitrous oxide have all continued to increase. However, the atmospheric concentrations of some of the chlorofluorocarbons have peaked and are now decreasing because of the effectiveness of the Montreal Protocol.
- *temperature:* global mean temperatures have continued to increase with the warmest three years of the last century all occurring since 1990;
- *precipitation:* globally, precipitation is continuing to increase. However, we have now shown that the spatial and temporal distribution of precipitation is changing in some regions of the world, e.g., in the U.S. there is now evidence of more precipitation in winter and an increase in heavy precipitation events in summer.
- *sea level:* the latest analysis confirms earlier conclusions that sea level has risen 10–25 cms over the last 100 years.

2. Attribution of the observed changes in climate:

- in contrast to the first assessment report, the second assessment report concluded that the observed changes in the Earth's climate over the last 100 years could not be ascribed to natural phenomena alone, and concluded that there was now a discernible human influence on the Earth's climate.

3. Projected changes in atmospheric composition, climate and climate-related parameters:

- *atmospheric composition:* the emissions scenarios work has become more sophisticated, but the bottom line conclusion largely remains the same, i.e., there is a wide range of plausible future greenhouse gas emissions, which primarily depends on population and economic growth, technological advances and governance structures.

- *climate sensitivity:* projected changes in climate depend upon projected changes in atmospheric composition (greenhouse gases and aerosols) and the sensitivity of the climate models to changes in atmospheric composition, i.e., the response function, which we have termed the climate sensitivity factor. In spite of our improved understanding of the climate system, there has been no change in our estimate of the climate sensitivity factor since the first assessment report, i.e., global mean surface temperatures are projected to increase from 1.0–4.5 degrees Centigrade at equilibrium in a doubled carbon dioxide world, with the best estimate being 2.5 degrees Centigrade.
- *aerosols:* the "cooling" role of aerosols was not recognized in the first assessment report, but was in the second assessment report.
- *temperature:* projected changes in global mean surface temperature in 2100 have varied from the first assessment report until now, but well within the uncertainty range and because of known factors. The business as usual best estimate projection for changes in global mean surface temperature in 2100 was 3.0 degrees Centigrade, within a range of 2.0–5.0 degrees Centigrade (the business as usual greenhouse gas scenario coupled with the range of climate sensitivity). In the second assessment report, the business as usual best estimate projection for a change in global mean surface temperature in 2100 was 2.0 degrees Centigrade within a range of 1.0–3.5 degrees Centigrade (four greenhouse gas scenarios coupled with the range of climate sensitivity). If the latest IPCC emissions scenarios are used in conjunction with a range of climate models the projected changes in mean surface temperature in 2100 would be from about 1.0–5.0 degrees Centigrade (six greenhouse gas scenarios coupled with the range of climate sensitivity). The decrease in the business as usual best estimate projection for changes in global mean surface temperature in 2100 between the first and second assessment report was due to lower projections of chlorofluorocarbon emissions (Montreal Protocol) and carbon dioxide emissions and the inclusion of sulfate aerosols in the models (sulfate aerosols tend to cool the atmosphere and hence partly offset the warming effect of the greenhouse gases).
- *precipitation:* projections of changes in precipitation have consistently shown an increase in global precipitation, with increases in the tropics, mid- and high-latitudes and decreases in the sub-tropics. The exact changes are model dependent.
- *sea level:* projected changes in global mean sea level in 2100 have varied slightly from the first assessment report until now, but well within the uncertainty range and because of known factors. The business as usual best estimate projection for changes in global mean sea level in 2100 was 65 cms, within a range of 30–110 cms. In the second assessment report, the business as usual best estimate projection for a change in global mean sea level in 2100 was 50 cms within a range of 15–95 cms. If the latest IPCC emissions scenarios are used in conjunction with a range of climate models the projected changes in mean sea level in 2100 would be from about 10–90 cms. The changes in projected sea level occur primarily because of changes in temperature projections, as well as in some cases because of small changes in the glacier, ice sheet and ocean models.

Question 2. You mentioned in your statement that the time to reverse the human-induced changes in the climate and the resulting environmental damages would not be years to decades but centuries to millennia. Is it reasonable to make any major conclusions on the future based upon models and data collection systems that may need further refinement?

Answer. Yes. While recognizing there are uncertainties associated with precisely quantifying changes in climate at the regional and global scale, and hence the associated impacts on human health, socio-economic sectors and ecological systems, stating that the time to reverse human-induced changes in the climate and the resulting environmental damages would not be years to decades but centuries to millennia is a robust conclusion. The conclusion primarily rests on an understanding of the lifetime/adjustment time of carbon dioxide, the major anthropogenic greenhouse gas. The lifetime of carbon dioxide is governed by the exchange of carbon dioxide between the atmosphere and the deep waters of the oceans. Whilst there is a rapid equilibration (less than five years) of carbon dioxide between the atmosphere and the surface waters of the oceans, it takes much longer (more than a century) for carbon dioxide in the atmosphere to equilibrate with the deep oceans. Our understanding of this feature of the carbon cycle is based on models that have been field-tested against tracer data, e.g., the rate of uptake and diffusion into the deep oceans of atmospheric chlorofluorocarbons and radio-active carbon (formed during the atomic bomb tests).

The small portion (15–25%) of human-induced changes in climate that can be attributed to short-lived gases, i.e., methane (a lifetime of about a decade) and tropospheric ozone (a lifetime of a few days) can be reversed much quicker. Conversely, reductions in sulfate aerosol precursor emissions (i.e., sulfur dioxide) would lead to a rapid increase in climate change because of the very short lifetime (days).

Question 3. Would you describe some of the technologies that can be used to mitigate climate change.

Answer. The IPCC Second Assessment Report concluded that there is a wide range of technologies that already exist that can be used to cost-effectively mitigate climate change. However, before listing some of them it is important to note that cost-effective mitigation of climate change (Article 3 of the UNFCCC) will be most effective through a combination of changes in both the policy framework and the fuller utilization of a wide of technologies in energy supply, energy demand and the agricultural/forestry sectors. In addition it should be recognized that stabilization of greenhouse gas concentrations in the atmosphere (Article 2 of the UNFCCC) will require the development and market penetration of new and improved technologies, hence the need for increased public and private sector funding for R&D.

All of the policy and technology options listed below are discussed in significant detail in IPCC assessments and Special Reports, e.g., technology transfer and land-use, land-use change and forestry.

Policy Framework: It is important to get the policy framework correct in order to stimulate the utilization of "climate-friendly" technologies and strategies, domestically and internationally. For example, if there are policies that distort the market, e.g., fossil fuel subsidies, they both discourage the efficient use of energy and the penetration of modern renewable energy technologies. An appropriate policy framework, augmented by education and training programs, would combine:

- command and control, e.g., energy efficiency standards, energy taxes;
- market mechanisms, e.g., domestic and international emissions rights and project-based carbon offset trading; removal of subsidies that increase greenhouse gas emissions; incentives for the use of new technologies during market build-up;
- voluntary measures.

Technologies and Strategies: There needs to be a concerted effort to produce and use energy more efficiently and to emit lower amounts of greenhouse gases, and to reduce emissions and increase the uptake of carbon in agricultural, forestry and rangeland systems. In addition to energy and land-use technologies, information technologies can be used, inter-alia, for the more efficient management of energy systems, improve the efficiency of transportation systems and decrease travel miles through telecommuting and teleconferencing.

- Supply side options include:
  - fuel switching (coal to gas)
  - increased power plant efficiency (co-generation)
  - carbon dioxide sequestration (carbon dioxide separation followed by long-term sequestration)
  - renewable energies, e.g., wind, solar electric, solar thermal, modern biomass, small-scale hydropower and geothermal
  - nuclear
- Demand-side options include:
  - transportation (e.g., lighter vehicles, increased combustion efficiency, alternate fuels (e.g., fuel cells), electric vehicles, hybrid vehicles (combustion/electric)—land-use planning can improve the efficiency of transportation systems.
  - commercial and residential buildings (e.g., building shells, lighting, heating and air conditioning systems, computers, appliances)
  - industry (e.g., processes, recycling)
- Agriculture, Forestry and Rangelands
  - improved agricultural (e.g., no-till) and grazing land management
  - agroforestry (only a significant option in developing countries)
  - afforestation, reforestation, slowing deforestation and improved forest management

○