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CLEAN AIR ACT: RISKS FROM GREENHOUSE GAS EMISSIONS

HEARING

BEFORE THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

SECOND SESSION

ON

THE ECONOMIC AND ENVIRONMENTAL RISKS ASSOCIATED WITH INCREASING GREENHOUSE GAS EMISSIONS

MARCH 13, 2002

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COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

ONE HUNDRED SEVENTH CONGRESS

SECOND SESSION

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CLEAN AIR ACT: RISKS FROM GREENHOUSE GAS EMISSIONS

WEDNESDAY, MARCH 13, 2002

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

The committee met, pursuant to notice, at 9:34 a.m. in room 406, Senate Dirksen Building, Hon. James M. Jeffords (chairman of the committee) presiding.

Present: Senators Jeffords, Voinovich, Smith, Chafee, and Corzine.

OPENING STATEMENT OF HON. JAMES M. JEFFORDS, U.S. SENATOR FROM THE STATE OF VERMONT

Senator JEFFORDS. Good morning. The hearing will come to order.

Today we will hear testimony on the economic and environmental risk of increasing greenhouse gas emissions. It is important to note that the hearing is not a debate about whether manmade emissions are causing warming. For the time being, that question has been settled by the National Academy of Sciences. An Academy report from June 2001 said,"Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and sub-surface ocean temperatures to rise, and human-induced warming and associated sea level rises are expected to continue through the 21st century."

We are fortunate to have today a witness here who has worked on that report.

What the committee will review is the magnitude of the possible injuries or losses that may be caused by this warming. I urge the witnesses to stay on that topic and help us assess the risk related to increasing greenhouse gas emissions.

One year ago today, the President formally notified the world and the Senate of his decision to unilaterally abandon the Kyoto Protocol. At the same time, he also abandoned his campaign promise to reduce carbon dioxide emissions, or the fourth "P" from powerplants. That was a serious blow to a sensible, market-based approach to reducing carbon emissions. As a result, the country has no actual policy in place to achieve a real emissions reduction target, so emissions will continue unabated. This is happening despite our international commitment in the Rio Agreement to reduce U.S. emissions to 1990 levels. Voluntary measures are no substitute and have failed to do more than slightly slow the rate of growth.

This situation concerns me and it should concern all of my colleagues. Unconstrained emissions will increase atmospheric concentrations. These will lead to greater global warming and provoke even greater climate changes.

Some of my concern is parochial. In Vermont, we rely on predictability of the seasons for our economic well-being and our quality of life. In the spring, maple syrup production is important. In the fall and summer, it is tourism. In the winter, it is skiing, snowboarding, and other outdoor recreation. It is safe to say that most Vermonters aren't interested in moving Hudson Bay to maintain their way of life.

Elsewhere in the country, my colleagues should be concerned about the potential impacts of climate change on public health, infrastructure, agriculture, and wildlife.

Sea-level rise should be of particular concern to my friends who represent coastal States, especially with growing areas. As Senator Stevens has noted, Alaska villages have already started to experience some of these effects. However, these gradual impacts may pale in comparison to what might happen with a sudden or abrupt change.

In December 2001, the National Academy said, "Greenhouse warming and other human alterations of the Earth's system may increase the possibility of large, abrupt, and unwelcome regional or global climactic changes." This should be a sobering statement that encourages action; instead, the debate often seems to be focused on the trees rather than the forest. But that information is not essential for Congress to act.

The potential calamity that awaits us through inaction is too serious for Congress to ignore. We acted on lead in gasoline and on ozone-depleting substances, even though we did not have perfect information. We made the right choice.

The science on climate change is sound enough to proceed with reductions now. Many carbon-intensive businesses have already begun to take action. They see a duty to their shareholders and to the public to start reducing these carbon risks.

Major insurance companies are increasingly concerned about the uncertainty of a changing climate in their financial exposure. Several markets are developing for the trading of greenhouse gas reduction credits, even in the United States.

It seems that there must be some level of economic or environmental risk associated with these emissions; otherwise, how could the credits have value, and why would anyone trade them? But they are being traded at $1 to $9 per ton.

Congress is often slow to act on complex problems like climate, especially without vigorous leadership from the White House. In this situation, the private sector may have to lead us in the right direction.

Unfortunately, in the meantime it seems to be business as usual on emissions. They will continue to grow, and we may reach atmospheric concentrations that haven't existed for hundreds of thousands of years. We need to know and be prepared for what that means for our committee, our plans, and our Nation.

I look forward to the panel's testimony. It will help us discover and better understand the risks that are posed by continuing to increase greenhouse gas emissions.

[The prepared statement of Senator Jeffords follows:]

STATEMENT OF HON. JAMES M. JEFFORDS, U.S. SENATOR FROM THE STATE OF VERMONT

Today we'll hear testimony on the economic and environmental risks of increasing greenhouse gas emissions. It's important to note that this hearing is not a debate about whether manmade emissions are causing warming. For the time being, that question has been settled by the National Academy of Sciences.

An Academy report from June 2001 said, "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise" . . . and . . . "Human-induced warming and associated sea level rises are expected to continue through the 21st century." We're fortunate to have a witness here today who worked on that report.

What the committee will review is the magnitude of the possible injuries or losses that may be caused by this warming. I urge the witnesses to stay on that topic and help us assess the risks related to increasing greenhouse gas emissions.

One year ago today, the President formally notified the world and the Senate of his decision to unilaterally abandon the Kyoto Protocol. At the same time, he also abandoned his campaign promise to reduce carbon dioxide emissions, or the fourth "P," from power plants. That was a serious blow to a sensible, market-based approach to reducing carbon emissions.

As a result, the country has no actual policy in place to achieve a real emissions reductions target. So, emissions will continue unabated.

This is happening despite our international commitment in the Rio Agreement to reduce U.S. emissions to 1990 levels. Voluntary measures are no substitute and have failed to do more than slightly slow the rate of growth.

This situation concerns me and it should concern all of my colleagues. Unconstrained emissions will increase atmospheric concentrations. These will lead to greater global warming and provoke even greater climate changes.

Some of my concern is parochial. In Vermont, we rely on the predictability of the seasons for our economic well-being and our quality of life.

In the spring, maple syrup production is important. In the fall and summer, it's tourism. In the winter, it's skiing, snowboarding and other outdoor recreation. It's safe to say that most Vermonters aren't interested in moving to Hudson Bay to maintain their way of life.

Elsewhere in the country, my colleagues should be concerned about the potential impacts of climate change on public health, infrastructure, agriculture and wildlife. Sea-level rise should be of particular concern to my friends who represent coastal states, especially with growing areas.

As Senator Stevens has noted, Alaskan villages have already started to experience some of these effects.

However, these gradual impacts may pale in comparison to what might happen with a sudden or abrupt change. In December 2001, the National Academy said, "greenhouse warming and other human alterations of the Earth system may increase the possibility of large, abrupt and unwelcome regional or global climatic events."

That should be a sobering statement that encourages action. Instead, the debate often seems to be focused on the trees rather than the forest.

There are even some people who think we should stop our efforts to assess the possible impact of global warming on our economy or our environment. They want to wait for perfect information. That seems unwise and irresponsible.

We must redouble our efforts to understand how global warming may affect us. We should continue working diligently to reduce the uncertainties of predictions.

I am hopeful that the President will soon send up the detailed global change budget, as required by the Global Change Research Act of 1990. That budget must keep the national assessment moving without delay or censorship.

But, that information is not essential for Congress to begin acting. The potential calamity that awaits us through inaction is too serious for Congress to ignore.

We acted on lead in gasoline and on ozone-depleting substances even though we did not have perfect information. We made the right choice. The science on climate change is sound enough to proceed with reductions now.

Many carbon intensive businesses have already begun to take action. They see a duty to their shareholders and to the public to start reducing their carbon risks.

Major insurance companies are increasingly concerned about the uncertainty of changing climate and their financial exposure. Several markets are developing for the trading of greenhouse gas reduction credits, even in the United States. It seems that there must be some level of economic or environmental risk associated with these emissions. Otherwise, how could the credits have value and why would anyone trade them? But, they are being traded at $1-$9 per ton.

Congress is often slow to act on complex problems like climate, especially without vigorous leadership from the White House. In this situation, the private sector may have to lead us in the right direction.

Unfortunately, in the meantime, it seems to be business as usual on emissions. They will continue to grow and we may reach atmospheric concentrations that haven't existed for hundreds of thousands of years.

We need to know and be prepared for what that means for our communities, our plans, and our nation.

I look forward to the panel's testimony. It will help us discover and better understand the risks that are posed by continuing to increase greenhouse gas emissions.

Senator JEFFORDS. Our first witness is Dr. Rowland.

Senator Voinovich, I note your arrival. If you have an opening statement, now is the time.

OPENING STATEMENT OF HON. GEORGE V. VOINOVICH, U.S. SENATOR FROM THE STATE OF OHIO

Senator VOINOVICH. Thank you, Mr. Chairman.

I welcome the panel.

I want to thank you for holding this hearing today on the economic and environmental risks associated with increasing greenhouse gas emissions. I think it is always important to try and understand the risks associated with the various policy decisions that we grapple with here in the Senate; however, Mr. Chairman, I want to make sure we don't rush past the underlying assumptions on the science of greenhouse gases and climate change and jump immediately to the worst case scenario effects. In courtroom terms, we are in danger here, I think, of passing a sentence before we have fully deliberated on the evidence.

Over the last year, I have chaired one hearing on climate change. I have now attended, including today, three others. There is no question in my mind that there is a real difference of opinion between the scientific experts on climate change.

It is amazing to me how certain groups have bought into the idea that everything is settled and they close their mind to conflicting evidence. I get letters from constituents and friends about climate change, and it appears that they just look at one set of information and have made a conclusion about it. Then what I do is, I send them the testimony that I've had at hearings and said, "Here, read all of it, and then you tell me what you think after reading both sides of this." There is a difference of opinion.

Greenhouse gas emissions and the climate change debate are real issues which deserve our attention and the attention of the best and brightest scientists in our country and the world. There are a number of issues which need to be addressed before we plan what to do about the worst case scenario, such as: what do the models tell us about past changes and climate patterns, and how well-suited are they to predict future changes? What do we know about the predicted range of climate temperatures due to manmade emissions over the next 50 to 100 years? If something needs to be done today, what are the available technology options and what would the cost be to society to implement those options? Finally, if we were to implement changes, what would the impact be?

I am told that if we were to implement the Kyoto Treaty completely, we would only avert the expected temperature change of .06 °C—that's .06 °C, which is substantially less than 1 °F. That's a .01 °C. To me that hardly seems significant, and maybe some of our witnesses will comment on that.

I'd also like to say a brief word about the President's climate change initiative. I know today's hearing was planned for the anniversary of the President's announcement on Kyoto—very good, Mr. Chairman. Instead of dwelling on Kyoto, which was a failed treaty and would never have passed the Senate and still would never pass the Senate, we should look at the President's initiative. To me, it seems to be a very reasonable approach and it is the only credible alternative proposed to date. By the way, it is one that's gaining support by many of our allies who would like to go forward and get something done on this issue and not have it be a long debate of the international community with nothing getting done. It provides the necessary funding for both the science and the technological research. It encourages companies to register their CO_2 emissions. It sets a national goal to reduce our carbon intensity, which is the best way to protect our economy and begin to address the issue.

Finally, in terms of the multi-emission strategy, as I've said repeatedly, I would support addressing CO_2, Mr. Chairman, in a voluntary way which encourages new technologies and practices such as carbon sequestration or anything else that's out there that we can look at, but I will not support a mandatory CO_2 reduction cap.

I think it is important that we do not let the CO_2 issue stand in the way of meaningful reductions of SO_2, NOx, and mercury. There are many people out there that want something done about those three emissions, many of them who live in your part of the country. We can sit here and have a chowder society and debate. I'd like to get on with dealing with those three so that we can improve the environment and at the same time, create an environment where we have reasonable energy costs for the people of this country.

Thank you.

[The prepared statement of Senator Voinovich follows:]

STATEMENT OF HON. GEORGE VOINOVICH, U.S. SENATOR FROM THE STATE OF OHIO

Mr. Chairman, thank you for holding this hearing today on the economic and environmental risks associated with increasing greenhouse gas emissions. I think it is always important to try and understand the risks associated with the various policy decisions we grapple with here in the Senate.

However, I want to make sure we don't rush past the underlying assumptions on the science of greenhouse gases and climate change and jump immediately to the worst-case scenario effects. In courtroom terms we are in danger here today of passing a sentence before we have fully deliberated the evidence.

Over the last year I have chaired one Hearing on Climate Change and have now attended three others. There is no question in my mind that there is a real difference of opinion between the scientific experts on climate change. It is amazing to me how certain groups have bought into the idea that everything is settled and they close their mind to conflicting evidence.

Greenhouse gas emissions and the climate change debate are real issues which deserve our attention and the attention of the best and brightest scientists in our country and the world. There are a number of issues which need to be addressed before we plan what to do about the worst-case scenarios such as:

• What do the models tell us about the past changes in climate patterns and how well suited are they to predict future changes?

• What do we know about the predicted range of climate temperatures due to man-made emissions over the next 50 to 100 years?

• If something needs to be done today, what are the available technology options and what would the cost be to society to implement them?

• Finally, if we were to implement changes, what would the impact be. I am told if we were to implement the Kyoto Treaty completely, we would only avert the expected temperature change by .06 degrees Celsius over the next 50 years. That hardly seems significant.

I would also like to say a brief word about the President's Climate Change Initiative. I know today's hearing was planned for the anniversary of the President's announcement on Kyoto. Instead of dwelling on Kyoto, which was a failed Treaty and would never have passed the Senate, we should look at his Initiative. To me it seems to be a very reasonable approach and it is the only credible alternative proposed to date.

• It provides the necessary funding for both the science and the technology research.

• It encourages companies to register their CO_2 emissions.

• It sets a national goal to reduce our carbon intensity, which is the best way to protect our economy and begin to address the issue.

Finally, in terms of the Multi-Emissions Strategy I have said repeatedly that I would support addressing CO_2 in a voluntary way which encourages new technologies and practices such as carbon sequestration. I will not support a mandatory CO_2 reduction cap. I think it is important that we do not let the CO_2 issue stand in the way of meaningful reduction of SO_2, NOx, and mercury.

Senator JEFFORDS. Senator Smith.

OPENING STATEMENT OF HON. BOB SMITH, U.S. SENATOR FROM THE STATE OF NEW HAMPSHIRE

Senator SMITH. Thank you very much, Mr. Chairman.

Let me just pick up on the Senator from Ohio comments. I want to compliment him for working together with this Senator. We have a number of issues which easily could put our States against each other, but it has been a cooperative effort. I agree with your comments regarding the technology that's out there that is bringing dramatic reductions in NOx, SO_2, and mercury. We have a partnership between a company in New Hampshire, Power Span, working with a company, working with a utility in Ohio. We're getting good results on that, and I think that's the kind of thing that brings us together to reach compromise and solutions, and I am very grateful for your cooperation on these issues.

We are this morning talking about economic and environmental risks associated with climate change, and certainly want to welcome all the witnesses, but specifically, Adam Markham from Portsmouth, NH. It is good to see you here. Mr. Markham will be discussing a recent report coordinated by the University of New Hampshire that describes much of the potential environmental and economic impact of climate change in New England—impact on industries, which is where we make money, skiing and—we don't have any sugar maple subsidies. We have peanut subsidies and tobacco subsidies, but no sugar maple subsidies. I'm not advocating any, either.

This study underscores concerns that I've shared with members of this committee about small, family-owned businesses that are at risk as a result of what we may or may not do.

These are just a few of the risks that New Hampshire would face with a potential change in climate. There are many more aspects to the question of risks posed by climate change than we could even get into today. But when we talk about risk, I think it is worth looking to those whose entire business is based on putting a price on risk, translating environmental risk into economic terms, and obviously that is the insurance industry. Insurance companies are motivated to seek the clearest risk information available on the subject of anything, and certainly climate change, as well. This motivation is not clouded by politics or agendas, but focused squarely on the bottom line.

I have had my share of disagreements with insurance companies on some of these issues, but accuracy in this kind of work is not a luxury. It's a necessity. If they don't estimate risks accurately, then somebody is going to go bankrupt—they will.

I would like to reference a document that's found on the website of one of the largest reinsurance companies in the world. It's called "Swiss Re." I would ask unanimous consent that this document be made a part of the record, Mr. Chairman.

Senator JEFFORDS. Without objection.

Senator SMITH. The document has a very interesting title, "Climate Research Does Not Remove the Uncertainty: Coping with the Risks of Climate Change." The title I think sums up our hearing today. The primary point of the paper is that climate change is happening and it poses financial risks. We're still unclear on how much of the change is natural and how much of it is human induced.

I have been to Woods Hole, MA. We've talked about these issues with a number of scientists. That's what I hear over and over again—is the change natural? How much of it is natural? How much of it is human induced? But there is change taking place. If you go back to the insurance industry and their customers, causes are of secondary importance in the face of weather-related losses.

So as we examine the risk question—and that's why I bring the insurance analogy up here—as we consider the entirety of the climate change debate, we should focus more attention on economic risk posed by any climate change, natural or human induced.

The study points out that our vulnerability to extreme weather conditions is increasing. This is because in a global economy, local weather can have international consequences. As an example, Swiss Re points to the flooding of the Far East Computer Chip Factory, causing supply bottlenecks through the entire technology sector. The paper points out that climate change is not needed for that example to occur.

But evidence does show, though, that human interference in the climate system exacerbates the problem caused by natural climate change, so the difference between natural variation in the climate and natural variation coupled with human influences may be small. We don't know yet. The scientists will continue to try to answer that question.

There are differences between forces that can cause either negligible damage or catastrophic loss. These are the intelligent thoughts of experienced businessmen and woman and people not driven by any political agenda. Their jobs are to accurately assess the economic risks posed by climate conditions, and they provide an excellent perspective for us to consider.

Let me just share one quote from the paper. "The climate problem cannot be ignored, nor will it be solved merely by calls for optimum climate protection. We need to find ways of implementing the necessary climate protection measures in a manner which is both socially and economically acceptable." That's reasonable counsel. Although I might doubt the authors ever intended it for this committee, I would urge that we listen to their advice.

Given the potential risk, we have to begin to explore reasonable ways of mitigating the potential economic damage, regardless of the cause of climate change.

I've strongly advocated a system based on incentives for innovative measures to reduce greenhouse gas. That's what Senator Voinovich was just talking about. We are working with the chairman on this. We have some differences. Hopefully they will be differences that we can bridge, but we do have differences. But I believe that capitalizing on innovation in the free market will meet whatever challenges are presented. We need to think out of the box.

Maybe technology will move a lot quicker in this area than the regulation that we propose. Maybe we won't need to worry about Kyoto because the technology that we are producing will export to the Third World countries and as they develop, they won't be making the same mistakes that we made. Just maybe that might work. It doesn't seem to me to make a lot of sense to try to get people involved in a treaty who won't abide by the treaty or can't abide by the treaty and don't have the means to abide by a treaty.

I don't think it is necessary to regulate through command and control carbon, for example, at powerplants to cut atmospheric levels of greenhouse gases. Let's get the technology working out there so people can make money and reduce carbon while we're doing it. We don't have to create economic damage as a means to avoid economic and environmental risk. There are other ways. We shouldn't be in the business of choosing winners and losers.

Regardless of whatever the policy answer is, one thing is for certain: absent a bipartisan approach to the resolution of this issue, we will achieve nothing, nothing at all. I've learned that as the chairman of this committee the hard way, frankly. We had two major issues when I was chairman of the committee. One was the Everglades and one was brownfields, and they have been lollygagging around here in the Senate for years. I had some strong views on both and couldn't get them passed, and we were able to work together, come up with a bipartisan solution, and found myself voting against amendments that I supported in order to stick with that solution as we move forward, and both of those pieces of legislation are now law. It is tough to deal with this. It is frustrating when you have people who differ with you on issues but you know in your heart you're going to have to compromise before you can get it done.

So, regardless of whatever the policy is, we will need to be bipartisan. We can't allow politics to trump reason and success. You know, good politics isn't always necessarily the right thing for the environment. I think we ought to let the chips fall where they may. But we do have a long tradition of bipartisanship in this committee, Mr. Chairman, as you well know, and I think it will continue. There's a tremendous diversity of opinion in this room on how to address these issues, but I'm confident that that diversity is both valuable and a challenge, and I look forward to meeting that challenge.

Thank you, Mr. Chairman.

Senator JEFFORDS. Thank you.

[The prepared statement of Senator Smith follows:]

STATEMENT OF HON. BOB SMITH, U.S. SENATOR FROM THE STATE OF NEW HAMPSHIRE

Good morning. Today we are here to talk about the economic and environmental risks associated with climate change.

I want to welcome all of our witnesses, and a special welcome to Adam Markham who has come down from New Hampshire. Mr. Markham will be discussing a recent report coordinated by the University of New Hampshire that describes much of the potential environmental and economic impact of climate change in New England—impact on industries such as skiing and sugar maple.

This study underscores concerns I have shared with members of this committee. Small, family-owned businesses are at risk. These are just a few of risks that New Hampshire would face—associated with the potential change in climate.

There are many more aspects to the question of risks posed by climate change than we could list today. When we talk about risk, I think it is worth looking to those whose entire business is based on putting a price on risk—translating environmental risk into economic terms—the insurance industry. Insurance companies are motivated to seek the clearest risk information available on subject of climate change.

This motivation is not clouded by politics or agendas, but focused squarely on the bottom line where accuracy is not a luxury. It is a necessity. If they do not estimate risks accurately, they will soon go bankrupt.

I would like reference a document that can be found on the web site of one of largest reinsurance companies in the world—Swiss Re. I would ask unanimous consent that this document be part of the record. The document bears the title "Climate Research Does Not Remove the Uncertainty: Coping With The Risks of Climate Change." The title pretty well sums up our hearing topic today.

The primary point of this paper is that climate change is happening and it poses financial risks. We still are unclear on how much of that change is natural and how much is human-induced. But for the insurance industry and their customers, CAUSES are of secondary importance in the face of weather-related losses.

As we examine the risk question, and as we consider the entirety of the climate change debate, we should focus more attention on economic risk posed by any climate change—natural or human induced. The study points out that our "vulnerability to extreme weather conditions is increasing." This is because in a global economy, local weather can have international consequences.

An example Swiss Re points to is the flooding of a Far East computer chip factory, causing supply bottlenecks for the entire technology sector.

The paper points out that climate change is not needed for that example to occur. But, evidence shows that human interference in the climate system exacerbates the problem already caused by natural climate change. The difference between natural variation in the climate, and natural variation coupled with human influences may be small. We don't know yet—the scientists will continue to try to answer that question.

There are small differences between forces that can cause either negligible damage or catastrophic loss. These are the intelligent thoughts of experienced businessmen and women—people not driven by any political agenda. Their jobs are to ACCURATELY assess the economic risks posed by climate conditions—and they provide an excellent perspective for us to consider. I would like to share one last quote from the paper,

> "The climate problem cannot be ignored, nor will it be solved merely by calls for optimum climate protection. We need to find ways of implementing the necessary climate protection measures in a manner which is both socially and economically acceptable."

I believe that is reasonable counsel and even though I doubt the authors ever intended it for this committee, I would urge that we heed their advice.

Given the potential risks, we must begin to explore reasonable ways of mitigating the potential economic damages—regardless of the causes of the climate change. I have strongly advocated a system based on incentives for innovative measures to reduce greenhouse gases.

I believe that capitalizing on innovation and the free market will meet whatever challenges are presented—we should think "out of the box."

I don't believe that it is necessary to regulate—through command-and-control—carbon at power plants to cut atmospheric levels of greenhouse gases. We don't have to create economic damage as means to avoid economic and environmental risks. There are other ways.

And we shouldn't be in the business of choosing winners and losers.

Regardless of whatever the policy answer is—one thing is for certain: absent a bipartisan approach, we will achieve nothing. We cannot allow politics to trump reason and success.

Fortunately, this committee has a long tradition of bipartisanship. I can assure you this—if a partisan approach is followed on this committee with this, or any other issue, the only thing that will be achieved is failure—what a terrible legacy that would be. There is tremendous diversity of opinion in this room on how to address these issues. That diversity is both valuable and a challenge.

But, this isn't the first time this committee has been faced with such a challenge. When people put political agendas aside and are willing to work toward a constructive solution, we ultimately find common ground. I have done my best to work on all environmental legislation applying the principles of cooperation, partnership, and bipartisanship.

It is my hope, Mr. Chairman, that we will continue to work together and find a good solution.

Thank you.

Senator JEFFORDS. Our first witness is Dr. F. Sherwood Rowland, the Donald Bren Research professor of chemistry and earth system science, the University of California.

Please proceed.

STATEMENT OF F. SHERWOOD ROWLAND, DONALD BREN RESEARCH PROFESSOR OF CHEMISTRY AND EARTH SCIENCE, UNIVERSITY OF CALIFORNIA IRVINE, IRVINE, CA

Mr. ROWLAND. I'm pleased to be here to testify to your committee, Senator Jeffords.

To Senator Voinovich, I will just say that I grew up in Ohio and my undergraduate education was at Ohio Wesleyan University.

I am here really as a member of a committee that was appointed by the National Academy of Sciences and made a report to the White House last June. I am an atmospheric scientist, and I will tell you something about that report.

A natural greenhouse effect has existed in Earth's atmosphere for thousands of years, warming the Earth's surface by a global average of 57 °F. During the 20th century, the atmospheric concentrations of a number of greenhouse gases have increased, mostly because of the actions of mankind.

Our current concern is not whether there is a greenhouse effect, because there is one, but rather how large will be the enhanced greenhouse effect from the additional accumulation in the atmosphere of these greenhouse gases.

Daily, the Earth intercepts energy from the sun, much of it in the visible wavelengths corresponding to the spectrum of colors from red to violet and the rest in ultraviolet and nearby infrared wavelengths. An equal amount of energy must escape from the Earth daily to maintain a balance, but this energy emission is controlled by the much cooler average surface temperature of the

Earth and occurs in wavelengths in what is called the “far infrared.”

If all of this terrestrially emitted infrared radiation were able to escape directly to space, then the required average temperature of the Earth would be 0 °F. However, the greenhouse gases—carbon dioxide, CO_2, methane, nitrous oxide, and others—selectively intercept some of this far infrared radiation, preventing its escape. A warmer Earth emits more infrared radiation and Earth with an average surface temperature of 57 °F was able to make up the shortfall from greenhouse gas absorption. However, at first slowly during the 19th century and then more rapidly during the 20th century, the atmospheric concentrations of these greenhouse gases increased, often because of the activities of mankind.

Other greenhouse gases have also been added, such as the chlorofluorocarbons, or CFCs, and tropospheric ozone. With more of these gases present in the atmosphere, more infrared will be intercepted and a further temperature increase will be required to maintain the energy balance.

Carbon dioxide is released by the combustion of fossil fuels—coal, oil, and natural gas—and its atmospheric concentration has increased from about 280 ppm as the 19th century began to 315 ppm in 1958 and 370 ppm now.

Water is actually the most significant greenhouse gas in absorbing infrared radiation, but the amount of gaseous water is controlled by the temperature of the world’s oceans and lakes.

Methane has a natural source from swamps, but is also released during agricultural activities—for example, from rice paddies while flooded and from cows and other ruminant animals and by other processes—and has increased from about 0.7 ppm in the early 1800’s to 1.5 ppm around 1978 and 1.77 ppm currently.

Nitrous oxide concentrations grew from 0.27 to 0.31 ppm during the 20th century, formed by microbial action in soils and waters on nitrogen-containing compounds, including nitrogen-containing fertilizers.

The chlorofluorocarbons or CFCs were not a natural part of the atmosphere but were first synthesized in 1928 and were then applied to a variety of uses—propellant gases for aerosol sprays, refrigerants in home refrigerators and automobile air conditioners, industrial solvents, manufacture of plastic foams, etc.

The CFC concentrations started from zero concentration in the 1920’s and rose rapidly during the latter part of the 20th century until the early 1990’s. They are no longer increasing because of the Montreal Protocol, an international ban on their further manufacture.

Tropospheric ozone is a globally important compound formed by photochemical reactions as a part of urban smog in hundreds of cities. Other potential influences on temperature changes for which the global average data are still very sparse include the concentrations of particulate matter, such as sulfate and black carbon aerosols.

Measurements of surface temperatures only became sufficiently broad in geographical coverage about 1860 to permit global averaging, with improved coverage as the years passed. The globally averaged surface temperature increased about 1.1 °F during the

20th century, with about half of this change occurring during the last 25 years. The year 1998 was the warmest year globally in the entire 140-year record, and the 1990's were the warmest decade.

Fluctuations in solar activity have been directly observed since the invention of the telescope 400 years ago, but accurate, direct measurements of total solar energy output have only been possible with the advent of satellite measurements in the late 1970's. These satellite data exhibit a small but definite cyclic variation over the last two decades, paralleling the 11-year solar sun spot cycle, but with little long-term difference in solar energy output contemporary with the rising global temperatures of the past two decades.

Predictions of future temperature responses require atmospheric model calculations which effectively simulate the past and then are extrapolated into the future with appropriate estimates of the future changes in atmospheric greenhouse gas concentrations. These models calculate the direct temperature increases that additional greenhouse gases will cause and the further feedbacks induced by these temperature changes. One of the most prominent of these feedbacks is the change in albedo, or surface reflectivity, in the polar north. When melting ice is replaced by open water, or melting snow replaced by bare ground, less solar radiation is reflected back to space and more remains at the surface, causing a further temperature increase.

The models also assume that more water will remain in the atmosphere in response to the temperature increases, providing another positive feedback.

There is an additional possible feedback from the changes in clouds—amount, composition, altitude. In present models, the cloud feedback is assumed to be small, but data for better evaluation are very difficult to obtain.

Extrapolations for 50 or 100 years in the future necessarily include hypotheses about future societal developments, including population growth, economic activity, etc. The Intergovernmental Panel on Climate Change, or IPCC, developed a large set of scenarios about the possible course of these events over the next century, with resulting model calculations of globally averaged temperature increases for the year 2100 relative to 1990, ranging from 2.5 °F to 10.4 °F, or 1.4 °C to 5.8 °C. These results were only a small part of the three IPCC reports issued during the year 2001 about climate change. Volume I of the IPCC reports treated the scientific bases; Volume II covered impacts, adaptation, and vulnerability; and Volume III, mitigation.

The National Academy of Sciences, in response to a May 2001, request from the White House and following discussions between the Administration and the Academy over some questions raised by the former, convened an 11-member scientific panel, which issued in June a 24-page report, "Climate Change Science: An Analysis of Some Key Questions," from a select committee of atmospheric scientists. I quote the first few sentences of this report and have appended the entire represent to this testimony. Many of these words were repeated by Senator Jeffords.

"Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and sub-surface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability."

The increasing global temperatures will have many consequences, often adverse in the long run. Because many of the causes of this temperature increase have their origin in the activities of mankind, actions can and should now be taken which will slow this rate of increase. I should say the last words are mine and not the Academy report. I think that we need to start taking actions that will ameliorate the problems of the greenhouse gases.

Thank you.

Senator JEFFORDS. Thank you very much, Dr. Rowland.

I think we will go through all of the witnesses first before questions.

Our second witness is Roger A. Pielke, Jr., associate professor, Center for Science and Technology Policy Research at the University of Colorado/Cooperative Institute for Research in Environmental Sciences in Boulder.

Go ahead.

STATEMENT OF ROGER A. PIELKE, JR., ASSOCIATE PROFESSOR, CENTER FOR SCIENCE AND TECHNOLOGY POLICY RESEARCH, UNIVERSITY OF COLORADO/COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES, BOULDER, CO

Mr. PIELKE. Thank you. I'd like to thank Chairman Jeffords and the committee for the opportunity to offer testimony this morning.

My name is Roger Pielke, Jr., and I am from the University of Colorado. On page 7 of my testimony, you'll find more details on my background.

In the time I have available, I would like to highlight the take-home points from my testimony. These are developed in greater detail in the written testimony and also in the peer-reviewed scientific papers on which they are based.

Before I proceed, I want to say that everything I'll present today is consistent with the NRC report that Dr. Rowland referred to and the IPCC, so it is starting with those scientific background documents as a starting point. There is no need—I agree with some of the statements made earlier—no need to question the level of science in those reports; however, as you will hear from me momentarily, it does lead to a range of different interpretations for policy.

The take-home points:

First, weather and climate have increasing impacts on economies and people around the world. Data is scattered, hard to come by, but the picture we are able to put together, largely based on economic data, is that the impacts are growing. I think the Swiss Re report you referred to and the insurance industry would back that up.

The primary cause for that growth in impacts is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se. This is not to say that climate does not change or has not changed or will not continue to change. This is only to say that when we look at the sensitivity of impacts to the various factors that lead to impacts, it takes both a climate event and an exposed society or exposed environment to lead to impacts.

This is shown dramatically on page 3, figure 3, of my testimony, where I show a picture of Miami Beach from 1926 and a picture of Miami Beach from near the present, near 2000. Not only does climate change, but society changes.

Taking the assumptions of the IPCC figure 6 on page 4, we compare the relative sensitivities of economic losses to tropical cyclones to society factors versus climate factors and find societal factors under the assumptions of the IPCC range from the 22-to-1 to a 60-to-1 increased, larger sensitivity than the climate impacts.

Again, not to discount the possibility of climate change, but to say to understand climate change we have to put it into the context of societal change.

To address increasing vulnerability and the growing impacts that result would require a broader conception of climate policy than now dominates the debate. We could do a whole lot to energy policy and not do very much to address the growing risk of climate change, climate variability to economies, people, and the environment around the world.

Therefore, we must begin to consider adaptation to climate to be as important as matters of energy policy when we talk about response options. Present discussion all but completely neglects adaptation to climate. Increased attention to adaptation would not mean that we should ignore energy policies or reduce the intensity which we want to improve energy policies, but instead it would be a recognition of the fact that changes in energy policy are insufficient to address the primary reasons underlying the trends and the societal impacts of weather and climate.

Again, another point to emphasize is my testimony is focused on the societal and economic impacts today. It is not focused on the environmental or ecological impacts of climate.

The Nation's investments in research, which I should say are considerable in the area of climate change, in my opinion could more efficiently focused on producing usable information for decisionmakers seeking to reduce vulnerabilities to climate.

Specifically, the present research agenda is focused, in my view, improperly on prediction of the distant climate future. We can spend a lot of money on research and argue for a long time what the climate future will be 50 to 100 years from now. The real test of what the climate future will be is when we actually experience the climate of that time.

Instead, I would suggest we are neglecting what are traditionally called "no regrets adaptation and mitigation opportunities." Instead of arguing about global warming, yes or no, the degree of risk in the far-distant future, we might be better served by addressing things like the present drought that is developing in the Northeast, for which, again, energy policy will not do much to mitigate.

In closing, I would like to leave you with the thought that climate change is much too important a topic to equate solely with energy policy. The last figure in my testimony, figure 7 on page 6, illustrates schematically how we might think about energy policy and climate policy, which do, indeed, have important overlaps but are not the same topic.

Thank you very much.

Senator JEFFORDS. Thank you, Doctor.

Our next witness is David Legates, a Ph.D. and C.C.M., director of the Center for Climatic Research, the University of Delaware, Newark, DE.

Please proceed.

STATEMENT OF DAVID R. LEGATES, DIRECTOR, CENTER FOR CLIMATIC RESEARCH, UNIVERSITY OF DELAWARE, NEWARK, DE

Mr. LEGATES. I would like to thank Senator Jeffords and the committee for inviting my commentary on this important topic. My basic background in research has been in precipitation, so you'll probably guess that I'm going to focus primarily on precipitation, and precipitation variability. With rain outside, it is probably a good topic to bring up today.

In my written testimony, I discuss some of the problems associated with determining climate change from both climate models and observations. In my limited presentation here, I'm going to examine an issue, which I feel focuses on an important environmental risk that we face—human-induced changes in climatic extremes—droughts, floods, and storminess.

Do climate models well represent the Earth's climate? Well, on three separate occasions, I have reviewed the ability of state-of-the-art climate models to simulate regional scale precipitation. The models poorly reproduce the observed precipitation, and that character of the models had not substantially changed over time. But, more importantly, climate models simply do not exhibit the observed variability. Both air temperature and precipitation exhibit little year-to-year fluctuation, which is quite unlike what we presently experience. This is crucial, because climatic extremes and not their mean values have the largest economic and environmental impacts.

Simply put, climate models cannot address issues associated with changes in the frequency of extreme events because they fail to simulate storm scale systems or to exhibit the observed variability. Moreover, many extreme weather events are so uncommon that we simply cannot determine their statistical frequency from the observed record, let alone determine how that frequency has changed over time. Determining anthropogenic changes in extreme weather events, either from modeling or observational standpoints, therefore, is nearly impossible.

Furthermore, it is unclear how much should be attributed to anthropogenic increases in atmospheric trace gases and how much will be simply a result of natural variability or measurement biases.

So I ask: is there a cause for concern that anthropogenic warming will lead to more occurrences of floods, droughts, and storminess? I point to the latest Intergovernmental Panel on Climate Change, the IPCC, Summary for Policymakers, which states that, "Global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods."

The mainstream media has frequently echoed this enhanced hydrologic cycle scenario; however, if one carefully reads the IPCC Technical Summary, you will find an admission that, "There is no compelling evidence to indicate that the characteristics of tropical and extra-tropical storms have changed. Recent analysis of changes in severe local weather do not provide compelling evidence to suggest long-term changes. In general, trends in severe weather events are notoriously difficult to detect because of their relatively rare occurrence and large spatial variability."

The IPCC further goes on to state that areas experiencing severe drought to severe wetness increased only to a small degree over the entire 20th century. Tom Karl and Richard Knight have concluded that as the climate has warmed, precipitation variability actually has decreased across much of the Northern hemisphere's mid-latitudes. Bruce Hayden, writing for the Water Sector of U.S. National Assessment, argues that little can or should be said about change in storminess in carbon-dioxide-enriched years.

Sinclair and Watterson recently noted that increased levels of atmospheric trace gases generally leads to a marked decrease in the occurrence of intense mid-latitude storms.

Clearly, claims that a warmer world will lead to more occurrences of droughts, floods, and storms are exaggerated.

So what should we do? I feel first we must continue to develop and preserve efforts at climate monitoring and climate change detection. Efforts to establish new global climate observing systems are useful, but we must preserve the stations that we presently have. There simply is no surrogate for a long-term climate record taken with the same instrumentation and located in essentially the same environmental conditions.

However, given that oceans cover nearly three-quarters of the Earth's surface, we must further develop satellite methods for monitoring the Earth's climate. We also need to better utilize a national network of WSR–88D, Nexrad weather radars to monitor precipitation and its variability.

But foremost we must focus on developing methods and policy that can directly save lives and can mitigate the economic devastation that often is associated with specific weather-related events.

Climate change discussions usually focus on increases in mean air temperatures or percentage changes in mean precipitation, but it is not changes in the mean fields on which we need to place our efforts. Loss of life and adverse economic and environmental impact occurs not when conditions are normal, but rather they occur as a result of extreme climatic events—floods, droughts, storms at all spatial scales. One thing I can guarantee is that, regardless of what impact anthropogenic increases in atmospheric trace gases will have, extreme weather events will continue to be a part of our life and they will continue to cause the most weather-related deaths and have the largest weather-related economic impacts.

Thus, we must focus on providing real-time monitoring of environmental conditions, which will yield to important benefits. First, it will provide immediate data to allow decisionmakers to make informed choices to protect citizens faced with these extreme weather events, and, if installed and maintained properly, it will assist with our long-term climate monitoring goals.

For example, the State of Delaware has undertaken a project to develop the most-comprehensive, highest-resolution, State-wide weather monitoring system available anywhere using our high-resolution weather data system technology.

So I conclude, therefore, that, regardless of what the future holds, employing real-time systems with a firm commitment to supporting and maintaining long-term climate monitoring goals is our best opportunity to reduce the risk of weather-related events on human activities.

I again thank the committee for inviting my commentary.

Senator JEFFORDS. Thank you.

Our next witness is Mr. Adam Markham, executive director of the Clean Air-Cool Planet, Portsmouth, NH.

Please proceed.

STATEMENT OF ADAM MARKHAM, EXECUTIVE DIRECTOR, CLEAN AIR-COOL PLANET, PORTSMOUTH, NH

Mr. MARKHAM. Good morning, Mr. Chairman and members of the committee. Thank you for inviting me here today. My name is Adam Markham. I am the executive director of Clean Air-Cool Planet.

There is compelling evidence and sound science to suggest that there are significant and severe risks to continued greenhouse gas emissions to the atmosphere. Future warming scenarios described in the New England Regional Assessment that Senator Smith just referenced give a 6 °F to 10 °F range for warming over the next century for New England. Such a change would result in Boston getting the climate of Richmond, VA, in the best case, and that of Atlanta, GA, in the worst case.

Risks identified in the regional assessment include a major threat to the maple syrup industry that Senator Jeffords mentioned. According to the most credible forest models, the sugar maple is one of the most sensitive trees to warming temperatures. Business-as-usual emission scenarios are almost certain to eventually drive the sugar maple northwards out of New England, entirely. For Vermont, alone, maple syrup is a more than $100 million industry, with over 2,000 mainly family-owned sugar producers.

A change in climate may also have severe repercussions for New England's winter tourism economy. A recent study of the past 19 years of weather data for the two most ski-dependent economies in New England, Vermont and New Hampshire, showed an average of 700,000 fewer ski visits in the years with the worst snow conditions. In New Hampshire, the industry generated $566 million in visitor spending in the year 2000, and it creates more than 10 percent of the State's winter jobs.

The indications are not good. There has been a 15 percent decrease in snowfall in northern New England since 1953.

Climate models also suggest that in the longer term global warming will transform the conifer forests of northern New England into the type of forests now found further south. The conditions that currently support northern hardwood forests, their habitats, and their wildlife will shift up to 300 miles north during the next 100 years, potentially causing the loss of these forests or their transformation into other types of forests over much of the landscape. More than 300,000 people in New England and New York are employed in the forest sector and would likely be affected by these sorts of changes.

Public health, too, is at risk. For example, 60,000 hikers a year visit Mt. Washington and the major peaks of the White Mountains. On hot summer days, air pollution poses a threat to hikers, especially at elevations above 3,000 feet. According to the regional assessment, there is a striking correlation between hot days—that's warmer than 90 °F—and high levels of ozone pollution.

Lyme disease is also a risk for people outdoors, and is on the increase in New York and parts of New England. Research on ticks suggests that warmer winters could increase the instance of Lyme disease and push its range further into northern New England.

Heat waves kill more people in the United States than hurricanes, flooding, or tornadoes. Heat-related deaths in the summer time could double under likely U.S. global warming scenarios. The poor, elderly populations are at particular risk, and northern cities may also be more at risk because people are less adapted to high temperatures.

The cost of climate impact in the coastal zones may be particularly large. Sea levels are currently rising at about a foot per century. This rate is increasing. The State of New Hampshire recently calculated that this will significantly increase the area of sea coast vulnerable to flooding and could turn 100-year storms into 10-year storms, or the damage from 10-year storms.

On the positive side, the Northeast States have long been leaders in reducing air pollution. New York's green building law, New Hampshire's greenhouse gas registry, and Massachusetts' full pollutant regulation were all firsts. Connecticut is at the forefront of efforts to support the development of commercial fuel cell technologies, and Efficiency Vermont is the Nation's first public energy efficiency utility. A first in the Nation bipartisan full pollutant bill recently passed strongly in the New Hampshire House.

In August 2001, the New England Governors and eastern Canadian premiers signed a climate change action plan with the ambitious, long-term goal of reducing greenhouse gases by 75 to 85 percent from current levels. Thirty-five cities and counties in the region have passed resolutions pledging to reduce greenhouse gas emissions and implement local climate action plans, and many businesses in the Northeast are convincingly demonstrating that common-sense investments in energy saving can pay off handsomely.

All over New England and the Northeast individuals, institutions, and corporations are inventing, exploring, and implementing innovative solutions to climate change, but this is not enough. Without effective national legislation, regional efforts such as those in the northeast will founder and may ultimately fail.

Energy efficiency and alternative fuels may be the real roots to energy security. If we are serious about reducing our reliance on foreign oil and about competing in world markets, we must produce more-efficient automobiles. If we want energy security and more jobs, we should aim to be producing 20 percent of our electricity from renewable resources by 2020. Federal controls on CO_2 I believe are essential and urgently needed.

If greenhouse gases are not curbed, climate change will likely transform the character of many of the things in New England that those of us who live there hold dear. The loss of sugar maples, changes in the northern forests, warmer winters, more frequent heat waves, and the distribution of coastal wetlands may eventually deliver a body blow to much of the region's character and economy.

Thank you for inviting me here today.

Senator JEFFORDS. Thank you, Mr. Markham.

Our next witness is Sallie Baliunas, astrophysicist from Harvard-Smithsonian Center for Astrophysics.

Thank you for coming, and please proceed.

STATEMENT OF SALLIE BALIUNAS, ASTROPHYSICIST, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS, CAMBRIDGE, MA

Ms. BALIUNAS. Thank you, Senator, and committee members for inviting me here. I've worked for 25 years studying the changes in the sun and the impact on life and climate of Earth.

The human effect on global warming remains a very serious scientific matter. A simulation that looks at the effect of the implementation of the Kyoto Protocol is included in my testimony. This is the Hadley Center's simulation for temperature change in the next 50 years, calling for a 1 °C rise in temperature. Implementing a Kyoto-type cut would avert the temperature rise by the year 2050 by only .06 °C. That shows that if the human concentrations of greenhouse gases in the atmosphere are a major problem, then much more steeper cuts than outline din the Kyoto Protocol are warranted, yet the Kyoto Protocol, itself, runs costs in most analysis of $100 to $400 billion a year, not insignificant.

That means that science remains critical to helping address this issue, and one key scientific question is: What has been the response of climate thus far to the small amount of energy that has been added by humans from greenhouse gases in the air?

Now, there has been substantial new Federal investment made very wisely, especially in space-based instrumentation, to address this key issue. The two capital tests that I talk about in my testimony are comparing the record of the surface temperature, which has warmed over the past 20 years, and the record of the lowest layer of air from about 5,000 to 28,000 feet.

The surface temperature has warmed in the 20th century, but there are three phases to the surface temperature record. There was a warming early in the 20th century, before most of the greenhouse gases were put into the air, peaking around 1940, followed by a cooling until the late 1970's, and then a recent warming.

Now, the recent surface warming may, indeed, have a human component, but the recent surface warming is about .1 °Ψ περ δεψαδε, ανδ τηατ ςοθλδ σετ αν θππερ λιμιτ το ςηατ τηε ηθμαν εφφεψτ ςοθλδ βε. Αψψθμθλατεδ οωερ α ψεντθρυ, τηατ σθγγεστσ 1 °Ψ ςαρμινγ.

Now, the computer simulations estimate more warming than that, but, in fact, that warming, seen from the surface, may not be primarily human at all. The computer simulations insist, or science insists, that not only the surface layer but the layer of air just above it must warm. Both must warm, and, in fact, the layer of air in the lower troposphere must warm faster and greater and much more steeply than the surface layer.

Those records have been brought before this committee before by John Christy. The NASA microwave sounder unit experiments aboard satellites now go back 21 years and cover essentially most of the Earth. Professor Christy's latest charts are shown in my testimony. The striking thing about the lower layer of air is that there are significant variations in temperature. On short time scales, for example, the very large El Niño warming pulse of 1997–98, but there is no long-term warming trend that is very significant, as forecast by the computer models. It is much smaller. The most warming that can be seen in the data of the lowest troposphere are .04 °C per decade.

Those satellite results, as you know from Professor Christy's previous testimonies, are validated by independent records made by radio sounds aboard balloons. Those records go back to 1957, which is a period that includes the recent rapid rise in the air's greenhouse gas concentration.

The balloon radio sound records and the satellite records both agree that there is no significant warming that can be attributed to human activities in the last 20 years or the last 40 years.

There is a very strong warming pulse called the "Great Pacific Climate Shift" apparent in the radio sound record in 1976–77, but so far no one can attribute that to human causes because it is something that the Pacific Ocean has been observed to do every 20 or 30 years prior to the great increase in greenhouse gases in the atmosphere.

Now, this is all good news. It means that the human global warming effect, if it is small—the best and most reliable data says that its amplitude is small and slow to develop, so that is creating a window of time and opportunity to continue to improve the observations of the computer simulations and to make better measurements of climate characteristics that are needed to address this issue. These remain essential to the problem of what to do.

Proposals like the Kyoto agreement to sharply cut greenhouse gas emissions are not enough, atmospherically speaking, yet temperature speaking the impacts have not shown up at the degree to which the models say that they should.

These cost estimates are severe, and these costs would fall disproportionately on America's poor and the world's elderly and poor, besides America's. So the window of opportunity is to continue the observations in order to better define the human magnitude of global warming, but our best and most reliable evidence says that it is quite small and slow to grow to date.

Senator JEFFORDS. Our next witness is Dr. Martin Whittaker, managing director of Innovest, Richmond Hill, Ontario, Canada.

Please proceed and welcome here.

STATEMENT OF MARTIN WHITTAKER, MANAGING DIRECTOR, INNOVEST, RICHMOND HILL, ONTARIO, CANADA

Mr. WHITTAKER. Thank you and good morning. We are very pleased and honored to be here, especially pleased because we think we have a story to tell that creates a positive link between corporate environmental performance and financial performance.

We are a pure research investment house. Our business is to provide impartial research to Wall Street on corporate, environmental, and social performance as it affects financial performance and shareholder value.

Climate change is an issue which cuts across all our research and one that seems to be of rising importance to the companies and to investors, alike. It is also an issue where the financial industry can play a positive leadership role, and I draw the committee's attention to the World Economic Forum held in Davos in February 2000, "The greatest challenge facing the world at the beginning of the 21st century is climate change. Not only is climate change the world's most pressing problem, it is also the issue where business could most effectively adopt a leadership role."

We see climate change as a source of business risk and opportunity—risk to both exposure to weather extremes, for example, in the insurance business, where each year now brings about 5.5 times as many weather-related natural disasters as 40 years ago, resulting in 13.6 times the insurance losses—that's according to Munich Re—but also risks to government policies to constrain greenhouse gas emissions, for example, in heavy greenhouse-gas-emitting industries, but also the opportunities through energy efficiency where companies can gain tangible financial benefits from energy efficiency measures, which also lower emissions, and also, of course, in the growing clean energy markets.

California, alone, has almost, I think, about $1 billion in export sales now in clean technologies, and that market will grow if we shift gradually toward a cleaner technology base.

This yin-yang risk opportunity image provides fiduciaries and companies with an opportunity not only to hedge emissions, hedge their exposures, but also to potentially increase their risks through a compounded effect. I'll explain that in a second.

I want to pick out five key combinations of trends from the submission that I made, which really explain why I think business attention is being more squarely focused on this climate change issue.

Growing sophistication in the understanding of the scientific impacts, as we've heard today, and a need really to see beyond Kyoto insofar as the wider sustainability context affects future greenhouse gas emissions. We think Kyoto is a critical first step toward that in focusing attention, but also the idea that economic win/win situations do exist and are there. We don't have time to go into them today, but we can certainly draw the committee's attention to examples of that.

Second, new thinking on the breadth of sectoral impacts. Risks are not just faced by greenhouse-gas-intensive heavy industries, but, as you've heard today, also tourism, agriculture, real estate, building materials, and, of course, finance, which is the sector we serve, but also, as regards the company impacts, we are seeing increasing differentials between companies, and so company strategy here can translate into future final performance, we think.

A third trend is really an evolution of the term "fiduciary responsibility" and the need to incorporate environmental and social issues into investment decisionmaking because they affect financial performance. This has been driven by the evolution of socially responsible investing, but it is now entering the mainstream, and the formation of the carbon disclosure project, which is a coalition of institutional investors now over $2 trillion in assets under management, are now engaged with, I think, 500 of the world's largest companies as shareholders to say, "This is a business risk issue. What are you doing?"

I think also this year we are going to see both the city of New York and the State of Connecticut will be filing shareholder resolutions on climate change in an effort to encourage greater transparency on that issue.

The fourth trend set is regulatory momentum both here and abroad. U.S. companies working in the United Kingdom, for example, in Europe, will be abiding by the regulations in those regions. That, I think, is a key reason why corporate attention is being focused on this issue, even though domestic support of Kyoto has waned, to say the least.

Last, the growing importance of disclosure, in general, to investors on hidden liabilities. Climate change liabilities may well fall under this rubric. The market is jittery over perceived corporate environmental performance and transgressions, and climate change liabilities may well be included there.

So I'd just like to wrap up with two recommendations, I suppose. We are a great believer in the power of the markets and creating a virtual circle whereby corporate environmental performance can be encouraged by financial institutions seeking that from their investee companies.

The effect of light regulatory action in the United Kingdom on requiring institutional investors to disclose their possession on social and environmental issues has had a tremendous effect in focusing business attention on these issues, and similar requirement on climate change in the spirit of the carbon disclosure project that I mentioned may well encourage investee company leadership on this issue and encourage the creation of carbon risk screening tools within the financial community.

I think we need to also finally educate the marketplace, the investment community certainly, but also companies and small- or medium-sized enterprises to encourage them to become more climate literate. The financial services industry can play a key role in that, and I think that if there is a message here it is: If we can get the political and investment communities working together to finance solutions, we would be on the right track, instead of getting bogged down in the nuances of the Kyoto Protocol.

Thank you.

Senator JEFFORDS. Thank you, Mr. Whittaker.

Our next and last witness is Jack D. Cogen, president of Natsource, New York, NY.

Please proceed.

STATEMENT OF JACK D. COGEN, PRESIDENT, NATSOURCE, NEW YORK, NY

Mr. COGEN. Good morning, Mr. Chairman and members of the committee. Thank you for inviting me to testify.

My name is Jack Cogen. I am president of Natsource, LLC, an energy and environmental commodity broker headquartered in New York City with offices in Washington, DC., Europe, Japan, Canada, and Australia.

My testimony will address the financial risk associated with climate change policy.

At the outset, I want to acknowledge that there are legitimate differences of opinion as to what should be the nature, degree, and timing of policy responses to the risk associated with climate change, itself. However, the role of Natsource is to work with clients who decide it is in their best interest to evaluate the extent of their financial exposure under possible greenhouse gas policies. Our clients make the threshold decision that they are at risk financially.

After that, the next step for them is to analyze the extent of their financial risk and develop strategies that make sense for mitigating that risk. Natsource contributes its policy and market expertise to helping clients assess and manage risk.

The client base of Natsource includes multi-national corporations, as well as foreign and domestic firms. Natsource assists them in quantifying their financial exposure under different policies that might be adopted to limit greenhouse gas emissions.

Our experience indicates that companies consider a variety of factors when they weigh the degree of risk they face and what to do about it. The primary factors are, No. 1, the probability they will be subject to emission limitation policies; and, No. 2, the potential direct and indirect costs of those policies to the company.

Natsource provides analysis, strategic advice, and market intelligence once a company decides to undertake a comprehensive risk assessment. Generally, we help clients assess their financial exposure by identifying policies that might be adopted, assigning probabilities to those policies—in other words, we're handicapping the committee—quantifying the net emissions shortfall or surplus the company faces under each policy, and estimating potential compliance cost based on the company's emissions profile, internal reduction opportunities, and our knowledge of various commodities available in the greenhouse gas emission markets.

Multi-national companies face an especially complicated risk, because they operate across multiple jurisdictions with different policies. In addition, many of these companies must evaluate the effect of climate change policies on the market demand for their products in different countries.

If potential compliance costs are substantial and the probability of emission limitations is significant enough, the next step for many companies is to develop a cost-effective risk management strategy. This involves assembling an optimal mix of measures for reducing of offsetting emissions. These include internal and external emission reduction projects, internal emission trading programs, and the use of external trading markets.

Companies choose to undertake emission reduction measures in spite of or because of policy uncertainty for a variety of reasons, including to reduce future compliance cost, gain experience in the greenhouse gas markets, maintain or enhance their environmental image, and place a value on internal reduction opportunities.

Greenhouse gas markets are evolving and will continue to evolve over the next several years. In the future, these markets will function more smoothly and with lower transaction costs as greenhouse gas policies become clearer and markets become more liquid.

Even now, more-sophisticated financial instruments such as call options are being used as a hedge against risk. Natsource recently complete the first comprehensive analysis of the greenhouse gas trading market for the World Bank. The analysis identified approximately 60 greenhouse gas transactions involving some 55 million tons of emissions. These numbers actually under-estimate the total number of transactions, because they do not include internal only transactions and small volume transactions.

Current market prices for greenhouse gas commodities range from less than $1 to over $9 per ton of carbon dioxide equivalent, depending on the type of commodity and vintage. I will add that the United Kingdom just over the past 2 days completed their auction for emission allowances in the direct sector there. The price has not yet been released, but the after market is already saying that you can buy a U.K. emissions allowance for 7 pounds per metric ton. You will find, by the way, that that will turn out to be much lower than the price that the U.K. government paid for them.

In conclusion, Mr. Chairman, a small but growing number of companies are beginning to more carefully analyze their financial risk under possible greenhouse gas policies. For a variety of reasons, some companies have decided to take steps now to reduce emissions, even though final policy decisions in most cases are still pending. As a consequence, these companies are able to take advantage of cost-effective opportunities provided by the market to reduce their financial exposure.

As the acid rate allowance system has demonstrated, emissions trading provides flexibility that can significantly lower the cost of emission reductions.

That concludes my remarks, Mr. Chairman. I would be glad to answer any questions you or other members of the committee may have.

Senator JEFFORDS. Thank you.

Thank all of the witnesses for very excellent and stimulating testimony.

Now it comes our time to have a chance to have a little dialog, and perhaps pursue our own specific desires, but, more hopefully and more importantly, further allow our understanding of what is going on.

Dr. Rowland, the Academy's 2001 report, which you helped write, was stunningly clear. It confirmed the seriousness of human-induced climate change, and it contains a real sense of urgency about the problem.

What should be done to reduce the risks that the report outlines and to clear up related scientific uncertainties?

Mr. ROWLAND. The Academy report, of course, did not go beyond basically the IPCC Volume I, the scientific bases. It did not go into adaptation and mitigation. Those have been the subjects of extensive discussion under IPCC with Volumes II and III, each of which are roughly 1,000 pages long, so that there is a very extensive literature on what the possibilities are.

I think that the recognition is always there, that carbon dioxide is spread throughout the world in energy use by everybody, more intensively in the United States than other places, but definitely there in India and China and every country, because, by and large, the development of civilization has paralleled the more-intensive use of energy, and that has been true in every country.

The problem that we face in the future is how to reduce the strict dependency that more energy is required to have a better standard of living, and that means we have to look at all aspects of the civilization.

I don't think there is any silver bullet that one can give that says, "If we did this, then everything would be taken care of." It means energy conservation, it means looking for alternative energy sources, it means more research on how to put carbon dioxide some place other than the atmosphere—that is, sequestration.

It has always been very inexpensive to release carbon dioxide to the atmosphere, and putting it anywhere else—trapping it at a power plant and putting it some place other than the atmosphere is clearly more expensive than just releasing it. So that's not a problem that is going to be easily solved, nor will it be a problem that can be solved without cost, but it is something that needs to be very, very intensively investigated.

I think that we have been in a situation in which we have, for the last 10 or 20 years, ignored the fact that carbon dioxide is accumulating, that there is a long-term problem, and it is going to require a solution that takes decades to bring about a society in which the energy dependence is not escalating as it is presently.

I don't have any good solutions other than all of those things which have been discussed before in a "no regrets" strategy. If you have energy conservation, then that is an improvement. If you have an alternative source that doesn't require releasing CO_2, that is an improvement.

I think in many countries, probably, there will be reliance on nuclear energy, which has a different problem, but it doesn't release carbon dioxide.

Senator JEFFORDS. The Academy's report says that, "National policy decisions made now will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in the century." The Administration's new policy decision appears to be business as usual. How will this policy affect the future?

Mr. ROWLAND. I think that what one has observed over the last 50 years, if you put carbon dioxide emissions and GNP and say carbon dioxide emissions per GNP, that that is a number which has been going down. That is, as you multiply GNP, you do not necessarily take up the carbon dioxide emissions at the same rate, and over a period of time, there have been efficiencies that have occurred. But that, alone, is not going to solve the problem, because GNP is going to go up steadily in the future.

I'll give you just one example that illustrates the problem of just doing dollars per GNP, and that is if you compare an SUV versus a high-mileage automobile. One uses much more gas, but they have to pay for that gas, and so the carbon dioxide emission per GNP unit is the same as far as the gasoline use of those two. What we really need to do is to have policies that get things done without as much expenditure of carbon dioxide for whatever that activity is. That means looking very much at the energy conservation side.

Senator JEFFORDS. Thank you. Is it generally safe to say that increasing greenhouse gas emissions is likely to increase the probability and the magnitude of negative impact on humans and ecosystems?

Mr. ROWLAND. As far as humans are concerned, the infrastructure that they live in has been built for the present climate, and if that climate starts to change, then that infrastructure is not necessarily the right one for the new climate.

The faster that that change occurs, the more the infrastructure gets out of whack, no longer the right one for that location, so that slowing climate change is almost as important as controlling greenhouse gas emissions totally.

There is no way that the world is going to stop emitting carbon dioxide without coming very close to doubling the amount that is in the atmosphere, and that means that some time over the next century or two we're going to have a very different climate. We don't know how much difference that is going to be, but we need to slow down the rate at which we approach that and, as the other Academy report says, "We have to worry about whether climate change may occur on a very short time scale."

The kind of question that is running around the climate community is whether climate is a dial where the warming just gradually changes, or whether it is a switch and you quickly go to a new climate. That's not something that we have any way of predicting, but it doesn't—just because we are changing slowly at a particular time does not mean that we will not yet come to some new position where the climate is just different than what it was.

Senator JEFFORDS. Senator Voinovich.

Senator VOINOVICH. Thank you, Mr. Chairman.

Dr. Rowland——

Senator JEFFORDS. I'm going to pick a witness, and you can pick your witness or go after the same one I did.

Senator VOINOVICH. I'm going to go after all of them.

Dr. Rowland, I'm interested in your opinions. In your written testimony you said that increased greenhouse gas concentrations are often because of the activities of mankind, and in your oral comments just now you said they were mostly caused by the activities of man. As I listened to the testimony, there is marked differences of opinion about the causality and the temperature of manmade activity and natural activity.

Mr. Markham, you talked about 6° increase in temp, Dr. Baliunas—who is from Ohio, very nice to see you again. I saw you at our energy meeting about 6 months ago—you talk about .06 °C increase in temperature. By the way, Dr. Markham, I'm going to get a hold of my sugar maple people to see if they feel the same way as you do about things, because I refer to our sugar maple industry as "Ohio gold." But, you know, there is a difference of opinion here.

For example, I'll get to one specific question. Dr. Legates, in his testimony, Mr. Markham discusses the potential effects of rising temperatures in the Northeast. The question is: Can the climate models predict with any accuracy whether manmade emissions will cause these effects? I mean, Mr. Markham, you had the most dire predictions that we had of anybody here at the table. It's, like, "It's the end in terms of your part of the world unless something is done."

The issue is: What's the basis of it? How do you get those results?

Dr. Legates, I'd like to have you comment on what he had to say. I'd like to know could you believe, Dr. Legates, that the climate models predict with any accuracy whether manmade emissions will cause the effects that we just heard from Mr. Markham.

Mr. LEGATES. I think there's a serious problem with climate models in that, like I say, they are designed to produce only the mean field, not its variability. What we're interested in with climate models is to try to see how the mean changes. The problem is that on very small spatial scales we get quite a bit different characteristics than we normally see in the environment.

For example, one of the things I've found that is characteristic of models from when I started looking at them in 1990 to just a couple years ago when I did another analysis is that in the southern Great Plains of the United States, almost every model has Colorado being much wetter than northeast Louisiana. I needn't tell you that that's not the way the real world works.

The issue with that then is, if we start to look at regional scale fluctuations, we can look at fluctuations on the mean field. But if that mean field is specified wrong, we know it is biased in this case in completely the wrong direction from the way precipitation variability exists, the question then becomes: if the model changes in a field, is that change a result of what would really happen, or is that change a result simply because our initial specification of the model is wrong; and hence the results are going to be entirely different from what might really happen?

So, to come back to sort of what he's saying, I have concerns when we simply average out the mean conditions and only look at changes in the mean, because when we look closer at climate models they don't reproduce the smaller scale spatial variability that really is important to climate. Climate is not just a global phenomenon. Global climate is a net result of regional scale fluctuations.

There are areas where we normally expect a lot of moisture, areas where we expect little moisture, and we have to maintain that fidelity in the climate system. By just averaging out and focusing on large-scale features, which is what climate models do, a lot of these subtle things get missed.

Senator VOINOVICH. Does anybody else want to comment on models?

Mr. Markham?

Mr. MARKHAM. Yes. I think the figures that I were giving you came from the New England regional assessment, and those were scenarios that were developed to give a broad range of potential changes in the New England region. I think it is certainly true that, as you take global models and look at what they will mean for a particular region or a particular place, then the accuracy of those potential predictions is less; nevertheless, what it shows is that there is very significant risk. This is also backed up by actual observed changes, so the New England regional assessment looks at an average of about 0.7 °F increase in temperature over the last century in New England.

Again, as you go more local you can see that there have been much greater increases in temperature over the century in southern New England, and precipitation various across the region, so the more local we go the more difficult it is to make predictions. Nevertheless, the general trend is toward observation of warming and likely increased warming.

Senator VOINOVICH. The real issue is that, in terms of public policy, that you have general trends and people grab a hold of the worst numbers, and then they say with these numbers you have to do this because if you don't do it the world is going to come to an end, you know, or we're in bad shape. Somewhere through this we need to try to get a balance of how we work things out.

Mr. Cogen, you talked about some of the businesses, I guess, over in England that are doing some things. Are they doing these things because of command and control, or are they doing it because they feel it is in their best interest to look at reducing carbon dioxide and have found it to be a good investment overall in terms of efficiency and just good citizenship?

Mr. COGEN. In the United Kingdom it is a mixture of both. The United Kingdom has put a carbon levy, which is a tax on carbon intensity, and then they have designed a trading program underneath it to give companies flexibility and the ability to reduce their tax by 80 percent, so it is a combination of the two.

Having said all that, many of the multi-nationals who are operating in the United Kingdom look at this as much from the sales side of their products and what the public expects of them, not just under the United Kingdom. Yesterday, in fact, the chairman of British Petroleum announced—I'm reading from "Air Daily," which is an industry publication—that they cut their greenhouse gas emissions by more than 9 million tons 8 years ahead of schedule. To quote the chairman, "I believe that the American people expect a company like BP to offer answers and not excuses."

That's clearly the positioning of a multi-national that this is an issue that they think their customer base cares about. It's not just something that the Government is doing from a command and control. So it is a market-driven force that is making BP do this internationally, as well as government incentives and requirements in the United Kingdom.

Senator VOINOVICH. I'm familiar with BP. I know Sir John Brown. They had great presence in Cleveland for a number of years. I think their colors even advanced their issue of trying to be good corporate citizens in climate.

The only comment I'm going to make is that the issue becomes, from a public policy point of view, in terms of command and control and that you must do this, and so forth, and my experience in Ohio when I was Governor is that we got involved in this 35/50 reduction in the 17 worst toxins and basically went to the companies and said, you know, "We think you ought to do this, and we're not going to demand that you do it, but we're going to suggest that you ought to look at this." It amazed me the number of companies that signed up and the impact that had in terms of reducing the 17 worse toxins in the State.

You've got a situation where you want to do something about a problem. There's a disagreement about what man is doing in regard to that, but there is no question that man has something to do with it. Then the issue is: what is the public policy response to that that will get at it, and at the same time not put you in a position where you are non-competitive or, in the alternative, have a dramatic impact on the economy and the well-being of the citizens that live in your respective communities.

Mr. Chairman, that's a real problem here, because, in terms of regionalism, we have a different economy in my part of the country than they have in the Northeast. It is a manufacturing based economy. Reasonable cost energy has been the basis of that economy. In the Northeast they have a different kind of economy. Our economy is impacting on their economy.

That's our challenge is how do we reconcile all of these things to the extent that we move ahead and get something done, rather than end up in a debating society or in multiple lawsuits that clog up the courts and don't do anything for improving the environment or dealing with the energy needs that we have in the country. You folks are the experts.

My time is up, but maybe the next time around you can maybe comment on that.

Mr. Chairman.

Senator JEFFORDS. Senator Chafee.

OPENING STATEMENT OF HON. LINCOLN CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. Thank you, Mr. Chairman. Thank the witnesses for their testimony.

I guess, to followup on Senator Voinovich, some countries, as Dr. Whittaker testified, are already implementing policy changes to comply with Kyoto, and Dr. Whittaker said that the European Union has already committed itself to a legally binding timetable for Kyoto implementation, and that Japan, the United Kingdom, and Canada have signaled their attempt to ratify the Kyoto Protocol during the coming weeks, so the other countries are doing it.

I guess my question is, Dr. Rowland said, "Unfortunately, that means a lot of them are turning to nuclear." Dr. Whittaker, is that what you're finding in the international community? Is that the sad reality? Is that the option?

Mr. WHITTAKER. That's not what we're finding. No. The benefits are really coming from greater efficiency, I would say, through the kind of mix of command and control and economic incentives that Jack talked about.

Senator CHAFEE. Do you want to repeat that again?

Mr. WHITTAKER. Yes. The mix of economic incentive and command and control is really what is helping businesses in those countries move toward solutions. I'll give an example of NTT, which is a Japanese telecoms company. I think it is Japan's largest electricity consumer. Over the next 10 years, it proposes to save about 100 billion yen through the adoption of clean energy technologies. Those types of actions are not coming from any legislation or from the Japanese government yet, although the Japanese government hasn't announced its intention to ratify. It may be a preemptive strike, sort of in anticipation of regulation, but still there are tangible benefits for NTT shareholders. I think that's the message that we're seeing time and time again in different parts of the world.

Senator CHAFEE. In your home country of Canada, how are they planning to comply with Kyoto? Is it more reliance on nuclear or the Hydro Quebec Power taking a slice out of the emissions of carbon dioxide? How is Canada going to comply? It's such a similar economy to our own.

Mr. WHITTAKER. If I knew the answer to that question, I would be very popular in Canada. They haven't decided yet. There is a tremendous amount of concern in Alberta, which is, of course, oil rich, and particularly the oil sands, which are extremely greenhouse gas intensive, to produce.

The role of emissions trading is going to be crucial in helping Canada achieve its targets, so it will be looking internationally to achieve credits, to buy credits to help offset its emissions in order to meet its targets.

It is also going to be encouraging its renewables and clean energy sector, and there are various efforts underway to expedite that already.

Again, it is a combination of approaches, but certainly the answer is not clear yet.

Senator CHAFEE. Thank you very much.

Senator Jeffords and Senator Lieberman have introduced a bill which would reduce the carbon dioxide emissions to the 1990 levels, probably the most aggressive bill in the Senate, I would say. I don't know if I can run down the panel and get a 30-second opinion on that bill before my time runs up.

Dr. Rowland.

Senator JEFFORDS. Well, you can take extra time for that.

Mr. ROWLAND. Reducing to the 1990 level of emissions would require substantial cutback, and the question of how much economic dislocation it would do would surely depend upon the rate at which that was done, but we are well above the—we have increased since 1997, continued to increase our CO_2 emissions, and so the 1990 goal has been receding from where we have been as a country.

It means that we really haven't taken hold of trying to cut back on a voluntary basis. As Senator Voinovich says, clearly Ohio is different from New Hampshire, Rhode Island, and it's different from California, and the solutions in each of those places for becoming more energy efficient may not be the same, and they require somebody who is there and who knows their particular conditions that can do that, but we have not adopted, as a country, that energy conservation is a major goal in order to minimize carbon dioxide emissions.

Mr. PIELKE. Let me say what may be, I guess, an unpopular truth here. I'm not familiar with this bill, but if we assume in a thought experiment full and comprehensive implementation of the Kyoto Protocol around the world, it is safe to say it's not going to do much at all to address the environmental and economic risks associated with climate change.

I should point out that the framework convention on climate change that the United States signed onto in the last decade makes a distinction in the term "climate change." It defines climate change as only those impacts that are the result of greenhouse gas impacts. Any other climate impact is not covered by the framework convention. So whether it is maple syrup growers or people worried about hurricanes or human life in developing countries, it doesn't make much sense from a policy perspective to try to separate out human climate impacts from non-human climate impacts. I would say it is a broader issue.

Mr. LEGATES. I'm also not familiar with the legislation, but I do recall in 1997 that American Viewpoint conducted a survey of State and regional climatologists, and one of the questions they did ask was: if we rolled back to 1990 levels, would it have a significant impact. I believe I remember somewhere between one-half and two-thirds of the respondents indicated that it would have little or no impact.

I don't think it would have much of an impact, either. My concern is that a lot of the variability, particularly a lot of the loss of life that we see is going to be as a result of the extreme events, and these extreme events are going to continue to occur. So we need to take into account, to some extent, how we alert the people, how we deal with growth along coasts, for example, and things like that. These issues would be impacted by climate change, but also in this case I think, while cutting back would be beneficial for some other reasons, I don't think it presently is necessary from a pure "global warming" standpoint.

Mr. MARKHAM. If you accept the science that greenhouse gas emissions are increasing the risk of climate change, then it seems to make sense to reduce CO_2 emissions, and this bill would do that.

I think that the target of 1990 is a good first-step target. It is an aggressive target, but it still won't take us back to the levels that are probably required.

Although it takes a long time to bring down the CO_2 level, CO_2 can stay up in the atmosphere for more than 100 years. We need to be acting now to protect future generations. I think that's why maple syrup is a good example, because people planted those trees for their children and grandchildren, usually. They can't harvest them for 40 or 50 years or so. So we need to be looking down the road and thinking about future generations, and we need to, I believe, be acting now to start reducing CO_2 emissions, and this bill would take us a long way in that direction.

Ms. BALIUNAS. Assuming the climate projections are accurate, then reducing to 1990 levels for the United States would mean about a 20 percent cutback in carbon-based energy use or carbon dioxide emissions. Replacing that—I agree with Dr. Rowland—is going to be extremely difficult to do, and yet climactically, temperature-wise, assuming the models are accurate, this averts, off the top of my head, less than .05 °C of the warming by the year 2050. So it is, on the one hand, extremely costly, and on the other hand ineffective. That's why it is important to realize that a policy like this is only a scant first step. There has to be much more done much more dramatically if one accepts the models. That's why the science is still very critical in this debate.

Mr. WHITTAKER. I guess the question is where would the emissions come from? If you look at the key source categories, the stationary—essentially, the power production sector, coal combustion sector, is the No. 1 by a country mile.

We've done some financial modeling around this issue and looked at what would happen if the top U.S. utilities all had to reduce their emissions to their own 1990 levels to 1998 levels and played around with different scenarios there. A softened Kyoto, which essentially is leveling at 1998 levels, corresponds to, according to our analysis, roughly 11 percent of the current total market capitalization of some of the most coal intensive utilities, so the financial cost of doing that, if that's what you wanted to do, would need to be taken into account.

Mr. COGEN. In discussions with our customers about Senator Jeffords' bill, the impact of it has been slightly different. It's not the details of the bill or whether it will pass or not pass, it's raising the conversation to a level that has to be taken seriously, and combined with a movement overseas to ratify Kyoto with the United Kingdom or Danish programs, with many regional or State programs here, it is forcing corporations—especially that have long-term assets planning cycles, whether it is 40 years for maple trees or 30 years on a power plant—to take this into consideration that we may be in a carbon strait in the future and what the effects of that would be. So I think it is galvanizing the conversation and forcing companies who have fiduciary responsibilities to make decisions to decide for themselves not so much on the science, but on the policy and what investigation decisions they will make under different policy regimes.

Senator Jeffords' bill is forcing them to take it seriously now, which is a good thing.

Senator JEFFORDS. Senator Corzine.

OPENING STATEMENT OF HON. JON S. CORZINE, U.S. SENATOR FROM THE STATE OF NEW JERSEY

Senator CORZINE. Mr. Chairman, I appreciate your holding the hearing. I had a formal statement I'll put in the record.

I feel like I am an interloper coming in at the end, and so I will pass, but I do want to emphasize how strongly I feel that we need to fully understand in the terms of science these risks that are associated with climate change.

I would just mention that there are studies that show the 127-mile shoreline in New Jersey is potentially at risk to complete erosion, something in a foot rise over the next 50 years. For a $40 billion industry, for enormous amounts of property, this is an issue that concerns the citizens of New Jersey, concerns me, and I think it should anyone.

I apologize for being late. We had three hearings at one time. But there is nothing more important, long-run, for my community and the people I represent than this issue.

[The prepared statement of Senator Corzine follows:]

STATEMENT OF HON. JON S. CORZINE, U.S. SENATOR FROM THE STATE OF NEW JERSEY

Thank you, Mr. Chairman. I appreciate you holding this hearing today on the economic and environmental risks of increasing greenhouse gas emissions.

I want to make just a few points before we begin to hear testimony from the panel.

The Science Warrants Action. First, I think that the science warrants a hard look at risks and potential impacts. Last year, the Intergovernmental Panel on Climate Change (IPCC) recently released its Third Assessment Report. The report as I read it indicated that the science is increasingly clear and alarming.

The report indicated that human activities, primarily fossil fuel combustion, have raised the atmospheric concentration of carbon dioxide to the highest levels in the last 420,000 years.

The report further indicated that the planet is warming, and that the balance of the scientific evidence suggests that most of the recent warming can be attributed to increased atmospheric greenhouse gas levels. Mr. Chairman, these IPCC findings were validated later in the year by the National Academy of Sciences.

Mr. Chairman, we also know that without concerted action by the United States and other countries, greenhouse gases emissions and concentrations will continue to increase. Climate models currently predict warming under all scenarios that have been considered. Even the smallest warming predicted by current models—2.5 degrees Fahrenheit over the next century—would represent the greatest rate of increase in global mean surface temperature in the last 10,000 years.

So while scientific uncertainty remains, I think the trend is clear. As a result, we need to focus on risks.

New Jersey and Other Coastal States Will be Impacted by Climate Change. For my State of New Jersey, Mr. Chairman, the threat of continued sea-level rise is one of the risks that I am most concerned about. With the exception of the 50-mile northern border with New York, New Jersey is surrounded by water. The state's Atlantic coastline stretches 27 miles. Fourteen of 21 counties have estuarine or marine shorelines. Rising sea level is already having impacts, by exacerbating coastal erosion, and causing inundation, flooding, and saline intrusions into ground water. The N.J. coastal area also supports one of New Jersey's largest industries—tourism.

Sea level is rising more rapidly along the U.S. coast than worldwide. Studies by EPA and others have estimated that along the Gulf and Atlantic coasts, a one-foot rise in the sea level is likely by 2050 and could occur as soon as 2025. In the next century, a two-foot rise is most likely but a four-foot rise is possible. So I'm concerned about this risk to my home state.

We Need to Take Steps to Reduce Risks. Given the state of the science and the risks we face, I think we need to take steps to reduce risks. The president's plan, which represents only an incremental step over business as usual, is simply not enough in my judgment.

At the state level, New Jersey is already taking aggressive steps to reduce emissions. The state has a plan to reduce greenhouse gas emissions to 3.5 percent below 1990 levels by 2005. Specifically, the plan would achieve a 6.2 million ton reduction through energy conservation initiatives in residential, commercial and industrial buildings, another 6.3 million ton reduction through innovative technologies in residential, commercial and industrial buildings, a 2.2 million ton reduction through energy conservation and innovative technologies in the transportation sector, a 4.5 million ton reduction through waste management improvements, and a half million ton reduction through natural resource conservation.

So I think what New Jersey is doing—under a plan that Governor Whitman got underway—shows that we can and should do much better than what the president proposed.

Support the Climate Titles in the Energy Bill. Finally, Mr. Chairman, I want to urge my colleagues to support the climate change titles in the energy bill. In particular, I want to urge my colleagues to support the registry provisions in Title XI of the bill. These provisions will require the largest emitters to report greenhouse gas emissions—as utilities are already required to do. These provisions also enable companies that undertake emissions reductions to register them, so that they will receive credit for their actions if reductions are required at any point in the future.

Taken together, Mr. Chairman, I believe that these greenhouse gas registry provisions will provide a powerful incentive for companies to take actions to reduce emissions. I know you agree, as you are a cosponsor of S. 1870, a bill containing similar provisions that I introduced in December. The energy bill registry provisions represent a compromise between S. 1870 and related legislation in the Energy and Commerce committees, and I urge my colleagues to support them.

Thank you, Mr. Chairman.

Senator JEFFORDS. Dr. Rowland.

Mr. ROWLAND. So far all of the discussion has been on controlling carbon dioxide, and there are other greenhouse gases. The one that

I would draw particular attention to is tropospheric ozone—that is, one of the components of smog is ozone formed by the interactions of nitrogen oxides and unburned hydrocarbons and light, and that mostly takes place in cities, although we have run into it experimentally in burning forests especially in the Southern hemisphere.

The failure to burn gasoline completely in an automobile results in the formation of ozone, which is a greenhouse gas. Then the hydrocarbons eventually become carbon dioxide, anyway, but on the way it produces another greenhouse gas that adds to the total interception of infrared radiation.

This is happening in hundreds of cities all over the world. It would be to our advantage and to the globe's advantage if the pollution problems of these cities, with respect to ozone, could be reduced, and that's something that is a problem in China; it's a problem in India; it is a problem in the United States and everywhere.

We know how to do it. In places like Los Angeles, the smog has been reduced by adopting certain policies. And, to the extent that we can get those policies in place in cities all over the world, then that reduces the amount of tropospheric ozone and is the equivalent of cutting back on some carbon dioxide because it is a greenhouse contributor.

So it doesn't get rid of the fact that the automobile eventually puts the carbon dioxide in the atmosphere, but on the way it also produces another problem, and if we could just go to clean-burning in an automobile, helping in reducing tropospheric ozone, and that helps because it is a greenhouse gas. So it is a policy that would be useful on our part to encourage and assist, if we can, in the cities that have these problems.

Senator JEFFORDS. You mentioned India. I have been to the places—India, China, and other places in that area—which have extensive coal burning, as you well know, and the problems there are much greater than we have here. Internationally, what should we be doing to try to assist in those countries having the capacity to reduce their pollution?

Mr. ROWLAND. In the cases of both India and China, they have very high ash coal, and much of their pollution in the cities comes about by having particles in the atmosphere coming about by burning coal that has material in it that's not going to burn. City pollution problems can be sort of divided in two categories. One has to do with producing particles, and that has a lot of bad things happening, particularly when you breathe them in. In addition, there are the photochemical problems that come from the chemical interactions that take place.

What I was talking about earlier would be trying to reduce the photochemical problems by adopting the kinds of procedures that have been put into place by the Southern California Air Quality District.

The question of getting the particles out of the air in Beijing and Delhi is a matter of people in China and India deciding on some way of using cleaner fuel to begin with. How they treat their coal in order to get rid of the particles before they burn it would be a very complicated problem. That's one that I don't know exactly how they would do it.

Senator JEFFORDS. Senator Voinovich?

Senator VOINOVICH. Yes. I would like to ask the witnesses: how many of you are familiar with President Bush's climate change initiative?

[Show of hands.]

Senator VOINOVICH. Senator Chafee asked you your opinion about Senator Jeffords' bill, and I have: Rowland, question mark; Pielke, question mark; no, Legates; yes, Milburn [sic]; no, Whittaker. I mean, no one really came out and said yes/no. You kind of all waffled to a degree except Mr. Markham.

Senator JEFFORDS. That shouldn't surprise you.

Senator VOINOVICH. Right.

Senator JEFFORDS. We do the same thing though.

Senator VOINOVICH. The way I summarize it, it provides the necessary funding for both the science and technology research, encourages companies to register their CO_2 emissions, sets a national goal to reduce our carbon intensity, which is the best way to protect our economy and begin to address the issue.

Anyhow, the No. 1 issue is: What do you think of that policy? No. 2, what other things should we be doing? We get into this whole issue of the technology and where we are in the models and the rest of that and where should we be investing our money in that regard. I'll make a comment before you answer the questions, but, Dr. Rowland, you're talking about coal in China and the ash problem. Whether we like it or not, regardless of what happens to Kyoto, a lot of these newly emerging economies are going to burn coal. Coal produces about 55 percent of our energy here in the United States, and my State is about 85 percent.

It seems to me that one of the greatest things that we could do as a matter of public policy, Mr. Chairman, would be to really put some money into clean coal technology and also provide some incentives so that we could go ahead and really do a job with that technology that could be exported around the world that would help deal with the problem that these countries are dealing with now.

If that's not what we're going to do, and faced with what the real world is, then we have to go to some other alternative source of energy. We talked about nuclear is what many others have said. Then what's left is gas, hydro, and then some of the renewables that we have, but most of us recognize that renewables produce about 1/10th of 1 percent of the energy in this country, so that's the real world we're dealing with.

I guess the issue is: how do you deal with the real world? In the remainder of my time, what do you think of the Bush policy? We'll start off with that.

Dr. Rowland.

Mr. ROWLAND. I'll make a response to your question about clean coal technology. Yes, there's no question that India and China are going to depend for the next decades very heavily on coal, and they both, unfortunately, have very poor coal, so if they could have technology available—that is, clean coal technology—then it would help them quite substantially with their own local environmental problems. Still, you end up with carbon dioxide from burning the coal. But we might be able, as part of the cleanup of their cities, to persuade them also to take care of the other aspects of air pollution that they have in the urban areas. But I'm sure that clean coal technology in India and China would be very beneficial to them and to the atmosphere, generally.

Mr. PIELKE. Let me say, from the standpoint of climate risk, the choice between, let's say, the Kyoto Protocol and the Bush plan, there is a distinction without a difference there. There are really no differences in risk because neither addresses the underlying causes of risk, which are the increasing vulnerability of society and the environment to climate events.

Clearly, there are economic, political, and symbolic——

Senator VOINOVICH. Can I?

Mr. PIELKE. Yes.

Senator VOINOVICH. That's really interesting. You're saying—and I want to make sure I understand. You're saying that, in your opinion, we're seeing, if you look at history, a much greater vulnerability to changes in natural climate types of things? In other words, is that—am I understanding that right?

Mr. PIELKE. Yes. What I'm saying is that, even in the context—forgetting about the natural versus human cause of climate change—climate has changed. I mean, it is clear in different locations over different time periods. But if you take a look, for example, at hurricanes, for which we have very good data, the same storm which would have caused $100 million inflation-adjusted in 1926 Miami, today would cause about $90 billion. That has nothing to do with the changing frequency or nature of storms, only that Miami Beach and associated property develop is much different than it was the beginning of the last century.

So when we're looking at risk and we're worried about impacts of climate, you can't just say, "We have more precipitation. Will the temperature be warmer," and so on. We also have to look at how the economy changes, how society changes, and so on.

When you put those two things together, by far the largest signal—and, again, this is talking about humans and not the environment—by far the largest signal are the changes we make every day, how we develop, how much more wealth we accumulate, where we live, and so on. Those are the determining factors in risk.

The insurance company insures against property damage. It doesn't ensure against number of storms.

Senator VOINOVICH. OK. So, again, I want to understand this. It's like Senator Corzine was talking about the coastline. In my State, the water level is way down, and I suspect it will go way up, and I haven't figured out what it is. Some people say that if somebody turns a spigot on it turns it up, but we know that isn't the case. But the question we have, like, for instance, when I was Governor, we did coastal plain. We advised people not to build in certain places. We required, when people buy a home now, that they've got to be given information about the erosion and some other things. Those are the kinds of things you're talking about that we'd better start thinking about in terms of our overall policies?

Mr. PIELKE. Yes. There's a disconnect here. I think Senator Corzine is properly concerned about erosion on the coast. But let's not kid ourselves. Let's not think that the choices we have before us on energy policy are going to make any difference whatsoever on what happens on the coast. Many other decisions that you folks will face will affect that, such as development, replenishment of beaches, and so on—the decisions that are made every day that go, I guess, underneath the radar screen of energy policy. But I think there is a policy disconnect here. If we are talking about energy policy and justifying changes in terms of beach erosion or water tables and so on, it is not in concert with how we understand how climate and people interact.

From that standpoint, I would say Bush versus Kyoto, you're talking to the wrong experts here. It may make sense from the standpoint of keeping our allies happy with respect to international relations or showing environmental symbolism, but it is not at all going to address these issues of risk.

I think it is time that the debate moved on to acknowledge that.

Senator JEFFORDS. Dr. Rowland.

Mr. ROWLAND. I'd comment about climate models and weather. The climate models are not designed to reproduce weather, and most of what Roger Pielke is talking about and also what Mr. Legates talked about are weather-related questions of how much precipitation there is very locally. When you live locally, then that's very important to you. It is what happens right there.

If you build on the barrier beach in Florida, then eventually you're going to get hit by a hurricane, and that's why he's saying that the beach damages weren't there in 1926. The beaches were there in 1926 and the hurricanes went over them, but people weren't there. If you build on them, then at some time it is going to hit you. That's the weather-related aspect.

The climate-related aspects have to do with 50 or 100 years, and there the question of the storms—the climate models don't reproduce storms. Storms happen, are created and produced on a much smaller spatial scale than the climate models can do.

If I give you an example for myself, I live on the coast in southern California. My office is about 4 miles inland. The weather is different there because there is a low hill, low hills in between, and 50 miles away there is a 12,000-foot mountain with snow on top of it.

If you have a climate model that has a box that is 100 miles by 100 miles, then the beach and the desert and the mountain are all in the same box. You can't predict any kind of weather out of that. For that you need a very much smaller-scale model, and if you build a smaller-scale model that only does the weather, then it does pretty well. They do pretty well on precipitation. But you can't expect a climate model to do that because the scales are so different. Climate modeling is really looking 50 to 100 years in the future and under conditions when the hydrological cycle would be three, four or five times as severely changed as now, and that's when they start worrying about the storms, but they can't predict them because that is much too fine a scale for their model.

Senator JEFFORDS. Mr. Markham, go ahead. I was going to ask you.

Mr. MARKHAM. Yes. I just wanted to respond to Senator Voinovich's question about the President's climate policy.

I think the simple answer to that is that that is a business as usual policy which will allow carbon emissions to increase over the next decade at roughly the same rate at which they've increased over the last decade, so, by tying the issue to carbon intensity rather than to overall CO_2 emissions, that policy is not a policy for reduction, it is a policy for continued increase. For that reason, I don't think that it will help us if our objective is to reduce greenhouse gas emissions.

I would also like to just say that I think it doesn't help to try and totally separate energy policy from response to climate change. We are almost certainly locked into a certain amount of climate change, to which we will have to adapt, but at the same time, by having a secure and sensible energy policy, we can reduce the potential future impacts. Climate change doesn't happen on its own, it happens in a context of social change. Wildlife habitats are unable to adapt to rapidly changing climate. The coasts—we are spending tens of millions of dollars on armoring the eastern coasts at the moment. As sea level accelerates over the next century, then that will be an increased cost, so we shouldn't always just talk about the cost of reducing emissions, we should also talk about the cost of not reducing emissions. I think the coastal zone is one of the areas where we need to look at that more closely.

Senator VOINOVICH. Dr. Baliunas.

Ms. BALIUNAS. The reason I abstained on the vote on the earlier bill is because I hadn't seen the full bill. I like Bush's bill because, for some reason, one is it focuses on the science, and the science is clearly the driver of the issue here. The models need improvement. They need improvement in the major greenhouse effect, which are 02 water vapor and the effect of clouds. Those are poorly to improperly modeled at present in all climate models. All climate models assume them to be, especially water vapor, strong positive feedback that amplifies any warming that would be there from, say, doubling carbon dioxide concentrations in the air. That is wrong. That has been demonstrated incorrect from the satellite data and the balloon data that we have. Those models are incorrect based on the surface data measurements. They are exaggerating the warming.

So anything that affords science to progress in those areas will give us a better definition of the risk, the amount, the amplitude of climate change from manmade sources. This has to be weighed against the cost.

Talking about cutting energy use in this country, carbon dioxide emissions, by 20 percent on a time scale of a decade is extremely costly. There is no way around it. One can only look at what Senator Chafee called the sad reality of nuclear to replace these. Renewables won't do it. Hydro is not going to expand in this country. Solar is not going to add on that scale. Wind towers are not going to add on that scale. So we're going to end up shutting down coal, adding a lot more natural gas, and adding nuclear. I just don't see how it is possible to do that.

But, in any case, the science says that the manmade emissions that are present are having a very small climate effect.

Senator VOINOVICH. Thank you.

Mr. WHITTAKER. I would only add that, from a business standpoint, certainly the policy encourages technology development, and if I was with a cogeneration or with a combined heat and power company right now, I would be quite pleased. I think my business is going to improve over the next few years.

We ask about how can we encourage China and India to embrace these new technologies. Well, there is a mechanism under the Kyoto Protocol called "a clean development mechanism," which is designed precisely to do that and to credit U.S. companies for doing so.

I would have liked to have seen mandatory reporting. I think disclosure on issues brings consistency, and the consistency of information is very valuable for those wishing to estimate companies, certainly in the financial services industry, which brings me on to my final point.

I would like to see more of a dialog with Wall Street and with the investment community. I think institutional investors are increasingly invested in the equities markets and have tremendous sway over companies, and the slightest level of concern expressed by investors would be a powerful catalyst, I think, for companies to look at this issue more seriously.

Senator JEFFORDS. Dr. Rowland.

Mr. ROWLAND. I should register dissent to what Dr. Baliunas said about the modeling of the clouds and the modeling of water vapor. In the consensus discussion of the Academy scientists that were involved, they agree that there are some uncertainties involved in any of that, but at the present modeling, assuming that the relative humidity would be the same and handling clouds as they are is as good as you can do at the present time for doing the modeling. It is not introducing a bias one way or the other.

Ms. BALIUNAS. I want to register dissent to the dissent, and that is they may be the best we can do today, but they are insufficient for making projections 50 to 100 years in the future. We cannot even explain the lower troposphere temperature of the last 20 to 40 years, where we've gone almost halfway to a doubling of carbon dioxide, equivalent carbon dioxide in the air—that is, summing all the greenhouse gases in the air.

The models make an error of a factor of at least five in projecting the warming. That error has to be due to the largest feedback, the largest gain, which is water vapor. It is a distribution of water vapor in the air. We don't have good measurements for it, the vertical distribution of it, and we don't know how it interacts with the rest of the climate system. Ditto for clouds.

Mr. PIELKE. I could. This dialog is exactly what's wrong with the climate change debate. This country spends an enormous amount of money—about $20 billion over the last 10 or 12 years—on climate change research, and, while we have a much better understanding and much better sense that yes, people can affect the climate, esteemed scientists such as these will be debating these issues far into the future. That's how science progresses.

But what hasn't come out of the Nation's $20 billion investment in research are more alternatives, more choices. The choices that we face today are essentially the same that were discussed in 1982, in 1985. It's, "Do we reduce CO_2? Yes or no?"

There are thousands, if not millions, of decisions made about climate every single day in each of your States, in my State, around the world. I think it is fair to ask if the scientific community is providing information that leads to a greater range of choices with respect to mitigation and adaptation to climate change. There's clearly a lot of reasons to change energy policy independent of climate and a lot of reasons to better adapt a climate independent of change.

It seems to me that the research that we're funding as a country is not leading to those choices, meaning that all of the science we get is fed into the same very narrow range that we'll be talking about in 10 years. So I think maybe it is time to think a little bit more broadly about the problem, because this hearing and the debate among scientists, if you look in 1985 or even 1982, when Representative Al Gore held hearings, is very similar, and yet our choices remain the same.

I would encourage you to do what you can to expand the choices available.

Senator JEFFORDS. Mr. Cogen.

Mr. COGEN. Thank you, Senator.

In responding to President Bush's proposals, I will take the same approach I took to Senator Jeffords' bill, which is not actually have an opinion, but I will say that we represent a lot of very large emitters, a lot of industrial companies are typically the companies that hire us—many, in fact, in the State of Ohio. There's three things that they're looking for in a bill, and I think maybe that's what I'd like to point out and focus.

One is flexibility. Universally they support market-based mechanisms for dealing with the problem as far as their solutions.

The second, which is the hardest to get under any environment, is some sort of regulatory certainty.

Senator VOINOVICH. Is what?

Mr. COGEN. Regulatory certainty. It is very hard to make investment decisions for long-term assets when you think the law might change in 5 or 6 years and you're talking about a 30-year asset.

Another issue, which goes to the issue of the voluntary nature of programs, is protection of baselines. That is, a number of companies have witnessed this, and certainly there has been talk over the years of credit for early action. I think that gets to the heart of it.

It is very hard to take a voluntary action now as a corporation for all of the good corporate citizens reasons and find out years later that you are now established at a lower baseline from which you must reduce because of a mandatory program, where if that is the case the best economic solution is, in fact, put as much carbon out as you can now so that you have a higher baseline that you have to reduce 10 percent off of.

That's the situation that we are actually seeing, especially under the trading program proposed in the European Union, that right now, for example, some chemical firms have taken great efforts and expense in reducing their nitrous oxide output, and we're finding that, in fact, the chemical industry is not under the trading program at all. Then there's talk, as a secondary, "Well, we'll put them in and then we'll establish the baseline pretty much on basic level, as they're doing now," when some of them have spent 10 years actually reducing their CO_2 equivalent out put. It might just all go away for them.

That, to me, is maybe the key issue that can be addressed is: if you're going to have any sort of voluntary program, how do you protect it? What assurances can be given that it is going to count later?

Senator JEFFORDS. Anyone—Dr. Rowland.

Mr. ROWLAND. I have just a comment about satellite measurements of temperature. We all know how thermometers work. We've all used them. A satellite can't do what a thermometer does, and that is contact the material directly. So if a satellite wants to measure temperature, it has to measure some kind of emission that gives radiation that travels 500 miles to the satellite. It doesn't get it just from the place that you want to measure it. It gets it from all through the atmosphere, so you have to have an algorithm that calculates it.

The history of the satellite measurements of temperature in the troposphere have been that the algorithm was shown that existed for quite a period of time, 5 or 10 years, had some problems in it. The same satellite doesn't stay there. There have been 9 or 10 of these satellites, and their orbits decay, and then you have to pass it from one to the next. So it is not just sticking your thermometer in and measuring it, which that at least we know how to do. It is a very—it often takes adjustment of the algorithm 5 or 10 times, and it is not clear to me that we've got the final algorithm for measuring tropospheric temperatures by satellite.

In the end, satellites always give you the global coverage that is needed, but interpretation of the measurement that actually reaches the satellite is a complicated thing, which is very valuable if more than one research group—if there are several research groups and they repeat and they can come together on it, and I don't think we're in that position on the tropospheric temperatures.

Senator JEFFORDS. Yes.

Mr. LEGATES. I agree, and that's one of the things I point out in my statement is that we need more work on satellite measurements. But I disagree strongly that a thermometer is a perfect measurement. A thermometer can measure temperature at a given point. The problem with that is a thermometer is good for measuring a temperature here but not for across the room, so we have a single thermometer located at, say, a National Weather Service observing site. It is representative only of that site, not of the larger region.

Now, the problem is that things change on that site over time. We've moved a lot of the stations around, for example, in the 1940's, early 1950's. We decided we really didn't need the Weather Services offices downtown, it was better to have them out at the airports, so we moved our thermometers out to the airports, which created discontinuity.

Well, what's happened over time? We've had urbanization. So the thermometers, which originally were in land outside of the cities, and now with a growing metropolis a lot of cases, these thermometers now are associated with urbanization right around the site. That is, the growth of cities leads to more asphalt and warmer conditions so we have the effect of urbanization biasing our measurement with the thermometers.

We also have changes in thermometers over time. We don't necessarily use the same type of thermometer in 1930 that we do now, so there is a discontinuity in instrumentation.

Most importantly, we only put thermometers over land surfaces. We have most of our observations associated with locations that are over land, that are at lower altitudes, that are generally in wetter conditions and in more economically developed countries.

So thermometer-based measurements are good only for a single point, but they don't give you a good indication as to what the actual background change has been, because there is a lot of variability and bias associated with taking a thermometer measurement.

Ms. BALIUNAS. I want to add that the lower troposphere measurements by satellite have been independently validated by balloons that are launched daily and make measurements in situ, and there are at least four sets of balloon measurements that are made independently across the world, groups that analyze it, and they agree with a high degree of correlation with the tropospheric data from satellites.

So the argument is that the lower troposphere data are probably on a very good footing. They cover almost essentially all the globe, as opposed to between 10 and 20 percent for the ground-based thermometer measurement data that have, as Dr. Legates has pointed out, have changed substantially over time and have many corrections made to their algorithms, as well.

Mr. PIELKE. Yes. I'd like to suggest that there's really no solution to the problem of climate change, but we can do better. I'd like to go on record as saying I'm a big supporter of using less energy, being cleaner in our energy use, and so on, but we don't need better thermometers, better satellites, or any of that to start making progress. There's a lot of so-called "low-hanging fruit." National security, alone, provides a compelling reason to be more efficient in our energy use.

It seems to me that in tackling the greenhouse gas emissions of 6 billion people focused on understanding the science 100 years in the future, we couldn't have created a problem that could be more easily gridlocked.

There's a lot of relatively easy, by comparison, steps—no regrets adaptation and no regrets mitigation—for which the debate over the science, while important, shouldn't stand in our way. We ought to be being better with our energy use and reduce our vulnerability to climate in any case, and we should start taking those steps. We should have taken them before, but we should start now instead of trying to wait for science to resolve itself.

Senator JEFFORDS. I'll give you all a last shot here. Dr. Rowland.

Mr. ROWLAND. I have no more.

Senator JEFFORDS. Mr. Legates.

Mr. LEGATES. [Shaking head negatively.]

Senator JEFFORDS. Mr. Markham.

Mr. MARKHAM. Just to say that I think the risks from greenhouse gas emissions are very great. The science—we have good, sound science. It's getting stronger every day. We know a lot more than we did 5, 10, or 15 years ago. As. Dr. Pielke says, there are many low-cost actions we can take now, which include both voluntary and hopefully regulatory actions like your bill.

Ms. BALIUNAS. The science has gotten extraordinarily better. The models still cannot be used to make reliable, credible predictions in the future. They fail validation by scientific testing. We should not hold this to energy policy.

Mr. WHITTAKER. Only to say that this is very definitely a business issue. It is a business risk and it is a business opportunity, and it will intensify in the coming years.

Mr. COGEN. Yes. I'll agree with that. From the business point of view, people are looking to the Senate for leadership. Businesses are taking actions and they want to see some regulatory framework for it.

Senator JEFFORDS. Let me ask this last question. Do any of you believe that it is safe to continue increasing manmade greenhouse gas emissions without any limit?

[All witnesses indicate in the negative.]

Senator JEFFORDS. No one says yes, and so that must be no, and we'll see you later. Thank you very much.

[Whereupon, at 11:42 a.m., the committee was adjourned, to reconvene at the call of the chair.]

[Additional statements submitted for the record follow:]

STATEMENT OF HON. JOSEPH LIEBERMAN, U.S. SENATOR FROM THE STATE OF CONNECTICUT

I thank Chairman Jeffords for calling this important hearing on the economic and environmental risks associated with increasing greenhouse gas emissions, and thank him for his leadership on this issue. The issues are timely, they are important, and the witnesses are impressive. I am sorry that I could not personally attend; I had a conflicting duty to chair a hearing of the Governmental Affairs Committee. I want to leave no doubt about the importance of this hearing.

The causes and potential effects of global warming have been well documented through the Intergovernmental Panel on Climate Change, an international process that is engaged in by over 2,000 scientists from around the world. The potential effects are serious and far-reaching.

Global warming is a global problem that requires a global solution. The international community has come together under the auspices of the United Nations Framework Convention on Climate Change to address the problem. The original 1992 agreement, signed by then-President Bush and unanimously ratified by the U.S. Senate, contained no mandatory targets or timetables for greenhouse gas emissions. It was important, however, for recognizing the problem and committing the countries of the world to an ongoing multilateral process to seek ways to reduce the threat of global warming. In 1997, the international community negotiated the Kyoto Protocol, which included binding targets and timetables for industrialized countries to reduce greenhouse gas emissions by a little over 5 percent by 2008–2012, as a first step in reducing global emissions of greenhouse gases. The United States committed to a 7 percent reduction. Other countries, including the European Union and Japan, are moving toward ratification of this agreement. The current administration has rejected the Kyoto Protocol and offered us what can best be described as a tepid response to what even the President describes is a very serious issue.

The United States has a large stake in the climate change debate; among other things, we have a very large land mass, with thousands of miles of coastline, and a very large population, magnifying the health threats associated with climate change. We also emit about 25 percent of the entire world's emissions of carbon dioxide, the most prevalent greenhouse gas, even though we have less than 5 percent of the world's population. We have a responsibility to ourselves as well as the world community to take action to reduce greenhouse gases. We led the international effort to protect the stratospheric ozone layer, and found a way to bridge differences between developed and developing countries. That system is working and we should be proud of the leadership the United States exhibited.

I fear we have now abdicated our leadership role. In 1989, then-President Bush, talking to Congress about the issue of acid rain declared that the "time for study alone is over . . . the time for action is now." The President then went on to work with the Congress to establish a market-based cap and trade program that significantly reduced emissions of sulfur dioxide, the main ingredient of acid rain. I would suggest that the current administration follow this example for carbon dioxide. I have been working with Chairman Jeffords and other progressive-minded Senators to move toward passage of S. 556, the Clean Power Act of 2001, which would set limits on carbon dioxide emissions from electric power plants, which are responsible for about 40 percent of U.S. carbon dioxide emissions. We have been working with colleagues from the other side of the aisle on this important first step on greenhouse gas emissions, and hope that we can reach an agreement to move forward. I am also working with Senator McCain to develop an economy wide cap and trade proposal for greenhouse gas emissions as one more step in re-establishing U.S. leadership in this critical area. As our distinguished witness Dr. Rowland, a Nobel laureate wrote in his testimony: "The increasing global temperatures will have many consequences, often adverse in the long run. Because of the many causes of this temperature increase have their origins in the activities of mankind, actions can and should now be taken which will slow this rate of increase."

Thank you Mr. Chairman, that concludes my opening statement.

STATEMENT OF HON. BEN NIGHTHORSE CAMPBELL, U.S. SENATOR FROM THE STATE OF COLORADO

Thank you, Mr. Chairman. I would like to welcome all of the witnesses, especially Professor Roger Pielke of the University of Colorado.

I look forward to the witnesses' testimony and hope that we can use your collective knowledge to reach a better understanding of the economic and environmental impacts of greenhouse gas emissions on global climate change.

Climate change or global warming has become one of the most talked about environmental issues for the last several years. The United States and other nations have spent millions of dollars to study climate change. It seems that the more we spend and study, the more we realize that we don't know.

Our studying climate change for the last 10 years has led us to two conclusions:

First, human activity has had an impact on the global climate. In announcing his global climate change strategy, President Bush acknowledged this fact.

However, our years of careful study have made, for policymakers, an even more important conclusion: that we have inadequate evidence to demonstrate humanity's affect on climate change. Since our science is unable to tell us the level of causation, science can't tell us what mitigation strategies we, in Congress, should pursue.

Throughout my career of public service I have tried to base my decisions on the best available information, particularly when those decisions have dramatic consequences on the lives of Coloradans. Unfortunately, in the case of global climate change, we are seeking to craft a policy with profound implications on completely inadequate and speculative information.

In his book, The Skeptical Environmentalist, Bjorn Lomborg (Bee-Yorn Lom-Borg) simply asked, "Do we want to handle global warming in the most efficient way or do we use global warming as a stepping stone to other political projects."

Even Mr. Lomborg, a Danish statistician, noted the political salience of the climate change debate. Unfortunately, this important issue has become so politicized that many people look past the facts and, instead, focus on doomsday scenarios.

In noting our lack of understanding of the Earth's climate system, one of our very own witnesses made an equally important point. In her testimony today, Doctor Sallies Baliunas stated, "A value judgment is prerequisite to evaluating the need for human mitigation of adverse consequences of climate change."

Again, "a value judgment is prerequisite." In short, since we don't have enough information, some suggest that we just assume that humans can mitigate adverse consequences of climate change.

Well, this Senator is not ready to make that assumption when making that leap of faith could result in the loss of countless U.S. jobs.

I am happy that the President has chosen to look at the facts in rejecting the Kyoto Protocol. He properly noted that greenhouse gas emissions is directly attributable to U.S. production and economic growth. In my state of Colorado, implementing Kyoto would have translated in the loss of 47,400 jobs and $2 billion in tax revenue by 2010.

I am not ready to make decisions with such consequences without adequate information.

We all make "value judgments" in policymaking. I would ask my friends to ask themselves what it is they value.

In making that "value judgment" I would ask them to consider the words of John Adams when he said: "Facts are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passions, they cannot alter the state of facts and evidence."

I look forward to the distinguished panel's testimony, and ask that my testimony be reported in the Record.

Thank you.

STATEMENT OF DR. F. SHERWOOD ROWLAND, BREN PROFESSOR OF CHEMISTRY AND EARTH SYSTEM SCIENCE, UNIVERSITY OF CALIFORNIA IRVINE, IRVINE, CA

A natural greenhouse effect has existed in Earth's atmosphere for thousands of years, warming the Earth's surface for a global average of 57 °F. During the 20th Century, the atmospheric concentrations of a number of "greenhouse gases" have increased, mostly because of the actions of mankind. Our current concern is not whether there is a greenhouse effect, because there is one, but rather how large will be the enhanced greenhouse effect from the additional accumulation in the atmosphere of these greenhouse gases.

The Earth intercepts daily energy from the sun, much of it in the visible wavelengths corresponding to the spectrum of colors from red to violet, and the rest in ultraviolet and nearby infrared wavelengths. An equal amount of energy must escape from the Earth daily to maintain a balance, but this energy emission is controlled by the much cooler average surface temperature of the Earth, and occurs in wavelengths in the Afar infrared". If all of this terrestrially emitted infrared radiation were able to escape directly to space, then the required average temperature of Earth would be 0 °F. However, the greenhouse gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and others—selectively intercept some of this far infrared radiation, preventing its escape. A warmer Earth emits more infrared radiation, and Earth with an average surface temperature of 57 °F was able to make up the shortfall from greenhouse gas absorption. However, at Exist slowly during the 19th century and then more rapidly throughout the 20th century, the atmospheric concentrations of these greenhouse gases increased, often because of the activities of mankind. Other greenhouse gases have also been added, such as the chlorofluorocarbons or CFCs, (CCl_2F_2, CCl_3F, etc.) and tropospheric ozone (O_3). With more of these gases present in the atmosphere, more infrared will be intercepted, and a further temperature increase will be required to maintain the energy balance.

Carbon dioxide is released by the combustion of fossil fuels—coal, oil and natural gas—and its atmospheric concentration has increased from about 280 ppm as the 19th century began to 315 ppm in 1958 and 370 ppm now. Water (H_2O) is actually the most significant greenhouse gas in absorbing infrared radiation, but the amount of gaseous water is controlled by the temperature of the world's oceans and lakes. Methane has a natural source from swamps, but is also released during agricultural activities—for example, from rice paddies while flooded, and from cows and other ruminant animals—and by other processes, increasing from about 0.70 ppm in the early 1800's to 1.52 ppm around 1978 and 1.77 ppm currently. Nitrous oxide concentrations grew from 0.27 to 0.31 ppm during the 20th century, formed by microbial action in soils and waters on nitrogen-containing compounds including fertilizers. The chlorofluorocarbons (CFCs) were not a natural part of the atmosphere, but were first synthesized in 1928, and were then, applied to a variety of uses—propellant gases for aerosol sprays, refrigerants in home refrigerators and automobile air conditioners, industrial solvents, manufacture of plastic foams, etc. The CFC concentrations started from zero concentration in the 1920's, and rose rapidly during the latter part of the 20th century until the early 1990's. They are no longer increasing because of the Montreal Protocol, an international ban on their further manufacture. Tropospheric ozone is a globally important compound formed by photochemical reactions as a part of urban smog in hundreds of cities. Other potential influences on temperature changes for which the globally averaged data are still very sparse include the concentrations of particulate matter such as sulfate and black carbon aerosols.

Measurements of surface temperatures only became sufficiently broad in geographical coverage about 1860 to permit global averaging with improved coverage as the years passed. The globally averaged surface temperature increased about 1.1 °F during the 20th century, with about half of this change occurring during the past 25 years. 1998 was the warmest year globally in the entire 140-year record, and the 1990's were the warmest decade. Fluctuations in solar activity have been directly observed wince the invention of the telescope 400 years ago, but accurate, direct measurements of total solar energy output have only been possible with the advent of satellite measurements in the late 1970's. These satellite data exhibit a small but definite cyclic variation over the last two decades, paralleling the 11-year solar sunspot cycle, but with little long term difference in solar energy output contemporary with the rising global temperatures of the past two decades.

Predictions of future temperature responses require atmospheric model calculations that effectively simulate the past, and then are extrapolated into the future with appropriate estimates of the future changes in atmospheric greenhouse gas concentrations. These models calculate the direct temperature increases that additional greenhouse gases will cause, and the further feedbacks induced by these temperature changes. One of the most prominent of these is the change in albedo (surface reflectivity) in the polar north—when melting ice is replaced by open water (or melting snow replaced by bare ground), less solar radiation is reflected back to space, and more remains at the surface causing a further temperature increase. The models also assume that more water will remain in the atmosphere inn response to the temperature increases, providing another positive feedback. There is an additional possible feedback from the changes in clouds—amount, composition, and altitude. In present models, the cloud feedback is assumed to be small, but data for better evaluation are very difficult to obtain.

Extrapolations for 50 or 100 years in the future necessarily include hypotheses about future societal developments, including population growth, economic activity, etc. The Intergovernmental Panel on Climate Change (IPCC) developed a large set of scenarios about the possible course of these events over the next century, with resulting model calculations of globally averaged temperature increases for the year 2100 relative to 1990 ranging from 2.5° to 10.4°F (1.4–5.8°C). These results were only a small part of the three IPCC reports issued during 2001 about Climate change. Volume I of the IPCC reports treated the "Scientific Basis", Volume II covered "Impacts, Adaptation and Vulnerability", and Volume III "Mitigation".

The National Academy of Sciences, in response to a May 2001 request from the White douse, and following discussions between the administration and the Academy over some questions raised by the former, convened an 11-member scientific panel, which issued in June a 24-page report "Climate Change Science. An Analysis of Some Key Questions" from a select committee of atmospheric scientists. I quote the first few sentences of this report, and have appended the entire report to this testimony: "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability."

The increasing global temperatures will have many consequences, often adverse in the long run. Because many of the causes of this temperature increase have their origin in the activities of mankind, actions can and should now be taken which will slow this rate of increase.

CLIMATE CHANGE SCIENCE

AN ANALYSIS OF SOME KEY QUESTIONS

Committee on the Science of Climate Change

Division on Earth and Life Studies

National Research Council

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Foreword

This study originated from a White House request to help inform the Administration's ongoing review of U.S. climate change policy. In particular, the written request (Appendix A) asked for the National Academies' "assistance in identifying the areas in the science of climate change where there are the greatest certainties and uncertainties," and "views on whether there are any substantive differences between the IPCC [Intergovernmental Panel on Climate Change] Reports and the IPCC summaries." In addition, based on discussions with the Administration, the following specific questions were incorporated into the statement of task for the study:

- *What is the range of natural variability in climate?*
- *Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates?*
- *How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change?*
- *What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?*
- *Do different greenhouse gases and other emissions have different draw down periods?*
- *Are greenhouse gases causing climate change?*
- *Is climate change occurring? If so, how?*
- *Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?*
- *How much of the expected climate change is the consequence of climate feedback processes (e.g., water vapor, clouds, snow packs)?*
- *By how much will temperatures change over the next 100 years and where?*
- *What will be the consequences (e.g., extreme weather, health effects) of increases of various magnitudes?*
- *Has science determined whether there is a "safe" level of concentration of greenhouse gases?*
- *What are the substantive differences between the IPCC Reports and the Summaries?*
- *What are the specific areas of science that need to be studied further, in order of priority, to advance our understanding of climate change?*

The White House asked for a response "as soon as possible" but no later than early June—less than one month after submitting its formal request.

The National Academies has a mandate arising from its 1863 charter to respond to government requests when asked. In view of the critical nature of this issue, we agreed to undertake this study and to use our own funds to support it.

A distinguished committee with broad expertise and diverse perspectives on the scientific issues of climate change was therefore appointed through the National Academies' National Research Council (see Appendix B for biographical information on committee members). In early May, the committee held a conference call to discuss the specific questions and to prepare for its 2-day meeting (May 21-22, 2001) in Irvine, California. The committee reviewed the 14 questions and determined that they represent important issues in climate change science and could serve as a useful framework for addressing the two general questions from the White House.

For the task of comparing IPCC Reports and Summaries, the committee focused its review on the work of IPCC Working Group I, which dealt with many of the same detailed questions being asked above. The committee decided to address the questions in the context of a brief document that also could serve as a primer for policy makers on climate change science. To aid in the presentation, the questions have been organized into seven sections, with the questions addressed in each section listed in *italics* at the beginning of that section.

While traditional procedures for an independent NRC study, including review of the report by independent experts, were followed, it is important to note that tradeoffs were made in order to accommodate the rapid schedule. For example, the report does not provide extensive references to the scientific literature or marshal detailed evidence to support its "answers" to the questions. Rather, the report largely presents the consensus scientific views and judgments of committee members, based on the accumulated knowledge that these individuals have gained—both through their own scholarly efforts and through formal and informal interactions with the world's climate change science community.

The result is a report that, in my view, provides policy makers with a succinct and balanced overview of what science can currently say about the potential for future climate change, while outlining the uncertainties that remain in our scientific knowledge.

The report does not make policy recommendations regarding what to do about the potential of global warming. Thus, it does not estimate the potential economic and environmental costs, benefits, and uncertainties regarding various policy responses and future human behaviors. While beyond the charge presented to this committee, scientists and social scientists have the ability to provide assessments of this type as well. Both types of assessments can be helpful to policy makers, who frequently have to weigh tradeoffs and make decisions on important issues, despite the inevitable uncertainties in our scientific understanding concerning particular aspects. Science never has all the answers. But science does provide us with the best available guide to the future, and it is critical that our nation and the world base important policies on the best judgments that science can provide concerning the future consequences of present actions.

I would especially like to thank the members of this committee and its staff for an incredible effort in producing this important report in such a short period of time. They have sacrificed many personal commitments and worked long weekends to provide the nation with their considered judgments on this critical issue.

Bruce Alberts
President
National Academy of Sciences

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Betsy Ancker-Johnson, General Motors Corporation (retired), Austin, Texas
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Andrew R. Solow, Woods Hole Oceanographic Institution, Massachusetts
Grace Wahba, University of Wisconsin, Madison

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Richard M. Goody (Harvard University) and Robert A. Frosch (Harvard University). Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

We would also like to thank the following individuals for their input regarding the IPCC process: John Christy, Haroon Kheshgi, Michael Mann, Jerry Meehl, Berrien Moore, Michael Oppenheimer, Joyce Penner, Ray Pierrehumbert, Michael Prather, Venkatachalam Ramaswamy, Ben Santer, Piers Sellers, Susan Solomon, Ron Stouffer, Kevin Trenberth, and Robert Watson.

Contents

Summary

Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability. Human-induced warming and associated sea level rises are expected to continue through the 21st century. Secondary effects are suggested by computer model simulations and basic physical reasoning. These include increases in rainfall rates and increased susceptibility of semi-arid regions to drought. The impacts of these changes will be critically dependent on the magnitude of the warming and the rate with which it occurs.

The mid-range model estimate of human induced global warming by the Intergovernmental Panel on Climate Change (IPCC) is based on the premise that the growth rate of climate forcing[1] agents such as carbon dioxide will accelerate. The predicted warming of 3°C (5.4°F) by the end of the 21st century is consistent with the assumptions about how clouds and atmospheric relative humidity will react to global warming. This estimate is also consistent with inferences about the sensitivity[2] of climate drawn from comparing the sizes of past temperature swings between ice ages and intervening warmer periods with the corresponding changes in the climate forcing. This predicted temperature increase is sensitive to assumptions concerning future concentrations of greenhouse gases and aerosols. Hence, national policy decisions made now and in the longer-term future will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century. Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments (either upward or downward).

Reducing the wide range of uncertainty inherent in current model predictions of global climate change will require major advances in understanding and modeling of both (1) the factors that determine atmospheric concentrations of greenhouse gases and aerosols, and (2) the so-called "feedbacks" that determine the sensitivity of the climate system to a prescribed increase in greenhouse gases. There also is a pressing need for a global observing system designed for monitoring climate.

The committee generally agrees with the assessment of human-caused climate change presented in the IPCC Working Group I (WGI) scientific report, but seeks here to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them. This articulation may be helpful to policy makers as they consider a variety of options for mitigation and/or adaptation. In the sections that follow, the committee provides brief responses to some of the key questions related to climate change science. More detailed responses to these questions are located in the main body of the text.

What is the range of natural variability in climate?

The range of natural climate variability is known to be quite large (in excess of several degrees Celsius) on local

[1]A climate forcing is defined as an imposed perturbation of Earth's energy balance. Climate forcing is typically measured in watts per square meter (W/m2).

[2]The sensitivity of the climate system to a prescribed forcing is commonly expressed in terms of the global mean temperature change that would be expected after a time sufficiently long for both the atmosphere and ocean to come to equilibrium with the change in climate forcing.

and regional spatial scales over periods as short as a decade. Precipitation also can vary widely. For example, there is evidence to suggest that droughts as severe as the "dust bowl" of the 1930s were much more common in the central United States during the 10th to 14th centuries than they have been in the more recent record. Mean temperature variations at local sites have exceeded 10°C (18°F) in association with the repeated glacial advances and retreats that occurred over the course of the past million years. It is more difficult to estimate the natural variability of global mean temperature because of the sparse spatial coverage of existing data and difficulties in inferring temperatures from various proxy data. Nonetheless, evidence suggests that global warming rates as large as 2°C (3.6°F) per millennium may have occurred during retreat of the glaciers following the most recent ice age.

Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates? Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?

The emissions of some greenhouse gases are increasing, but others are decreasing. In some cases the decreases are a result of policy decisions, while in other cases the reasons for the decreases are not well understood.

Of the greenhouse gases that are directly influenced by human activity, the most important are carbon dioxide, methane, ozone, nitrous oxide, and chlorofluorocarbons (CFCs). Aerosols released by human activities are also capable of influencing climate. (Table 1 lists the estimated climate forcing due to the presence of each of these "climate forcing agents" in the atmosphere.)

Concentrations of carbon dioxide (CO_2) extracted from ice cores drilled in Greenland and Antarctica have typically ranged from near 190 parts per million by volume (ppmv) during the ice ages to near 280 ppmv during the warmer "interglacial" periods like the present one that began around 10,000 years ago. Concentrations did not rise much above 280 ppmv until the Industrial Revolution. By 1958, when systematic atmospheric measurements began, they had reached 315 ppmv, and they are currently ~370 ppmv and rising at a rate of 1.5 ppmv per year (slightly higher than the rate during the early years of the 43-year record). Human activities are responsible for the increase. The primary source, fossil fuel burning, has released roughly twice as much carbon dioxide as would be required to account for the observed increase. Tropical deforestation also has contributed to carbon dioxide releases during the past few decades. The excess carbon dioxide has been taken up by the oceans and land biosphere.

Like carbon dioxide, methane (CH_4) is more abundant in Earth's atmosphere now than at any time during the 400,000 year long ice core record, which dates back over a number of glacial/interglacial cycles. Concentrations increased rather smoothly by about 1% per year from 1978, until about 1990. The rate of increase slowed and became more erratic during the 1990s. About two-thirds of the current emissions of methane are released by human activities such as rice growing, the raising of cattle, coal mining, use of land-fills, and natural gas handling, all of which have increased over the past 50 years.

A small fraction of the ozone (O_3) produced by natural processes in the stratosphere mixes into the lower atmosphere. This "tropospheric ozone" has been supplemented during the 20th century by additional ozone, created locally by the action of sunlight upon air polluted by exhausts from motor vehicles, emissions from fossil fuel burning power plants, and biomass burning.

Nitrous oxide (N_2O) is formed by many microbial reactions in soils and waters, including those acting on the increasing amounts of nitrogen-containing fertilizers. Some synthetic chemical processes that release nitrous oxide have also been identified. Its concentration has increased approximately 13% in the past 200 years.

Atmospheric concentrations of CFCs rose steadily following their first synthesis in 1928 and peaked in the early 1990s. Many other industrially useful fluorinated compounds (e.g., carbon tetrafluoride, CF_4, and sulfur hexafluoride, SF_6), have very long atmospheric lifetimes, which is of concern, even though their atmospheric concentrations have not yet produced large radiative forcings. Hydrofluorocarbons (HFCs), which are replacing CFCs, have a greenhouse effect, but it is much less pronounced because of their shorter atmospheric lifetimes. The sensitivity and generality of modern analytical systems make it quite unlikely that any currently significant greenhouse gases remain to be discovered.

What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?

Besides greenhouse gases, human activity also contributes to the atmospheric burden of aerosols, which include both sulfate particles and black carbon (soot). Both are unevenly distributed, owing to their short lifetimes in the atmosphere. Sulfate particles scatter solar radiation back to space, thereby offsetting the greenhouse effect to some degree. Recent "clean coal technologies" and use of low sulfur fuels have resulted in decreasing sulfate concentrations, especially in North America, reducing this offset. Black carbon aerosols are end-products of the incomplete combustion of fossil fuels and biomass burning (forest fires and land clearing). They impact radiation budgets both directly and indirectly; they are believed to contribute to global warming, although their relative importance is difficult to quantify at this point.

How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change? Do different greenhouse gases and other emissions have different draw down periods?

TABLE 1 Removal Times and Climate Forcing Values for Specified Atmospheric Gases and Aerosols

Forcing Agent	Approximate Removal Times[3]	Climate Forcing (W/m^2) Up to the year 2000
Greenhouse Gases		
Carbon Dioxide	>100 years	1.3 to 1.5
Methane	10 years	0.5 to 0.7
Tropospheric Ozone	10-100 days	0.25 to 0.75
Nitrous Oxide	100 years	0.1 to 0.2
Perfluorocarbon Compounds (Including SF_6)	>1000 years	0.01
Fine Aerosols		
Sulfate	10 days	–0.3 to –1.0
Black Carbon	10 days	0.1 to 0.8

[3]A removal time of 100 years means that much, but not all, of the substance would be gone in 100 years. Typically, the amount remaining at the end of 100 years is 37%; after 200 years 14%; after 300 years 5%; after 400 years 2%.

Is climate change occurring? If so, how?

Weather station records and ship-based observations indicate that global mean surface air temperature warmed between about 0.4 and 0.8°C (0.7 and 1.5°F) during the 20th century. Although the magnitude of warming varies locally, the warming trend is spatially widespread and is consistent with an array of other evidence detailed in this report. The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.05°C (0.09°F) averaged over the layer extending from the surface down to 10,000 feet, since the 1950s.

The observed warming has not proceeded at a uniform rate. Virtually all the 20th century warming in global surface air temperature occurred between the early 1900s and the 1940s and during the past few decades. The troposphere warmed much more during the 1970s than during the two subsequent decades, whereas Earth's surface warmed more during the past two decades than during the 1970s. The causes of these irregularities and the disparities in the timing are not completely understood. One striking change of the past 35 years is the cooling of the stratosphere at altitudes of ~13 miles, which has tended to be concentrated in the wintertime polar cap region.

Are greenhouse gases causing climate change?

The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue. The stated degree of confidence in the IPCC assessment is higher today than it was 10, or even 5 years ago, but uncertainty remains because of (1) the level of natural variability inherent in the climate system on time scales of decades to centuries, (2) the questionable ability of models to accurately simulate natural variability on those long time scales, and (3) the degree of confidence that can be placed on reconstructions of global mean temperature over the past millennium based on proxy evidence. Despite the uncertainties, there is general agreement that the observed warming is real and particularly strong within the past 20 years. Whether it is consistent with the change that would be expected in response to human activities is dependent upon what assumptions one makes about the time history of atmospheric concentrations of the various forcing agents, particularly aerosols.

By how much will temperatures change over the next 100 years and where?

Climate change simulations for the period of 1990 to 2100 based on the IPCC emissions scenarios yield a globally-averaged surface temperature increase by the end of the century of 1.4 to 5.8°C (2.5 to 10.4°F) relative to 1990. The wide range of uncertainty in these estimates reflects both the different assumptions about future concentrations of greenhouse gases and aerosols in the various scenarios considered by the IPCC and the differing climatic sensitivities of the various climate models used in the simulations. The range of climate sensitivities implied by these predictions is generally consistent with previously reported values.

The predicted warming is larger over higher latitudes than over low latitudes, especially during winter and spring, and larger over land than over sea. Rainfall rates and the frequency of heavy precipitation events are predicted to increase, particularly over the higher latitudes. Higher evaporation rates would accelerate the drying of soils following rain events, resulting in lower relative humidities and higher daytime temperatures, especially during the warm season. The likelihood that this effect could prove important is greatest in semi-arid regions, such as the U.S. Great Plains. These predictions in the IPCC report are consistent with current understanding of the processes that control local climate.

In addition to the IPCC scenarios for future increases in greenhouse gas concentrations, the committee considered a scenario based on an energy policy designed to keep climate change moderate in the next 50 years. This scenario takes into account not only the growth of carbon emissions, but also the changing concentrations of other greenhouse gases and aerosols.

Sufficient time has elapsed now to enable comparisons between observed trends in the concentrations of carbon dioxide and other greenhouse gases with the trends predicted in previous IPCC reports. The increase of global fossil fuel carbon dioxide emissions in the past decade has averaged 0.6% per year, which is somewhat below the range of IPCC scenarios, and the same is true for atmospheric methane concentrations. It is not known whether these slowdowns in growth rate will persist.

How much of the expected climate change is the consequence of climate feedback processes (e.g., water vapor, clouds, snow packs)?

The contribution of feedbacks to the climate change depends upon "climate sensitivity," as described in the report. If a central estimate of climate sensitivity is used, about 40% of the predicted warming is due to the direct effects of greenhouse gases and aerosols. The other 60% is caused by feedbacks. Water vapor feedback (the additional greenhouse effect accruing from increasing concentrations of atmospheric water vapor as the atmosphere warms) is the most important feedback in the models. Unless the relative humidity in the tropical middle and upper troposphere drops, this effect is expected to increase the temperature response to increases in human induced greenhouse gas concentrations by a factor of 1.6. The ice-albedo feedback (the reduction in the fraction of incoming solar radiation reflected back to space as snow and ice cover recede) also is believed to be important. Together, these two feedbacks amplify the simulated climate response to the greenhouse gas forcing by a factor of 2.5. In addition, changes in cloud cover, in the relative amounts of high versus low clouds, and in the mean and vertical distribution of relative humidity could either enhance or reduce the amplitude of the warming. Much of the difference in predictions of global warming by various climate models is attributable to the fact that each model represents these processes in its own particular way. These uncertainties will remain until a more fundamental understanding of the processes that control atmospheric relative humidity and clouds is achieved.

What will be the consequences (e.g., extreme weather, health effects) of increases of various magnitude?

In the near term, agriculture and forestry are likely to benefit from carbon dioxide fertilization and an increased water efficiency of some plants at higher atmospheric CO_2 concentrations. The optimal climate for crops may change, requiring significant regional adaptations. Some models project an increased tendency toward drought over semi-arid regions, such as the U.S. Great Plains. Hydrologic impacts could be significant over the western United States, where much of the water supply is dependent on the amount of snow pack and the timing of the spring runoff. Increased rainfall rates could impact pollution run-off and flood control. With higher sea level, coastal regions could be subject to increased wind and flood damage even if tropical storms do not change in intensity. A significant warming also could have far reaching implications for ecosystems. The costs and risks involved are difficult to quantify at this point and are, in any case, beyond the scope of this brief report.

Health outcomes in response to climate change are the subject of intense debate. Climate is one of a number of factors influencing the incidence of infectious disease. Cold-related stress would decline in a warmer climate, while heat stress and smog induced respiratory illnesses in major urban areas would increase, if no adaptation occurred. Over much of the United States, adverse health outcomes would likely be mitigated by a strong public health system, relatively high levels of public awareness, and a high standard of living.

Global warming could well have serious adverse societal and ecological impacts by the end of this century, especially if globally-averaged temperature increases approach the upper end of the IPCC projections. Even in the more conservative scenarios, the models project temperatures and sea levels that continue to increase well beyond the end of this century, suggesting that assessments that examine only the next 100 years may well underestimate the magnitude of the eventual impacts.

Has science determined whether there is a "safe" level of concentration of greenhouse gases?

The question of whether there exists a "safe" level of concentration of greenhouse gases cannot be answered directly because it would require a value judgment of what constitutes an acceptable risk to human welfare and ecosystems in various parts of the world, as well as a more quantitative assessment of the risks and costs associated with the various impacts of global warming. In general, however, risk increases with increases in both the rate and the magnitude of climate change.

What are the substantive differences between the IPCC Reports and the Summaries?

The committee finds that the full IPCC Working Group I (WGI) report is an admirable summary of research activities in climate science, and the full report is adequately summarized in the *Technical Summary*. The full WGI report and its *Technical Summary* are not specifically directed at policy. The *Summary for Policymakers* reflects less emphasis on communicating the basis for uncertainty and a stronger emphasis on areas of major concern associated with human-induced climate change. This change in emphasis appears to be the result of a summary process in which scientists work with policy makers on the document. Written responses from U.S. coordinating and lead scientific authors to the committee indicate, however, that (a) no changes were made without the consent of the convening lead authors (this group represents a fraction of the lead and contributing authors) and (b) most changes that did occur lacked significant impact.

It is critical that the IPCC process remain truly representative of the scientific community. The committee's concerns focus primarily on whether the process is likely to become less representative in the future because of the growing voluntary time commitment required to participate as a lead or coordinating author and the potential that the scientific process will be viewed as being too heavily influenced by governments which have specific postures with regard to treaties, emission controls, and other policy instruments. The United States should promote actions that improve the IPCC process while also ensuring that its strengths are maintained.

What are the specific areas of science that need to be studied further, in order of priority, to advance our understanding of climate change?

Making progress in reducing the large uncertainties in projections of future climate will require addressing a number of fundamental scientific questions relating to the buildup of greenhouses gases in the atmosphere and the behavior of the climate system. Issues that need to be addressed include (a) the future usage of fossil fuels, (b) the future emissions of methane, (c) the fraction of the future fossil-fuel carbon that will remain in the atmosphere and provide radiative forcing versus exchange with the oceans or net exchange with the land biosphere, (d) the feedbacks in the climate system that determine both the magnitude of the change and the rate of energy uptake by the oceans, which together determine the magnitude and time history of the temperature increases for a given radiative forcing, (e) details of the regional and local climate change consequent to an overall level of global climate change, (f) the nature and causes of the natural variability of climate and its interactions with forced changes, and (g) the direct and indirect effects of the changing distributions of aerosols. Maintaining a vigorous, ongoing program of basic research, funded and managed independently of the climate assessment activity, will be crucial for narrowing these uncertainties.

In addition, the research enterprise dealing with environmental change and the interactions of human society with the environment must be enhanced. This includes support of (a) interdisciplinary research that couples physical, chemical, biological, and human systems, (b) an improved capability of integrating scientific knowledge, including its uncertainty, into effective decision support systems, and (c) an ability to conduct research at the regional or sectoral level that promotes analysis of the response of human and natural systems to multiple stresses.

An effective strategy for advancing the understanding of climate change also will require (1) a global observing system in support of long-term climate monitoring and prediction, (2) concentration on large-scale modeling through increased, dedicated supercomputing and human resources, and (3) efforts to ensure that climate research is supported and managed to ensure innovation, effectiveness, and efficiency.

1

Climate, Climate Forcings, Climate Sensitivity, and Transient Climate Change

CLIMATE

Climate is the average state of the atmosphere and the underlying land or water, on time scales of seasons and longer. Climate is typically described by the statistics of a set of atmospheric and surface variables, such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice. The statistics may be in terms of the long-term average, as well as other measures such as daily minimum temperature, length of the growing season, or frequency of floods. Although climate and climate change are usually presented in global mean terms, there may be large local and regional departures from these global means. These can either mitigate or exaggerate the impact of climate change in different parts of the world.

A number of factors contribute to climate and climate change, and it is useful to define the terms climate forcings, climate sensitivity, and transient climate change for discussion below.

CLIMATE FORCINGS

A climate forcing can be defined as an imposed perturbation of Earth's energy balance. Energy flows in from the sun, much of it in the visible wavelengths, and back out again as long-wave infrared (heat) radiation. An increase in the luminosity of the sun, for example, is a positive forcing that tends to make Earth warmer. A very large volcanic eruption, on the other hand, can increase the aerosols (fine particles) in the lower stratosphere (altitudes of 10-15 miles) that reflect sunlight to space and thus reduce the solar energy delivered to Earth's surface. These examples are natural forcings. Human-made forcings result from, for example, the gases and aerosols produced by fossil fuel burning, and alterations of Earth's surface from various changes in land use, such as the conversion of forests into agricultural land. Those gases that absorb infrared radiation, i.e., the "greenhouse" gases, tend to prevent this heat radiation from escaping to space, leading eventually to a warming of Earth's surface. The observations of human-induced forcings underlie the current concerns about climate change.

The common unit of measure for climatic forcing agents is the energy perturbation that they introduce into the climate system, measured in units of watts per square meter (W/m^2). The consequences from such forcings are often then expressed as the change in average global temperature, and the conversion factor from forcing to temperature change is the sensitivity of Earth's climate system. Although some forcings—volcanic plumes, for example—are not global in nature and temperature change may also not be uniform, comparisons of the strengths of individual forcings, over comparable areas, are useful for estimating the relative importance of the various processes that may cause climate change.

CLIMATE SENSITIVITY

The sensitivity of the climate system to a forcing is commonly expressed in terms of the global mean temperature change that would be expected after a time sufficiently long for both the atmosphere and ocean to come to equilibrium with the change in climate forcing. If there were no climate feedbacks, the response of Earth's mean temperature to a forcing of 4 W/m^2 (the forcing for a doubled atmospheric CO_2) would be an increase of about 1.2°C (about 2.2°F). However, the total climate change is affected not only by the immediate direct forcing, but also by climate "feedbacks" that come into play in response to the forcing. For example, a climate forcing that causes warming may melt some of the sea ice. This is a positive feedback because the darker ocean absorbs more sunlight than the sea ice it replaced. The responses of atmospheric water vapor amount and clouds probably generate the most important global climate feedbacks. The nature and magnitude of these hydrologic feedbacks give rise to the largest source of uncertainty about climate sensitivity, and they are an area of continuing research.

As just mentioned, a doubling of the concentration of carbon dioxide (from the pre-Industrial value of 280 parts per million) in the global atmosphere causes a forcing of 4 W/m^2. The central value of the climate sensitivity to this change is a global average temperature increase of 3°C (5.4°F), but with a range from 1.5°C to 4.5°C (2.7 to 8.1°F) (based on climate system models: see section 4). The central value of 3°C is an amplification by a factor of 2.5 over the direct effect of 1.2°C (2.2°F). Well-documented climate changes during the history of Earth, especially the changes between the last major ice age (20,000 years ago) and the current warm period, imply that the climate sensitivity is near the 3°C value. However, the true climate sensitivity remains uncertain, in part because it is difficult to model the effect of cloud feedback. In particular, the magnitude and even the sign of the feedback can differ according to the composition, thickness, and altitude of the clouds, and some studies have suggested a lesser climate sensitivity. On the other hand, evidence from paleoclimate variations indicates that climate sensitivity could be higher than the above range, although perhaps only on longer time scales.

TRANSIENT CLIMATE CHANGE

Climate fluctuates in the absence of any change in forcing, just as weather fluctuates from day to day. Climate also responds in a systematic way to climate forcings, but the response can be slow because the ocean requires time to warm (or cool) in response to the forcing. The response time depends upon the rapidity with which the ocean circulation transmits changes in surface temperature into the deep ocean. If the climate sensitivity is as high as the 3°C mid-range, then a few decades are required for just half of the full climate response to be realized, and at least several centuries for the full response.[1]

Such a long climate response time complicates the climate change issue for policy makers because it means that a discovered undesirable climate change is likely to require many decades to halt or reverse.

Increases in the temperature of the ocean that are initiated in the next few decades will continue to raise sea level by ocean thermal expansion over the next several centuries. Although society might conclude that it is practical to live with substantial climate change in the coming decades, it is also important to consider further consequences that may occur in later centuries. The climate sensitivity and the dynamics of large ice sheets become increasingly relevant on such longer time scales.

It is also possible that climate could undergo a sudden large change in response to accumulated climate forcing. The paleoclimate record contains examples of sudden large climate changes, at least on regional scales. Understanding these rapid changes is a current research challenge that is relevant to the analysis of possible anthropogenic climate effects.

[1]The time required for the full response to be realized depends, in part, on the rate of heat transfer from the ocean mixed layer to the deeper ocean. Slower transfer leads to shorter response times on Earth's surface.

2

Natural Climatic Variations

What is the range of natural variability in climate?

Climate is continually varying on time scales ranging from seasons to the lifetime of Earth. Natural climate changes can take place on short time scales as a result of the rapid alterations to forcings (as described in section 1). For example, the injection of large quantities of sulfur dioxide (SO_2), which changes to sulfuric acid droplets, and fine particulate material into the stratosphere (the region between 10 and 30 miles altitude where the temperature rises with increasing altitude) by major volcanic eruptions like that of Mt. Pinatubo in 1991 can cause intervals of cooler than average global temperatures. Climate variability also can be generated by processes operating within the climate system—the periodic rapid warming trend in the eastern Pacific Ocean known as El Niño being perhaps the best known example. Each of these different processes produces climate variability with its own characteristic spatial and seasonal signature. For example, El Niño typically brings heavy rainstorms to coastal Ecuador, Peru, and California and droughts to Indonesia and Northeast Brazil.

Over long time scales, outside the time period in which humans could have a substantive effect on global climate (e.g., prior to the Industrial Revolution), proxy data (information derived from the content of tree rings, cores from marine sediments, pollens, etc.) have been used to estimate the range of natural climate variability. An important recent addition to the collection of proxy evidence is ice cores obtained by international teams of scientists drilling through miles of ice in Antarctica and at the opposite end of the world in Greenland. The results can be used to make inferences about climate and atmospheric composition extending back as long as 400,000 years. These and other proxy data indicate that the range of natural climate variability is in excess of several degrees C on local and regional space scales over periods as short as a decade. Precipitation has also varied widely. For example, there is evidence to suggest that droughts as severe as the "dust bowl" of the 1930s were much more common in the central United States during the 10th to 14th centuries than they have been in the more recent record.

Temperature variations at local sites have exceeded 10°C (18°F) in association with the repeated glacial advances and retreats that occurred over the course of the past million years. It is more difficult to estimate the natural variability of global mean temperature because large areas of the world are not sampled and because of the large uncertainties inherent in temperatures inferred from proxy evidence. Nonetheless, evidence suggests that global warming rates as large as 2°C (3.6°F) per millennium may have occurred during the retreat of the glaciers following the most recent ice age.

3

Human Caused Forcings

Are concentrations of greenhouse gases and other emissions that contribute to climate change increasing at an accelerating rate, and are different greenhouse gases and other emissions increasing at different rates?

Is human activity the cause of increased concentrations of greenhouse gases and other emissions that contribute to climate change?

What other emissions are contributing factors to climate change (e.g., aerosols, CO, black carbon soot), and what is their relative contribution to climate change?

How long does it take to reduce the buildup of greenhouse gases and other emissions that contribute to climate change?

Do different greenhouse gases and other emissions have different draw down periods?

Are greenhouse gases causing climate change?

GREENHOUSE GASES

The most important greenhouse gases in Earth's atmosphere include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), ozone (O_3), and the chlorofluorocarbons (CFCs including CFC-12 (CCl_2F_2) and CFC-11 (CCl_3F)). In addition to reflecting sunlight, clouds are also a major greenhouse substance. Water vapor and cloud droplets are in fact the dominant atmospheric absorbers, and how these substances respond to climate forcings is a principal determinant of climate sensitivity, as discussed in Section 1. The CO_2, CH_4, N_2O and H_2O are both produced and utilized in many biological processes, although the major source of gaseous water is evaporation from the oceans. Ozone is created in the atmosphere by reactions initiated by sunlight. The CFCs are synthetic compounds developed and released into the atmosphere by humankind. In addition, sulfur hexafluoride (SF_6) and perfluorocarbon gases such as carbon tetrafluoride (CF_4) are very potent and nearly inert greenhouse gases with atmospheric lifetimes much longer than 1000 years.

The natural atmosphere contained many greenhouse gases whose atmospheric concentrations were determined by the sum of the ongoing geophysical, biological, and chemical reactions that produce and destroy them. The specific effects of humankind's activities before the industrial era were immersed in all of the natural dynamics and became noticeable only in the immediate vicinity, as with the smoke from small fires. The theoretical realization that human activities could have a global discernible effect on the atmosphere came during the 19th century, and the first conclusive measurements of atmospheric change were made during the last half of the 20th century. The first greenhouse gas demonstrated to be increasing in atmospheric concentration was carbon dioxide, formed as a major end product in the extraction of energy from the burning of the fossil fuels—coal, oil, and natural gas—as well as in the burning of biomass.

The common characteristics of greenhouse gases are (1) an ability to absorb terrestrial infrared radiation and (2) a presence in Earth's atmosphere. The most important greenhouse gases listed above all contain three or more atoms per molecule. Literally thousands of gases have been identified as being present in the atmosphere at some place and at some time, and all but a few have the ability to absorb terrestrial infrared radiation. However, the great majority of these chemical compounds, both natural[1] and anthropogenic, are removed in hours, days, or weeks, and do not accumulate in significant concentrations. Some can have an indirect greenhouse effect, as with carbon monoxide (CO).[2] If the average survival time for a gas in the atmosphere is a year or longer, then the winds have time to spread it throughout the lower atmosphere, and its absorption of terrestrial infrared radiation occurs at all latitudes and longitudes. All the listed greenhouse gases except ozone are released to the atmosphere at Earth's surface and are spread globally throughout the lower atmosphere.

The lifetime of CH_4 in the atmosphere is 10-12 years. Nitrous oxide and the CFCs have century-long lifetimes before they are destroyed in the stratosphere. Atmospheric CO_2 is not destroyed chemically, and its removal from the atmosphere takes place through multiple processes that transiently store the carbon in the land and ocean reservoirs, and ultimately as mineral deposits. A major removal process depends on the transfer of the carbon content of near-surface waters to the deep ocean, which has a century time scale, but final removal stretches out over hundreds of thousands of years. Reductions in the atmospheric concentrations of these gases following possible lowered emission rates in the future will stretch out over decades for methane, and centuries and longer for carbon dioxide and nitrous oxide.

Methane, nitrous oxide, and ozone all have natural sources, but they can also be introduced into the atmosphere by the activities of humankind. These supplementary sources have contributed to the increasing concentrations of these gases during the 20th century.

Carbon Dioxide

While all of the major greenhouse gases have both natural and anthropogenic atmospheric sources, the nature of these processes varies widely among them. Carbon dioxide is naturally absorbed and released by the terrestrial biosphere as well as by the oceans. Carbon dioxide is also formed by the burning of wood, coal, oil, and natural gas, and these activities have increased steadily during the last two centuries since the Industrial Revolution. That the burning of fossil fuels is a major cause of the CO_2 increase is evidenced by the concomitant decreases in the relative abundance of both the stable and radioactive carbon isotopes[3] and the decrease in atmospheric oxygen. Continuous high-precision measurements have been made of its atmospheric concentrations only since 1958, and by the year 2000 the concentrations had increased 17% from 315 parts per million by volume (ppmv) to 370 ppmv. While the year-to-year increase varies, the average annual increase of 1.5 ppmv/year over the past two decades is slightly greater than during the 1960s and 1970s. A marked seasonal oscillation of carbon dioxide concentration exists, especially in the northern hemisphere because of the extensive draw down of carbon dioxide every spring and summer as the green plants convert carbon dioxide into plant material, and the return in the rest of the year as decomposition exceeds photosynthesis. The seasonal effects are quite different north and south of the equator, with the variation much greater in the northern hemisphere where most of Earth's land surface and its vegetation and soils are found.

The atmospheric CO_2 increase over the past few decades is less than the input from human activities because a fraction of the added CO_2 is removed by oceanic and terrestrial processes. Until recently, the partitioning of the carbon sink between the land and sea has been highly uncertain, but recent high-precision measurements of the atmospheric oxygen:nitrogen (O_2:N_2) ratio have provided a crucial constraint: fossil fuel burning and terrestrial uptake processes have different O_2:CO_2 ratios, whereas the ocean CO_2 sink has no significant impact on atmospheric O_2. The atmospheric CO_2 increase for the 1990s was about half the CO_2 emission from fossil fuel combustion, with the oceans and land both serving as important repositories of the excess carbon, i.e., as carbon sinks.

Land gains and loses carbon by various processes: some natural-like photosynthesis and decomposition, some connected to land use and land management practices, and some responding to the increases of carbon dioxide or other nutrients necessary for plant growth. These gains or losses dominate the net land exchange of carbon dioxide with the atmosphere, but some riverine loss to oceans is also significant. Most quantifiable, as by forest and soil inventories, are the above- and below-ground carbon losses from land clearing and the gains in storage in trees from forest recovery and management. Changes in the frequency of forest fires, such as from fire suppression policies, and agricultural practices for soil conservation may modify the carbon stored by land. Climate variations, through their effects on plant growth and decomposition of soil detritus, also have large effects on terrestrial carbon fluxes and storage on a year-to-year basis. Land modifications, mainly in the middle latitudes of the northern hemisphere, may have been a net source of carbon dioxide to the atmosphere over much of the last century. However, quantitative estimates have only been possible over the last two decades, when forest clearing had shifted to the tropics. In the 1980s land became a small net sink for

[1]While the activities of mankind are part of the natural world, the convention exists in most discussions of the atmosphere that "natural processes" are those that would still exist without the presence of human beings; those processes that are significantly influenced by humans are called "anthropogenic".

[2]Both carbon monoxide and methane are removed from the atmosphere by chemical reaction with hydroxyl (OH). An increase in the carbon monoxide uses up hydroxyl, slowing methane removal and allowing its concentration and greenhouse effect to increase.

[3]Fossil fuels are of biological origin and are depleted in both the stable isotope ^{13}C and the radioactive isotope ^{14}C, which has a half-life of 5600 years.

carbon, that is, the various processes storing carbon globally exceeded the loss due to tropical deforestation, which by itself was estimated to add 10-40% as much carbon dioxide to the atmosphere as burning of fossil fuels. In the 1990s the net storage on land became much larger, nearly as large as the ocean uptake. How land contributes, by location and processes, to exchanges of carbon with the atmosphere is still highly uncertain, as is the possibility that the substantial net removal will continue to occur very far into the future.[4]

Methane

Methane is the major component of natural gas and it is also formed and released to the atmosphere by many biologic processes in low oxygen environments, such as those occurring in swamps, near the roots of rice plants, and the stomachs of cows. Such human activities as rice growing, the raising of cattle, coal mining, use of land-fills, and natural-gas handling have increased over the last 50 years, and direct and inadvertent emissions from these activities have been partially responsible for the increase in atmospheric methane. Its atmospheric concentration has been measured globally and continuously for only two decades, and the majority of the methane molecules are of recent biologic origin. The concentrations of methane increased rather smoothly from 1.52 ppmv in 1978 by about 1% per year until about 1990. The rate of increase slowed down to less than that rate during the 1990s, and also became more erratic; current values are around 1.77 ppmv. About two-thirds of the current emissions of methane are released by human activities. There is no definitive scientific basis for choosing among several possible explanations for these variations in the rates of change of global methane concentrations, making it very difficult to predict its future atmospheric concentrations.

Both carbon dioxide and methane were trapped long ago in air bubbles preserved in Greenland and Antarctic ice sheets. These ice sheets are surviving relics of the series of ice ages that Earth experienced over the past 400,000 years. Concentrations of carbon dioxide extracted from ice cores have typically ranged between 190 ppmv during the ice ages to near 280 ppmv during the warmer "interglacial" periods like the present one that began around 10,000 years ago. Concentrations did not rise much above 280 ppmv until the Industrial Revolution. The methane concentrations have also varied during this 400,000 year period, with lowest values of 0.30 ppmv in the coldest times of the ice ages and 0.70 ppmv in the warmest, until a steady rise began about 200 years ago toward the present concentrations. Both carbon dioxide and methane are more abundant in Earth's atmosphere now than at any time during the past 400,000 years.

Other Greenhouse Gases

Nitrous oxide is formed by many microbial reactions in soils and waters, including those processes acting on the increasing amounts of nitrogen-containing fertilizers. Some synthetic chemical processes that release nitrous oxide have also been identified. Its concentration remained about 0.27 ppmv for at least 1,000 years until two centuries ago, when the rise to the current 0.31 ppmv began.

Ozone is created mainly by the action of solar ultraviolet radiation on molecular oxygen in the upper atmosphere, and most of it remains in the stratosphere. However, a fraction of such ozone descends naturally into the lower atmosphere where additional chemical processes can both form and destroy it. This "tropospheric ozone" has been supplemented during the 20th century by additional ozone—an important component of photochemical smog—created by the action of sunlight upon pollutant molecules containing carbon and nitrogen. The most important of the latter include compounds such as ethylene (C_2H_4), carbon monoxide (CO), and nitric oxide released in the exhaust of fossil-fuel-powered motor vehicles and power plants and during combustion of biomass. The lifetime of ozone is short enough that the molecules do not mix throughout the lower atmosphere, but instead are found in broad plumes downwind from the cities of origin, which merge into regional effects, and into a latitude band of relatively high ozone extending from 30°N to 50°N that encircles Earth during Northern Hemisphere spring and summer. The presence of shorter-lived molecules, such as ozone, in the troposphere depends upon a steady supply of newly formed molecules, such as those created daily by traffic in the large cities of the world. The widespread practice of clearing forests and agricultural wastes ("biomass burning"), especially noticeable in the tropics and the Southern Hemisphere, contributes to tropospheric ozone.

The chlorofluorocarbons (CFCs) are different from the gases considered above in that they have no significant natural source but were synthesized for their technological utility. Essentially all of the major uses of the CFCs—as refrigerants, aerosol propellants, plastic foaming agents, cleaning solvents, and so on—result in their release, chemically unaltered, into the atmosphere. The atmospheric concentrations of the CFCs rose, slowly at first, from zero before first synthesis in 1928, and then more rapidly in the 1960s and 1970s with the development of a widening range of technological applications. The concentrations were rising in the 1980s at a rate of about 18 parts per trillion by volume (pptv) per year for CFC-12, 9 pptv/year for CFC-11, and 6 pptv/year for CFC-113 (CCl_2FCClF_2). Because these molecules were

[4]The variations and uncertainties in the land carbon balance are important not only in the contemporary carbon budget. While the terrestrial carbon reservoirs are small compared to the oceans, the possibility of destabilizing land ecosystems and releasing the stored carbon, e.g. from the tundra soils, has been hypothesized.

identified as agents causing the destruction of stratospheric ozone,[5] their production was banned in the industrial countries as of January 1996 under the terms of the 1992 revision of the Montreal Protocol, and further emissions have almost stopped. The atmospheric concentrations of CFC-11 and CFC-113 are now slowly decreasing, and that of CFC-12 has been essentially level for the past several years. However, because of the century-long lifetimes of these CFC molecules, appreciable atmospheric concentrations of each will survive well into the 22nd century.

Many other fluorinated compounds (such as carbon tetrafluoride, CF_4, and sulfur hexafluoride, SF_6), also have technological utility, and significant greenhouse gas capabilities. Their very long atmospheric lifetimes are a source of concern even though their atmospheric concentrations have not yet produced large radiative forcings. Members of the class of compounds called hydrofluorocarbons (HFCs) also have a greenhouse effect from the fluorine, but the hydrogen in the molecule allows reaction in the troposphere, reducing both its atmospheric lifetime and the possible greenhouse effect. The atmospheric concentrations of all these gases, which to date are only very minor greenhouse contributors, need to be continuously monitored to ensure that no major sources have developed. The sensitivity and generality of modern analytic systems make it unlikely that any additional greenhouse gas will be discovered that is already a significant contributor to the current total greenhouse effect.

AEROSOLS

Sulfate and carbon-bearing compounds associated with particles (i.e., carbonaceous aerosols) are two classes of aerosols that impact radiative balances, and therefore influence climate.

Black Carbon (soot)

The study of the role of black carbon in the atmosphere is relatively new. As a result it is characterized poorly as to its composition, emission source strengths, and influence on radiation. Black carbon is an end product of the incomplete combustion of fossil fuels and biomass, the latter resulting from both natural and human-influenced processes. Most of the black carbon is associated with fine particles (radius <0.2 μm) that have global residence times of about one week. These lifetimes are considerably shorter than those of most greenhouse gases, and thus the spatial distribution of black carbon aerosol is highly variable, with the greatest concentrations near the production regions. Because of the scientific uncertainties associated with the sources and composition of carbonaceous aerosols, projections of future impacts on climate are difficult. However, the increased burning of fossil fuels and the increased burning of biomass for land clearing may result in increased black carbon concentration globally.

Sulfate

The precursor to sulfate is sulfur dioxide gas, which has two primary natural sources: emissions from marine biota and volcanic emissions. During periods of low volcanic activity, the primary source of sulfur dioxide in regions downwind from continents is the combustion of sulfur-rich coals; less is contributed by other fossil fuels. In oceanic regions far removed from continental regions, the biologic source should dominate. However, model analyses, accounting for the ubiquitous presence of ships, indicate that even in these remote regions combustion is a major source of the sulfur dioxide. Some of the sulfur dioxide attaches to sea-salt aerosol where it is oxidized to sulfate. The sea salt has a residence time in the atmosphere on the order of hours to days, and it is transported in the lower troposphere. Most sulfate aerosol is associated with small aerosols (radius <1 μm) and is transported in the upper troposphere with an atmospheric lifetime on the order of one week. Recent "clean coal technologies" and the use of low sulfur fossil fuels have resulted in decreasing sulfate concentrations, especially in North America and regions downwind. Future atmospheric concentrations of sulfate aerosols will be determined by the extent of non-clean coal burning techniques, especially in developing nations.

CLIMATE FORCINGS IN THE INDUSTRIAL ERA

Figure 1 summarizes climate forcings that have been introduced during the period of industrial development, between 1750 and 2000, as estimated by the IPCC. Some of these forcings, mainly greenhouse gases, are known quite accurately, while others are poorly measured. A range of uncertainty has been estimated for each forcing, represented by an uncertainty bar or "whisker." However, these estimates are partly subjective, and it is possible that the true forcing falls outside the indicated range in some cases.

Greenhouse Gases

Carbon dioxide (CO_2) is probably the most important climate forcing agent today, causing an increased forcing of about 1.4 W/m^2. CO_2 climate forcing is likely to become more dominant in the future as fossil fuel use continues. If fossil fuels continue to be used at the current rate, the added

[5]Eighty-five percent of the mass of the atmosphere lies in the troposphere, the region between the surface and an altitude of about 10 miles. About 90% of Earth's ozone is found in the stratosphere, and the rest is in the troposphere.

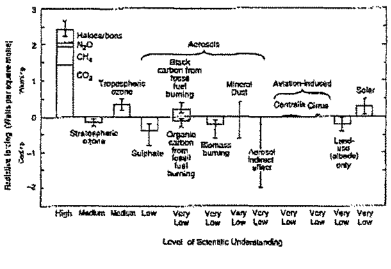

FIGURE 1 The global mean radiative forcing of the climate system for the year 2000, relative to 1750, and the associated confidence levels with which they are known. (From IPCC, 2001; reprinted with permission of the Intergovernmental Panel on Climate Change.)

CO_2 forcing in 50 years will be about 1 W/m^2. If fossil fuel use increases by 1-1.5% per year for 50 years, the added CO_2 forcing instead will be about 2 W/m^2. These estimates account for the non-linearity caused by partial saturation in some greenhouse gas infrared absorption bands, yet they are only approximate because of uncertainty about how efficiently the ocean and terrestrial biosphere will sequester atmospheric CO_2. The estimates also presume that during the next 50 years humans will not, on a large scale, capture and sequester the CO_2 released during fossil-fuel burning.

Other greenhouse gases together cause a climate forcing approximately equal to that of CO_2. Any increase in CH_4 also indirectly causes further climate forcing by increasing stratospheric H_2O (about 7% of the CH_4 is oxidized in the upper atmosphere), as well as by increasing tropospheric O_3 through reactions involving OH and nitrogen oxides. The total climate forcing by CH_4 is at least a third as large as the CO_2 forcing, and it could be half as large as the CO_2 forcing when the indirect effects are included.

Methane is an example of a forcing whose growth could be slowed or even stopped entirely or reversed. The common scenarios for future climate change assume that methane will continue to increase. If instead its amount were to remain constant or decrease, the net climate forcing could be significantly reduced. The growth rate of atmospheric methane has slowed by more than half in the past two decades for reasons that are not well understood. With a better understanding of the sources and sinks of methane, it may be possible to encourage practices (for example, reduced leakage during fossil-fuel mining and transport, capture of land-fill emissions, and more efficient agricultural practices) that lead to a decrease in atmospheric methane and significantly reduce future climate change. The atmospheric lifetime of methane is of the order of a decade, therefore, unlike CO_2, emission changes will be reflected in changed forcing rather quickly.

Tropospheric ozone (ozone in the lower 5-10 miles of the atmosphere) has been estimated to cause a climate forcing of about 0.4 W/m^2. Some of this is linked to methane increases as discussed above, and attribution of the ozone forcing between chemical factors such as methane, carbon monoxide, and other factors is a challenging problem. One recent study, based in part on limited observations of ozone in the late 1800s, suggested that human-made ozone forcing could be as large as about 0.7-0.8 W/m^2. Surface level ozone is a major ingredient in air pollution with substantial impacts on human health and agricultural productivity. The potential human and economic gains from reduced ozone pollution and its importance as a climate forcing make it an attractive target for further study as well as possible actions that could lead to reduced ozone amounts or at least a halt in its further growth.

Aerosols

Climate forcing by anthropogenic aerosols is a large source of uncertainty about future climate change. On the basis of estimates of past climate forcings, it seems likely that aerosols, on a global average, have caused a negative climate forcing (cooling) that has tended to offset much of the positive forcing by greenhouse gases. Even though aerosol distributions tend to be regional in scale, the forced climate response is expected to occur on larger, even hemispheric and global, scales. The monitoring of aerosol properties has not been adequate to yield accurate knowledge of the aerosol climatic influence.

Estimates of the current forcing by sulfates fall mainly in the range −0.3 to −1 W/m^2. However, the smaller values do not fully account for the fact that sulfate aerosols swell in size substantially in regions of high humidity. Thus, the sulfate forcing probably falls in the range −0.6 to −1 W/m^2. Further growth of sulfate aerosols is likely to be limited by concerns about their detrimental effects, especially acid rain, and it is possible that control of sulfur emissions from combustion will even cause the sulfate amount to decrease.

Black carbon (soot) aerosols absorb sunlight and, even though this can cause a local cooling of the surface in regions of heavy aerosol concentration, it warms the atmosphere and, for plausible atmospheric loadings, soot is expected to cause a global surface warming. IPCC reports have provided a best estimate for the soot forcing of 0.1-0.2 W/m^2, but with large uncertainty. One recent study that accounts for the larger absorption that soot can cause when it is mixed internally with other aerosols suggests that its direct forcing is at least 0.4 W/m^2. It also has been suggested that the indirect effects of black carbon—which include reducing low-level cloud cover (by heating of the layer), making clouds slightly "dirty" (darker), and lowering of the albedo of snow and sea ice—might double this forcing to 0.8 W/m^2. The conclusion is that the black carbon aerosol forcing is uncertain but may be substantial. Thus there is the possibility that decreasing black carbon emissions in the future could have a cooling effect that would at least partially compensate for the warming that might be caused by a decrease in sulfates.

Other aerosols are also significant. Organic carbon aerosols are produced naturally by vegetation and anthropogenically in the burning of fossil fuels and biomass. Organic carbon aerosols thus accompany and tend to be absorbed by soot aerosols, and they are believed to increase the toxicity of the aerosol mixture. It is expected that efforts to reduce emissions of black carbon would also reduce organic carbon emissions. Ammonium nitrate (not included in Figure 1) recently has been estimated to cause a forcing of –0.2 W/m^2.

Mineral dust, along with sea salt, sulfates, and organic aerosols, contributes a large fraction of the global aerosol mass. It is likely that human land-use activities have influenced the amount of mineral dust in the air, but trends are not well measured. Except for iron-rich soil, most mineral dust probably has a cooling effect, but this has not been determined well.

The greatest uncertainty about the aerosol climate forcing—indeed, the largest of all the uncertainties about global climate forcings—is probably the indirect effect of aerosols on clouds. Aerosols serve as condensation nuclei for cloud droplets. Thus, anthropogenic aerosols are believed to have two major effects on cloud properties: the increased number of nuclei results in a larger number of smaller cloud droplets, thus increasing the cloud brightness (the Twomey effect), and the smaller droplets tends to inhibit rainfall, thus increasing cloud lifetime and the average cloud cover on Earth. Both effects reduce the amount of sunlight absorbed by Earth and thus tend to cause global cooling. The existence of these effects has been verified in field studies, but it is extremely difficult to determine their global significance. Climate models that incorporate the aerosol-cloud physics suggest that these effects may produce a negative global forcing on the order of 1 W/m^2 or larger. The great uncertainty about this indirect aerosol climate forcing presents a severe handicap both for the interpretation of past climate change and for future assessments of climate changes.

Other Forcings

Other potentially important climate forcings include volcanic aerosols, anthropogenic land use, and solar variability. Stratospheric aerosols produced by large volcanoes that eject gas and dust to altitudes of 12 miles or higher can cause a climate forcing as large as several watts per square meter on global average. However, the aerosols fall out after a year or two, so unless there is an unusual series of eruptions, they do not contribute to long-term climate change.

Land-use changes, especially the removal or growth of vegetation, can cause substantial regional climate forcing. One effect that has been evaluated in global climate models is the influence of deforestation. Because forests are dark and tend to mask underlying snow, the replacement of forests by crops or grass yields a higher albedo surface and thus a cooling effect. This effect has been estimated to yield a global cooling tendency in the industrial era equivalent to a forcing of –0.2 W/m^2. Land use changes have been an important contributor to past changes of atmospheric carbon dioxide. However, the impacts of such changes on climate may be much more significant on regional scales than globally, and largely act through changes of the hydrologic cycle. Such impacts are currently poorly characterized because they depend on complex modeling details that are still actively being improved.

Solar irradiance, the amount of solar energy striking Earth, has been monitored accurately only since the late 1970s. However, indirect measures of solar activity suggest that there has been a positive trend of solar irradiance over the industrial era, providing a forcing estimated at about 0.3 W/m^2. Numerous possible indirect forcings associated with solar variability have been suggested. However, only one of these, ozone changes induced by solar ultraviolet irradiance variations, has convincing observational support. Some studies have estimated this indirect effect to enhance the direct solar forcing by 0.1 W/m^2, but this value remains highly uncertain. Although the net solar forcing appears small in comparison with the sum of all greenhouse gases, it is perhaps more appropriate to compare the solar forcing with the net anthropogenic forcing. Solar forcing is very uncertain, but almost certainly much smaller than the greenhouse gas forcing. It is not implausible that solar irradiance has been a significant driver of climate during part of the industrial era, as suggested by several modeling studies. However, solar forcing has been measured to be very small since 1980, and greenhouse gas forcing has certainly been much larger in the past two decades. In any case, future changes in solar irradiance and greenhouse gases require careful monitoring to evaluate their future balance. In the future, if greenhouse gases continue to increase rapidly while aerosol forcing moderates, solar forcing may be relatively less important. Even in that case, however, the difference between an increasing and decreasing irradiance could be significant and affect interpretation of climate change, so it is important that solar variations be accurately monitored.

4

Climate System Models

Climate system models are an important tool for interpreting observations and assessing hypothetical futures. They are mathematical computer-based expressions of the thermodynamics, fluid motions, chemical reactions, and radiative transfer of Earth climate that are as comprehensive as allowed by computational feasibility and by scientific understanding of their formulation. Their purpose is to calculate the evolving state of the global atmosphere, ocean, land surface, and sea ice in response to external forcings of both natural causes (such as solar and volcanic) and human causes (such as emissions and land uses), given geography and initial material compositions. Such models have been in use for several decades. They are continually improved to increase their comprehensiveness with respect to spatial resolution, temporal duration, biogeochemical complexity, and representation of important effects of processes that cannot practically be calculated on the global scale (such as clouds and turbulent mixing). Formulating, constructing, and using such models and analyzing, assessing, and interpreting their answers make climate system models large and expensive enterprises. For this reason, they are often associated, at least in part, with national laboratories. The rapid increase over recent decades in available computational speed and power offers opportunities for more elaborate, more realistic models, but requires regular upgrading of the basic computers to avoid obsolescence.

Climate models calculate outcomes after taking into account the great number of climate variables and the complex interactions inherent in the climate system. Their purpose is the creation of a synthetic reality that can be compared with the observed reality, subject to appropriate averaging of the measurements. Thus, such models can be evaluated through comparison with observations, provided that suitable observations exist. Furthermore, model solutions can be diagnosed to assess contributing causes of particular phenomena. Because climate is uncontrollable (albeit influenceable by humans), the models are the only available experimental laboratory for climate. They also are the appropriate high-end tool for forecasting hypothetical climates in the years and centuries ahead. However, climate models are imperfect. Their simulation skill is limited by uncertainties in their formulation, the limited size of their calculations, and the difficulty of interpreting their answers that exhibit almost as much complexity as in nature.

The current norm for a climate system model is to include a full suite of physical representations for air, water, land, and ice with a geographic resolution scale of typically about 250 km. Model solutions match the primary planetary-scale circulation, seasonal variability, and temperature structures with qualitative validity but still some remaining discrepancies. They show forced responses of the global-mean temperature that corresponds roughly with its measured history over the past century, though this requires model adjustments. They achieve a stable equilibrium over millennial intervals with free exchanges of heat, water, and stress across the land and water surfaces. They also exhibit plausible analogues for the dominant modes of intrinsic variability, such as the El Niño/Southern Oscillation (ENSO), although some important discrepancies still remain. At present, climate system models specify solar luminosity, atmospheric composition, and other agents of radiative forcing. A frontier for climate models is the incorporation of more complete biogeochemical cycles (for example, for carbon dioxide). The greater the sophistication and complexity of an atmospheric model, the greater the need for detailed multiple measurements, which test whether the model continues to mimic observational reality. Applications of climate models to past climate states encompass "snapshots" during particular millennia, but they do not yet provide for continuous evolution over longer intervals (transitions between ice ages).

5

Observed Climate Change During the Industrial Era

Is climate change occurring? If so, how?

Are the changes due to human activities?

THE OCCURRENCE OF CLIMATE CHANGE

A diverse array of evidence points to a warming of global surface air temperatures. Instrumental records from land stations and ships indicate that global mean surface air temperature warmed by about 0.4-0.8°C (0.7-1.5°F) during the 20th century. The warming trend is spatially widespread and is consistent with the global retreat of mountain glaciers, reduction in snow-cover extent, the earlier spring melting of ice on rivers and lakes, the accelerated rate of rise of sea level during the 20th century relative to the past few thousand years, and the increase in upper-air water vapor and rainfall rates over most regions. A lengthening of the growing season also has been documented in many areas, along with an earlier plant flowering season and earlier arrival and breeding of migratory birds. Some species of plants, insects, birds, and fish have shifted towards higher latitudes and higher elevations. The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.05°C (0.09°F) averaged over the layer extending from the surface down to 10,000 feet, since the 1950s.

Pronounced changes have occurred over high latitudes of the Northern Hemisphere. Analysis of recently declassified data from U.S. and Russian submarines indicates that sea ice in the central Arctic has thinned since the 1970s. Satellite data also indicate a 10-15% decrease in summer sea ice concentration over the Arctic as a whole, which is primarily due to the retreat of the ice over the Siberian sector. A decline of about 10% in spring and summer continental snow cover extent over the past few decades also has been observed. Some of these high latitude changes are believed to be as much or more a reflection of changes in wintertime wind patterns as a direct consequence of global warming per se. The rate of warming has not been uniform over the 20th century. Most of it occurred prior to 1940 and during the past few decades. The Northern Hemisphere as a whole experienced a slight cooling from 1946-75, and the cooling during that period was quite marked over the eastern United States. The cause of this hiatus in the warming is still under debate. The hiatus is evident in averages over both Northern and Southern Hemispheres, but it is more pronounced in the Northern Hemisphere. One possible cause of this feature is the buildup of sulfate aerosols due to the widespread burning of high sulfur coal during the middle of the century, followed by a decline indicated by surface sulfate deposition measurements. It is also possible that at least part of the rapid warming of the Northern Hemisphere during the first part of the 20th century and the subsequent cooling were of natural origin—a remote response to changes in the oceanic circulation at subarctic latitudes in the Atlantic sector, as evidenced by the large local temperature trends over this region. Suggestions that either variations in solar luminosity or the frequency of major volcanic emissions could have contributed to the irregular rate of warming during the 20th century cannot be excluded.

The IPCC report compares the warming of global mean temperature during the 20th century with the amplitude of climate variations over longer time intervals, making use of recent analyses of tree ring measurements from many different sites, data from the Greenland ice cores, and bore hole temperature measurements. On the basis of these analyses, they conclude that the 0.6°C (1.1°F) warming of the Northern Hemisphere during the 20th century is likely to have been the largest of any century in the past thousand years. This result is based on several analyses using a variety of proxy indicators, some with annual resolution and others with less resolved time resolution. The data become relatively sparse prior to 1600, and are subject to uncertainties related to spatial completeness and interpretation making the results somewhat equivocal, e.g., less than 90% confidence. Achieving greater certainty as to the magnitude of climate variations before that time will require more extensive data and analysis.

Although warming at Earth's surface has been quite pronounced during the past few decades, satellite measurements beginning in 1979 indicate relatively little warming of air temperature in the troposphere. The committee concurs with the findings of a recent National Research Council report,[1] which concluded that the observed difference between surface and tropospheric temperature trends during the past 20 years is probably real, as well as its cautionary statement to the effect that temperature trends based on such short periods of record, with arbitrary start and end points, are not necessarily indicative of the long-term behavior of the climate system. The finding that surface and troposphere temperature trends have been as different as observed over intervals as long as a decade or two is difficult to reconcile with our current understanding of the processes that control the vertical distribution of temperature in the atmosphere.

THE EFFECT OF HUMAN ACTIVITIES

Because of the large and still uncertain level of natural variability inherent in the climate record and the uncertainties in the time histories of the various forcing agents (and particularly aerosols), a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established. The fact that the magnitude of the observed warming is large in comparison to natural variability as simulated in climate models is suggestive of such a linkage, but it does not constitute proof of one because the model simulations could be deficient in natural variability on the decadal to century time scale. The warming that has been estimated to have occurred in response to the buildup of greenhouse gases in the atmosphere is somewhat greater than the observed warming. At least some of this excess warming has been offset by the cooling effect of sulfate aerosols, and in any case one should not necessarily expect an exact correspondence because of the presence of natural variability.

The cooling trend in the stratosphere, evident in radiosonde data since the 1960s and confirmed by satellite observations starting in 1979, is so pronounced as to be difficult to explain on the basis of natural variability alone. This trend is believed to be partially a result of stratospheric ozone depletion and partially a result of the buildup of greenhouse gases, which warm the atmosphere at low levels but cool it at high levels. The circulation of the stratosphere has responded to the radiatively induced temperature changes in such a way as to concentrate the effects in high latitudes of the winter hemisphere, where cooling of up to 5°C (9°F) has been observed.

There have been significant changes in the atmospheric circulation during the past several decades: e.g., the transition in climate over the Pacific sector around 1976 that was analogous in some respects to a transition toward more "El Niño-like" conditions over much of the Pacific, and the more gradual strengthening of the wintertime westerlies over subpolar latitudes of both Northern and Southern Hemispheres. Such features bear watching, lest they be early indications of changes in the natural modes of atmospheric variability triggered by human induced climate change. To place them in context, however, it is worth keeping in mind that there were events of comparable significance earlier in the record, such as the 1930s dust bowl.

[1] *Reconciling Observations of Global Temperature Change*, 2000.

6

Future Climate Change

How much of the expected climate change is the consequence of climate feedback processes (e.g., water vapor, clouds, snow packs)?

By how much will temperatures change over the next 100 years and where?

What will be the consequences (e.g., extreme weather, health effects) of increases of various magnitude?

Has science determined whether there is a "safe" level of concentration of greenhouse gases?

ESTIMATING FUTURE CLIMATE CHANGE

Projecting future climate change first requires projecting the fossil-fuel and land-use sources of CO_2 and other gases and aerosols. How much of the carbon from future use of fossil fuels will be seen as increases in carbon dioxide in the atmosphere will depend on what fractions are taken up by land and the oceans. The exchanges with land occur on various time scales, out to centuries for soil decomposition in high latitudes, and they are sensitive to climate change. Their projection into the future is highly problematic.

Future climate change depends on the assumed scenario for future climate forcings, as well as upon climate sensitivity. The IPCC scenarios include a broad range of forcings. One scenario often used for climate model studies employs rapid growth rates such that annual greenhouse gas emissions continue to accelerate. This is a useful scenario, in part because it yields a reasonably large "signal/noise" in studies of the simulated climate response. More important, it provides a warning of the magnitude of climate change that may be possible if annual greenhouse gas emissions continue to increase. There are sufficient fossil fuels in the ground to supply such a scenario for well over a century.

IPCC scenarios cover a broad range of assumptions about future economic and technological development, including some that allow greenhouse gas emission reductions. However, there are large uncertainties in underlying assumptions about population growth, economic development, life style choices, technological change, and energy alternatives, so that it is useful to examine scenarios developed from multiple perspectives in considering strategies for dealing with climate change. For example, one proposed growth scenario[1] for the next 50 years notes that CO_2 emissions have grown by about 1% annually in the past 20 years and assumes a zero growth rate for CO_2 emissions until 2050 (that is, constant emissions). The scenario also focuses on forcings from non-CO_2 greenhouse gases such as methane, and assumes a zero growth rate for them (that is, atmospheric amounts in 2050 similar to those in 2000). Plausible assumptions for technological progress and human factors were proposed to achieve this trajectory for radiative forcing. This scenario leads to a predicted temperature increase of 0.75°C by 2050, approximately half of that resulting from more conventional assumptions. One rationale for focusing first on 2050 rather than 2100 is that it is more difficult to foresee the technological capabilities that may allow reduction of greenhouse gas emissions by 2100.

Scenarios for future greenhouse gas amounts, especially for CO_2 and CH_4, are a major source of uncertainty for projections of future climate. Successive IPCC assessments over the past decade each have developed a new set of scenarios

[1]Hansen, J., M. Sato, R. Ruedy, A. Lacis, and V. Oinas, Global warming in the twenty-first century: an alternative scenario, *Proceedings of the National Academy of Sciences*, 97: 9875-9880, 2000.

with little discussion of how well observed trends match with previous scenarios. The period of record is now long enough to make it useful to compare recent trends with the scenarios, and such studies will become all the more fruitful as years pass. The increase of global fossil fuel CO_2 emissions in the past decade, averaging 0.6% per year, has fallen below the IPCC scenarios. The growth of atmospheric CH_4 has fallen well below the IPCC scenarios. These slowdowns in growth rates could be short-term fluctuations that may be reversed. However, they emphasize the need to understand better the factors that influence current and future growth rates.

Global warming will not be spatially uniform, and it is expected to be accompanied by other climate changes. In areas and seasons in which there are large temperature changes, feedbacks may be much larger than their global values. An example of such regionally large effects is the ice-albedo feedback. Reduced snow cover and sea and lake ice will be important at high latitudes and higher elevations, especially during winter and spring. In the presence of the higher temperatures, atmospheric water vapor concentration and precipitation will also be higher. Determining the net ice-albedo feedback effect is complicated by its connections to other aspects of the hydrologic and energy cycles. Clouds may change to amplify or reduce its effect. Increased precipitation with warming at the margin of ice and snow may act to either reduce or amplify this effect, e.g., reducing the effect by increasing snow levels where it is below freezing. Changing vegetation cover likewise can introduce major modification.

An increase in the recycling rate of water in the hydrologic cycle is anticipated in response to higher global average temperatures. Higher evaporation rates will accelerate the drying of soils following rain events, thereby resulting in drier average conditions in some regions, especially during periods of dry weather during the warm season. The drier soils, with less water available for evapotranspiration, will warm more strongly during sunlight hours resulting in higher afternoon temperatures, faster evaporation, and an increase in the diurnal temperature range. The effect is likely to be greatest in semi-arid regions, such as the U.S. Great Plains. The faster recycling of water will lead to higher rainfall rates and an increase in the frequency of heavy precipitation events.

There is a possibility that global warming could change the behavior of one or more of the atmosphere's natural modes of variability such as ENSO or the so-called North Atlantic or Arctic Oscillation. Such changes could lead to complex changes in the present-day patterns of temperature and precipitation, including changes in the frequency of winter or tropical storms. Higher precipitation rates would favor increased intensity of tropical cyclones, which derive their energy from the heat that is released when water vapor condenses.

Temperatures are expected to increase more rapidly over land compared to oceans because of the ocean's higher heat capacity and because it can transfer more of the trapped heat to the atmosphere by evaporation. Over land, the warming has been—and is expected to continue to be—larger during nighttime than during daytime.

Consequences of Increased Climate Change of Various Magnitudes

The U.S. National Assessment of Climate Change Impacts, augmented by a recent NRC report on climate and health, provides a basis for summarizing the potential consequences of climate change.[2] The National Assessment directly addresses the importance of climate change of various magnitudes by considering climate scenarios from two well-regarded models (the Hadley model of the United Kingdom and the Canadian Climate Model). These two models have very different globally-averaged temperature increases (2.7 and 4.4°C (4.9 and 7.9°F), respectively) by the year 2100. A key conclusion from the National Assessment is that U.S. society is likely to be able to adapt to most of the climate change impacts on human systems, but these adaptations may come with substantial cost. The primary conclusions from these reports are summarized for agriculture and forestry, water, human health, and coastal regions.

In the near term, agriculture and forestry are likely to benefit from CO_2 fertilization effects and the increased water efficiency of many plants at higher atmospheric CO_2 concentrations. Many crop distributions will change, thus requiring significant regional adaptations. Given their resource base, the Assessment concludes that such changes will be costlier for small farmers than for large corporate farms. However, the combination of the geographic and climatic breadth of the United States, possibly augmented by advances in genetics, increases the nation's robustness to climate change. These conclusions depend on the climate scenario, with hotter and drier conditions increasing the potential for declines in both agriculture and forestry. In addition, the response of insects and plant diseases to warming is poorly understood. On the regional scale and in the longer term, there is much more uncertainty.

Increased tendency toward drought, as projected by some models, is an important concern in every region of the United States even though it is unlikely to be realized everywhere in the nation. Decreased snow pack and/or earlier season melting are expected in response to warming because the freeze line will be moving to higher elevations. The western part of

[2]Except where noted, this section is based on information provided in the U.S. National Assessment. U.S. Global Change Research Program, "Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change", 2001, Cambridge University Press, 612 pp.

the nation is highly dependent on the amount of snow pack and the timing of the runoff. The noted increased rainfall rates have implications for pollution run-off, flood control, and changes to plant and animal habitat. Any significant climate change is likely to result in increased costs because the nation's investment in water supply infrastructure is largely tuned to the current climate.

Health outcomes in response to climate change are the subject of intense debate. Climate change has the potential to influence the frequency and transmission of infectious disease, alter heat- and cold-related mortality and morbidity, and influence air and water quality. Climate change is just one of the factors that influence the frequency and transmission of infectious disease, and hence the assessments view such changes as highly uncertain.[3] This said, changes in the agents that transport infectious diseases (e.g., mosquitoes, ticks, rodents) are likely to occur with any significant change in precipitation and temperature. Increases in mean temperatures are expected to result in new record high temperatures and warm nights and an increase in the number of warm days compared to the present. Cold-related stress is likely to decline whereas heat stress in major urban areas is projected to increase if no adaptation occurs. The National Assessment ties increases in adverse air quality to higher temperatures and other air mass characteristics. However, much of the United States appears to be protected against many different adverse health outcomes related to climate change by a strong public health system, relatively high levels of public awareness, and a high standard of living. Children, the elderly, and the poor are considered to be the most vulnerable to adverse health outcomes. The understanding of the relationships between weather/climate and human health is in its infancy and therefore the health consequences of climate change are poorly understood. The costs, benefits, and availability of resources for adaptation are also uncertain.

Fifty-three percent of the U.S. population lives within the coastal regions, along with billions of dollars in associated infrastructure. Because of this, coastal areas are more vulnerable to increases in severe weather and sea level rise. Changes in storm frequency and intensity are one of the more uncertain elements of future climate change prediction. However, sea level rise increases the potential damage to coastal regions even under conditions of current storm intensities and can endanger coastal ecosystems if human systems or other barriers limit the opportunities for migration.

In contrast to human systems, the U.S. National Assessment makes a strong case that ecosystems are the most vulnerable to the projected rate and magnitude of climate change, in part because the available adaptation options are very limited. Significant climate change will cause disruptions to many U.S. ecosystems, including wetlands, forests, grasslands, rivers, and lakes. Ecosystems have inherent value, and also supply the country with a wide variety of ecosystem services.

The impacts of these climate changes will be significant, but their nature and intensity will depend strongly on the region and timing of occurrence. At a national level, the direct economic impacts are likely to be modest. However, on a regional basis the level and extent of both beneficial and harmful impacts will grow. Some economic sectors may be transformed substantially and there may be significant regional transitions associated with shifts in agriculture and forestry. Increasingly, climate change impacts will have to be placed in the context of other stresses associated with land use and a wide variety of pollutants. The possibility of abrupt or unexpected changes could pose greater challenges for adaptation.

Even the mid-range scenarios considered in the IPCC result in temperatures that continue to increase well beyond the end of this century, suggesting that assessments that examine only the next 100 years may well underestimate the magnitude of the eventual impacts. For example a sustained and progressive drying of the land surface, if it occurred, would eventually lead to desertification of regions that are now marginally arable, and any substantial melting or breaking up of the Greenland and Antarctic ice caps could cause widespread coastal inundation.[4]

"Safe" Level of Concentration of Greenhouse Gases

The potential for significant climate-induced impacts raises the question of whether there exists a "safe" level of greenhouse gas concentration. The word "safe" is ambiguous because it depends on both viewpoint and value judgment. This view changes dramatically if you are part of an Eskimo community dependent on sea ice for hunting, or an inhabitant of a coastal city, or a farm community. It depends on whether an industry is robust or sensitive to climate change. The viewpoint changes distinctly between countries with sufficient resources for adaptation and poorer nations. Value judgments become particularly important when assessing the potential impacts on natural ecosystems. The question can be approached from two perspectives. The first issue is whether there is a threshold in the concentration of greenhouse gases that, if exceeded, would cause dramatic or catastrophic changes to the Earth system. The second issue

[3] *Under the Weather: Climate, Ecosystems, and Infectious Disease*, 2001.

[4] Appreciable desertification on a regional scale could take place within a decade or two. Many centuries would be required for substantial melting of the ice sheets to occur and the likelihood of a breakup during this century is considered to be remote.

is whether the consequences of greenhouse warming, as a function of the concentration of greenhouse gases, are sufficiently well known that the scientific community can define "an acceptable concentration" based on an analysis of potential risks and damages. The first issue is best addressed by examining Earth's history. Guidance for the second issue can be derived from assessments of the impacts of climate change.

A variety of measurements demonstrate that CO_2 has varied substantially during Earth's history, reaching levels between three and nine times pre-industrial levels of carbon dioxide prior to 50 million years ago. During the periods of hypothesized high carbon dioxide concentrations, there are strong indicators of warmth (although many different factors have contributed to climate change during Earth's history). These indicators include warm deep-sea temperatures and abundant life within the Arctic Circle. There are also some records of abrupt warming (thousands of years) in Earth's history that may be related to atmospheric greenhouse concentrations, which caused significant perturbations to the Earth system. The global temperature increases determined for some of these warm periods exceed future projections from all climate models for the next century. These changes are associated with some extinctions, and both the periods of warmth and abrupt transitions are associated with the large-scale redistribution of species. However, a substantial biosphere is evident (i.e., no catastrophic impact tending toward wholesale extinctions) even with substantially higher CO_2 concentrations than those postulated to occur in response to human activities.

The course of future climate change will depend on the nature of the climate forcing (e.g., the rate and magnitude of changes in greenhouse gases, aerosols) and the sensitivity of the climate system. Therefore, determination of an acceptable concentration of greenhouse gases depends on the ability to determine the sensitivity of the climate system as well as knowledge of the full range of the other forcing factors, and an assessment of the risks and vulnerabilities. Climate models reflect a range of climate sensitivities even with the same emission scenario. For example, the consequences of climate change would be quite different for a globally-averaged warming of 1.1°C (2.0°F) or a 3.1°C (5.6°F) projected for the IPCC scenario in which CO_2 increases by 1% per year leading to a doubling from current levels in the next 70 years.

Both climate change and its consequences also are likely to have a strong regional character. The largest changes occur consistently in the regions of the middle to high latitudes. Whereas all models project global warming and global increases in precipitation, the sign of the precipitation projections varies among models for some regions.

The range of model sensitivities and the challenge of projecting the sign of the precipitation changes for some regions represent a substantial limitation in assessing climate impacts. Therefore, both the IPCC and the U.S. National Assessment of Climate Change Impacts assess potential climate impacts using approaches that are "scenario-driven." In other words, models with a range of climate sensitivities are used to assess the potential impacts on water, agriculture, human health, forestry, and the coastal zones, nationally and region by region. The differences among climate model projections are sufficiently large to limit the ability to define an "acceptable concentration" of atmospheric greenhouse gases. In addition, technological breakthroughs that could improve the capabilities to adapt are not known. Instead, the assessments provide a broader level of guidance:

- The nature of the potential impacts of climate change increases as a function of the sensitivity of the climate model. If globally-averaged temperature increases approach 3°C (5.4°F) in response to doubling of carbon dioxide, they are likely to have substantial impacts on human endeavors and on natural ecosystems.
- Given the fact that middle and high latitude regions appear to be more sensitive to climate change than other regions, significant impacts in these regions are likely to occur at lower levels of global warming.
- There could be significant regional impacts over the full range of IPCC model-based projections.
- Natural ecosystems are less able to adapt to change than are human systems.

In summary, critical factors in defining a "safe" concentration depend on the nature and level of societal vulnerability, the degree of risk aversion, ability and/or costs of adaptation and/or mitigation, and the valuation of ecosystems, as well as on the sensitivity of the Earth system to climate change.

7

Assessing Progress in Climate Science

What are the substantive differences between the IPCC Reports and the Summaries?

What are the specific areas of science that need to be studied further, in order of priority, to advance our understanding of climate change?

The committee was asked to address these two questions. The first involved evaluating the IPCC Working Group I report and summaries in order to identify how the summaries differ from the report. The second question involved characterizing areas of uncertainty in scientific knowledge concerning climate change, and identifying the research areas that will advance the understanding of climate change.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The full text of the IPCC Third Assessment Report on *The Scientific Basis* represents a valuable effort by U.S. and international scientists in identifying and assessing much of the extensive research going on in climate science. The body of the WGI report is scientifically credible and is not unlike what would be produced by a comparable group of only U.S. scientists working with a similar set of emission scenarios, with perhaps some normal differences in scientific tone and emphasis.

However, because the IPCC reports are generally invoked as the authoritative basis for policy discussions on climate change, we should critically evaluate this effort so that we can offer suggestions for improvement. The goal is a stronger IPCC that will lead to better definitions of the nature of remaining problems, a clarity in expressing both robust conclusions and uncertainties, and thus aid achievement of the best possible policy decisions. We must also consider options for an improved process, given the enormous and growing investment required by individual scientists to produce this assessment. Three important issues directed to this goal are described below.

The IPCC Summary for Policy Makers

The IPCC WGI *Summary for Policymakers* (SPM) serves an obviously different purpose than the scientific working group reports. When one is condensing 1,000 pages into 20 pages with a different purpose in mind, we would expect the text to contain some modifications. After analysis, the committee finds that the conclusions presented in the SPM and the *Technical Summary* (TS) are consistent with the main body of the report. There are, however, differences. The primary differences reflect the manner in which uncertainties are communicated in the SPM. The SPM frequently uses terms (e.g., likely, very likely, unlikely) that convey levels of uncertainty; however, the text less frequently includes either their basis or caveats. This difference is perhaps understandable in terms of a process in which the SPM attempts to underline the major areas of concern associated with a human-induced climate change. However, a thorough understanding of the uncertainties is essential to the development of good policy decisions.

Climate projections will always be far from perfect. Confidence limits and probabilistic information, with their basis, should always be considered as an integral part of the information that climate scientists provide to policy and decision makers. Without them, the IPCC SPM could give an impression that the science of global warming is "settled," even though many uncertainties still remain. The emission scenarios used by the IPCC provide a good example. Human decisions will almost certainly alter emissions over the next century. Because we cannot predict either the course of human populations, technology, or societal transitions with any clarity, the actual greenhouse gas emissions could be either greater or less than the IPCC scenarios. Without an understanding of the sources and degree of uncertainty, decision makers could fail to define the best ways to deal with the serious issue of global warming.

Modification of the Scientific Text After Completion of the SPM

The SPM results from a discussion between the lead authors and government representatives (including also some non-governmental organizations and industry representatives). This discussion, combined with the requirement for consistency, results in some modifications of the text, all of which were carefully documented by the IPCC. This process has resulted in some concern that the scientific basis for the SPM might be altered. To assess this potential problem, the committee solicited written responses from U.S. coordinating lead authors and lead authors of IPCC chapters, reviewed the WGI draft report and summaries, and interviewed Dr. Daniel Albritton who served as a coordinating lead author for the IPCC WGI *Technical Summary*. Based on this analysis, the committee finds that no changes were made without the consent of the convening lead authors and that most changes that did occur lacked significant impact. However, some scientists may find fault with some of the technical details, especially if they appear to underestimate uncertainty. The SPM is accompanied by the more representative *Technical Summary* (TS). The SPM contains cross-references to the full text, which unfortunately is not accessible until a later date, but it does not cross-reference the accompanying TS.

The IPCC as Representative of the Science Community

The IPCC process demands a significant time commitment by members of the scientific community. As a result, many climate scientists in the United States and elsewhere choose not to participate at the level of a lead author even after being invited. Some take on less time-consuming roles as contributing authors or reviewers. Others choose not to participate. This may present a potential problem for the future. As the commitment to the assessment process continues to grow, this could create a form of self-selection for the participants. In such a case, the community of world climate scientists may develop cadres with particularly strong feelings about the outcome: some as favorable to the IPCC and its procedures and others negative about the use of the IPCC as a policy instrument. Alternative procedures are needed to ensure that participation in the work of the IPCC does not come at the expense of an individual's scientific career.

In addition, the preparation of the SPM involves both scientists and governmental representatives. Governmental representatives are more likely to be tied to specific government postures with regard to treaties, emission controls, and other policy instruments. If scientific participation in the future becomes less representative and governmental representatives are tied to specific postures, then there is a risk that future IPCC efforts will not be viewed as independent processes.

The United States should promote actions that improve the IPCC process while also ensuring that its strengths are maintained. The most valuable contribution U.S. scientists can make is to continually question basic assumptions and conclusions, promote clear and careful appraisal and presentation of the uncertainties about climate change as well as those areas in which science is leading to robust conclusions, and work toward a significant improvement in the ability to project the future. In the process, we will better define the nature of the problems and ensure that the best possible information is available for policy makers.

RESEARCH PRIORITIES

The underlying scientific issues that have been discussed in this report and the research priorities that they define have evolved over time. For this reason, many have been identified previously in NRC reports.[1]

Predictions of global climate change will require major advances in understanding and modeling of (1) the factors that determine atmospheric concentrations of greenhouse gases and aerosols and (2) the so called "feedbacks" that determine the sensitivity of the climate system to a prescribed increase in greenhouse gases. Specifically, this will involve reducing uncertainty regarding: (a) future usage of fossil fuels, (b) future emissions of methane, (c) the fraction of the future fossil fuel carbon that will remain in the atmosphere and provide radiative forcing versus exchange with the oceans or net exchange with the land biosphere, (d) the feedbacks in the climate system that determine both the magnitude of the change and the rate of energy uptake by the oceans, which together determine the magnitude and time history of the temperature increases for a given radiative forcing, (e) the details of the regional and local climate change consequent to an overall level of global climate change, (f) the nature and causes of the natural variability of climate and its interactions with forced changes, and (g) the direct and indirect effects of the changing distributions of aerosol. Because the total change in radiative forcing from

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[1]*Decade-to-Century-Scale Climate Variability and Change: A Science Strategy*, 1998; *The Atmospheric Sciences Entering the Twenty-First Century*, 1998; *Adequacy of Climate Observing Systems*, 1999; *Global Environmental Change: Research Pathways for the Next Decade*, 1999; *Improving the Effectiveness of U.S. Climate Modeling*, 2001; *The Science of Regional and Global Change: Putting Knowledge to Work*, 2001.

other greenhouse gases over the last century has been nearly as large as that of carbon dioxide, their future evolution also must be addressed. At the heart of this is basic research, which allows for creative discoveries about those elements of the climate system that have not yet been identified, or studied.

Knowledge of the climate system and projections about the future climate are derived from fundamental physics and chemistry through models and observations of the atmosphere and the climate system. Climate models are built using the best scientific knowledge of the processes that operate within the climate system, which in turn are based on observations of these systems. A major limitation of these model forecasts for use around the world is the paucity of data available to evaluate the ability of coupled models to simulate important aspects of past climate. In addition, the observing system available today is a composite of observations that neither provide the information nor the continuity in the data needed to support measurements of climate variables. Therefore, above all, it is essential to ensure the existence of a long-term observing system that provides a more definitive observational foundation to evaluate decadal- to century-scale variability and change. This observing system must include observations of key state variables such as temperature, precipitation, humidity, pressure, clouds, sea ice and snow cover, sea level, sea-surface temperature, carbon fluxes and soil moisture. Additionally, more comprehensive regional measurements of greenhouse gases would provide critical information about their local and regional source strengths.

Climate observations and modeling are becoming increasingly important for a wide segment of society including water resource managers, public health officials, agribusinesses, energy providers, forest managers, insurance companies, and city planners. In order to address the consequences of climate change and better serve the nation's decision makers, the research enterprise dealing with environmental change and environment-society interactions must be enhanced. This includes support of (a) interdisciplinary research that couples physical, chemical, biological, and human systems, (b) improved capability of integrate scientific knowledge, including its uncertainty, into effective decision support systems, and (c) an ability to conduct research at the regional or sectoral level that promotes analysis of the response of human and natural systems to multiple stresses.

Climate research is presently overseen by the U.S. Global Change Research Program (USGCRP). A number of NRC reports[2] have concluded that this collection of agencies is hampered organizationally in its ability to address the major climate problems. The ability of the United States to assess future climate change is severely limited by the lack of a climate observing system, by inadequate computational resources, and by the general inability of government to focus resources on climate problems. Efforts are needed to ensure that U.S. efforts in climate research are supported and managed to ensure innovation, effectiveness, and efficiency. These issues have been addressed by NRC reports, but more examination is needed.

[2] *Global Environmental Change: Research Pathways for the Next Decade*, 1999; *Improving the Effectiveness of U.S. Climate Modeling*, 2001; *The Science of Regional and Global Change: Putting Knowledge to Work*, 2001

Appendixes

A

Letter from the White House

THE WHITE HOUSE
WASHINGTON

May 11, 2001

Dr. Bruce Alberts
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418

Dear Dr. Alberts:

The Administration is conducting a review of U.S. policy on climate change. We seek the Academy's assistance in identifying the areas in the science of climate change where there are the greatest certainties and uncertainties.

We would also like your views on whether there are any substantive differences between the IPCC Reports and the IPCC summaries.

We would appreciate a response as soon as possible.

Sincerely yours,

John M. Bridgeland
Deputy Assistant to the President
for Domestic Policy and
Director, Domestic Policy Council

Gary Edson
Deputy Assistant to the
President for International
Economic Affairs

B

Biographical Sketches of Committee Members and Staff

Dr. Ralph J. Cicerone *(Chair)* is the chancellor of the University of California at Irvine and the Daniel G. Aldrich Professor in the Department of Earth System Science and the Department of Chemistry. His areas of research include atmospheric chemistry; sources of gases that affect climate and the composition of the global atmosphere, especially methane and nitrous oxide; and the ozone layer and human influence on it. He is a member of the National Academy of Sciences. Dr. Cicerone received his Ph.D. from the University of Illinois.

Dr. Eric J. Barron is Director of the Earth and Mineral Sciences Environment Institute and Distinguished Professor of Geosciences at Pennsylvania State University. His specialty is paleoclimatology/paleoceanography. His research emphasizes global change, specifically numerical models of the climate system and the study of climate change throughout Earth's history. Dr. Barron is a fellow of the American Geophysical Union and the American Meteorological Society. He has served on several National Research Council committees, including, most recently, the Grand Challenges in the Environmental Sciences and the Task Group on Assessment of NASA Plans for Post-2000 Earth Observing Missions. He is currently the chair of the Board on Atmospheric Sciences and Climate. Dr. Barron received his Ph.D. from the University of Miami.

Dr. Robert E. Dickinson is a professor of dynamics and climate in the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. His research interests include the dynamics of atmospheric planetary waves, stratospheric dynamics, models of global structure and dynamics of terrestrial and planetary thermosphere, NLTE infrared radiative transfer in planetary mesopheres, global climate modeling and processes, the role of land processes in climate systems, the modeling role of vegetation in regional evapotranspiration, and the role of tropical forests in climate systems. Dr. Dickinson is a member of the National Academy of Sciences and the recipient of the Revelle medal of the American Geophysical Union (AGU) and the Rossby award of the American Meteorological Society. He is currently president-elect of the AGU. Dr. Dickinson received his Ph.D. from the Massachusetts Institute of Technology.

Dr. Inez Y. Fung is the Richard and Rhoda Goldman Distinguished Professor for the Physical Sciences, Director of the Center for Atmospheric Sciences, and a professor in the Department of Earth and Planetary Science and the Department of Environmental Sciences, Policy and Management at the University of California at Berkeley. Her research expertise is in large-scale numerical modeling of biogeochemical cycles and their interaction with climate. Her research also includes climate change, remote sensing of earth systems, investigations of atmosphere-ocean interactions, and atmosphere-biosphere interactions. She is a member of the National Academy of Sciences, a fellow of the American Geophysical Union and the American Meteorological Society, and a recipient of NASA's Exceptional Scientific Achievement Medal. Dr. Fung received her Sc.D. from the Massachusetts Institute of Technology.

Dr. James E. Hansen is head of the NASA Goddard Institute for Space Studies. His research interests include radiative transfer in planetary atmospheres, interpretation of remote sounding of planetary atmospheres, development of simplified climate models and three-dimensional global climate models, current climate trends from observational data, and projections of man's impact on climate. He is a member of the National Academy of Sciences and a fellow of the

American Geophysical Union. Dr. Hansen received his Ph.D. from the University of Iowa.

Mr. Thomas R. Karl is Director of the National Climatic Data Center of the National Oceanic and Atmospheric Administration. Before this he served as the senior scientist where his research interests included global climate change, extreme weather events, and trends in global and U.S. climate over the past 100 years. Mr. Karl is a fellow of the American Meteorological Society and the American Geophysical Union and served as the chair of the National Research Council's Climate Research Committee. He was a coordinating lead author for the IPCC Working Group I Third Assessment Report. Mr. Karl received his M.S. from the University of Wisconsin.

Dr. Richard S. Lindzen is the Alfred P. Sloan Professor of Meteorology in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology. His research interests include dynamic meteorology and climatology, specifically upper atmosphere dynamics, waves and instability, climate sensitivity, regional and interannual variability of weather, tropical meteorology, monsoons, mesoscale systems, clear air turbulence, climate dynamics, and general circulation. He is a member of the National Academy of Sciences and a fellow of the American Association for the Advancement of Science. He was a lead author for the IPCC Working Group I Third Assessment Report. Dr. Lindzen received his Ph.D. from Harvard University.

Dr. James C. McWilliams is the Slichter Professor of Earth Sciences in the Department of Atmospheric Sciences and the Institute for Geophysics and Planetary Physics at the University of California at Los Angeles. His research focuses on the fluid dynamics of Earth's oceans and atmosphere, both their theory and computational modeling. Particular subjects of interest include the maintenance of general circulations; climate dynamics; geostrophically and cyclo-strophically balanced dynamics in rotating, stratified fluids; vortex dynamics; the planetary boundary layers; planetary-scale thermohaline convection, the roles of coherent structures of turbulent flows in geophysical and astrophysical regimes; numerical methods; coastal ocean modeling and statistical estimation theory. He is a fellow of the American Geophysical Union and has served on the National Research Council's Climate Research Committee and Board on Atmospheric and Sciences. Dr. McWilliams received his Ph.D. from Harvard University.

Dr. F. Sherwood Rowland is the Donald Bren Research Professor of Chemistry and Earth System Science at the University of California at Irvine. His research interests include atmospheric chemistry (stratospheric ozone, trace compounds in the troposphere on a global basis); chemical kinetics, in particular, gas phase reactions of chlorine, fluorine, and hydrogen; and radiochemistry, specifically tracer studies with radioactive isotopes. Dr. Rowland is a member of the National Academy of Sciences where he currently serves as Foreign Secretary. He is also a member of the Institute of Medicine. He has received numerous awards including the Nobel Prize in Chemistry in 1995 and the Revelle medal of the American Geophysical Union. Dr. Rowland received his Ph.D. from the University of Chicago.

Dr. Edward S. Sarachik is a professor in the Department of Atmospheric Sciences and an adjunct professor in the School of Oceanography at the University of Washington. His research interests focus on large-scale atmosphere-ocean interactions, seasonal variations in the tropical oceans, the role of the ocean in climate change, and biogeochemical cycles in the global ocean. Dr. Sarachik is a fellow of the American Geophysical Union, the American Meteorological Society, and the American Association for the Advancement of Science. He has served on numerous National Research Council committees including the Climate Research Committee, the Tropical Ocean/Global Atmosphere (TOGA) Advisory Panel (chair), and the Panel on Improving U.S. Climate Modeling (chair). Dr. Sarachik received his Ph.D. from Brandeis University.

Dr. John M. Wallace is a professor of atmospheric sciences and co-director of the University of Washington Program on the Environment. From 1981-98 he served as director of the (University of Washington/NOAA) Joint Institute for the Study of the Atmosphere and the Ocean. His research specialties include the study of atmospheric general circulation, El Niño, and global climate. He is a member of the National Academy of Sciences; a fellow of the American Association for the Advancement of Science, the American Geophysical Union (AGU), and the American Meteorological Society (AMS); and the recipient of the Rossby medal of the AMS and Revelle medal of the AGU. Dr. Wallace received his Ph.D. from the Massachusetts Institute of Technology.

Dr. Vaughan C. Turekian *(Study Director)* is a Program Officer with the Board on Atmospheric Sciences and Climate. He received his B.S. from Yale University, where he specialized in Geology and Geophysics and International Studies. He received his Ph.D. in Environmental Sciences from the University of Virginia in 2000 where he used stable bulk and compound-specific isotope analyses to characterize the sources and processing of aerosols in marine air.

RESPONSES OF SHERWOOD ROWLAND TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. The Academy's 2001 report, which you helped write, was stunningly clear. It confirmed the seriousness of human-induced climate change. And, it contains a real sense of urgency about the problem. Beyond the comments you made at the hearing, are there other things that the U.S. Government should do to reduce the risks that the report outlines and to clear up related scientific uncertainties?

Response. I believe that it is important to begin carrying out diverse policies which will have an ameliorating effect on climate change. For too many years, the world has operated with little regard to the long term effects of increasing population, increasing energy use per capita, and rather indiscriminate discharge of waste materials into the environment. The global system is so immense and so complicated that a very large set of policy changes are needed. What we need is the establishment of a mind-set that recognizes these problems, and begins to take steps toward solutions. Once the general direction begins to change, more and more opportunities will appear which can accelerate the progress.

Question 2. The Academy's report says that "national policy decisions made now . . . will influence the extent of any damage suffered by vulnerable human populations and ecosystems later in this century." The Administration's new policy decision appears to be business as usual. How will this policy affect the future, in terms of greenhouse gas concentrations?

Response. The history of the past two centuries is a period in which most of the advances in standard of living have been accompanied by the progressive substitution of animal power for human power and then machine power for animal power. These changes have been accompanied, of course, by the increasing use of energy to supply the machine power—first steam from wood burning, then coal, oil and natural gas combustion as power sources. We urgently need to develop policies by which the major industrial powers can maintain sustainable prosperity, while the developing countries seek sustainable development. These changes will surely need to be accompanied by more careful disposal of the waste products from energy production.

Question 3. As you and all the other witnesses indicated, it is not safe to continue increasing greenhouse gas emissions without limit. What needs to be done to assure that we can avert the point of no return or "dangerous levels" of "greenhouse gas concentrations?

Response. We are unlikely to know enough because of the extreme complexity of the global system and its interconnections to permit identification of "points of no return" or to know a precise value of a "dangerous level" until we have passed the first, or exceeded the latter. Under the circumstances, this argues for doing what we can to slow the rate of change in the hope that we can recognize the dangers before we have passed the choke point.

Question 4. The NAS report advocates, "Maintaining a vigorous, ongoing program of basic research, funded and managed independently of the climate assessment activity, will be crucial for narrowing . . . uncertainties . . . In addition, the research enterprise dealing with environmental change and the interactions of human society with the environment must be enhanced." 'What are your views of current Federal-level research programs' direction and budgets for achieving these ends?

Response. The need for separation of research versus assessment is the difference between exploring and judging. Assessment involves judging the adequacy of the present understanding of the system by, for example, its ability to reproduce the observations in that system. Exploring will often mean the postulation of a different possible explanation, devising an appropriate test, and then discarding the explanation if it fails the test—but carrying out a continuing series of postulates and tests.

Question 5. To date, much of the research regarding the environmental, human health, or economic impacts of climate change has been limited to projections for the next 100–150 years, or assuming a doubling of atmospheric CO_2. What are the risks of climate change on a longer timeframe, or those associated with a tripling or quadrupling of atmospheric CO_2? Does the NAS plan to update its 2001 report?

Response. Answering the second question first, the main purpose of the NAS report of 2001 was evaluation of the state of understanding of the Earth's climate system, for which the IPCC 2001 report, and particularly in its Volume 1 on the "Scientific Base", was the latest and most complete compilation. This NAS report was prepared in about 5 weeks by a group of 11 scientists quite familiar with the content and preparation of the IPCC report, while the IPCC report itself was the product of 5 years of work by about 3,000 scientists. Until the next IPCC report is ready in 2006 or 2007, another NAS report is quite unlikely. Reports on specific, limited aspects can certainly be anticipated, as that need rises.

The further out in the future the projection, the greater the uncertainty. Probably the ultimate worry is captured by the phrase "runaway greenhouse", as applied to our sister planet Venus, which has an atmospheric much thicker than ours, composed mostly of carbon dioxide, and surface temperatures which will not permit biological life, at least in the forms existing on Earth. Of course, no one knows the history of the Venusian atmosphere, so that the phrase might be totally misleading.

Question 6. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. My experience with the atmospheric problem of "stratospheric ozone depletion" makes me answer this question with the reply "some problem that has not yet been identified, some surprise." In 1984, the scientific community was quite aware that chlorofluorocarbons (CFCs) were reaching the stratosphere and decomposing there with the release of chlorine atoms, which could then react with the molecules of ozone in the stratosphere. What only a few scientists knew then was that were particles, polar stratospheric clouds, present in the very cold stratosphere over Antarctica. What only a few other scientists knew then—none of them in the first group, who likewise were ignorant of this other development—was that some chemical reactions between two types of chlorine containing molecules, hydrogen chloride and chlorine nitrate, could occur on the surfaces of particles, thereby facilitating the removal of ozone. Then, the "Antarctic ozone hole" was discovered, and reported in 1985 by the British scientist Joe Farman, and suddenly the 1984 view that ozone loss would occur slowly over a period of several decades was replaced by the knowledge that ozone loss could occur extremely rapidly, and that major losses were already happening every spring in the Antarctic.

What would be the surprise? Probably the unexpected collapse of some ecosystem. I won't provide an example of an unexpected collapse, because then it would probably be said that I, or scientists in general, expected it. The basic point is that the climate system is still very much under study, and when and how it goes about changing an area under active investigation.

Responses of Sherwood Rowland to Additional Questions from Senator Smith

Question 1. Dr. Pielke testified that "the primary cause for . . . growth in impact is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se." Do you agree with this claim? Why or why not?

Response. The first 75 years of the 20th century were a time of great population growth, and relatively little change in climate. During the last 25 years, the global temperature has risen steadily, and signs of climate change are beginning to be seen in many locations. Over the whole century then, climate change should not be expected to have caused a great change in impacts. The questions for the future include a mixture of the consequences from increasing global population coupled with the extra impositions from temperature rise. The larger the temperature increase the larger the role this climatic fluctuation will play in impacts on civilization.

Question 2. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought. . . ." Do you agree with that proposition? Why or why not?

Response. The arguments in most of the scientific world are not about global warming, yes or no, but rather about the nuances of the global warming which is occurring. There are always the simultaneous needs for putting out the present fire, and also developing a long term strategy to use non-combustible materials and install sprinkler systems.

Question 3. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. I wrote in the summer of 2000 the following (see "U.S. Policy and the Global Environment", Donald Kennedy and John Riggs, editors) "None of the currently available remedial responses, such as the Kyoto Protocol, provide a solution to the problems brought about by climate change. Rather they are directed toward slowing the pace of change, amelioration, and adaptation rather than cure. Consequently, the climate change problem will be much more serious by the year 2050 and even more so by 2100."

The development of an adequate response to the climate change problem will surely require many different approaches, strengthening and altering possible control efforts over time. The Kyoto Protocol is one possible initial step, and the only one that is seriously on the table at the present time. It has some built-in weaknesses, such as the basic rule built into the future negotiations during the 1992 Rio de Janeiro conference that excluded India and China and other developing countries from any control efforts in Kyoto. By now, too, the choice of 1990 as the base comparison year might well be replaced by some year nearer to the present. However, the most important need is a signal to the world that global warming is a problem about which many different groups should be thinking and acting in efforts to slow it down-and if Kyoto is not the signal, then another process should be proposed that would also provide a start toward the control of emissions of greenhouse gases.

Question 4. Since the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B," that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. The temperatures in Antarctica seem to be simultaneously warming on the low altitude fringes and cooling in the central ice plateau. The breakup of the Ice Sheet occurs at sea level, and the warming there may facilitate the breakup. There are also quite plausible scientific suggestions that link central-cooling/peripheral-warming observations to the lesser amounts of ozone now found in the Antarctic stratosphere, and the consequent lesser conversion of ultraviolet light to heat in the absence of ozone in the central core of the polar vortex. But sole cause? Almost all geoscientific events occur under circumstances in which there are a mixture of causes, although sometimes these second and third contributing causes are minor.

Question 5a. Included in the hearing record as part of my opening statement was a Swiss Re report titled, "Climate research does not remove the uncertainty; Coping with the risks of climate change". Please explain why you agree or disagree with the following assertions or conclusions from that report: "There is not one problem but two: natural climate variability and the influence of human activity on the climate system."

Response. Certainly. Any changes induced by man's activities are superimposed on a system which has its own inherent variability to begin with.

Question 5b. It is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that maximum strength and frequency of extreme weather conditions at a given location cannot be predicted.

Response. I am not in the insurance business. If there are really no parametric limits to the maximum strength and frequency of extreme weather conditions at a given location, then it is hard for an outsider to see how the company would set their insurance rates. I would think the largest problem an insurance company encounters in considering climate change is that the statistically observed probability of disasters over the previous 100 or 200 years may no longer be applicable to the new, warmer climate.

Question 5c. Swiss Re considers it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which-if they are not confirmed will in time turn to carefree relief; and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measure to counter a threat of this kind.

Response. These are straw-man arguments-"collapse of the climate system" versus "short-term expediency"

Question 6. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. I can't give a why/why-not answer to this question. Vulnerability is a function of the strength of the precautions taken. When processes for strengthening are developed, people allow this improvement to push into areas that were formerly thought to be vulnerable.

RESPONSES OF SHERWOOD ROWLAND TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. I have not devoted any scientific time to emission estimates for 100 years from now. The largest present question for me is the future demand for nuclear power. I can imagine either limit might turn out to be the world situation 50 years from now—either that nuclear power will be essentially banned worldwide by 2050, or that nuclear power will be the dominant global energy source by 2050, furnishing more electricity than coal, oil and natural gas combined.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis?

Response. I would certainly assume that the conclusions about the economic impact of carbon dioxide reductions would be drastically dependent upon the global acceptance of nuclear power at that point in the future.

Question 2. Where do we need to concentrate research to better understand climate modeling and the scientific uncertainties?

Response. A constant tension exists between the demand for a more finely gridded atmospheric model in order to look for the regional effects of climate change, and the need for a more elaborate data set with which to compare the model calculations. Higher powered computers are needed for more detailed calculations; measurements are needed to furnish the "ground truth" which can validate the models.

Question 3. What technologies offer the most realistic opportunity to reduce man-made emissions with the least detrimental impact to the economy?

Response. Nuclear power is the obvious answer here, but whether the country will accept nuclear power as a replacement for coal, oil and gas remains to be seen. One doesn't read much about the French experience with their heavy reliance on nuclear power. Every energy source has its associated environmental problem(s) but nuclear power plants are not a source of greenhouse gas emissions.

Question 4. What are the effects of removing black soot from the atmosphere?

Response. From a theoretical point of view, black soot serves to absorb solar energy into the soot particle, rather than reflecting the radiation back to space. From a quantitative point of view, the contribution of black soot is an enormous question mark. The material does not last long in the atmosphere before dropping out, and is quite variable in time and space. Measurements of the global effects of black soot would require detailed daily measurements all over the world in order to have an appropriate average for the world. Such data do not exist.

Question 5. What are the benefits of using U.S. clean coal technology in countries like China and India in terms of removing black soot?

Response. To the locals, obviously cleaner air. On a global warming basis, highly uncertain in the absence of the global daily coverage mentioned above.

Question 6. Who wrote the Summary of the NRC's June 2001 "Climate Change Science" report? Can you document the uncertainties reflected in the underlying report?

Response. The first conference call led to agreement among the committee members about the general nature and the individual components of the report, and then to multiple assignments to create drafts on particular topics. As the report took shape, the chairman began drawing out the essence of each and circulating that for comment and discussion. Basically, the report and its summary were written by the committee members with the chair a very active participant in almost all of the individual discussions.

The decision was made early not to provide individual documentation and references for this report because of the time constraints. Almost all of the uncertainties mentioned in the "Climate Change Science" report are discussed in the IPCC reports, both the Summary for Policy Makers, and Volume One, "The Scientific Base", but are not individually referenced.

Question 7. Please provide the documentation of how the NRC report addressed the satellite, weather balloon and surface temperature measurements.

Response. This question had been addressed separately by another NRC committee, with a report issued in 1999. The chairman of that committee was a member of the Climate Change Science committee.

Question 8. Who wrote the IPCC summary for policymakers?

Response. I was not part of the IPCC process, and know only anecdotally that the listed authors appear to have worked much like the Climate Change Science committee, except that their interactions were stretched out over months and years.

Question 9. Which uncertainties in the underlying IPCC Working Group reports were also reflected in the NRC (June 2001) report?

Response. I think that the same general sets of uncertainties were involved in both, but the IPCC Working Group reports cover more than 2500 pages as published and obviously can discuss uncertainties on a more micro scale.

Question 10. In your written testimony you said that increased greenhouse gas concentrations are "often because of the activities of mankind." Yet in you oral comments you said they were "mostly caused by the activities of man." There is a significant difference between "often" and "mostly." Many people attach much meaning to the individual words of the IPCC Reports and other Climate Reports. Could you explain what you meant in your two different testimonies?

Response. The two terms "often" and "mostly" are complementary, and both are different from "always" because some of the emission sources for some of the greenhouse gases are of natural origin. For those molecules with both natural sources and releases by the activities of mankind, the source is no longer distinguishable when the molecule is in the atmosphere, but the increase in the atmospheric concentration is then usually caused by the addition of the anthropogenic source rather than by a change in the non-human processes. There are many different greenhouse gases and many different ways in which mankind causes them to be put into the atmosphere. Thirty years ago discussions about global warming might be alternately described as "the carbon dioxide problem". Then, in the 1970's a succession of measurements showed increasing concentrations in the atmosphere of methane, nitrous oxide, and the chlorofluorocarbons (CFC–11, CFC–12 and CFC–113, and the alternate description became "the greenhouse gas problem". The only important greenhouse gas not listed as such is water vapor, for which the atmospheric concentration is controlled by the temperature of the ocean through evaporation. With further research, the greenhouse gas list was expanded to include sulfur hexafluoride, the perfluorocarbons (such as CF_4 and C_2F_6) and the hydrofluorocarbons (such as CH_2FCF_3, now the common refrigerant 134A in automobile air conditioners.). Volume One of the IPCC 2001 report lists 64 greenhouse gases. Carbon dioxide, methane and nitrous oxide have been components of the atmosphere for hundreds of thousands of years, and have always had natural sources. However, for each of three molecules, there now exist substantial sources of emissions under the control of mankind, and most of the *increase*, in their concentrations arises from these widely varying activities of mankind: burning of coal, gas and oil for carbon dioxide, release from rice paddies and cattle for methane, microbial action on fertilizers for nitrous oxide. For the other 60+ molecules, no natural sources are known and their presence in the atmosphere results from chemical synthesis by man, and then release to the atmosphere unchanged. These compounds are used in a very wide variety of human activities, with the common characteristic that release to the atmosphere unchanged is the usual occurrence. When it comes to evaluation of the cumulative greenhouse effect of all of these gases, then carbon dioxide is the most important, accounting for roughly half of the total, with methane and nitrous oxide having significant roles. The incremental changes in the total greenhouse gas effect are mostly the product of some activity of mankind.

STATEMENT OF DR. ROGER A. PIELKE, JR., UNIVERSITY OF COLORADO, BOULDER, CO

I thank the chairman and the committee for the opportunity to offer testimony this morning on the economic and environmental risks associated with increasing greenhouse gas emissions.

My name is Roger Pielke, Jr. and I am an Associate Professor of Environmental Studies at the University of Colorado where I also direct the CIRES Center for Science and Technology Policy Research. My research focuses on the connections of science and decisionmaking. A short biography can be found at the end of my written testimony.

In my oral testimony I'd like to highlight six "take home points," which are developed in greater detail in my written testimony and in the various peer-reviewed scientific papers cited therein.

TAKE HOME POINTS

• Weather and climate have growing impacts on economies and people around the world.[1]

• The primary cause for the growth in impacts is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate per se.[2]

• To address increasing vulnerability, and the growing impacts that result, requires a broader conception of "climate policy" than now dominates debate.[3]

• We must begin to consider adaptation to climate to be as important as matters of energy policy in discussion of response options. Present discussion all but completely neglects adaptation.[4]

• Increased attention to adaptation would not mean that we should ignore energy policies, but instead is a recognition that changes in energy policy are insufficient to address the primary reasons underlying trends in the societal impacts of weather and climate.[5]

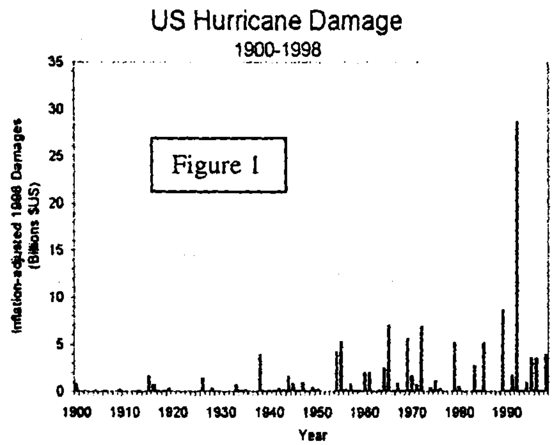
• The nation's investments in research could be more efficiently focused on producing usable information for decisionmakers seeking to reduce vulnerabilities to climate. Specifically, the present research agenda is improperly focused on prediction of the distant climate future.[6]

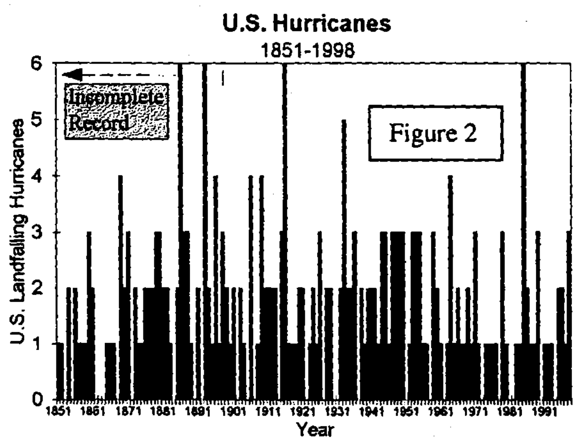
The remainder of this document develops these points through a case study focused on tropical cyclones. Considerably more detail can be found in the set of peer-reviewed articles cited in support of the arguments presented here.

Policy debate and advocacy on the issue of climate change frequently focus on the potential future impacts of climate on society, usually expressed as economic damage or other human outcomes. Today I would like to emphasize that societal impacts of climate are a joint result of climate phenomena (e.g., hurricanes, floods, and other extremes) and societal vulnerability to those phenomena. The paper concludes that policies focused on reducing societal vulnerability to the impacts of climate have important and under-appreciated dimensions that are independent of energy policy.

In the climate change debate, people often point to possible increases in extreme weather events (e.g., hurricanes, floods, and winter storms) as a potentially serious consequence of climate change for humans around the world. For instance, the January 22, 1998 issue of Newsweek carried the following headline: "THE HOT ZONE: Blizzards, Floods, and Hurricanes, Blame Global Warming." In this testimony I use the case of hurricanes to illustrate the interrelated climate-society dimensions of climate impacts. Research indicates that societal vulnerability is the single most important factor in the growing damage related to extreme events. An implication of this research for policy is that decisionmaking at local levels (such as related to land use, insurance, building codes, warning and evacuation, etc.) can have a profound effect on the magnitude and significance of future damage.[7]

Figure 1 shows economic damage (adjusted for inflation) related to hurricane landfalls in the United States, 1900–1998.[8] Because damage is growing in both frequency and intensity, one possible interpretation of this figure is that hurricanes have become more frequent and possibly stronger in recent decades. However, while hurricane frequencies have varied a great deal over the past 100+ years, they have not increased in recent decades (Figure 2, provided courtesy of C. Landsea, NOAA).[9] To the contrary, although damage increased during the 1970's and 1980's, hurricane activity was considerably lower than in previous decades.


US Hurricane Damage
1900-1998
Inflation-adjusted 1998 Damages (Billions $US)
Figure 1
Year


U.S. Hurricanes
1851-1998
Incomplete Record
Figure 2
U.S. Landfalling Hurricanes
Year

To explain the increase in damage it is necessary to consider factors other than climate. In particular, society has changed enormously during the period covered by Figure 2. Figures 3a and b show this dramatically. Figure 4a shows a stretch of Miami Beach in 1926. Figure 3b shows another perspective of Miami Beach from recent years. The reason for increasing damages is apparent from the changes easily observable in these figures: today there is more potential for economic damage than in the past due to population growth and increased wealth (e.g., personal property).

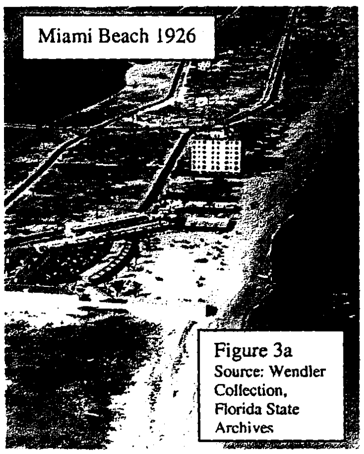


Figure 3a
Source: Wendler Collection, Florida State Archives

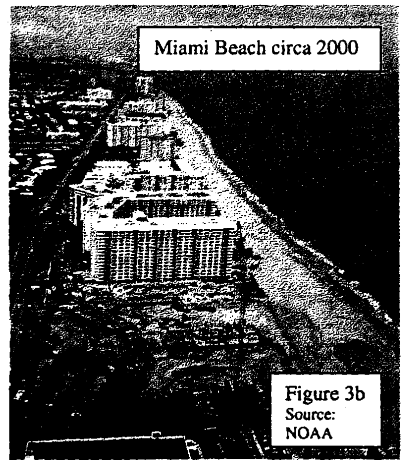


Figure 3b
Source: NOAA

Figure 4b shows the increase in population along the Gulf and Atlantic coasts for 168 coastal counties from Texas through Maine (Figure 4a). In 1990, the population of Miami and Ft. Lauderdale (2 counties) exceeded the combined population of 107 counties from Texas to Virginia.[10] Clearly, societal changes such as coastal population growth have had a profound effect on the frequency and magnitude of impacts from weather events such as hurricanes.[11]

U.S. Atlantic and Gulf Coastal Counties

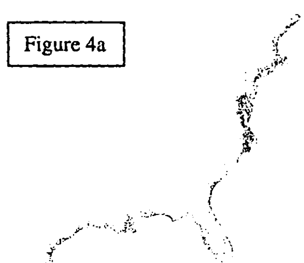


Figure 4a

POPULATION BY COASTAL COUNTY

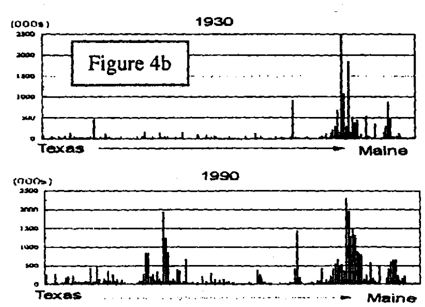


Figure 4b

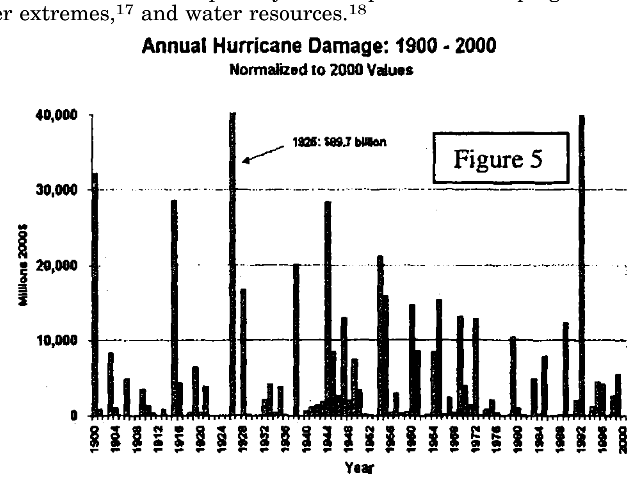
3

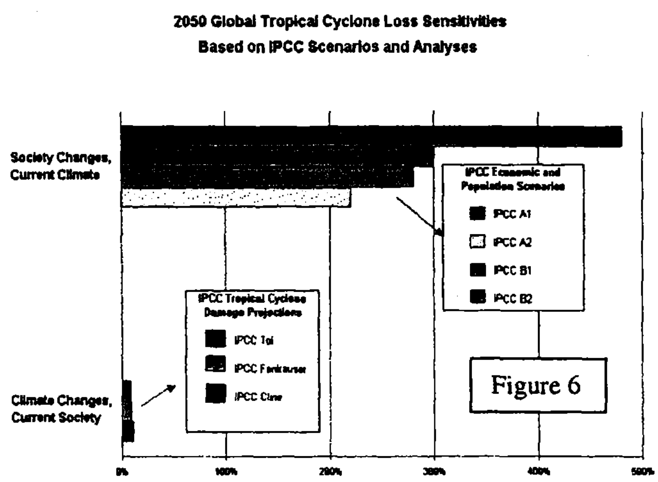
One way to present a more accurate perspective on trends in hurricane-related impacts is to consider how past storms would affect present society. A 1998 paper presented a methodology for "normalizing" past hurricane damage to present day values (using wealth, population and inflation). Figure 5 shows the historical losses of Figure 1 normalized to 2000 values.[12]

The normalized record shows that the impacts of Hurricane Andrew, at close to $40 billion (2000 values), would have been far surpassed by the Great Miami Hurricane of 1926, which would cause an estimated $90 billion damage had it occurred in 2000. We can have confidence that the normalized loss record accounts for societal changes because the adjusted data contains climatological information, such as the signal of El Niño and La Niña.[13]

The normalization methodology provides an opportunity to perform a sensitivity analysis of the relative contributions of climate changes and societal changes, as projected by the Intergovernmental Panel on Climate Change (IPCC), to future tropical cyclone damages. Figure 6 shows the results of this analysis.[14] The three blue bars show three different calculations (named for their respective authors) used by IPCC in its Second Assessment Report for the increase in tropical cyclone-related damage in 2050 (relative to 2000) resulting from changes in the climate, independent of any changes in society. The four green bars show the sensitivity of tropical cyclone-related damage in 2050 (relative to 2000) resulting from changes in society based on four different IPCC population and wealth scenarios used in its Third Assessment Report. These changes are independent of any changes in climate.

Figure 6 illustrates dramatically the profound sensitivity of future climate impacts to societal change, even in the context of climate changes projected by the IPCC. The relative sensitivity of societal change to climate change ranges from 22 to 1 (i.e., smallest societal sensitivity and largest climate sensitivity) to 60 to 1 (i.e., largest societal sensitivity and smallest climate sensitivity). This indicates that insofar as tropical cyclones are concerned, steps taken to modulate the future climate (e.g., via greenhouse gas emissions or other energy policies) would only address a very small portion of the increasing damages caused by tropical cyclones. Similar results have been found for tropical cyclone impacts in developing countries,[15] flooding,[16] other extremes,[17] and water resources.[18]





The perspective offered in this discussion paper raises the possibility that the U.N. Framework Convention on Climate Change (FCCC) has a critical, but largely unrecognized flaw with profound implications for policy. Under the FCCC the term "climate change" is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods." This definition stands in stark contrast to the broader definition used by the Intergovernmental Panel on Climate Change (IPCC) which states that climate change is "any change in climate over time whether due to natural variability or as a result of human activity."

As a consequence of the FCCC definition, "adaptation" refers to actions in response to climate changes attributable solely to greenhouse gas emissions. It does not refer to efforts to improve societal responses to "natural" climate variability. Consequently, adaptation has only "costs" because adaptive responses would by definition be unnecessary if climate change could be prevented. Hence, it is logical for many conclude that preventative action is a better policy alternative and recommend adaptive responses only to the extent that proposed mitigation strategies will be unable to prevent changes in climate in the near future. But this overlooks the fact that even if energy policy could be used intentionally to modulate future climate, other factors will play a much larger role in creating future impacts and are arguably more amenable to policy change.

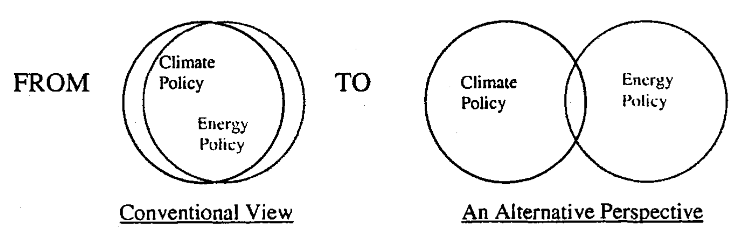
Based on these results implicit in the work of the IPCC and shown in Figure 6, an increased focus on "adaptation" makes sense under any climate scenario. But the Framework Convention is structured to deal only with the growth in impacts related to the greenhouse gas impacts on the climate (the blue bars) and not the profound societal vulnerability (green bars) that will dominate future climate impacts under any climate change scenario.

Consider that the International Red Cross estimates that in the 1990's around the world, weather and climate events were directly related to more than 300,000 deaths and more than U.S. $700 billion in damages.[19] Many of these human losses are preventable and economic losses are manageable with today's knowledge and technologies.[20] Simple steps taken to reduce societal vulnerability to weather and climate could also make society more resilient to future variability and change. Seen from this perspective, costs of adaptation could easily be exceeded by the benefits of better dealing with the impacts of climate, irrespective of future changes in climate and their causes. The Framework Convention's definitional gerrymandering of "climate change" according to attribution prejudices policy and advocacy against such common sense activities.

An implication of this work is that policy related to societal impacts of climate has important and under-appreciated dimensions that are independent of energy policy. It would be a misinterpretation of this work to imply that it supports either business-as-usual energy policies, or is contrary to climate mitigation. It does suggest that if a policy goal is to reduce the future impacts of climate on society, then energy policies are insufficient, and perhaps largely irrelevant, to achieving that goal. Of course, this does not preclude other sensible reasons for energy policy action related to climate (such as ecological impacts) and energy policy action independent of climate change (such as national security, air pollution reduction and energy efficiency).[21] It does suggest that reduction of human impacts related to weather and climate are not among those reasons, and arguments and advocacy to the contrary are not in concert with research in this area.

Figure 7

A Change in perspective is needed ...



The arguments presented in this testimony highlight a need to distinguish "climate policy" from "energy policy" (Figure 7). "Climate policy" refers to the actions that organizations and individuals take to reduce their vulnerability to (or enhance opportunities afforded by) climate variability and change.[22] From this perspective governments and businesses are already heavily invested in climate policy. In the context of hurricanes and floods, climate policies might focus on land use, insurance, engineering, warnings and forecasts, risk assessments, and so on. These are the policies that will make the most difference in reducing the future impacts of climate on society.

The conventional view is that climate policy is energy policy. However, much of the debate and discussion on climate change revolves around energy policy and ignores the fact that such policies, irrespective of their merit, can do little to address growing societal vulnerabilities to climate around the world. In all contexts, improving policies targeted on the societal impacts of climate depends on a wide range of factors other than energy policy. Consequently, in light of the analyses presented here, a common interest objective of climate policy would be to improve societal and environmental resilience to climate variability and change, and to reduce the level of vulnerability. Climate policy should be viewed as a complement, not an alternative, to energy policies.

FIGURE CAPTIONS

Figure 1. U.S. hurricane damage 1900–1998, adjusted for inflation to 1998 values.

Figure 2. U.S. hurricane landfalls, 1851–1998, figure courtesy of C. Landsea.

Figure 3a. Miami Beach, 1926. Photo from the Wendler Collection, Florida State Archives.

Figure 3b. Miami Beach, recent decades. Undated photo from the NOAA Arcive.

Figure 4a. Map of 168 coastal counties from Texas through Maine.

Figure 4b. Population of the 168 coastal counties from Texas through Maine for 1930 and 1990 based on U.S. Census data.

Figure 5. Historical losses from hurricanes adjusted to 2000 values based on inflation, population, and wealth. The graph suggests the damage that would have occurred had storms of past years made landfall with the societal conditions of 2000.

Figure 6. A sensitivity analysis of the impacts of tropical cyclones in 2050 based on the assumptions of the Intergovernmental Panel on Climate Change. The green bars show sensitivity of future impacts to societal changes and the blue bars show sensitivity to climate changes. Societal changes are the overwhelmingly dominant factor.

Figure 7. How our perspective on "global warming" might change. Rather than defining climate policy as energy policy, we might instead more clearly distinguish the two with implications for research and policy.

ENDNOTES

[1]For a review, see Kunkel, K., R. A. Pielke, Jr., S. A. Changnon, 1999: Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review, Bulletin of the American Meteorological Society, 80:1077–1098, online at *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/bams8006.pdf*

[2]For documentation of this assertion, see Pielke and Landsea (1997), Kunkel et al. (1999), Pielke et al. (2000), Pielke and Downton (2000), Downton and Pielke (2001), cited in the endnotes below.

[3]For an in depth presentation of this perspective, see Sarewitz, D., R. A. Pielke, Jr., 2000: Breaking the Global-Warming Gridlock. The Atlantic Monthly, July:55–64, online at

http://www.theatlantic.com/cgi-bin/o/issues/2000/07/sarewitz.htm

[4]For discussion, see Pielke, Jr., R. A., 1998: Rethinking the role of adaptation in climate policy. Global Environmental Change, 8:159–170, online at

http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/1998.13.pdf

[5]See Pielke, Jr., R. A., R. Klein, and D. Sarewitz, 2000: Turning the Big Knob: An Evaluation of the Use of Energy Policy to Modulate Future Climate Impacts, Energy and Environment, 11:255–276, online at *http://sciencepolicy.colorado.edu/pielke/knob/index.html*

[6]On the use of predictions in decisionmaking see Sarewitz, D., R. A. Pielke, Jr., and R. Byerly, (eds.), 2000: Prediction: Science, Decision-Making and the Future of Nature. Island Press: Washington, DC. On the history and performance of the U.S. global Change Research program, see Pielke, Jr., R. A., 2000. Policy History of the U.S. Global Change Research Program: Part I, Administrative Development. Global Environmental Change, 10:9–25. Pielke, Jr., R. A., 2000: Policy History of the U.S.

Global Change Research Program: Part II, Legislative Process. Global Environmental Change, 10:133–144. Pielke Jr., R. A., 1995. Usable Information for Policy: An Appraisal of the U.S. Global Change Research Program. Policy Sciences, 38:39–77, online at: *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/1995.07.pdf*

[7]See Sarewitz and Pielke 2000, op. cit.

[8]For discussion, see Pielke, Jr., R. A., and C. W. Landsea, 1998: Normalized Hurricane Damages in the United States: 1925–1995. Weather and Forecasting, 13:351–361, online at *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/wf13.pdf*

[9]See Landsea, C. L., R. A. Pielke, Jr., A. Mestas-Nuñez, and J. Knaff, 1999: Atlantic Basin Hurricanes:

Indicies of Climate Changes, Climatic Change, 42:89–129, online at *http://www.aoml.noaa.gov/hrd/Landsea/atlantic/index.html*

See also Landsea, C. W., C. Anderson, N. Charles, G. Clark, J. Partagas, P. Hungerford, C. Neumann and M. Zimmer, 2001: The Atlantic Hurricane Data base Re-analysis Project: Documentation for the 1851–1885 Addition to the HURDAT Data base. Chapter for the Risk Prediction Initiative book, R. Murnane and K. Liu, Editors. Online: *http://www.aoml.noaa.gov/hrd/hurdat/index.html*

[10]Pielke, Jr., R. A., and R. A. Pielke, Sr., 1997: Hurricanes: Their Nature and Impacts on Society.

John Wiley and Sons Press: London.

[11]See Kunkel et al. 1999, op. cit.

[12]After Pielke and Landsea, 1998, op. cit.

[13]Pielke, Jr., R.A., and C.W. Landsea, 1999: La Niña, El Niño, and Atlantic Hurricane Damages in the United States. Bulletin of the American Meteorological Society, 80:2027–2033, online at *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/bams8010.pdf*

[14]Details on this sensitivity analysis can be found in Pielke et al. 2000, op. cit.

[15]Pielke, Jr., R. A., J. Rubiera, C. Landsea, M. Molina, and R. Klein, 2001: Hurricane Vulnerability in Latin America and the Caribbean, Natural Hazards Review, (in review).

[16]Pielke, Jr., R.A., and M.W. Downton, 2000: Precipitation and damaging floods: Trends in the United States, 1932–1997. Journal of Climate, 13:3625–3637, online at *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/jc1320.pdf* and, Downton, M. and R. Pielke, Jr., 2001. Discretion Without Accountability: Climate, Flood Damage and Presidential Politics, Natural Hazards Review, 2:157–166, online at *http://sciencepolicy.colorado.edu/pielke/hp—roger/pdf/downtonpielke2001.pdf*

[17]See Kunkel et al. 1999, op. cit.

[18]C. J. Vörösmarty, P. Green, J. Salisbury, and R. B. Lammers, 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth, Science 289: 284–288. D.P. Lettenmaier, A.W. Wood, R.N. Palmer, E.F. Wood, and E.Z. Stakhiv, 1999, Water Resources Implications of Global Warming: A U.S. Regional Perspective, Climatic Change, 43:537–579.

[19]International Federation of Red Cross and Red Crescent Societies (IFRC), 2000.World Disasters Report, www.ifrc.org.

[20]See, e.g., D. Mileti, 2000. Second Assessment of Natural Hazards, (Joseph Henry Press).

[21]See, e.g., F. Laird 2001, Just say no to emissions reductions targets, Issues in Science and Technology, Winter, online: *http://www.nap.edu/issues/17.2/laird.htm* R. Brunner 2001. Science and the Climate Change Regime, Policy Sciences 34:1–33.

[22]Note that here I use the broad definition of "climate change" used by the IPCC: ". . . related to any source" rather than the more restricted definition of the FCCC which defines climate change only in terms of those changes directly or indirectly attributable "to human activity that alters the composition of the global atmosphere . . . " For discussion, see Pielke, Jr., R. A., 1998, op. cit.

RESPONSES OF DR. ROGER A. PIELKE, JR. TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. In your testimony, you provided some estimates of the costs of adapting our communities and infrastructure to a changing climate. Obviously, we need to do a much better job of discouraging development in vulnerable areas. How do your cost projections take into account the risks associated with abrupt climate changes described in the Academy's December 2001 report?

Response. The sensitivity analyses reported in my testimony (based on Pielke et al. 2000) rely on the assumptions of the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) for both changes in climate and changes in society. Because the IPCC did not consider abrupt climate changes for the particular impacts we evaluated, neither does our analysis.

I served as a member of the Academy committee that prepared the Abrupt Climate Change report. We discussed at great length the topic of economic and ecological impacts associated with abrupt climate change, and Chapter 5 of our report focused on that topic. The committee's main recommendation that focused on reducing risk associated with abrupt climate change is entirely consistent with the approach recommended in my testimony. I reproduce that particular recommendation (number 5 in the report, Abrupt Climate Change: Inevitable Surprises, National Research Council, 2002, pp. 164–165) in its entirety here:

Recommendation 5. Research should be undertaken to identify "no-regrets" measures to reduce vulnerabilities and increase adaptive capacity at little or no cost. No-regrets measures may include low-cost steps to: slow climate change; improve climate forecasting; slow biodiversity loss; improve water, land, and air quality; and develop institutions that are more robust to major disruptions. Technological changes may increase the adaptability and resiliency of market and ecological systems faced by the prospect of damaging abrupt climate change. Research is particularly needed to assist poor countries, which lack both scientific resources and economic infrastructure to reduce the vulnerabilities to potential abrupt climate changes."

Reference: Pielke, Jr., R. A., R. Klein, and D. Sarewitz, 2000: Turning the Big Knob: An Evaluation of the Use of Energy Policy to Modulate Future Climate Impacts. Energy and Environment, 11, 255–276.

Question 2. How do those cost projections consider the impacts on intangible assets, such as cultural heritage, scenery, and other quality of life-related matters?

Response. The sensitivity analysis presented in my testimony was based on three different analyses used by the IPCC for projecting tropical cyclone damage in 2050. Pielke et al. 2000 summarizes these projections as follows:

- Cline (1992) relied on Emanuel's (1987) estimate that the destructive potential of tropical cyclones could rise by 40–50 percent under a doubling of greenhouse gases. The study assumed U.S. annual average hurricane losses of $1.5 billion and that damage would rise linearly with increased intensity. Cline thus multiplied $1.5 billion by 50 percent to project an increase in annual U.S. hurricane-caused damages of $750 million. Cline assumed that increased damage from global warming would be more than linear in relation to rising temperatures and estimated that annual hurricane-related damages from a 10 °C warming could be as high as $6.4 billion (Cline 1992).
- Fankhauser (1995) assumed worldwide annual average tropical cyclone damages of $1.5 billion and loss of 15,000–23,000 lives. This study also relied on Emanuel's estimate of a 40–50 percent increase in tropical cyclone intensity resulting from a 4.2 °C warming. It adjusted this to 28 percent for a 2.5 °C warming and assumed storm damages increase exponentially with intensity. Thus, the study multiplied 28 percent by 1.5 by $1.5 billion to arrive at an estimate of $630 million in additional worldwide annual average hurricane-related damages due to a 2.5 °C warming. It also estimated that an additional 8,000 deaths would occur, which were valued at $2.1 billion, bringing total additional tropical cyclone-related worldwide losses to $2.7 billion. Fankhauser estimated that the U.S. share of these damages would be $223 million ($115 million from destruction, $108 million from lost lives).
- Tol (1995) assumed that tropical cyclone intensity will increase 50 percent due to a 2.5 °C warming, and that a fraction of the damages are related quadratically to an increase in intensity. This study estimated that additional tropical cyclone-related damages from a doubling of greenhouse gases in 1988 dollars will be $.3 billion in the United States and Canada and $1.4 billion worldwide, but did not describe the baseline damage estimates.

Reference and source for references cited above: Pielke, Jr., R. A., R. Klein, and D. Sarewitz, 2000: Turning the Big Knob: An Evaluation of the Use of Energy Policy to Modulate Future Climate Impacts. Energy and Environment, 11:255–276.

Question 3. As you know, this committee is very interested in the effects of disasters on public infrastructure. We have jurisdiction over FEMA, water supplies, highways, etc. What work is being done to quantify the costs of investments that could be made now to reduce the impacts of disasters and climate change on human-made and natural systems?

Response. I suggested in my testimony "the possibility that the U.N. Framework Convention on Climate Change (FCCC) has a critical, but largely unrecognized flaw with profound implications for policy. Under the FCCC the term "climate change" is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods." This definition stands in stark contrast to the broader definition used by the Intergovernmental Panel on Climate Change (IPCC) which states that climate change is "any change in climate over time whether due to natural variability or as a result of human activity." As a consequence of the FCCC definition, "adaptation" refers to actions in response to climate changes attributable solely to greenhouse gas emissions. It does not refer to efforts to improve societal responses to "natural" climate variability. Consequently, adaptation has only "costs" because adaptive responses would by definition be unnecessary if climate change could be prevented. Hence, it is logical for many to conclude that preventative action is a better policy alternative and recommend adaptive responses only to the extent that proposed mitigation strategies will be unable prevent changes in climate in the near future. But this overlooks the fact that even if energy policy could be used intentionally to modulate future climate, other factors will play a much larger role in creating future impacts and are arguably more amenable to policy change."

As a consequence, very little work (both in an absolute and relative sense) has been done to evaluate adaptation alternatives. In 1996 the IPCC wrote that adaptation offers a "very powerful option" for responding to climate change and ought to be viewed as a "complement" to mitigation efforts (IPCC 1996, 187–188). Yet, the IPCC also wrote "little attention has been paid to any possible tradeoff between both types of options." (IPCC 1996, 250). These conclusions, in my view, remain current today.

Reference: Intergovernmental panel on Climate Change (IPCC), 1996. Climate Change 1995: Economic and Social Dimensions of Climate Change, J. P. Bruce et al. (eds.), Cambridge University Press.

Question 4. You mention in your testimony that "decisionmaking at local levels . . . can have a profound effect on the magnitude and significance of future damage." Are local governments beginning to make the connection between urban and land use planning and vulnerabilities to climate change? Do you know of any efforts to disseminate academic research findings and recommendations regarding climate change adaptation techniques to local governments and communities?

Response. If local governments are beginning to make the connection between urban and land use planning and vulnerabilities to climate change, they are doing so on an ad hoc and unsystematic basis. A considerable effort in government, academia and the private sector exists in the United States (and globally) to improve decisionmaking with respect to "hazards." However, this effort is largely separate in both research and action from the climate change community. In 1997 I wrote of this in an editorial (*http://sciencepolicy.colorado.edu/zine/archives/1–29/5.html*):

"The concept of "mitigation" is central to the natural disaster policy in the United States. At the same time, the concept of "mitigation" is also central to ongoing debate about global climate change. But as used by the natural disaster community and the climate change community, the term "mitigation" takes on almost exactly opposite meanings. Natural hazard mitigation is defined by the Federal Emergency Management Agency (FEMA) as "a sustained action taken to reduce or eliminate the long-term risk to people and property from natural hazards and their effects." A recent FEMA report on Costs and Benefits of Natural Hazard Mitigation provides examples of mitigation, which include business interruption insurance, wind shutters, building codes, and community relocation. Climate change mitigation is defined by the Intergovernmental Panel on Climate Change (IPCC) as "actions that prevent or retard the increase of atmospheric greenhouse gas concentrations by limiting current and future emissions from sources of greenhouses gases and enhancing potential sinks." What the natural hazards community calls mitigation, the climate change community calls "adaptation" which the IPCC defines as "any adjustment—whether passive, reactive, or anticipatory—that can respond to anticipated or actual consequences associated with climate change." The different use of terminology creates a situation that is potentially confusing for policymakers and other practitioners. While academics often work in communities that are relatively isolated from one another, policymakers typically do not. And since natural hazards are one of the threats being associated with climate change, it is probably worth paying attention to the words used in this regard. At a minimum, the conflicting terminology is symptomatic of the general lack of interaction between the hazards and climate change communities. In the climate change world, there is a tension between those who seek to prevent climate change through energy policies (i.e., climate change mitigation) and those who emphasize adaptation (i.e., natural hazards mitigation). To date, the advocates of prevention have dominated the debate. This creates a disincentive for the natural hazards community to play a significant role in the development of climate policy, which is unfortunate, as without a doubt the knowledge gained by the hazards community has an important role to play in the climate policies of the future."

Question 5. You also state, "Many . . . human losses are preventable and economic losses are manageable with today's knowledge and techniques . . . . [C]osts of adaptation could easily be exceeded by the benefits of better dealing with the impacts of climate, irrespective of future changes in climate and their causes." What are some specific examples of adaptation strategies or investments that you recommend vulnerable coastal communities implement today that could prove to be cost-effective in the long-term?

Response. There is a considerable list of activities that might be considered under the label "adaptation" for reducing vulnerability to climate impacts along the coasts, including improving land use, insurance, evacuation, ecosystem management, and other policies. A starting point for understanding the breadth of such activities is the NOAA Coastal Services Center, *http://www.csc.noaa.gov/*. In collaboration with the H. John Heinz III Center for Science, Economics, and the Environment, the NOAA CSC contributed to the publication of a book that discusses a wide range of efforts that would address coastal vulnerability:

The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation. Washington, DC: Island Press, 2000. 220 pp. ISBN 1–55963–756–0 (paper).

Question 6. As you and all the other witnesses indicated, it is not safe to continue increasing greenhouse gas emissions without limit. What needs to be done to assure that we can avert the point of no return or "dangerous levels" of greenhouse gas concentrations?

Response. I reject the premise underlying this question. As I stated in my testimony, any policy designed to reduce risks and vulnerabilities to climate impacts on environment and society is necessarily incomplete if focused exclusively on energy policies. Consequently, any energy policy including instantaneous, magical abatement of emissions would be insufficient to address growing risks and vulnerability to future climate impacts. As I concluded in my testimony:

"It would be a misinterpretation of this work to imply that it supports either business-as-usual energy policies, or is contrary to climate mitigation. It does suggest that if a policy goal is to reduce the future impacts of climate on society, then energy policies are insufficient, and perhaps largely irrelevant, to achieving that goal. Of course, this does not preclude other sensible reasons for energy policy action related to climate (such as ecological impacts) and energy policy action independent of climate change (such as national security, air pollution reduction and energy efficiency). It does suggest that reduction of human impacts related to weather and climate are not among those reasons, and arguments and advocacy to the contrary are not in concert with research in this area."

Question 7. In an answer to a question from Senator Chafee regarding your opinion on achieving the 1990 level of emissions, our UNFCC target, by the date (2007) set in the Clean Power Act, you said that ". . . full and comprehensive implementation of the Kyoto Protocol around the world . . . is not going to do much at all to address the environment and economic risks associated with climate change." Does that mean you believe that the potential social, economic, and environmental costs associated with long-term global warming cannot or will not be reduced by reducing anthropogenic emissions? If so, how does that comport with the statement in question 5?

Response. This question focuses on the issue raised in the sensitivity analysis presented in my testimony. Climate impacts are a joint result of climate events and the vulnerability to such impacts of human or natural systems. Both climate and human and natural systems are subject to change. The assertion presented in my testimony was, "The primary cause for the growth in impacts is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate per se." This is borne out by a growing body of research. If impacts are indeed the result of changes in climate and vulnerability, it would only make sense that policies designed to address climate-related risks would focus on both changes in climate and vulnerability. This is the essence of my proposal to recognize that climate policy has important and under-appreciated dimensions that are independent of energy policy. Such dimensions would include the sorts of adaptation strategies referred to in Question 5 above. Further, because there are important reasons to improve the nation's energy policies other than climate change (e.g., for reasons of national security, human health, and economic efficiency), it may make pragmatic sense to expand national discussion of energy policy beyond a narrow focus on global warming to the exclusion of other, perhaps more compelling, reasons for improving national energy policies. The bottom line is that even if the Kyoto Protocol were fully and successfully implemented, it would do little to address "social, economic, and environmental costs associated with long-term global warming" and additional steps would be needed. Thus, whatever one's perspective on the Kyoto Protocol, whether viewing it as a "first step" or a "dead end," there is no controversy that additional efforts are needed.

Question 8. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. I see two risks. First, when humans alter the Earth system, there are risks of unforeseen, unintended effects on that system. A second risk, which has largely gone unnoticed, is that in focusing primarily on the potential risks to the Earth system resulting in changes to that system, we neglect to observe that (a) environmental and societal impacts associated with human-climate interactions can in many cases be addressed through a focus on reducing vulnerability to those impacts, and (b) that there are many "no-regrets" energy policy actions that make immediate sense irrespective of climate change. Both the science and policy communities appear to be neglecting the second type of risk and as a consequence there is a large opportunity cost in actions not taken to improve climate policies and energy policies. The most feasible way to address both types of risk is to follow a "no-regrets" strategy of reducing vulnerability to climate variability and change (i.e., to improve adaptation) and as well to improve the nation's energy policies with respect to national security, human health, and economic efficiency.

On this, see:

Sarewitz, D., R. A. Pielke, Jr., 2000: Breaking the Global-Warming Gridlock. The Atlantic Monthly, 286(1), 55–64. *http://www.theatlantic.com/cgi-bin/o/issues/2000/07/sarewitz.htm*

RESPONSES OF DR. ROGER A. PIELKE, JR. TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th Century, the atmospheric concentrations of a number of greenhouse gasses have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

Response. I agree with the IPCC conclusions.

Question 2. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. See my answer to Question 7 from Senator Jeffords. There is no controversy that if the goal of the Kyoto Protocol is to reduce the risks of future climate impacts on the environment and society, even if fully implemented, it cannot meet this goal, for reasons discussed at length in my testimony. Consequently, whether or not Kyoto is fully implemented, considerable additional policy action will be needed to address climate impacts on society and the environment. However, as I noted in the question and answer period of the hearing, there are other reasons to implement the Kyoto Protocol, such as considerations of international relations, national security, environmental symbolism, etc. It may well be that such considerations lead to support for full implementation of the Kyoto Protocol, completely independent of risk associated with climate impacts. My testimony and this answer focus on the role of the Kyoto Protocol in reducing risk of climate impacts.

Question 3. Since the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B," that has been attributed to climate change. What specific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. I have no special expertise to contribute to this subject.

Question 4a. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty; Coping with the risks of climate change" (copy attached). Please explain why you agree or disagree with the following assertions or conclusions from that report: "There is not one problem but two: natural climate variability and the influence of human activity on the climate system."

Response. I would frame the problem a bit differently. There are changes in climate, caused by many reasons, including human activity. There are also changes in society and caused by society to the environment that result in increased vulnerability to climate impacts. This definition of the problem underlies the recommendations presented in my testimony.

See Sarewitz, D., R. A. Pielke, Jr., 2000: Breaking the Global-Warming Gridlock. The Atlantic Monthly, 286(1), 55–64. *http://www.theatlantic.com/cgi-bin/o/issues/2000/07/sarewitz.htm*

Question 4b. It is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted.

Response. Agreed. Along with colleagues we have examined the role of prediction in decisionmaking and arrive at substantially similar conclusions.

See: Sarewitz, D., R. A. Pielke, Jr., and R. Byerly, (eds.), 2000: Prediction: Science, Decision-Making and the Future of Nature. Island Press: Washington, DC.

Question 4c. Swiss Re considers it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which—if they are not confirmed—will in time turn to carefree relief; and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind.

Response. Agreed and I point you to my answer to Question 1 from Senator Jeffords for elaboration.

Question 5. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. Vulnerability to extreme weather has increased as populations and wealth have grown and more people have located in exposed locations. This perspective is now well documented in the peer-reviewed literature. A 1999 review (Kunkel et al. 1999) concluded, ". . . increasing losses are primarily due to increasing vulnerability arising from a variety of societal changes, including a growing population in higher risk coastal areas and large cities, more property subject to damage, and lifestyle and demographic changes subjecting lives and property to greater exposure." Numerous other references supporting this conclusion are provided in my testimony.

Reference: Kunkel, K., R. A. Pielke Jr., S. A. Changnon, 1999: Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review. Bulletin of the American Meteorological Society, 80:1077–1098.

RESPONSES OF DR. ROGER A. PIELKE, JR. TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. I have no special expertise to contribute to this subject.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis.

Response. I have no special expertise to contribute to this subject.

Question 2. Please provide an assessment of the approaches of various States to address normal beach erosion?

Response. I have no special expertise to contribute to this subject.

Question 3. How significant are the effects of land use changes versus other input to climate models?

Response. I have no special expertise to contribute to this subject.

Question 4. If the estimates that Kyoto would cost the United States between $100 and $400 billion per year to implement are true and the results would just be a change of 0.06 degrees Celsius; would money be better spent on programs like Project Impact (a program at FEMA which helps communities mitigate against future natural disasters by encouraging different building techniques in disaster-prone areas)? Are Kyoto-like reductions cost effective? Please explain.

Response. The answer to this question is predicated upon the answer to a prior question, “Cost effective with respect to what criteria and outcomes?” If the goal of the Kyoto Protocol is to reduce future climate impacts, then it is clearly insufficient, and perhaps even irrelevant. However, there are other reasons why implementation of the Protocol might make sense, which would lead to different conclusions as to its cost effectiveness. See my answer to Question 2 from Senator Smith for discussion.

See Sarewitz, D., R. A. Pielke, Jr., 2000: Breaking the Global-Warming Gridlock. The Atlantic Monthly, 286(1), 55–64. *http://www.theatlantic.com/cgi-bin/o/issues/2000/07/sarewitz.htm*

RESPONSE OF DR. ROGER A. PIELKE, JR. TO AN ADDITIONAL QUESTION FROM SENATOR CAMPBELL

Question. You mentioned in your testimony that, “The present research agenda is improperly focused on prediction of the distant climate future.” I am inclined to agree. What sorts of research, in your expert opinion, would be of immediate benefit in relation to adaptation to climate change?

Response. To answer this question I point you to the testimony at an April 17, 2002, House Science Committee hearing of my colleague Radford Byerly, who was asked by the committee:

“How could a climate initiative yield information of greater relevance to end-users, people who make decisions related to climate?”

Dr. Byerly’s response is worth quoting at length.

“To assure that a research program generates information of great relevance to end-uses, the users must be involved in planning and evaluating the research. That is, they must have a say in what research is done and in what counts as a success. Users must be able to ensure that research addresses their problems, and delivers usable results.

In the present program climate scientists typically develop information they want to develop, i.e., answers to scientific questions, and then try to get bewildered users to use it (the users may never have heard of the scientific question). Research results become a solution looking for a problem.

Sound research programs dedicated to problem solving typically have three phases: A beginning—planning, a middle—the research, and an end—application and evaluation. The present program is almost all in the middle phase, that is, it is scientific research on scientific questions.

A better program, i.e., a program that would do more toward solving identified problems, would be conducted as follows: Research would be preceded by a planning phase in which users and scientists would identify and define specific problems to be attacked, as well as specific questions and information needs, and would look ahead to the application of the results. At this planning stage the primary sources of information about the problems are future users, the owners of the problems, not climate scientists. This planning process can be thought of as the researchers taking joint ownership of the problem with the users. The researchers do not relieve the users of responsibility, but together they take responsibility for solving the problem. Then in the middle the research is done, and new information is obtained and published. This second phase is often erroneously considered the entire project. Finally, in the third phase the results are applied in the field by the users on their problem and the research is evaluated in terms of how it helps solve the problems.

We hope that users will eagerly, fruitfully use the information, since they participated in planning the research. But such planning is hard and unfamiliar. Users may not express their needs clearly, or researchers may not hear them, and not every project will succeed. This is why the projects must be evaluated based on success in the field. Research projects unsuccessful in addressing the problem are terminated and successful ones are continued or replicated in a new context, as appropriate. That is, you correct and iterate.

Of course provision is made for projects that are making good progress in a demonstrably practical direction. In this way a program of projects solving real problems is grown. Along the way good science of a different kind is done.”

Dr. Byerly’s testimony can be view in its entirety at:

http://sciencepolicy.colorado.edu/homepages/rbverly/house testimony apr 2002/index.html

STATEMENT OF DAVID R. LEGATES, DIRECTOR, CENTER FOR CLIMATIC RESEARCH, UNIVERSITY OF DELAWARE

I would like to thank the committee for inviting my commentary on the important topic of the economic and environmental risks associated with increasing greenhouse gas emissions.

As a matter of introduction, my background in global change research has focused primarily on precipitation measurement and an examination of precipitation variability. My Ph.D. dissertation resulted in the compilation of the most reliable, highest resolution, digital air temperature and precipitation climatology available to date. Today, these fields still are being used to evaluate general circulation model (GCM) simulations of present-day climate and to serve as input fields for hydrological and climatological analyses. In particular, my research has focused on the accuracy of and biases associated with precipitation measurement and on the attempt to use existing climatological time-series to determine long-term fluctuations in climate. I also was a member of the United States delegation at the joint USA/USSR Working Meeting on Development of Data Sets for Detecting Climate Change held in Obninsk, Russia on September 11–14, 1989 where a joint protocol for data exchange was signed.

Indeed, an answer to the question, "Do we have the capability to determine whether we are changing our climate" is of obvious concern to both scientists and policymakers. I agree strongly that we need to enact sensible environmental policy—one that is based on scientific fact with foreseeable outcomes that can reasonably be expected to have beneficial results. As a scientist, I choose here to focus my comments on the scientific basis of climate change and the capabilities of the climate models, as that is my area of expertise. In the past, we have recognized a need for cleaner air and cleaner water, demonstrated the problems associated with detrimental human influences, and developed policy that has resulted in our air and water becoming markedly cleaner than they were just 30 years ago. I urge that this issue be treated with the same common-sense approach.

PROBLEMS WITH THE OBSERVATIONAL RECORD LEAVES QUESTIONS UNANSWERED

In light of my research on climatological observations, particularly precipitation, I have come to realize that looking for long-term trends in climate data is a very difficult undertaking. Precipitation data, for example, exhibit many spurious trends resulting from, in part, biases associated with the process of measuring precipitation. Indeed, attempts to measure snowfall using automatic methods have proven to be largely useless and, given the biases associated with measuring snowfall by traditional human-observed rain gages, our estimates of snowfall can be underestimates by almost a factor of two. Urban development of the environment surrounding the rain gage and, in particular, changes in rain gage design and the location of rain gages over time has adversely affected our ability to ascertain climatic trends in precipitation. Even a cursory examination of our most reliable records of precipitation shows that we frequently move meteorological stations, change instrumentation, and even the environment surrounding the site changes over time, which undermines attempts to answer the question "Is the climate changing?" Furthermore, precipitation is a highly variable field so, from a purely statistical standpoint, it is difficult to ascertain a small climate change signal from this high year-to-year variability. Air temperature measurements also are subject to these same measurement difficulties; in fact, the IPCC agrees that—as much as one-fifth of the observed rise in air temperature may be attributable to urbanization effects. As some of this change may be a direct result of natural climatic fluctuations, attributing a cause to any detected changes also is an extremely difficult undertaking. Indeed, as has been argued, "the data are dirty"!

Moreover, nearly all of our surface-based observations are taken from land-based meteorological stations, leaving the nearly 70 percent of the Earth's surface covered by oceans largely unobserved. In particular, location of these land-based stations is biased toward midlatitudes, low elevations, wetter climates, and technologically developed nations. Efforts to use sea surface temperatures over the oceans as a surrogate for air temperature measurements are largely invalid as the two temperatures are not often commensurate. This "land" bias, in my view, is one of the main limiting factors in using the observational record to infer global trends.

Satellite observations of air temperature and precipitation have proven very useful in addressing the climate change question in that they provide a complete coverage of the Earth's surface and are not subject to the biases associated with meteorological observing sites on the ground. Spencer and Christy's analysis of air temperature changes over the lower portion of the troposphere for the last 20 years exhibits no significant climate change signal as does an analysis using regularly launched weather balloorigi,—This is in stark contrast to the observed surface air temperature rise of 0.6° ± 0.2°C that has occurred over the entire twentieth century. A blue-ribbon panel convened to address this apparent discrepancy concluded that the temperature of the lower atmosphere might have remained relatively constant while an increase in near surface air temperature was observed. Some have argued that the surface warming is a delayed response to warming that had earlier occurred in the troposphere, although the abrupt warming of the troposphere is not consistent with expected scenarios of anthropogenic warming. The National Academy of Sciences (NAS) concluded that the difference between surface air temperatures and those of the troposphere was real but inconsistent with anthropogenic warming scenarios. In particular, the NAS only considered whether the satellite and surface records could both be correct and yet contradictory; they never addressed the issue of whether the surface records could, in fact, be biased.

Another problem in tying the observed increases in air temperature to an anthropogenic cause is timing. Most of the warming in the observed record occurred during two periods: 1910 to 1945 and 1970 to present. Much of the warming actually predates the rise in anthropogenic trace gas emissions, which makes it difficult to ascribe anthropogenic causes to the entire record. Indeed, we know that our observed record began in the late 1800's when air temperature measurements were sparse and more prone to bias. This timing also coincides with the demise of the Little Ice Age—a period of cooler-than-normal conditions that lasted from the middle portion of the last millennium to about the mid-1800's. Thus, it is unclear how much of the observed warming should be attributed to anthropogenic increases in atmospheric trace gases and how much of it is simply natural variability or measurement bias.

MODELING THE COMPLEX CLIMATIC SYSTEM IS AN EXTREMELY DIFFICULT TASK

In theory, therefore, climate models should be our best ability to study climate change. With models, we are not constrained by biased and limited observing systems or by contamination by other signals; but rather, we can alter the simulated climate and see "what if" while holding everything else constant. Such models, however, are predicated on their ability to replicate the real climate—after all, if climate models cannot replicate what we observe today, how can their prognostications of climate change possibly be expected to be transferable to the real world? Although I am not a climate modeler, much of my research has focused on comparing observations with climate model simulations of present-day conditions. Thus, I am very familiar with what climate models can and cannot do.

I am dismayed by the fact that much of the rather limited success in simulating average conditions by most climate models is achieved at the expense of changing some parameters to highly unrealistic values. For example, some models drastically change the energy coming from the sun to levels that are well beyond those that solar physicists have observed. Many models employ what are called "flux adjustments", which can only be described as finagling factors to make the average, present-day surface air temperatures look reasonable. One has to question why such overt deviations from reality are necessary if, in fact, the models are able to realistically represent our climate system.

In defense of climate modelers, I will say that they have a very difficult and daunting task. The climate system is extremely complex. Clouds, land surface processes, the cryosphere (ice and snow), precipitation forming mechanisms, the biosphere, and atmospheric circulation, just to name a few, are complex components of the global climate system that are not well understood or modeled appropriately at the scale employed by general circulation models. In essence, the climate change response can be directly affected by our parameterizations of many of these components. For example, an important question that now is being asked is "Why is the warming exhibited by transient climate models not being seen in the observed record?" There has been much discussion on the impacts of aerosols, black soot, high altitude clouds, and other so-called "wild cards" in the climate system—are they masking the climate change signal or should they be adding to it? How climate modelers treat these unknown processes in their models can affect dramatically the model simulations. Indeed, there are likely additional issues that we have not yet encountered.

CLIMATE MODELS CANNOT REPRODUCE A KEY CLIMATIC VARIABLE: PRECIPITATION

Despite these issues, do climate models well represent the Earth's climate? On three separate occasions—in 1990, 1996, and again in 2000—I have reviewed the ability of state-of-the-art climate models to simulate regional-scale precipitation. In general, the models poorly reproduce the observed precipitation and that characteristic of the models has not substantially changed over time. One area where the models have been in continued agreement has been in the Southern Great Plains of the United States. In all three studies, the varied models I have examined agree that northeastern Colorado receives substantially more precipitation than northwestern Louisiana! That is in marked contrast with reality where Louisiana is obviously wetter than Colorado. But the important ramification of this is that if precipitation is badly simulated in a climate model, then that will adversely affect virtually every other aspect of the model simulation. Precipitation affects the energy, moisture, and momentum balances of the atmosphere and directly affects the modeling of the, atmosphere, the hydrosphere, the biosphere, and the cryosphere. In turn, a bad representation of these components will again adversely impact the precipitation simulation. In short, anything done wrong in a climate model is likely to be exhibited in the model simulation of precipitation and, in turn, errors in simulating precipitation are likely to adversely affect the simulation of other components of the climate system. Given its integrative characteristic, therefore, precipitation is a good diagnostic for determining how well the model actually simulates reality, especially since simple "tuning" adjustments cannot mask limitations in the simulation, as is the case with air temperature.

If we examine climate model output a bit further, we uncover another disturbing fact—climate models simply do not exhibit the same year-to-year or even within-season variability that we observe. Precipitation in a climate model does not arise from organized systems that develop, move across the Earth's surface, and dissipate. Instead, modeled precipitation can best be described as "popcorn-like", with little if any spatial coherency. On a year-to-year basis, both air temperatures and precipitation exhibit little fluctuation, quite unlike what we experience. This is particularly important because it is the climatic extremes and not their means that have the biggest adverse impacts. Simply put, climate models cannot begin to address issues associated with changes in the frequency of extreme events because they fail to exhibit the observed variability in the climate system.

I attach a piece I wrote regarding the climate models used in the National Assessment and their evaluation with my climatology, which further highlights our uncertainties in climate models. In fact, the National Assessment itself recognized that both the Canadian Global Coupled Model and the Hadley Climate Model from Great Britain used by the, Assessment provide more extreme climate change scenarios than other models that were available and that had been developed in the United States. Neither model is reasonably able to simulate the presentday climate conditions.

OUR OBSERVATIONAL CAPABILITIES ARE IN JEOPARDY

Given that our observational record is inconclusive and that model simulations are fraught with problems, on what can we agree? In my view, there are two main courses of action that we should undertake. First, we need to continue to develop and preserve efforts at climate monitoring and climate change detection. Efforts to establish new global climate observing systems are useful, but we need to preserve the stations that we presently have. There is no surrogate for a long-term climate record taken with the same instrumentation and located in essentially the same environmental conditions. Modernization efforts of the National Weather Service to some extent are undermining our monitoring of climatic conditions by moving and replacing observing sites, thereby further introducing inhomogeneities into these climate records. Some nations of the world have resorted to selling their data, which has adversely impacted our assessments of climate change. However, given that oceans cover nearly three-quarters of the Earth's surface, we need to exploit and further develop satellite-derived methods for monitoring the Earth's climate. We also need to better utilize the national network of WSR88D weather radars to monitor precipitation.

But foremost, we need to focus on developing methods and policy that can directly save lives and mitigates the economic devastation that often is associated with specific weather-related events. Climate change discussions tend to focus on increases in mean air temperatures or percentage changes in mean precipitation. But it is not changes in the mean fields on which we need to place our efforts. It would be rather easy to accommodate even moderately large changes in mean air temperature, for example, if there were no year-to-year variability. Loss of life and adverse economic impact resulting from the weather occurs not when conditions are "normal"; but rather, as a result of extreme climatic events: heat waves, cold outbreaks, floods, droughts, and storms both at small (tornado, thunderstorm, high winds, hail, lightning) and large scales (hurricanes, tropical storms, nor'easters). The one thing that I can guarantee is that regardless of what impact anthropogenic increases in atmospheric trace gases will have, extreme weather events will continue to be a part of our life and they will continue to be associated with the most weather-related deaths and the largest economic impact resulting from the weather.

Ascertaining anthropogenic changes to these extreme weather events is nearly impossible. Climate models cannot even begin to simulate storm-scale systems, let alone model the full range of year-to-year variability. Many of these events are extremely uncommon so that we cannot determine their statistical frequency of occurrence from the observed record, let alone determine how that frequency may have been changing over time. While we need to continue to examine existing climate records for insights and to develop reliable theory to explain plausible scenarios of change, the concern is whether we can enact policy now that will make a difference in the future.

However, is there cause for concern that anthropogenic warming will lead to an enhanced hydrologic cycle; that is, will there be more variability in precipitation resulting in more occurrences of floods and droughts? The IPCC Summary for Policy Makers states:

> Global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions.

However, if one reads the technical summary of Working Group I, we find that:

> *There is no compelling evidence to indicate that the characteristics of tropical and extratropical storms have changed. Owing to incomplete data and limited and conflicting analyses, it is uncertain as to whether there have been any long-term and large-scale increases in the intensity and frequency of extra-tropical cyclones in the Northern Hemisphere. Recent analyses of changes in severe local weather (e.g., tornadoes, thunderstorm days, and hail) in a few selected regions do not provide compelling evidence to suggest long-term changes. In general, trends in severe weather events are notoriously difficult to detect because of their relatively rare occurrence and large spatial variability.*

The IPCC goes on to further state "there were relatively small increases in global land areas experiencing severe droughts or severe wetness over the 20th century". Karl and Knight, who conducted a detailed study on precipitation variability across the United States, concluded that as the climate has warmed, variability actually has decreased across much of the Northern Hemisphere's midlatitudes, a finding they agree is corroborated by some computer models. Hayden, writing for the Water Sector of the U.S. National Assessment, agrees that no trend in storminess or storm frequency variability has been observed over the last century and that "little can or should be said about change in variability of storminess in future, carbon dioxide enriched years." Soden concluded, "even the extreme models exhibit markedly less precipitation variability than observed." In addition, Sinclair and Watterson have noted that, in fact, climate models tend to indicate that increased levels of atmospheric trace gases leads to a "marked decrease in the occurrence of intense storms" outside the tropics and they argue that claims of enhanced storminess from model simulations are more the result of models that fail to conserve mass. Clearly, claims that anthropogenic global warming will lead to more occurrences of droughts, floods, and storms are wildly exaggerated.

Thus, I believe it stands to reason that we need to focus on providing real-time monitoring of environmental conditions. This will have two benefits: it will provide immediate data to allow decisionmakers to make informed choices to protect citizens faced with these extreme weather events and, if installed and maintained properly, it will assist with our long-term climate monitoring goals. Such efforts are presently being developed by forward-looking states. For example, I am involved with a project, initiated by the State of Delaware in cooperation with FEMA, the National Weather Service, and Computational Geosciences Inc. of Norman, Oklahoma, to develop the most comprehensive, highest resolution, statewide weather monitoring system available anywhere. Louisiana and Texas also have expressed interests in using our High-Resolution Weather Data System technology for real-time statewide weather monitoring. Regardless then of what the future holds, employing real-time monitoring systems, with a firm commitment to supporting and maintaining long-term climate monitoring goals, proves to be our best opportunity to minimize the impact of weather on human activities.

FINAL THOUGHTS: THE SCIENCE IS NOT YET IN

In 1997, I had the pleasure to chair a panel session at the Houston Forum that included seven of the most prominent climate change scientists in the country. At the close of that session, I asked each panelist the question, "In 2002, given 5 more years of observations, 5 more years of model development, and 5 more years of technological advances and knowledge about the climate system, will we have an answer to the question of whether our climate is changing as a result of anthropogenic increases in trace gas emissions?" The panel, which consisted of both advocates and skeptics, agreed that we would have a definitive answer probably not by 2002, but certainly by 2007. I disagreed then and I continue to disagree today. I fear that the issue has become so politically charged that the political process will always cloud the true search for scientific truth. But more than that, I feel the climate system is far more complex than we ever imagined—so much so that we still will not have a definitive answer by 2007.

I again thank the committee for inviting my commentary on this important topic.

A Layman's Guide to the General Circulation Models Used in the National Assessment

by

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Executive Summary

The U.S. National Assessment of the Potential Consequences of Climate Variability and Change for the Nation intends to "provide a detailed understanding of the consequences of climate change for the nation." This report argues that the National Assessment will not be able to provide policymakers and the public with useful information on climate change because of its reliance on flawed computer climate models. These models, which are intended to describe climate only on a very large scale, are currently used by the National Assessment to describe possible scenarios of regional climate change in the U.S. Because current models cannot accurately represent the existing climate without manipulation, they are unlikely to render reliable global climate scenarios or provide useful forecasts of future climate changes in regions of the United States as small as the Midwest, West or South.

The Guide explains how General Circulation Models (GCMs) describe changes in the complex factors that make up our climate, such as atmospheric changes, interaction of the land, sea, and air, and the role of clouds in climate. The strengths and weaknesses of climate models are discussed and the report shows how researchers attempt to answer the important questions about global warming as they refine their use of GCMs.

The two climate models used in the U.S. National Assessment are then described with reference to their similarities and differences. The limitations of these models – the Canadian Global Coupled Model and the Hadley Climate Model from Great Britain– are outlined with special emphasis on their inability to provide useful regional scenarios of climate change. The report concludes with an analysis of how well these two models reproduce the present-day climate as a benchmark for their ability to reproduce future climate.

Key findings in this report include:

- The utility of current GCMs is limited by our incomplete understanding of the climate system and by our ability to transform this incomplete understanding into mathematical representations. It is common practice to "tune" GCMs to make them represent current conditions more accurately, but the need for this manipulation casts serious doubt on their ability to predict future conditions. Because all factors are interconnected in climate modeling, an error in one field will adversely affect the simulation of every other variable.

- To reduce complexity and computational time, GCMs treat surfaces as uniform and average the flows of moisture and energy between the land surface and the atmosphere over large areas. But the extensive variability of the land surface and the effects that even small-scale changes can have make modeling land-surface interactions quite difficult.
- The National Assessment itself recognized that both the models that it selected provide a more extreme climate change scenario than other models that were available and that had been developed in the U.S.
- Both models offer incomplete modeling of the effects of individual greenhouse gases, including water vapor and atmospheric sulfates. The CGCM1 in particular fails to model sea ice dynamics and offers a simplistic treatment of land-surface hydrology. Predicted temperature increases over various regions of the United States differ considerably between the two models; these predictions fail to correspond with observed precipitation variability and contradict each other.
- In general, the Hadley model simulation is closer to the observed climate in the United States than the Canadian simulation, although both models produced considerable differences from observations. This, again, cast serious doubt on the models' ability to simulate future climate change.

Conclusion: Given these uncertainties, using the available GCMs to assess the potential for climate change in specific regions is not likely to yield valid and consistent results. GCMs can provide possible scenarios for climate change, but at the present level of sophistication, they are not reliable enough to be used as the basis for public policy. Using GCMs to make predictions about local climate change in the United States is not legitimate.

A Layman's Guide to the General Circulation Models Used in the National Assessment

INTRODUCTION

What is a General Circulation Model (GCM)?

The word "model" usually conjures up images of a miniature replica of a real object. Model trains, automobiles, and airplanes, for example, are intended to be scale-reduced versions of the original. Models are judged by their attention to detail, and sometimes functionality, with respect to their real counterparts and are quite distinct from "toys", which also are intended to resemble the original but lack the attention to detail and functionality.

In science, the word "model" has a similar, but broader, meaning. Models can be physical replicas; for example, a model may be a smaller version of a larger habitat for a given animal or plant species. A model also, however, can be a working representation of a difficult concept, such as a model of an atom, for example. In this case, the model is simply a more useful way to describe and analyze a portion of nature that is only partially understood and observable. Usually, such models can be described by a set of mathematical equations - some from fundamental laws, and some empirical – rather than being a true physical replica.

General circulation models (or GCMs) are a further example of the latter definition. They are not physical reproductions of the earth and its climate system but instead are mathematical representations of the physical laws and processes that govern and dictate the climate of the earth. As such, they are *computer models* – computer programs that are able to solve the complex interactions among these mathematical equations to derive fields of air temperature, humidity, winds, precipitation, and other variables that define the earth's climate. General circulation models are limited both by our understanding of what drives, shapes, and affects the climate of the earth as well as how the earth's climate responds to a variety of external forces -- in addition to the speed and capabilities of modern-day computers.

The Concept of Space in GCMs

If we were to build a GCM, our first and fundamental decision would be the selection of the model's concept of space – how we choose to physically describe the three-dimensions of the atmosphere. Here we have two fundamental choices: the model can either be a *Cartesian grid* model or it can be a *spectral* model.

Conceptually, the Cartesian grid climate model is easier to understand and grasp, although it is less flexible and recently seems to be the less desirable choice among climate modelers. Consider a set of building blocks that might be toys for a young child. We could arrange the blocks in the form of a regular lattice where the face of every block is flush against another block. We could make this wall of blocks several blocks high and several blocks wide. Thus, each block in the center of the wall is adjacent to six other blocks – one above, one below, and four adjacent to each horizontal face.

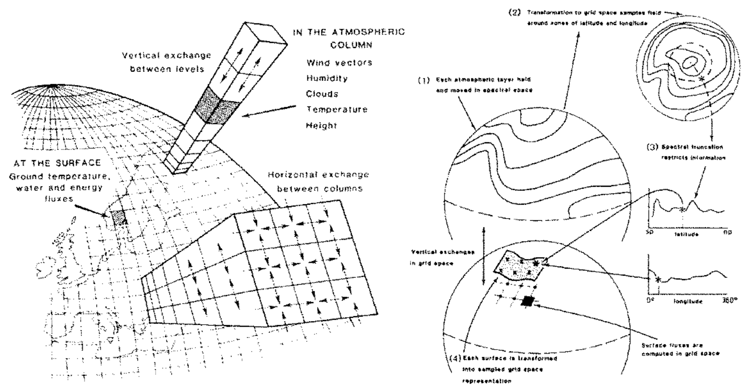
In a Cartesian grid model, we extend the concept of these building blocks to represent hypothetical "blocks" of atmosphere, stacked adjacent to and on top of each other in the same manner we stacked the child's building blocks (Figure 1). Since the earth's surface is a sphere, however, we extend these blocks around the globe until they reach the blocks on the other end. Thus, in our climate model, every block has an adjacent partner on each of its four horizontal faces – our "wall" of blocks extends around the globe and covers the entire earth's surface. The only edges that exist are the blocks on the bottom and those on the top. Here, however, the blocks on the bottom are in contact with the earth's surface and can be used to describe the interactions between the atmosphere and the land surface. Although the atmosphere really has no "top" (air simply becomes thinner with height until its density approaches zero), the blocks on top of our stack can be used to represent the vertical extent of the atmosphere.

Since each block has six faces, we will simply describe (mathematically) the flows of energy, mass, and other physical quantities between one of our atmospheric boxes and the six adjacent boxes. We assume that each box is homogeneous; temperature, humidity, and other atmospheric variables can only vary between boxes and not within a box. Each of these variables is associated with the location (both horizontally and vertically) of the center of the box. As the box centers form a lattice or a grid around the earth's surface, the name "Cartesian grid model" is justified.

A typical Cartesian grid model will employ a lattice of approximately 72 boxes by 90 boxes (2½° of latitude by 4° of longitude) stacked about 15 boxes high. The more boxes that are employed, more spatial resolution is obtained but at the expense of increased computer time. This choice of resolution is usually appropriate to allow sufficient spatial variability within a reasonable amount of computer run time.

By contrast, the *spectral* model does not use the concept of "boxes" at all but relies on a framework that is harder to grasp. Imagine a tabletop covered by several sheets of paper stacked on top of one another. Each sheet represents a different atmospheric layer. Vertically, the interaction between the layers is similar to the vertical interaction between the boxes that we saw with the Cartesian grid model. However, the horizontal representation of the field is not described by interactions among boxes; but rather, it is presented and manipulated in the form of waves. Just as energy is carried through the ocean in the form of oceanic waves, we can represent flows of energy and mass along each atmospheric layer using a series of waves having different amplitudes and frequencies (called *spherical harmonics*). Although these waves are difficult to describe, one can think of them as a series of sine and cosine curves (true really only in the east-west direction) that, when taken together, can be used to represent the spatial variability of any field (Figure 2). Grid values, akin to the representation of the Cartesian grid model, are computed from these waves and the horizontal and vertical resolutions become commensurate with those of Cartesian grid models.

At the same spatial resolution, spectral models have the advantage in that they can more easily (or compactly) describe a field than a Cartesian grid model. Thus, computation times are reduced. Moreover, spatial resolutions can be changed more easily with a spectral model, which allows for more flexibility and adaptability. Some have argued that Cartesian grid GCMs are



Representation of three-dimensional space in general circulation models (GCMs). Cartesian GCMs (left) use a concept similar to a series of stacked boxes, while spectral GCMs (right) use a series of waves and smoothly varying functions. Both representations, however, use the Cartesian analog (*i.e.*, stacked boxes or stacked waves in their representation of the vertical dimension. (Figure taken from Henderson-Sellers and McGuffie, 1987).

more satisfactory than their spectral counterparts for a variety of reasons, including the fact that it is possible for spectral models to violate some of the fundamental laws of physics (to produce negative mass, a physical impossibility, for example). This can occur since the use of waves (as in a spectral model) implies the field must be smoothly varying – a constraint that is often inappropriate for many atmospheric fields. Precipitation, for example, exhibits significantly steep spatial gradients, which makes the representation of a precipitation field using smoothly varying wave patterns very difficult. In 1987, McGuffie and Henderson-Sellers wrote that Cartesian grid models will, in time, be favored over spectral models owing to increased computational power and the need to reduce these gradient anomalies associated with spectral modeling. The computational advantage gained from the use of spectral models over the past decade, however, led to a proliferation of spectral GCMs, which still represent the majority of the GCMs used today.

Describing Atmospheric Processes in a GCM

Having chosen our framework for spatial representation, the next step is to describe the atmospheric processes that govern the earth's climate. First, we must define the equations that drive atmospheric dynamics – processes that lead to atmospheric motions. We must require that the model conserve energy, since we know from the first law of thermodynamics that energy cannot be created nor destroyed. Our GCM also must conserve mass; although Einstein showed that matter may be converted into energy, that occurrence is insignificant in the atmosphere. Momentum also must be conserved since an object in motion tends to remain in motion. We also use the *ideal gas law*, which states that the pressure of the atmosphere is proportional to both its density and temperature. There are additional equations that describe more complicated atmospheric properties that also must be conserved.

Next, we define equations describing the physics of the atmosphere – processes that describe energy exchanges within the atmosphere. In GCMs, three-dimensional, time-dependent equations govern the rate of change of atmospheric variables including air temperature, moisture, horizontal winds and the height for each atmospheric layer, and surface air pressure. These equations describe, for example, the effect of vertical air motions and absorbed energy on air temperature, the rate of atmospheric pressure changes with respect to height in the atmosphere, relationships between atmospheric moisture, cloud formation and condensation/precipitation, and the interaction between clouds and the energy balance. Clouds can play a key role in the energy balance of the earth since they reflect incoming energy from the sun, but trap outgoing "heat" energy from the earth. Thus, modeling of clouds and their effects on the energy and moisture balances is important to GCM prognostications of climate change scenarios.

Except for the representation and treatment of clouds, all spectral GCMs at this point are essentially the same, and so too are all Cartesian GCMs. The reason is that there really are not many ways (only minor variations on the theme exist) to describe the dynamics and physics of the atmosphere within our chosen spatial framework. Where models within their respective classes differ substantially is with regard to their modeling of atmospheric interactions with the earth's surface.

Modeling Surface Processes in a GCM

The critical component of most GCMs is their treatment of interactions between the atmosphere and the earth's surface. Oceans, lakes, and other bodies of water provide substantial amounts of moisture and energy to the atmosphere. Modeling them is important since nearly three-quarters of the earth is covered by water and the ocean is a fluid -- always in constant motion. Thus, in addition to the atmosphere, the oceans provide an important mechanism for the redistribution of energy around the earth. Their circulation must be modeled and the energy and moisture transfers between the ocean and the atmosphere must be appropriately described. In addition, much of the world's oceans are saline and quite deep. Interactions between temperature and salinity (called the thermohaline circulation) are extremely important to the earth's climate but are not well understood. Moreover, deep ocean water can store atmospheric gasses, to be released at a much later time when concentration of these gasses is much lower. Modeling of such processes within a GCM is extremely difficult.

With respect to modeling the oceans, sea ice plays an important role in shaping the earth's climate. When air temperatures drop below freezing, the surface of the ocean may become frozen, creating a barrier to energy and moisture flows between the ocean waters and the atmosphere above. In the presence of sea ice, the atmosphere is deprived of moisture and energy from the relatively warmer waters below, thus causing the atmosphere to become colder and drier and cause a positive feedback to sea ice formation. Sea ice, however, moves with the combined forces (often in different directions) of oceanic circulation and surface winds. This causes sea ice to become broken in some places (called leads) and piled up to form hills and ridges in others. Thus, sea ice is not uniform and modeling these interactions is extremely difficult and not well understood.

But the biggest challenge to GCM modeling is the representation of the interactions between the atmosphere and the land surface. If you take a quick glance around your environment, you will see that the land surface is quite heterogeneous -- trees, shrubs, grasses, roads, houses, streams, *etc.* often coexist within a single square mile. In our Cartesian grid GCM, however, our "boxes" are often several *hundred* miles wide and we must assume that everything within the box is homogeneous. Spectral GCMs have similar spatial resolutions and assume that everything, including the land surface, is smoothly varying. Thus, the sheer nature of surface heterogeneity makes modeling the land surface within a GCM very difficult.

Couple that now with the fact that interactions between the land surface and the atmosphere are extremely complex. Plants try to conserve water and so shut down many vital functions when water supplies run low. However, each plant species behaves differently; for example, trees have deeper roots than short grasses and, therefore, their access to water is different. Plant use of water, even in times of ample moisture supply, differs widely among plant species that, of course, often coexist. Snow and ice cover are dictated by air temperature and precipitation, but old snow has different characteristics than newly fallen snow. To reduce complexity, GCMs simply try to simulate the flows of moisture and energy between the land surface and the atmosphere in the aggregate. But given the extensive heterogeneity of the land surface and the effects that even small, sub-resolution scale changes can have -- well, to say that modeling land surface interactions is difficult would be an extreme understatement!

THE GCMS OF THE NATIONAL ASSESSMENT

Rather than discuss all possible ways in which climate models can represent various climate-shaping processes, let us focus on the two models used in the United States National Assessment -- GCMs from the Canadian Centre for Climate Modeling and Analysis and the Hadley Centre for Climate Prediction and Research. Both models are well documented and results from and specifications of both models are widely available to the scientific community. For selection by the National Assessment Synthesis Team (US National Assessment, 2000), climate models were chosen based on the criteria that the model must:

1) be a coupled atmosphere-ocean general circulation model that includes a comprehensive representation of the atmosphere, oceans, and land surface,
2) include the diurnal cycle of solar radiation to provide estimates of fluctuations in maximum and minimum air temperature and to represent the development of summertime convective rainfall,
3) be capable, to the best extent possible, of representing significant aspects of climate variations (*e.g.*, El Nino/Southern Oscillation),
4) provide the highest practicable spatial and temporal resolution -- about 200 miles in longitude and 175 to 300 miles in latitude -- over the central United States,
5) allow for an interface with higher resolution regional modeling studies,
6) must be able to simulate the time-evolution of the climate from at least 1900 (beginning of the detailed historical record) to at least 2100 using a well-documented scenario for changes in atmospheric composition that accounts for time-dependent changes in greenhouse gas and aerosol concentrations,
7) have results that are available in time for use in the National Assessment,
8) have been developed by groups participating in the development of the Third Assessment Report of the IPCC for compatibility and the model must be well documented, and
9) allow for a wide array of results to be openly provided on the WWW.

Items (1-3) are important in that significant influences on the climate (diurnal cycle, oceans, land surface, and other processes) are included, although most models now do include these features and some of the assessments of model performance (*e.g.*, simulation of El Nino/Southern Oscillation) are tenuous, given our limited understanding of the process. As expected, the chosen models must afford the highest spatial and temporal resolution (Item 4) and their results must be useful for regional-scale modeling applications (Item 5). For simulation purposes, the model data must be from a transient climate simulation (*i.e.*, it allows for changes in atmospheric constituents over time) that extends both back and forward in time about 100 years from the present (Item 6). Finally, Items (7-9) are purely administrative criteria, although virtually all modeling groups participate in the IPCC and compatibility with the IPCC really should not be an issue (Item 8). It was deemed important to include at least two models in the National Assessment, to provide a more balanced presentation and allow for a spectrum of model uncertainties and differences. Both the Canadian Centre and Hadley Centre models fit these criteria.

The Canadian Climate Centre Model

The Canadian Global Coupled Model (CGCM1), developed by the Canadian Climate Centre, is a spectrally-based model with a spatial resolution of approximately 3.75° of latitude by 3.75° of longitude (about 260 miles by 185 miles over the United States) and ten vertical atmospheric layers. The ocean model coupled to this atmosphere has a spatial resolution of 1.8° of latitude by 1.8° of longitude (about 125 miles by 90 miles) and twenty-nine vertical layers. Given the complexity and the importance of modeling the oceans, a higher spatial resolution is often required by most ocean model components of GCMs. In the oceans, we are interested in simulating the exchanges of energy and moisture between the ocean and the atmosphere, as well as simulating the redistribution of energy within the oceans. This redistribution of energy occurs both horizontally (ocean circulation) and vertically. Vertical motions also allow for heating and cooling of the deeper ocean waters and their absorption of greenhouse gases. This, of course, is immensely important in a proper simulation of the earth's climate.

Because the ocean responds to different spatial and temporal scales than those which drive atmospheric processes, coupling an ocean model to an atmospheric GCM is a complicated task. Often, the modeling of energy and moisture exchanges results in values that are completely unreasonable -- they differ considerably from observations. To rectify such conditions, GCMs often resort to a "flux-adjustment" of ocean-atmosphere interactions; that is, they force the exchanges of heat and moisture between the simulated oceans and the simulated atmosphere to meet prescribed distributions. This flux-adjustment process is used to dictate that the coupled model correctly simulates the oceanic circulation of salinity and temperature (*i.e.*, the thermohaline circulation). In the case of the CGCM1, the model is flux adjusted.

Sea ice modeling is even more tenuous than ocean modeling, but certainly as important. Many models incorporate both the formation and movement of sea ice (dynamics) as well as their inhibition of the exchange of heat and moisture between the ocean and the atmosphere (thermodynamics). In the case of the CGCM1, the thermodynamics are modeled, but sea ice dynamics are not. Seasonal distributions of sea ice are prescribed to be consistent with seasonal observations.

Equally difficult is the modeling of land surface interactions -- exchanges of energy and moisture between the atmosphere and the vegetation/soil surface. Land surface models can be highly simplistic, where the surface color, temperature, and moisture characteristics correspond to average conditions and variations. In such formulations, the land surface hydrology is modeled by what is termed the "bucket method". Soil water is held in a theoretical "bucket" -- water can be put into the bucket (through precipitation) and removed from the bucket (through evaporation and plant transpiration). A simple resistance function models the rate of water removal from the bucket by plant water usage and soil evaporation. The bucket has a finite depth, so that when precipitation overflows the bucket, the excess moisture becomes streamflow (although streamflow is not directly modeled). Land surface components of GCMs can be quite complex, however, where interactions between plants and their responses to changing atmospheric and soil moisture conditions are modeled. Within the CGCM1, the land surface hydrology is modeled by a modified bucket method. Seasonal and diurnal fluctuations in solar energy are usually included in most models used today; this is true as well for the CGCM1.

Atmosphere chemistry in some GCMs, and in the CGCM1 in particular, is treated in a rather crude manner. Time-varying effects of individual greenhouse gases (*e.g.*, carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, and ozone) are not modeled; but rather, temporal increases in a single greenhouse gas -- carbon dioxide -- are used as a surrogate. Here, the assumption is that atmospheric greenhouse gas concentrations will increase 1% (compounded) per year until 2100. In other models, the individual effect of each greenhouse gas is considered separately. In addition to greenhouse gases, changing concentrations of sulfate aerosols also are important to modeling climate change. Atmospheric sulfates, large sulfur-based particles suspended in the atmosphere, originating from both anthropogenic and natural sources, are widely believed to reflect incoming solar energy, thereby diminishing the potential global warming signal. Although the chemistry can be complex, some models attempt to simulate their direct effects and changes in aerosol concentrations over time. The CGCM1, however, simply models aerosols as a change (increase) in the reflectance of solar energy reaching the surface of the earth, without modeling the actual dynamics and properties of sulfate aerosols.

At equilibrium (when no further change in air temperature occurs), the response of the CGCM1 model to a doubling of concentrations of greenhouse gases (specifically, carbon dioxide) is an increase of 3.5°C (6.3°F) in the globally averaged air temperature (Boer *et al.*, 1992), which occurs by about 2050 (Figure 2). Over the United States by 2030, the model simulates summer increases of between 1° and 3°C (1.8° to 5.4°F) over the entire United States. Winter increases of 2° to 4°C (3.6° to 7.2°F) are modeled over western and central areas of the United States while 0° to 2°C (0.0° to 3.6°F) changes are modeled over eastern portions. Winter precipitation increases in the west and decreases elsewhere while summer changes are largely unpredictable (both increases and decreases are observed).

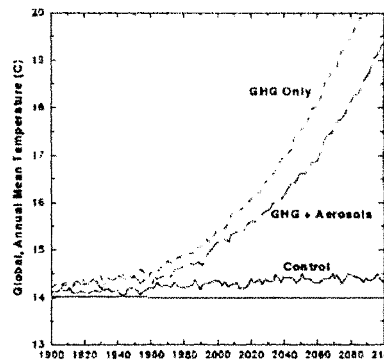


Figure 2: Simulations of climate change using the CGCM1 model with changes in greenhouse gas concentrations (GHG Only), greenhouse gases and atmospheric aerosols (GHG+Aerosols), and with no changes (Control). (Figure from Boer *et al.*, 1992).

The Hadley Centre Model

By contrast with the CGCM1, the Hadley Climate Model (HadCM2), developed by the Hadley Centre for Climate Prediction and Research of the United Kingdom Meteorological Office, is a Cartesian grid model with a spatial resolution of approximately 2.5° of latitude by 3.75° of longitude (about 175 miles by 185 miles over the United States) and nineteen vertical atmospheric layers. Its coupled ocean model has the same horizontal resolution with twenty vertical layers and also is flux-adjusted. In the HadCM2, sea ice dynamics are modeled, as well as their influence on the exchange of heat and moisture between the ocean and the atmosphere.

The HadCM2 uses a more sophisticated approach to modeling land surface hydrology. Several soil layers are used and the flow of moisture between these soil layers (through percolation downward through the soil) is modeled. The model provides a more detailed and specific treatment of the plant canopy, including the area of ground covered by leaves and the response of the leaves to water stress. Both seasonal and diurnal cycles of solar energy variations are incorporated into the model.

As with the CGCM1, the HadCM2 GCM applies the same modeling strategy for the treatment of atmospheric chemistry. Temporal increases in carbon dioxide only are specified. Individual effects of other greenhouse gases such as methane, nitrous oxide, and ozone, for example, are not modeled but are incorporated into the effects of a change in carbon dioxide. Atmospheric sulfates are modeled only as a change in the surface reflectance of solar energy (albedo) while their actual dynamics and the individual properties are not included. This is consistent with the formulation used by the CGCM1.

For a doubling of atmospheric carbon dioxide concentrations, the response of the HadCM2 is an increase in the globally averaged air temperature of 2.6°C (4.7°F). Over the United States, the model simulates increases of from 1° to 3°C (1.8° to 5.4°F) over the eastern third of the nation and increases from 1° to 4°C (1.8° to 7.2°F) over the western two-thirds. Precipitation is modeled to increase in the western and eastern thirds of the nation during winter while changes in winter precipitation in the central Great Plains and summer precipitation everywhere is mixed (both increases and decreases are observed).

Table 1: Comparison between the Canadian Climate Centre Model (CGCM1) and the Hadley Centre Model (HadCM2).

Variable	CGCM1	HadCM2
Atmospheric Model		
North-South Resolution	3.75° (about 260 miles)	2.5° (about 175 miles)
East-West Resolution	3.75° (about 185 miles)	3.75° (about 185 miles)
Vertical Resolution	10 layers	19 layers
Oceanic Model	Flux Adjusted	Flux Adjusted
North-South Resolution	1.8° (about 125 miles)	2.5° (about 175 miles)
East-West Resolution	1.8° (about 90 miles)	3.75° (about 185 miles)
Vertical Resolution	29 layers	20 layers
Land Surface Hydrology	Modified Bucket Method	Detailed Plant Canopy
Seasonal Solar Cycle	Yes	Yes
Diurnal Solar Cycle	Yes	Yes
Treatment of Multiple Greenhouse Gases	Carbon Dioxide Used as a Surrogate	Carbon Dioxide Used as a Surrogate
Treatment of Atmospheric Aerosols	Change in Surface Reflectance Only	Change in Surface Reflectance Only
Equilibrium Change for a Doubling of Carbon Dioxide	3.5°C (6.3°F)	2.6°C (4.7°F)

THE UTILITY AND LIMITATIONS OF GCM SCENARIOS

Limitations in climate modeling

GCMs are designed to be descriptions of the full three-dimensional structure of the earth's climate and often are used in a variety of applications, including the investigation of the possible role of various climate forcing mechanisms and the simulation of past and future climates. Given what we have seen regarding the abilities of GCMs, it appears that such models have the potential to simulate accurately changes in the real climate. However, we must remember several important issues. First, GCMs are limited by our incomplete understanding of the climate system and how the various atmospheric, land surface, oceanic, and ice components interact with one another. But in addition, GCMs are further limited by our ability to transform this incomplete understanding into mathematical representations. We may have a general feel for the complex interrelationships between the atmosphere and the oceans, for example, but expressing this understanding in a set of mathematical equations is much more difficult. Second, GCMs are limited by their own spatial and temporal resolutions. Computational complexity and finite restrictions on computing power reduce GCM simulations to coarse generalities. As a result, many small-scale features, which may have significant impact on the local, regional, or even global climate, are not represented. Thus, we must recognize that GCMs, at best, can only present a gross thumbnail sketch. Regional assessments over areas encompassing many GCM grid cells are the finest scale resolution that can be expected. It is inappropriate, and grossly misleading, to select results from a single grid cell and apply it locally. It cannot be over emphasized that GCM representations of the climate can be evaluated at a spatial resolution no finer than large regional areas, seldom smaller than a region defined by a square a thousand miles (at least several GCM grid cells) on a side. Even the use of "nested grid models" (models which take GCM output and resolve it to finer scale resolutions) does not overcome this limitation since results from the GCM simulation drives such models and no mechanism is available to feedback the results of such finer-scale models to the GCM.

A third limitation in GCMs is that given the restrictions in our understanding of the climate system and its computational complexity, some known phenomena are simply not reproduced in climate models. Hurricanes and most other forms of severe weather (*e.g.*, nor'easters, thunderstorms, and tornadoes) simply cannot be represented in a GCM owing to the coarse spatial resolution. Other more complex phenomena resulting from interactions among the elements that drive the climate system may be limited or even not simulated at all. Phenomena such as El Ninõ and La Ninã, the Pacific Decadal Oscillation, and other complex interrelationships between the ocean and the atmosphere, for example, are inadequately reproduced or often completely absent in climate model simulations. Such indicators should be flags that something fundamental is lacking in the GCM. These phenomena should be produced in the model as a result of our specification of climate interactions and driving mechanisms; their absence indicates a fundamental flaw in either our understanding of the climate system, our mathematical representation of the process, the spatial and temporal limitations imposed by finite computational power, or all three of the above.

An assessment of the efficacy of any climate model, therefore, must focus on the ability of the model to simulate the present climate conditions. If a model cannot simulate what we know to be true, then it is unlikely that model prognostications of climate change are believable. However, a word of caution is warranted. It is common practice to "tune" climate models so that they better resemble present conditions. This is widely acceptable, because many parameters in GCMs cannot be specified directly and their values must be determined through empirical trial-and-error. However, this raises the concern that a GCM may adequately simulate the present climate, not because the model correctly represents the processes that drive the earth's climate; but rather, because it has been tuned to do so. Thus, the model may appear to provide a good simulation of the earth's climate, when in fact the model may poorly simulate climate change mechanisms. In other words, a GCM may provide an adequate simulation of the present-day climate conditions, but it does so for the wrong reasons. Model efficacy in simulating present-day conditions, therefore, is not a guarantee that model-derived climate change scenarios will be reasonable. To address this question, modelers often employ simulations of past climates, such as the Holocene or the Pleistocene, to see if the model provides the kind of climate that we can infer existed during such epochs. Of course, our knowledge of pre-historical climate conditions is tenuous and extremely crude, which limits the utility of such evaluations.

A final limitation in climate modeling is that in the climate system, everything is interconnected. In short, anything you do wrong in a climate model will adversely affect the simulation of every other variable. Take precipitation, for example. Precipitation requires moisture in the atmosphere and a mechanism to cause it to condense (causing the air to rise over mountains, by surface heating, as a result of weather fronts, or by cyclonic rotation). Any errors in representing the atmospheric moisture content or precipitation-causing mechanisms will result in errors in the simulation of precipitation. Thus, GCM simulations of precipitation will be affected by limitations in the representation and simulation of topography, since mountains force air to rise and condense to produce orographic (mountain-induced) precipitation (*e.g.*, the coastal mountain ranges of Washington and Oregon). Incorrect simulations of air temperature also will adversely affect the simulation of precipitation since the ability of the atmosphere to store moisture is directly related to its temperature. If winds, air pressure, and atmospheric circulation are inadequately represented, then precipitation will be adversely affected since the atmospheric flow of moisture that may condense into precipitation will be incorrect. Plant transpiration and soil evaporation also provide moisture for precipitation; therefore, errors in the simulation of soil moisture conditions will adversely affect the simulation of precipitation. Simulation of clouds solar energy reaching the ground will affect estimates of surface heating which adversely affects the simulation of precipitation. Even problems in specifying oceanic circulation or sea ice concentrations will affect weather patterns, which affect precipitation simulations. In sum, the simulation of precipitation is adversely affected by inaccuracies in the simulation of virtually every other climate variable.

However, inaccuracies in simulating precipitation, in turn, will adversely affect the simulation of virtually every other climate variable. Condensation releases heat to the atmosphere and forms clouds, which reflect energy from the sun and trap heat from the earth's surface -- both of which affect the simulation of air temperature. As a result, this can affect the simulation of winds, air pressure, and atmospheric circulation. Since winds drive the circulation of the upper layers of the ocean, the simulation of ocean circulation also is affected. Air temperature conditions also contribute to the model simulation of sea ice formation, which would be adversely affected. Precipitation is the only source of soil moisture; hence, inadequate simulations of precipitation will adversely affect soil moisture conditions and land surface hydrology. Vegetation also responds to precipitation availability so that the entire representation of the biosphere can be adversely affected. Clearly, the interrelationships among the various components that comprise the climate system make climate modeling difficult. Keep in mind, however, that it is not just the long-term average and seasonal variations that are of interest. Demonstrating that precipitation is highest over the tropical rainforests and lowest in the subtropical deserts is not enough. Climate change is likely to manifest itself in small regional fluctuations. Moreover, we also are interested in intra-annual (year-to-year) variability. Much of the character of the earth's climate is in how it varies over time. A GCM that simulates essentially the same conditions year after year clearly is missing an important component of the earth's climate. Thus, the evaluation of climate change prognostications using GCMs must be made in light of the model's ability to represent the holistic nature of the climate and its variability. Interestingly, the National Assessment admits, "results suggest that the GCMs likely do not adequately include all of the feedback processes that may be important in determining the long-term climate" (United States National Assessment, 2000:23).

It should be noted that GCMs are not weather prediction models. Their utility is not in predicting, for example, whether it will rain in southern England on the morning of July 14, 2087. Rather, we are interested in determining whether the probability of precipitation will be substantially different from what it is today -- in both the frequency and intensity of precipitation events. In general, we want to know whether the summer of 2055 is likely to be warmer or colder than present conditions, and by how much. As such, GCMs are only used appropriately to address the likelihood of changes over large spatial and temporal scales -- assessing changes for specific dates or locations is beyond the scope of GCM utility.

How the National Assessment employs models

In the United States National Assessment, three approaches are used to determine the anthropogenic effects of climate change. The first approach is to examine the historical record, back to the late 1800s, to look for trends or changes that might possibly be linked to human sources. Unfortunately, the climate record reflects not just changes linked to anthropogenic activities, but a whole host of fluctuations caused by natural sources and uncertainties induced by changes to the instrumentation, station network and its environment, *etc.* The second approach is to use "sensitivity/vulnerability analysis" -- address the degree of change required to cause significant impacts in areas of critical human concern and its probability of occurrence. Such speculations are based, in large part, on the results of analysis from both the historical record and model prognostications.

Our focus here is on the third approach used in the National Assessment -- the use of climate models (GCMs in particular) to assess the potential for anthropogenic climate change. While GCMs provide quantitative assessments of such changes (*i.e.*, they assign numerical values to changes and their probabilities), the limitations discussed above can lead to some skepticism of such assessments. In particular, we need to pay close attention to the uncertainties or "error bars" associated with the numbers generated by the models. Indeed, the Draft of Chapter 1 of the National Assessment indicates that GCMs are not perfect predictors of future climates, but argue that they "can be used to provide important and useful information about potential long-term climate changes over periods of up to a few centuries on hemispheric scales and across the [United States], but care must be taken in interpreting regionally specific and short-term aspects of the model simulations" (US National Assessment, 2000:23). Although the National Assessment goes on to highlight all of the caveats associated with the use of model projections, model results are nevertheless shown in high resolution and without assessment of uncertainties, which allows many results gleaned from the models to transcend these caveats and concerns.

In the National Assessment, as well as in most modeling applications, GCM estimates of climate change scenarios are developed by taking the difference between the model simulated change and the model representation of the present climate conditions. For example, if the model simulated a present climate of 10°C (50°F) that was to change to 15°C (59°F) under a given climate change scenario, then the climate change prognostication would be for an increase of 5°C (9°F). For precipitation, the rate is computed as a percentage, not as a difference; thus, if for the present climate, we have a precipitation rate of 4 mm per day that changes to 6 mm per day under climate change, the climate change prognostication would be for an increase in precipitation of 50%. Note that the observed values are not used -- thus, it is important that the model be compared to the observations to determine how reasonable these changes might be.

Limitations in interpreting results from the models used in the National Assessment

It is laudable that the National Assessment considered more than a single model although it is recognized that the evaluation of too many models would have become unwieldy. It is also was significant that the two models be of different type -- one a spectral GCM and the other a Cartesian grid GCM. As previously discussed, and as pointed out in Chapter 1 of the National Assessment, interpretation of the results from these two models must be accompanied by a great deal of care, owing to the inherent limitations in applying the results from GCM simulations. In particular, however, the choice of the two models recommended for use in the National Assessment, namely, the Canadian Climate Centre (CGCM1) and Hadley Centre (HadCM2) models is rather odd. It is widely recognized, and even mentioned by the National Assessment, that the CGCM1 provides a more extreme climate change scenario than other models that were considered but not used. To a large extent, this same criticism holds for the HadCM2 as well. It also is particularly intriguing that neither of the two selected models was developed by a group within the United States, especially when viable alternatives exist.

In part, the extreme scenarios developed by these two models result from the use of overly simplistic formulations of key model components. For example, the CGCM1 has the simplest treatment of land surface hydrology of all models considered; namely, a bucket model for soil moisture. Other models use a soil layer model with an explicit treatment of vegetation interactions. It has been widely demonstrated that bucket models overly simplify and grossly bias the representation of the hydrological cycle. Since precipitation, soil evaporation, and plant transpiration are components of not only the water balance, but the energy balance as well, such simplistic treatments greatly undermine the ability of the model to represent the climate. It is surprising that the National Assessment used a model employing such a simplistic treatment of land surface hydrology, particularly in light of the fact that clearly better alternatives exist.

With respect to sea ice models, the CGCM1 has the most simplistic treatment of all the models considered -- it lacks a dynamic component that other models possess. Although sea ice modeling is very difficult, a proper sea ice model is important to simulate the fluxes of energy and moisture between the atmosphere and the ocean at high latitudes. Since virtually all models indicate the greatest response of air temperature by greenhouse gas forcing will occur in the high latitudes, selection of a model that incorporates an inferior sea ice component is extremely puzzling. This is likely to overemphasize the effect of high latitude warming, which, in part, may be a major reason why prognostications of the CGCM1 are on the extreme side.

Furthermore, the CGCM1does not treat all greenhouse gases independently (the effect of them is lumped into an "effective" CO_2 surrogate) and includes the effect of atmospheric aerosols only changing the surface reflectance of solar energy. Given the potential importance of sulfur masking/mitigation of the anthropogenic greenhouse gas change signal, and decreasing concentrations of methane, this overly simplistic treatment may overstate the effect of such an important component of the anthropogenic global warming issue.

In considering the effect of greenhouse gases, it must be remembered that the most important greenhouse gas is not carbon dioxide, but water vapor. As we saw earlier, treatment of the oceans and, in particular, the land surface hydrology play an important role in determining correct levels of atmospheric humidity. Inaccuracies in precipitation rates also adversely affect atmospheric concentrations of water vapor. But couple this with the fact that the two models tend to provide estimates of surface air temperatures that are several degrees too cold. Since the amount of water vapor in the air at a relative humidity of 100% (saturated conditions) increases exponentially with increasing air temperature, the atmospheric moisture content is likely to be underestimated by a cold model. Water vapor has a relatively high specific heat -- meaning it takes more energy to raise the temperature of a water vapor molecule. Dry air is easier to warm; hence it is easier to achieve warming in a model that starts out with less water vapor in its atmosphere. Furthermore, it takes energy to evaporate water -- energy that with a drier atmosphere would contribute to additional warming.

In an evaluation of the intra-annual variability in climate models, Soden (2000) compared observations of precipitation variability with several GCMs, including those used in the National Assessment (Figure 3). He concluded, "Not only do the GCMs differ with respect to the observations, but the models also lack coherence among themselves...even the extreme models exhibit markedly less precipitation variability than observed." Virtually no climate model adequately resolves the intra-annual climate variability.

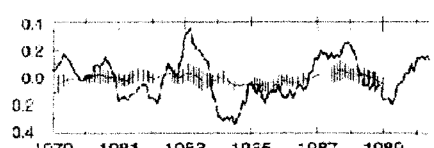


Figure 3: Precipitation rate in mm day^{-1} as observed (thick solid line) and as simulated by an ensemble of GCMs (thin solid line). Vertical lines on the GCM ensemble show the intra-annual variability among the GCMs mean. (from Soden, 2000)

Earlier it was mentioned that it is important to evaluate the efficacy of the GCMs with respect to their ability to reproduce the present-day climate. Doherty and Mearns (1999) have provided a comparison of historical simulations of the two models used in the National Assessment against observational data. In general, they conclude that both models have significant problems in their representation of topography -- the western United States is represented simply as one large hill beginning at sea level along the West coast and descending into the Great Plains. This problem manifests itself in cold and wet biases over the Rocky Mountains. When these problems with topography are coupled with the high spatial variability and the coarse spatial resolution of the models, results of climate change scenarios for detailed regions in the western United States is, in their words, "highly questionable". In general, the HadCM2 simulation is closer to the observed climate than that of the CGCM1, although both models exhibit considerable differences from the observations. They conclude, "researchers should exercise extreme caution in the conclusions they draw from impacts analysis using the output from these climate models, given the uncertainty of the model results, especially on a regional scale."

With regard to air temperature, Doherty and Mearns (1999) mapped the differences between the model mean climatology and an air temperature climatology developed by Legates and Willmott (1990b). In addition to the overall cold bias of both models, Doherty and Mearns found that air temperatures over the northern United States and Canada differ from the observations by as much as 12°C (21.6°F)! Topographically induced underestimates in air temperature are obvious in both models over the Rocky Mountains. In the central Plains, both models overestimate air temperature by up to 6°C (10.8°F) in summer, which is likely to overestimate summer drying, leading to an overestimate of drought frequency. Overall, both models exhibit similar patterns of biases in air temperature with warmer-than-observed conditions in winter and autumn in the northern United States and colder-than-observed conditions in the western United States in all seasons. Both models make the central United States too warm in summer and autumn.

Precipitation is difficult to simulate in a GCM, owing to the interrelationships among other climate variables noted earlier. In addition, precipitation mechanisms occur at scales well below the spatial and temporal resolution of most GCMs, the precipitation forming process is not fully understood, and numerical instabilities may arise with small amounts of moisture. Doherty and Mearns (1999) also mapped differences between the model mean climatology and a precipitation climatology developed by Legates and Willmott (1990a). As with air temperature, considerable overestimates exist over the Rocky Mountains in both models as a direct result of their inadequate representation of topography -- differences are as much as 6 mm day^{-1} (7.1 inches per month) are observed in parts of the Rocky Mountains. Note that this is twice the mean monthly precipitation in some areas! Overestimates also are observed in the northeastern United States in spring and summer by as much as 3 mm day^{-1} (3.5 inches per month) while precipitation in the southeastern United States and lower Mississippi River Basin during winter and summer is underestimated by as much as 3 mm day^{-1} (3.5 inches per month). Both models exhibit similar patterns of biases, although the regions of bias tend to be somewhat smaller in the HadCM2.

One conclusion of the National Assessment is of an enhanced hydrologic cycle over the United States -- increased precipitation variability and storminess. The ramifications are obvious; more floods and droughts will increase the potential losses and uncertainty of our future world. However, is this a rational conclusion? Karl *et al.* (1997) noted, "Variability in much of the Northern Hemisphere's midlatitudes has decreased as the climate has become warmer. Some computer models also project decreases in variability." This seems to be in direct opposition to the claims of both the Intergovernmental Panel on Climate Change (IPCC) and the National Assessment. Hayden (1999), in a paper written for and presented at a national conference to discuss the content of the National Assessment (and later published in a refereed journal), indicated that the observations show "there has been no trend in North America-wide storminess or in storm frequency variability found in the record of storm tracks for the period 1885-1996 ... It is not possible, at this time, to attribute the large regional changes in storm climate to elevated atmospheric carbon dioxide." With regard to the model projections, he states, "[Model] projections of North American storminess shows no sensitivity to elevated carbon dioxide. It would appear that statements about storminess based on [model] output statistics are unwarranted at this time. ... It should also be clear that little can or should be said about change in variability of storminess in future, carbon dioxide enriched years." Sinclair and Watterson (1999) further go on to conclude that for areas such as the United States, "doubled CO_2 leads to a marked decrease in the occurrence of intense storms." Both in general and in particular, GCMs do not exhibit an enhancement of the hydrologic cycle; nevertheless, the National Assessment decided to ignore this fact.

Concluding statements

In light of our discussion, climate models should be thought of as useful tools to assess our understanding of the climate system and to examine interrelationships among various components of the climate system. At present, and at least into the near foreseeable future, the uncertainties associated with model simulations make their projections only a single possible scenario, at best. Historically, assessments of climate change have steadily become less extreme as more climate feedback mechanisms are included in the models. Overall, it appears that anthropogenic climate change estimates are still uncertain (given the discrepancies between most models) and, when coupled with the slower-than-predicted warming present in the historical record, the true climate changes are likely to be at or below the lowest model estimates, with some of these changes having potentially beneficial effects.

Table 2: Selected projections from the Canadian Climate Centre Model (CGCM1) and the Hadley Centre Model (HadCM2) over the United States by 2030 (taken from Doherty and Mearns, 2000)

	Air Temperature					
	Winter			**Summer**		
	Eastern	Central	Western	Eastern	Central	Western
CGCM1	0° to 2°C	2° to 4°C	2° to 4°C	1° to 3°C	1° to 3°C	1° to 3°C
HadCM2	1° to 3°C	1° to 4°C	1° to 4°C	0° to 1°C	0° to 3°C	1° to 2°C
	Precipitation (in mm per day)					
	Winter			**Summer**		
	Eastern	Central	Western	Eastern	Central	Western
CGCM1	-2.0 to 0.0	-2.0 to 0.0	0.0 to +3.0	-1.0 to +0.5	-1.0 to +0.5	-0.5 to +0.5
HadCM2	0.0 to +1.0	-0.5 to +1.0	0.0 to +2.0	-0.5 to +1.0	-0.5 to +1.0	-0.5 to +1.0

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RESPONSES OF DR. DAVID R. LEGATES, TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. As you and all the other witnesses indicated, it is not safe to continue increasing greenhouse gas emissions without limit. What needs to be done to assure that we can avert the point of no return or "dangerous levels" of green house gas concentrations?

Response. In response to your question, I would ask, "What are 'dangerous levels' or the 'point of no return'?" I do not think there is a definition of dangerous levels of carbon dioxide in this context—we are not anywhere near levels of carbon dioxide that would inhibit our ability to extract sufficient oxygen from the atmosphere. Given too that many actions to reduce or eliminate greenhouse gas production are concomitant with additional problems, I do not see that I can define a level beyond which we cannot pass.

My suggestion would be that we should seek to reduce the production of greenhouse gases where there clearly is another benefit to the reduction. For example, less reliance on foreign sources of fossil fuels would be beneficial to our national security and if they could be replaced by conservation, enhanced efficiency, and/or 'cleaner' sources, then less greenhouse gases would be produced. Thus, I am in favor of technology that reduces emissions of greenhouse gases as a by-product; but I strongly argue that reduction of greenhouse gases for reduction sake is not cost effective or, in many cases, even potentially beneficial.

Question 2. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. To be able to define risk, one must be able to ascertain solid evidence of the effect of our actions. At present, we can neither determine the effects of anthropogenic increases in greenhouse gases nor guarantee that all effects will be detrimental. Most arguments in favor of reducing emissions are that if there is an impact, it must be detrimental because change is always bad. Over the last 1,000 years, we have seen climate change dramatically—from the Medieval Warm Period to the Little Ice Age to the warmer period we now enjoy. During those periods, civilization has adapted to that change and I do not see why adaptation to a globally warmed world cannot be considered. Moreover, I remain unconvinced that (1) global climate change will be detrimental to either humans or ecosystems as a whole or (2) that it will be as significant as climate models purport that change will be.

Personally, I feel that the greatest risk we face in the next 30–50 years as a result of the atmosphere will come from extreme weather events. Floods, droughts, heat waves, cold spells, and storms from hurricanes to nor'easters to flash flooding to lightning and high winds to tornados will take the most lives and cause the most economic damage. We will still be forced to face these extreme weather events regardless of what climate change scenario plays out. Thus, in keeping with my earlier Senate testimony, the most feasible way to reduce our risk from climate change is to develop strategies to mitigate the effects of extreme weather events. Forward-looking efforts such as the Delaware Environmental Observing System (DEOS) that is supported by the State of Delaware will yield benefits now and in the future—especially if global warming results in an increase in the frequency and intensity of these extreme weather events (a scenario that is not supported by current research, however). I would argue that money spent toward disaster mitigation (education, evacuation, and minimization of the impact) would be much better utilized than money spent toward the reduction of greenhouse gas emissions.

RESPONSES OF DR. DAVID R. LEGATES, TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th Century, the atmospheric concentrations of a number of greenhouse gasses have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

I do not think this statement is debatable. We know that many industrialized activities emit carbon dioxide, methane, and other greenhouse gases either as a direct result (e.g., burning fossil fuels) or an indirect result (e.g., cattle feedlots which increase methane production) of human activities. Virtually all long-term measurements of greenhouse gases (most notably in Hawaii and Antarctica) have exhibited an increase in these gases as industrialization has occurred. Thus, the rise in concentrations of these gases is well documented and we have explicit anthropogenic sources for the rise in their concentrations.

Question 2. Dr. Pielke testified that "the primary cause for . . . growth in impact is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se. " Do you agree with this claim? Why or why not?

Response. Whether climate change occurs or not is largely irrelevant, what is relevant is the impact climate change is likely to have on ecosystems and human activities. In some sense, to state that we are increasingly vulnerable to climate variability and change is to recognize that an increasing population base is more likely to be vulnerable to a change of any kind. Thus my answer is a qualified "I agree", with a caveat that a definition of "increasing vulnerability" must be provided. I do not agree that all climate change must necessarily be bad, nor do I agree that human and environmental systems cannot adjust to climate change.

Question 3. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought . . . " Do you agree with that proposition? Why or why not?

Response. In my testimony, I argued that both human and environmental systems are most vulnerable to climate extremes—floods, droughts, heat waves, cold outbreaks, and severe weather. Debating whether the temperature will rise 1.5°C or 4 °C is academic; what will claim the most lives and provide the greatest economical damage are the extreme events. That is why in my testimony I focused on whether research indicates climate extremes are likely to change. Since we cannot state with any certainty that a future, warmed world is likely to exhibit any higher frequencies of extreme weather events, our focus therefore is better placed on efforts to prepare and warn our citizens for these extreme events. That was essentially a conclusion of my testimony.

As for a discussion of the present drought, a quest for the cause for the drought is an academic exercise. Regardless of the cause, I can guarantee that we will have droughts again in the future. Thus, we would be better served by addressing how we can better manage our existing water resources in the future, than in focusing on whether drought frequency is likely to change in the future.

Question 4. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. As it exists, I would agree that the Kyoto Protocol should not be ratified by the United States. In ignoring obvious sources of greenhouse gas emissions from developing countries and in focusing on a system of "credits", it appears to be more of a political "we're doing something" statement rather than an attempt to address the true issue. In my testimony, I cited an American Viewpoint survey of State and regional climatologists who agreed by nearly a 2-to-1 margin that going back to 1990 emission levels (a more stringent approach than Kyoto) would have little or no impact on global warming. I agree with the majority of these climatologists and note that such measures are likely to have dire economic consequences for virtually no return on the climate change issue. Thus, I would argue that a better approach would be one that reduces emissions where other benefits outweigh the climate change concern and one that allows us to cope with extreme weather events.

I also do not agree with a modified Kyoto Protocol where restrictions in greenhouse gas emissions are relaxed in times of an economic downturn. All this would do is ignore climate change when the economy is bad and enact restrictions to squelch a booming economy. The Kyoto Protocol, in my view, is bad for the United States economy while doing virtually nothing to the climate. It is a system that should be abandoned and not tweaked.

Question 5. Since the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B, " that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause for the phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. There is no scientific evidence that climate change is the sole cause for the phenomenon. The hydrology of Antarctica is one of mass balance. In most of the United States, it snows and the snow melts, eventually. But the temperature of Antarctica is so cold that it does not melt, and subsequent yearly snowfall is added to the snow that already exists. This snowpack becomes compressed and forms ice, which slowly migrates out to the ice shelves over the oceans. Due to the topography, ice breaks off rather frequently forming the traditional icebergs that we find in the North Atlantic, for example. But in Antarctica, the ice extends over water until it becomes fragile and breaks off. Thus, calving (breaking off) of icebergs is a relatively common event.

Before satellites, we did not have frequent observations of Antarctica. Thus, we do not know how frequent icebergs of this size form. With satellites, we are able to see them when they occur but our limited observational period precludes an assessment of the frequency of occurrence. Given though that it is a natural process, I cannot agree that climatic change is the sole cause. However, winds over the Southern Ocean during El Niño events are diverted southward over the Antarctic Peninsula. Researchers have noted that sea ice decreases during this time, which allows winds to pound surf against the ice sheet resulting in weakening of the structure. This may be a reason why large breakups of the Larsen Ice Sheet has occurred during major El Niño events.

Prescribing anthropogenic assistance to the breakup of Larsen B is extremely difficult. How is it possible to know whether anthropogenic influences provided any assistance in the breakup of Larsen B? Although I am not a supporter of them, we could turn to climate models for assistance. Assuming that climate models provide our best assessment of climate change effects, I note that in the latest analysis of the National Center for Atmospheric Research (NCAR) model (Dai et al., Journal of Climate, February 2001) that near the Antarctic Peninsula (where Larsen B is located), a change of less than 1 °C is shown for the climate of 2100. This value is the least amount of any change anywhere over the Southern Ocean. So, I think it would be fair to say that climate models indicate little climate change for this region, which leads me to conclude that little scientific evidence exists that anthropogenic influences played a substantial role in the breakup of Larsen B.

Question 6a. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty; Coping with the risks of climate change" (copy attached). Please explain why you agree or disagree with the following assertions or conclusions from that report: There is not one problem but two; natural climate variability and the influence of human activity on the climate system.

I would agree that there are two issues that must be considered when trying to assess causes for climate change—natural climate variability and anthropogenic effects. In that sense, I would agree. However, the article postulates that we need to avert anthropogenic influences on the climate (problem #1), while simultaneously preparing for unexpected extreme weather occurrences (problem #2). I agree wholeheartedly with arguments to offset the second proposed problem. However, science has not determined the extent, either in magnitude or in effect, of the anthropogenic influence. In that light, how can we determine risk if we do not have solid evidence of the effect of our actions? Their argument seems to be that if there might be an impact, it will be detrimental because change is always bad and therefore the change must be averted. Environmental systems have adapted to change for eons and the human journey has been to both cause change (usually for the better) and adapt to changes. Their "global climate protection" is "to avoid anthropogenic intervention in the natural climate system when potential consequences cannot be foreseen." Since science cannot ascertain the consequences, we must avert all possible changes. But taken literally, it is impossible to remove all human influences on the climate—cities must be eliminated, we must go back to a pre-industrial revolution age, etc. Good risk strategy is not to avoid all change at all costs; but rather to assess the effects of such change and outweigh the bad with the good.

Question 6b. ". . . it is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted."

This statement is the crux of my Senate testimony. We need to be more concerned with protecting ourselves from extreme weather conditions and be less concerned by the small changes that may occur to mean global air temperature. We can be sure that this new century will contain floods, droughts, heat waves, and storms of all kinds and sizes. And we have no evidence the frequency or magnitude of these events will change in a globally warmed world. Moreover, we cannot guarantee that we have seen the worst event that is possible under current natural conditions. Therefore, I agree with this statement—natural disasters will not abate in the future, regardless of any effects of anthropogenic climate change, and we must be poised to deal with them.

Question 6c. "Swiss Re considers it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which—if they are not confirmed—will in time turn to carefree relief, and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind."

In essence, this is simply common-sense practice—don't cry wolf and don't ignore the problem. As for fear mongering, every extreme weather event is accompanied by "This could be caused by global warming!" or "We can expect more of these with global warming!" It helps drum up support for the cause and when the future is 2100, it becomes difficult to ever find unconfirmed claims. Moreover if mitigation is undertaken, then unconfirmed claims are cause for celebration—"See, we did something about it!"—while the occurrence of extreme events are a rally for still more action. In the case of climate change, it seems that fear mongering yields substantial benefits with little concern for the onset of carefree relief due to the fact that effects are likely to occur only in the distant future.

As for ignoring the problem for short-term expediency, I would agree. Ignoring potential problems can have serious ramifications at a later date. However, with respect to anthropogenic climate change, we have not ascertained the degree to which humans are changing the climate nor have we determined the extent to which anthropogenic climate change poses a hazard. To determine risk, you have to be able to determine the probability of occurrence. In this debate, we have neither determined what will occur nor its probability. Thus, it is irresponsible to simply declare that the change must be bad and it must be stopped at virtually all costs, particularly when the result of such actions can have dire consequences themselves.

As a climatologist, I find the phrase "a collapse of the climate system" unintelligible. Economic systems can collapse, infrastructures can collapse, and buildings can collapse. But the climate system is a process that continues on. Too much carbon dioxide in the atmosphere will NOT bring an end to climatic processes or the Earth's climate. As such, the physics of the climate system will not collapse; they will continue on. In attempting to quantify the "system collapse", Swiss Re postulates that "small increases in average temperature . . . can cause low pressure systems to shift from their usual paths and the frequency of heavy rainfall in a particular region to suddenly increase significantly". What this tells me is that the authors of the Swiss Re piece do not have a good understanding of the climate system or the issues that are involved. No research of which I am aware indicates that such changes are likely. Little credible evidence exists to suggest that a small increase in air temperature will result in a major shift to precipitation patterns. In fact, precipitation is so poorly simulated in climate models, that traditional low pressure systems are not even represented by them.

Question 7. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. As per my Senate testimony, I definitely do agree that our vulnerability to extreme weather conditions is increasing. More people demanding more water usage will exacerbate droughts when they occur. Channelization of rivers (e.g., the Mississippi and the Missouri) will enhance flood peaks and confine river flow, resulting in flooding of downstream areas that are not protected by levees or flooding large portions of inhabited areas if a levee break occurs. Continued building on and urban development of coastal areas will put larger numbers of people at risk and require more extensive evacuation procedures during nor'easters and tropical storm/hurricane landfalls. With more people, the impact of thunderstorms, hailstorms, lightning, high winds, and tornadoes are bound to increase.

Note that in my testimony, I indicated little evidence points to an enhancement of extreme weather conditions under a globally warmed world. The above-mentioned extreme weather conditions presently lead to the greatest loss of life and the greatest economic impact of weather—not the increase of mean global air temperature. They will continue to do so in the future. Thus, I will continue to argue that better warning systems and preparation for these extreme weather events should be our primary meteorological concern, not global warming.

RESPONSES OF DR. DAVID R. LEGATES, TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. My question is "what is so magical about 550 ppm?" That number is as contrived as any other number—there is no way to guarantee that effects resulting from 550 ppm will not be detrimental but that effects from, say 575 ppm, will be. As I am not an advocate of the Kyoto Protocol, I cannot advocate specific CO_2 concentration targets. Moreover, CO_2 is not the only greenhouse gas. Note that levels of methane (CH_4) have leveled off to rates far below those postulated by the Intergovernmental Panel on Climate Change (IPCC). Moreover, water is the most important greenhouse gas; more important than carbon dioxide or methane. Thus, defining CO_2 levels is a nice way to perform bookkeeping but not a good way to conduct science.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis?

Response. Unfortunately, economics is not my area of expertise, as I am a climatologist. Thus, I am not aware of any economic analyses of the effect of such reductions.

Question 2. Please provide your assessment of the surface temperature measurements including documentation of the location of the measurement sites on land and at sea.

Response. In my testimony, I indicated that I felt thermometer measurements were generally good estimates of the temperature record at that location. Given that the effect of urbanization (growth of cities around the stations) has been prevalent during the twentieth century, we would expect that surface air temperature measurements would exhibit significant air temperature increases. Sites where urbanization has not been observed usually show little trend. Moreover, weather stations tend to be moved over time. This is done for a variety of purposes (e.g., moving stations from downtown to the airports in the 1940's) but it results in a discontinuity in the station record—the new site is seldom identical to the old location. Thus, a bias is introduced which is difficult to distinguish from a climate change signal.

My view is that surface air temperature measurements are too biased to provide a complete picture of global patterns of air temperature. First, they tend to be biased toward lower elevations, middle-latitudes, denser populations, and industrialized countries (see Addendum #1). Moreover, they only provide coverage of about two-thirds of the globe with oceanic areas remaining underrepresented. Ship reports, used by Legates and Willmott (Addendum #2) are useful for producing climatological averages but not for discerning temporal trends. Second, they represent the temperature at a height of only about 5.5 feet. This is well within the atmospheric boundary layer where urbanization and other biases due to the station location are prevalent.

Locations of the 17,986 terrestrial air temperature stations that were used in my global precipitation data base are presented in Addendum #1. This figure is taken from Legates and Willmott (1990), the text of which is included as Addendum #2. Note section 2.3, Reliability Concerns, that discusses the assessment of the surface temperature measurements.

Question 3. Has there been any comprehensive assessment of the accuracy of the surface temperature measurements?

Response. I include Addendum #2 that includes a paper describing my global air temperature climatology. It contains a summary of and several references to papers that describe the accuracy of air temperature measurements.

I also would note the National Research Council Report, Reconciling Observations of Global Temperature Change, chaired by John M. Wallace. Although many media outlets touted this report as the death-knell for climate change skeptics, the report does provide an assessment of surface temperature records (which show substantial warming) relative to satellite and radiosonde observations (which show little warming). Moreover, the report concludes that warming is real and that surface thermometers and satellites and radiosondes are likely measuring different things, most notably that the thermometers are solely surface observations (below 10 feet) whereas satellites and radiosondes (balloon observations) integrate temperature over the lower troposphere.

Question 4. What are the effects of removing black soot from the atmosphere?

Response. In February 2001, Stanford scientist Mark Jacobson published an article in Nature which indicated that the warming effect from the atmospheric aerosol carbon (black soot) was more than twice what the Intergovernmental Panel on Climate Change (IPCC) has assigned to it. Black soot also is likely to reduce cloud cover by heating portions of the atmosphere, thereby evaporating condensed water. This implies that much of the warming the IPCC projected to occur as a result of policies to reduce atmospheric aerosols would be offset since black carbon would also be removed. This has posed a problem since some have suggested that sulfate aerosols have countered the warming the climate models indicate should have occurred. Thus, anti-pollution measures to remove sulfate aerosols would result in a dramatic increase in the Earth's temperature.

Black soot, however, exerts a warming effect that is exceeded by emissions only of carbon dioxide and is almost equal to the cooling caused by sulfate aerosols, Jacobson concluded. What this means is that the removal of both sulfate aerosols and black soot using electrostatic precipitators in smokestacks—which occurs since both particles are about the same size—negates any effect the IPCC suggests should occur as a result of anti-pollution efforts.

From a health standpoint, it is desirable to reduce the concentrations of black soot and sulfate aerosols. From a climatic change standpoint, the removal of black soot would remove a large contributor to global warming. This would occur with obvious health benefits. Moreover, anti-pollution measures should have no net effect on the Earth's temperature since the net effect of sulfate aerosols and black soot should be near zero.

What this entire argument on black soot and sulfate aerosols should indicate is that the science of climate change is still highly uncertain. The effects of both black soot and sulfate aerosols come with large uncertainties. Removal of black soot would seem to be a benefit both to atmospheric pollution concerns as well as to those concerned about anthropogenic warming. But further research might find that there are other effects—maybe positive, maybe negative—that can be attributed to the presence of these aerosols. Thus, I reiterate that it is impossible to determine the extent of our risk when the effects of atmospheric composition are extremely uncertain.

Question 5. What are the benefits of using U.S. clean coal technology in countries like China and India in terms of removing black soot?

Response. Although this is not in my area of expertise, I would argue that clean coal technology would be beneficial to developing countries whose economies are still dependent on coal. However, I always am concerned about exporting technology and how it may be used in ways that we did not intend. Clean coal technology should decrease emissions of pollutants (sulfate aerosols and black soot), which are a particular problem in developing countries. However, by increasing burning efficiency, more CO_2 will be released as a result.

Question 6. Please provide your assessment of the models used in the New England Regional Assessment referred to by Mr. Markham. Also, please comment on the use of these models for driving impact studies. If available, please provide any alternative assessments for States in New England.

Response. The U.S. National Assessment prescribed the models used in the New England Regional Assessment. Thus, the models used were the Canadian Climate Centre Model and England's Hadley Centre Model. I have provided an extensive assessment of these models in a manuscript published by the George C. Marshall Institute. That manuscript was appended to my Senate testimony.

In summary, these models were out of date at the time the National Assessment went to press. Moreover, they provided two of the most extreme climate scenarios of all models the Assessment had from which to choose. As for driving impact studies, I will note that for current conditions, both models simulated a wetter climate for eastern Colorado than for northwestern Louisiana! The "trick" that is used is to simply ignore the current field but look at changes from the present-day simulation to the doubled CO_2 Simulation. Obviously, if one is interested in regional-scale impacts, it is important that the model reproduces the salient features of the regional climate.

Question 7. Please provide an assessment of the models used in the reports by Swiss RE and Munich RE, including their use to predict local impacts.

Response. In their discussion, Swiss RE cites only the Switzerland National Research Programme 31 (NFP 31) as a source for their information. The Swiss National Research Programme is their equivalent of our National Science Foundation. In the documentation of NFP 31, I found the following climate model reference: "A regional climate model for the Alpine region," by Lüthi et al. (1997). Only an abstract is available but they note, "The modelling suite employed comprises a doubly nested system with an outer coarse mesh model (horizontal resolution ~56km) capable of capturing synoptic-scale features and an embedded fine-mesh model . . . (horizontal resolution ~14km) that can simulate meso-scale flow systems." Regional climate models are driven by General Circulation Models (GCMs) but the report gives no mention as to the specific model references.

As there are no large-scale modeling groups in Switzerland, my educated guess would be that their model would not be substantially different from those cited by the IPCC, and may likely include the Hadley Centre GCM. I provide an assessment of the climate models used in the U.S. National Assessment in my manuscript published by the George C. Marshall Institute and appended to my original Senate testimony. Many of the same criticisms of these two models hold for other models as well.

As for the prediction of local impacts, this study appears to use nested modeling—an approach where higher resolution models are used to look at local fluctuations. These models are driven by the coarser resolution GCMs and, as a consequence, inherit their biases and errors. Thus, the local assessments are only as good as the large-scale forcing which, for GCMs, is not very accurate.

RESPONSES OF DR. DAVID R. LEGATES, TO ADDITIONAL QUESTIONS FROM SENATOR CAMPBELL

Question 1. In your testimony, you expressed concern over what you termed "land bias". That nearly three fourths of the Earth's surface is covered by water and goes largely unobserved. Therefore, much of our available data on global warming may not in fact be wholly accurate. You also mention that some countries actually sell their data to interested parties, also potentially tainting that information. What efforts are being made to correct these situations?

Response. Clearly, it is virtually impossible to instrument the oceans in the same way we have instrumented land areas. We do have ship reports; however, they tend to be biased in a number of ways. First, ships, for obvious reasons, tend to avoid storms if at all possible. This provides a "fair weather bias" that affects our estimates. Second, most ships are moving targets (there are some reports from fixed-position ships) and provide air temperature estimates that are integrated over large areas and do not represent a single point. Third, ships are large metal objects that generate their own heat and have different characteristics than the open ocean. This problem is akin to the urbanization effect we see with land-based thermometers.

Thus, our only real source of obtaining a spatially representative sample of global air temperatures is through remote sensing. Much of the work by Roy Spencer and John Christy has been based on attempting to compile a long-term temperature record using satellite remote sensing. Using their analysis, we see that satellite-derived air temperature has not exhibited a marked increase as suggested by land-based thermometers. This lack of a trend has also been observed with radiosonde data (balloons); traditionally, weather balloons are used twice daily around the world to sample the vertical profile of the atmosphere, including air temperature.

As for the fact that countries have been selling their data, Dr. Mike Hulme of the Climatic Research Unit at the University of East Anglia relayed this information to me. His unit has been the source of many of the air temperature and precipitation time-series that have been displayed. These countries are largely Third World, which see the data as a potential source of income. Efforts are ongoing to encourage these countries to participate in the global telecommunication of weather data, largely through the World Meteorological Organization. In some cases, financial support has been supplied. I participated in the first protocol that allowed the U.S. and USSR to exchange data for climate research (back in 1990); such efforts have now been extended to an international scope. However, I would conclude that global cooperation in this area is still lacking.

Question 2. You mention in your testimony that perhaps 20 percent or less of the observed global increase in temperature may be due to the activities of mankind. What are other likely causes of global warming?

Response. I believe my intent was to state that 20 percent or less of the observed global increase in temperature was due to anthropogenic increases in greenhouse gases. Variations in solar output are an obvious source of some of the changes in global temperatures we have seen. Dr. Sallie Ballunias probably can offer comment that is more up-to-date on this topic. However, I also would strongly argue that much of the observed global increase in air temperature is due to the effect of urbanization. Over time, weather stations that originally were sited in open, rural settings have become increasingly surrounded by sprawling urban areas. Several researchers have documented time-series of air temperature for rural versus urbanized stations and have found that air temperature increases with urbanization, while little change occurs with rural observations. This effect is well documented; the "urban heat island" occurs due to a decrease in evaporation and an increase in absorption of solar radiation that results when forests and grasslands are replaced by cities. While urbanization technically can be considered as a humaninduced effect, I strongly differentiate increased temperatures due to urbanization from a rise in air temperature resulting from increased greenhouse gases. Thus, urbanization, in my view, is largely responsible for most of the air temperature rise that we have seen in the observed, land-based air temperature record.

I would further argue that land surface changes (such as urbanization, but also including deforestation and desertification) have probably a bigger effect on the Earth's climate than atmospheric constituents. Land surface interactions are a big component of the surface energy balance, although they are not well represented within climate models. Models are more tuned to study the radiative balance of the atmosphere, which is probably why the models are very sensitive to changes in greenhouse gases.

Natural climatic variability is also another likely source of rising air temperatures. In the late 1800's, we emerged from a relatively cool period known as the "Little Ice Age". It is therefore not unexpected that air temperatures would rise during the last century after the end of a period during which colder temperatures were experienced for 300 to 400 years. Before then, the Medieval Warm Period exhibited globally warmer air temperatures. I would note that many civilizations thrived during this period even though they were in a lesser position than we are to adapt to climate change.

ADDENDUM #1

Mean Seasonal and Spatial Variability in Global Surface Air Temperature 13

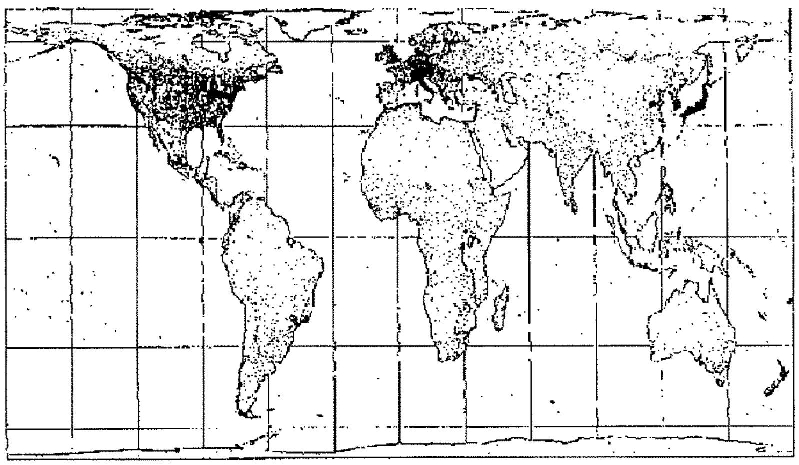

Fig. 1. Locations of the 17986 terrestrial air temperature stations contained in the edited and merged data set. Twelve mean monthly surface air temperatures are available for each station

From: Legates, D.R., and C.J. Willmott (1990). Mean Seasonal and Spatial Variability in Global Surface Air Temperature. *Theoretical and Applied Climatology*, **41**(1):11–21.

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Theoretical and Applied Climatology

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Mean Seasonal and Spatial Variability in Global Surface Air Temperature

D. R. Legates[1] and C. J. Willmott[2]

With 7 Figures

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Summary

Using terrestrial observations of shelter-height air temperature and shipboard measurements, a global climatology of mean monthly surface air temperature has been compiled. Data were obtained from ten sources, screened for coding errors, and redundant station records were removed. The combined data base consists of 17986 independent terrestrial station records and 6955 oceanic grid-point records. These data were then interpolated to a 0.5° of latitude by 0.5° of longitude lattice using a spherically-based interpolation algorithm. Spatial distributions of the annual mean and intra-annual variance are presented along with a harmonic decomposition of the intra-annual variance.

1. Introduction

Virtually every component of the earth-atmosphere system influences and is influenced by surface air temperature (temperature of the air at a standard height above the ground). Radiative properties of the atmosphere, the availability and state of water, wind currents, surface albedo, solar angle, and clouds, for example, all are directly related to the temperature of the air within the planetary boundary layer (Willmott, 1987). Surface air temperature, in other words, is a "state" variable that expresses a current or integrated condition of the atmosphere within the boundary layer.

Due to its integrated nature, surface air temperature is used in a wide variety of climatological applications. Climate models, for instance, use surface air temperature in the estimation of ground, sensible, and latent heat fluxes as well as for computing atmospheric counterradiation (Washington and Parkinson, 1986). In turn, the model-simulated air temperature field often is used to evaluate the performance of these models. Climatic change too, allegedly induced by greenhouse gases, urbanization, or other environmental factors is manifested largely in the surface air temperature field (cf., Jones and Kelly, 1983; Jones et al., 1986; Hansen and Lebedeff, 1987). Other investigations employ surface air temperature to delineate weather types or climatic regions, estimate evapotranspiration, or evaluate human comfort (Oliver and Fairbridge, 1987). Owing to the importance of surface air temperature and our incomplete knowledge of it, improved representations continue to be needed, especially at the large scale.

Large-scale, surface air temperature climatologies have been deficient because of spatially uneven terrestrial station distributions, near complete absence of reliable oceanic measurements, and coarse grid resolutions. The air temperature climatology presented here represents an improvement inasmuch as it consists of a dense network of terrestrial stations and includes shipboard measurements. It may, in fact, be the highest resolution, global air temperature climatology available. Remotely-sensed estimates of surface air temperature are not considered since the technology is not yet mature and long-term means are not available. Their exclusion also allows this climatology to serve as an independent ground truth against which remotely-sensed data may be compared.

2. Station and Shipboard Observations

2.1 Terrestrial Measurements

Global archives of shelter-height air temperature have been compiled by Wernstedt (1972), Willmott et al. (1981), and the National Center for Atmospheric Research (Spangler and Jenne, 1984) and they are used in this study. Wernstedt (1972) and Willmott et al. (1981) encoded and published monthly climate averages for 10 687 and 13 461 stations, respectively. Monthly averages, however, had to be computed from 2 721 monthly time-series contained in the National Center for Atmospheric Research (NCAR) archive. Using only these three archives, adequate spatial coverage can be achieved for most of the terrestrial surface with the exceptions of Antarctica, Australia, New Guinea, China, and other parts of the Far East. To improve the spatial resolution in these regions, additional monthly averages were obtained from eighty-one stations in Antarctica (van Rooy, 1957; Schwerdtfeger, 1984), forty-eight stations in Australia and New Guinea (CSIRO, 1962–71; ADND, 1965), and 417 stations in China and the Far East (Nuttonson, 1947; Terjung et al., 1985).

Virtually all the data were used in order to achieve a dense spatial resolution. These data then do not represent climatic normals but, rather, they are based on time-periods of differing lengths. Most of the data were compiled between 1920 and 1980 and so this climatology is generally representative of that sixty-year period with a bias toward the data-rich latter years.

Potential coding errors were identified by interpolating monthly averages (see next section) for each station location using only the surrounding stations. When the absolute difference between a recorded and interpolated monthly value was greater than 5 °C, the recorded observation was checked for accuracy. Station location (i.e., the encoded latitude and longitude) also was evaluated to ensure that it was located within the recorded political division (country, state, or province). For the NCAR stations (which were recorded only to the nearest tenth of a degree), an atlas was consulted (Rand McNally & Co., 1980).

Monthly climatic averages for 27 415 stations then were merged into a single database. Many of the stations, however, were represented within more than one archive; therefore, it was necessary to combine or delete "redundant" records.

Redundant records either 1) had the same latitude and longitude or 2) were located within 0.05° of latitude and longitude from one another and had virtually identical station names. Airport and downtown stations, however, were not considered redundant. It also was assumed that no two records *within* a single source were redundant.

Redundant records were merged into a single record on the basis of record length. Each redundant record first was classified into one of three categories: 1) records for which the time period (dates) was known, 2) records for which only the total number of years was known, or 3) records of unknown duration. Redundant records of unknown duration were deleted in favor of dated records or those of known duration. When redundant records all were of unknown duration, arithmetic averages were taken to obtain the merged record. Duration only records were discarded in favor of dated records unless the dated record was of climatically short duration (i.e., less than ten years). Redundant duration-only records were merged by taking a weighted average where the number of years of record served as the weights. Dated records similarly were merged, that is, using the length of the non-overlapping portion of the records as the weights (Legates, 1987).

After editing and merging, 17 986 independent station records were obtained. Station locations are mapped on a cylindrical equal-area projection to facilitate the comparison and interpretation of regional station densities (Fig. 1). This simple projection translates latitude (θ_i) only (not longitude) according to

$$\theta_i' = \frac{\pi}{2} \sin \theta_i \tag{1}$$

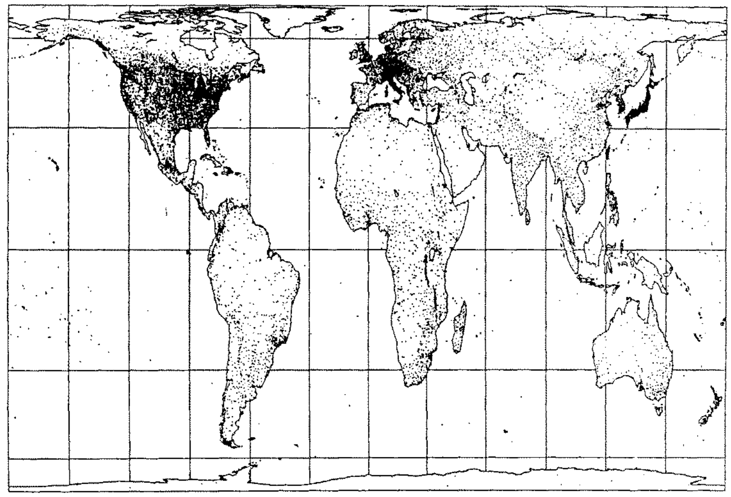

Fig. 1. Locations of the 17986 terrestrial air temperature stations contained in the edited and merged data set. Twelve mean monthly surface air temperatures are available for each station

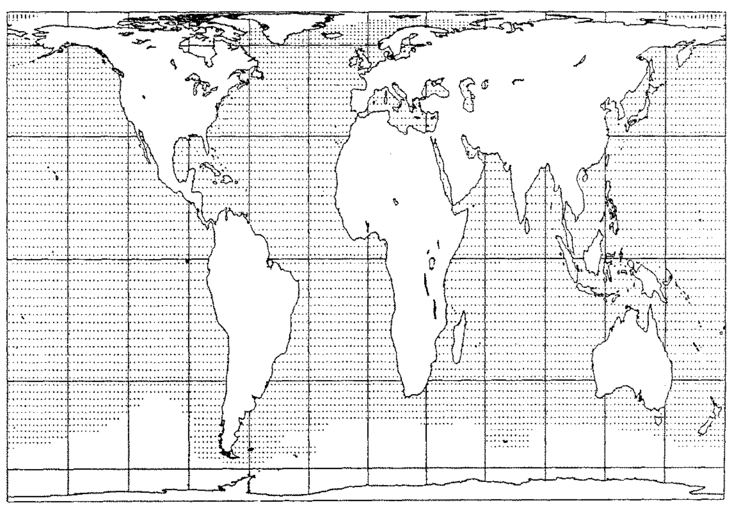

Fig. 2. Locations of the 6955 oceanic grid boxes for which median monthly air temperature was evaluated. Mapped grid-point locations are associated with the center of each 2° of latitude by 2° of longitude box

where θ_i' is the projected latitude. A relatively dense station network exists in the industrialized countries of North America, Europe, and East Asia. In arid, mountainous, and polar regions, however, low station densities are apparent.

2.2 Oceanic Estimates

Oceanic measurements of surface air temperature were taken from the Comprehensive Ocean-Atmospheric Data Set (COADS) for the period 1950–1979 (Fletcher et al., 1983; Slutz et al., 1985; Woodruff, 1985; Woodruff et al., 1987). Within COADS, nearly fifty-million shipboard reports were condensed into 6 955 median monthly estimates for 2° of latitude by 2° of longitude boxes (Fig. 2). After a compatibility evaluation (discussed below), these gridded median records were combined with the terrestrial station records. Even coverage is apparent for most of the world's oceans except for much of the Southern and Arctic Oceans.

Median air temperature, such as contained in COADS, can be used as an unbiased estimate of the mean air temperature. Legates (1987), for instance, has demonstrated that, for a global network of stations, median monthly air temperature differed from the mean by less than 0.1 °C fifty percent of the time and by less than 0.5 °C ninety-five percent of the time. Over the oceans, median air temperature, therefore, was assumed to be compatible with the terrestrial mean data and was used as a surrogate for that field.

2.3 Reliability Problems

Calculation of means from the daily minimum and maximum measurements often introduces a bias because of asymmetry in the diurnal variation of air temperature. Schaal and Dale (1977), for example, have demonstrated that mean daily air temperature computed from a single maximum and a single minimum (common practice for much of the world) may produce estimates that are different from the true (time-integrated) daily mean by as much as 1 °C. This error also can be accentuated by variations in the time of observation from place to place (Mitchell, 1958; Baker, 1975).

Jones et al. (1986) indicate that many non-first-order weather stations in the United States take more morning observations than evening observations. This translates into a decrease in the mean daily air temperature below the true value. Mean monthly estimates (averages of the daily means), therefore, will not adequately represent the true values. Jones et al. (1986) suggest transforming monthly averages "to anomaly values [calculated] from a common reference period" (p. 162). While this does not address the problem of removing bias from the reference period, it underscores this inadequacy in the mean field.

Changes in instrumentation, exposure, and station location are additional problems associated with long-term air temperature records (Jones et al., 1986). Many station moves, for instance, were documented in the NCAR data (Spangler and Jenne, 1984) – stations which moved more than 0.1° of latitude or longitude were in fact treated as different stations. Mitchell (1953) determined, however, that instrument and exposure changes have only a small effect on decadal averages at least within the United States. Environmental effects such as urbanization may have a more significant impact although their effects may be considered representative of actual changes in the ambient temperature field.

Variable thermometer heights are a potential source of discrepancy between the land and ocean measurements. On land, surface air temperature is usually measured at shelter-height – approximately four feet (1.22 meters) above the ground. Oceanic measurements of surface air temperature, however, are taken at a shipboard height of twelve meters (Woodruff, 1987). Since the lapse rate usually is small over the oceans (cf., Fleagle et al., 1958), differences between measurements taken at twelve meters and 1.22 meters should be rather small.

No viable means of correcting these biases on a global scale was apparent and, therefore, no correction was made. The existence of such biases in this and other large-scale data sets should be recognized, however, and this presentation of these data should be interpreted accordingly.

3. Grid-Point Interpolation

Station data and oceanic box averages then were interpolated to the nodes of a 0.5° of latitude by 0.5° of longitude lattice. Many procedures have been developed for interpolating grid-point values from irregularly-spaced data (cf., Lam, 1983; Bennett et al., 1984) although most were designed for interpolation at small spatial scales. At such scales, a flat or planar earth is a reasonable approximation. At large or global scales, however, this assumption is generally inappropriate. Willmott et al. (1985b) have shown, for example, that nontrivial interpolation errors can arise when these cartesian-based (planar) methods are used to interpolate large-scale climate fields. Here then the interpolation procedure must account for the sphericity of the earth.

Legates (1987) evaluated several spectral filtering and local-search procedures for use in interpolating global air temperature and precipitation. He concluded that the spherical adaptation of Shepard's (1968; 1984) numerical approximation method (discussed by Willmott et al., 1985b) was a reliable technique. This procedure, therefore, was used in the interpolations presented here.

An estimate of the temperature field, $\hat{T}$, at any point can be calculated using weighted averages (Willmott et al., 1985b) according to

$$\hat{T} = \frac{\sum_{i=1}^{N} W_i (T_i + \Delta T_i)}{\sum_{i=1}^{N} W_i} \tag{2}$$

where W_i is a weight, T_i is the observed average air temperature at latitude θ_i and longitude Φ_i, and ΔT_i is a term that accounts for the local spatial gradient. It (ΔT_i) also allows for the extrapolation of peaks and valleys beyond the range of the N nearby values of T_i. A selected number of "nearest neighbors" or closest points, N, is chosen to lessen the calculations. Following Shepard (1968), N ranges from a minimum of four to a maximum of ten – the actual number depends on the spatial distribution of these nearest neighbors.

Shepard's weight, W_i, can be written

$$W_i = S_i^{\gamma} (1 + D_i) \tag{3}$$

where S_i is the distance component and D_i is the directional component. All geometric calculations (e.g., of the distance and directional components) are made in spherical coordinates to account for the curvature of the earth. While Shepard used a value of 2.0 for γ, Legates (1987) determined that 0.95 is optimal for these air temperature data and, therefore, it is used here. Inclusion of the directional weight assures that clusters of nearest neighbors are not given an undue influence. Willmott et al. (1985b) give a more complete discussion of the spherical version of Shepard's algorithm and additional modifications are outlined by Legates (1987).

Using this algorithm, grid-point values of mean monthly surface air temperature were interpolated to the 0.5° by 0.5° lattice. Isotherms then were laced among the gridded temperatures and projected onto the same equal-area projection used for the station locations. Shading between the isotherms is used to enhance pattern recognition.

4. Global Surface Air Temperature

4.1 Annual Mean

Mean annual surface air temperature, as expected, is generally highest in low latitudes and decreases toward the poles (Fig. 3). Large regions having air temperatures greater than 27.5 °C are found in southern portions of the Sahara Desert and are especially pronounced over the oceans of Monsoon Asia. Over the southern Sahara, clear skies and small solar zenith angles combine with negligible evapotranspiration to produce very high surface air temperatures. High temperatures also are common in the western equatorial Pacific and the eastern Indian Oceans; in this instance, due to solar heating of already warm equatorial waters (U.S. Navy, 1981). Terrestrial mean air temperatures within this region (greater than 27.5 °C) are often cooler than oceanic areas due partially to relief – elevations commonly exceed 1 000 meters. Elevation also contributes to the south polar region being cooler than its northern counterpart.

Effects of warm and cold coastal currents can be seen in the Atlantic, Pacific, and Indian Oceans. Warm currents such as the Gulf Stream, Kuroshio, and Brazil Current increase the local surface air temperatures as well as the temperature gradients across coastlines. Marked average air temperature differences appear between offshore and onshore points that are just a few kilometers apart. Cold currents (mainly the California, Peru, Benguela, and Canaries Currents) decrease the local surface air temperatures and weaken north-south air temperature gradients.

Altitude also affects annual mean surface air temperature. Latitudinally anomalous low temperatures, for instance, are apparent over the

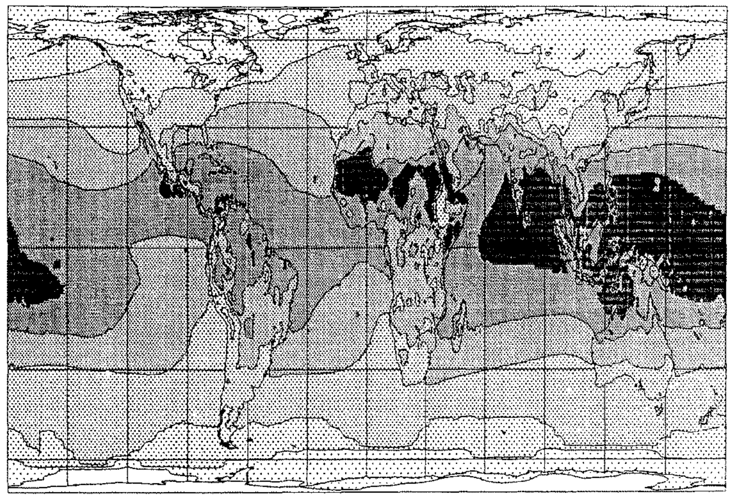

Fig. 3. Mean annual surface air temperature. Isotherms are −20.0 °C, 0.0 °C, 10.0 °C, 20.0 °C, 25.0 °C, and 27.5 °C. Areas with mean air temperatures below −20 °C are unshaded while areas with mean air temperatures greater than 27.5 °C are dark grey (e.g., over much of the western equatorial Pacific)

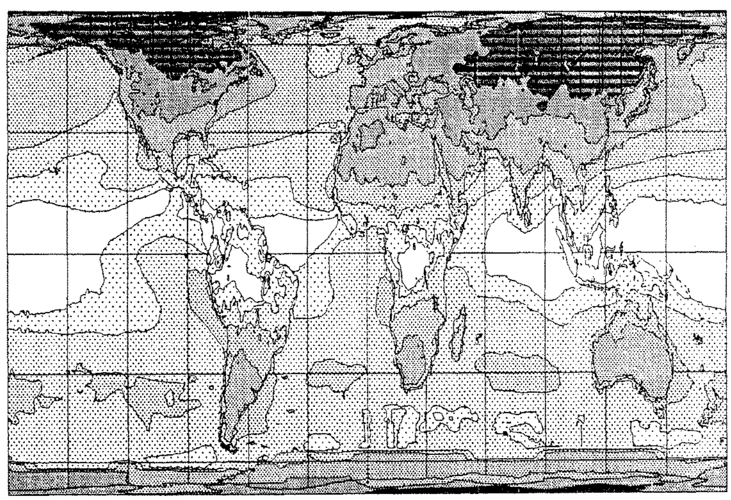

Fig. 4. Temporal standard deviations of the mean monthly surface air temperatures. Isotherms are 0.5 °C, 1.0 °C, 2.0 °C, 4.0 °C, 8.0 °C, and 12.0 °C. Areas with standard deviations less than 0.5 °C are unshaded while areas with standard deviations greater than 12 °C are dark grey (e.g., over Siberia)

Andes, Himalayas, Alps, and Rocky Mountains as well as over the high plateaus of Tibet, Iran, Ethiopia, and Brazil. Owing to the high-resolution of these data, even relatively small mountain ranges including the Pyrenees and the mountains of eastern Equatorial Africa exhibit their effects on surface air temperature. Mountainous islands such as New Zealand, Tasmania, New Guinea, Madagascar, Sri Lanka, and Sumatra also exhibit nontrivial decreases in average air temperature. Variations in mean annual air temperature are apparent even over small islands including St. Helena and the Cape Verde, Caroline, Fiji, Mariana, Marshall, and Solomon Island chains.

4.2 Average Intra-Annual Variation

Intra-annual variation in monthly surface air temperature is described by the temporal standard deviation of the twelve mean monthly values. The standard deviation field is inversely related to the annual mean field; that is, the largest values usually appear in high latitudes and the minimum is along the equator (Fig. 4). Within much of the intertropical convergence zone, deviations over the oceans are less than 0.5 °C while they exceed 12.0 °C poleward of the continental interiors of North America, Asia, and Antarctica. Intra-annual variations in surface air temperature generally are larger in the northern hemisphere owing to the greater land area.

The well-known moderating influence of the oceans on surface air temperature also is evident in the standard deviations. This effect is primarily a result of the oceans' 1) larger heat capacity, 2) lower albedo (except at high solar zenith angles), 3) increased latent heat exchange, 4) deeper penetration of sunlight, and 5) vertical mixing of heat. In addition to the large-scale manifestations of this effect (ocean-continent differences), it also is apparent at the small scale. Many small islands such as the Falkland, Canary and Mascarene Islands and New Caledonia, for example, exhibit greater temperature variations than the surrounding ocean.

In mid-latitudes, intra-annual variations in surface air temperature are smaller on the western side of each continent (e.g., Mediterranean Climate) than on the eastern side (e.g., Subtropical Humid Climate). Conversely, tropical climates exhibit smaller intra-annual variations on the eastern side (e.g., Tropical Wet-and-Dry Climate) than on the western side (e.g., Tropical Desert Climate). Atmospheric circulation patterns and the timing of precipitation (winter maxima for Mediterranean Climate; high-sun maxima for Tropical Wet-and-Dry) regulate the release of latent heat and establish these patterns.

While elevation plays an important role in decreasing the surface air temperature, its influence on the intra-annual variation appears to be minimal. The Alps, Atlas, Himalayas, Pyrenees, and the Great Dividing Range (Australia), for example, do not significantly alter the general poleward increase in intra-annual variation. A slight decrease is observed, however, along the front-range of the Rocky Mountains and along the Sierra Nevada.

Anomalous regions of high intra-annual variation are observed in the southern portions of the Pacific, Atlantic, and Indian Oceans. These areas occur near the center of the counter-clockwise, oceanic gyres that are prevalent at approximately 30° S. Although these anomalies are intriguing, we have found no physical basis for the enhancement of the seasonal variance in these regions. A possible explanation may be that the mean air temperatures averages for these areas are based on a relatively small number of ship traverses and may not adequately represent the true mean field. Anomalously low intra-annual variations that appear farther south are probably attributable to interpolation since almost no data exist in these areas (Fig. 2).

4.3 Seasonality

Using a lower-resolution subset of the 0.5° by 0.5° field, monthly mean surface air temperature was decomposed into the annual mean (Fig. 3) and the first two annual harmonics (Figs. 5 and 6). This subset is associated with (approximately) a 4° of latitude by 5° of longitude grid in the projected (θ_i') coordinates. All grid-point records were not evaluated because the spatial density of nodes is too high to effectively present in the form of a vector map (cf., Fig. 5).

Sabbagh and Bryson (1962) were among the first to use harmonic decomposition to evaluate a large-scale climate field (i.e., precipitation in Canada). Hsu and Wallace (1976) later used harmonic analysis to evaluate terrestrial precipita-

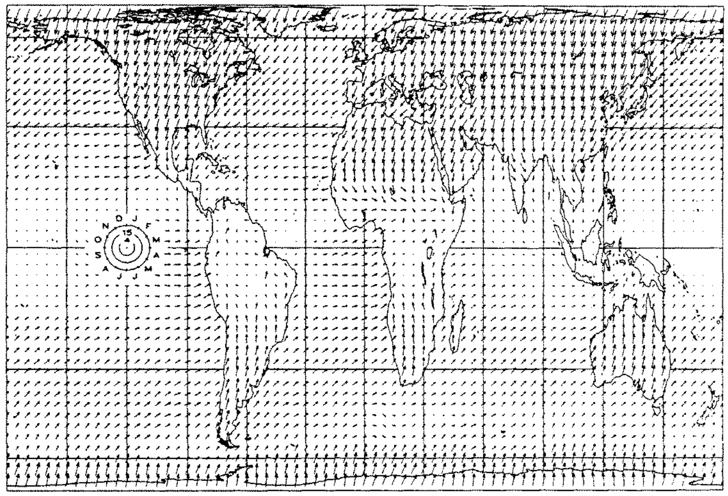

Fig. 5. First temporal harmonic of the average monthly air temperatures (°C). Amplitude is proportional to the length of the arrow (measured from the center of the scale/dial) while the occurrence of the maximum in time is given by its direction (edge of the scale/dial)

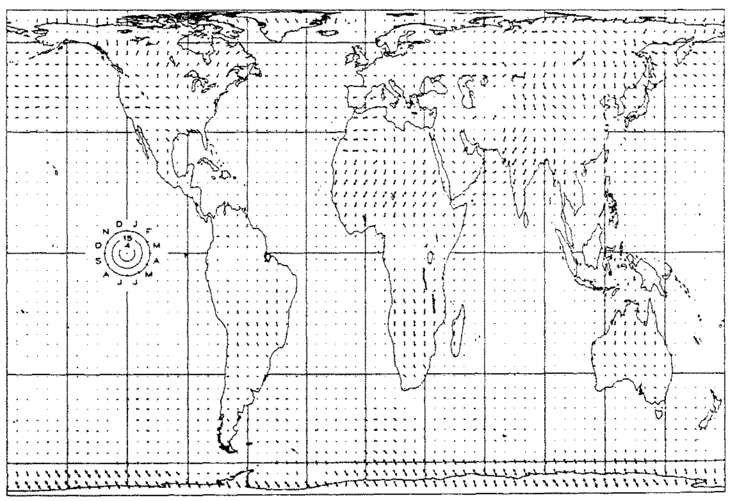

Fig. 6. Second temporal harmonic of the average monthly air temperatures (°C). Amplitude is proportional to the length of the arrow (measured from the center of the scale/dial) while the occurrence of the maxima in time is given by its directions (edge of the scale/dial)

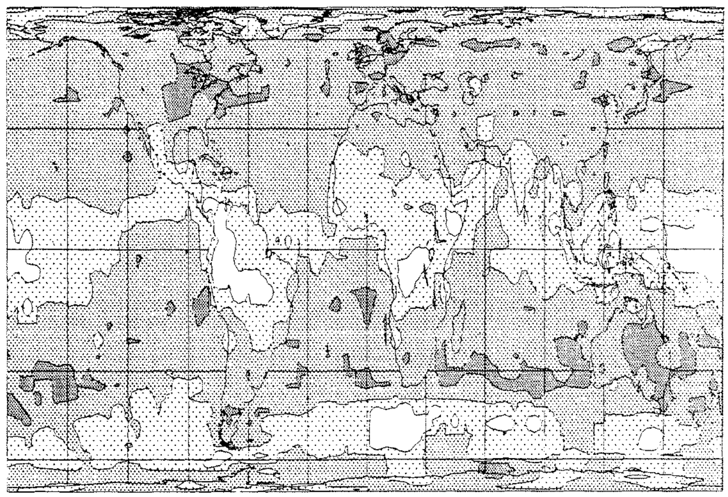

Fig. 7. Percent of the temporal variance explained in the mean monthly surface air temperatures (r^2) by the first two harmonics. Isolines are 90.0, 99.0, and 99.9 percent. Areas where r^2 is less than 90.0 percent are unshaded while areas where r^2 is greater than 99.9 percent are dark grey (e.g., over the central United States)

tion. Willmott et al. (1985a) also used harmonics to describe seasonal variations, albeit in snow cover, soil moisture, and evapotranspiration. Following Willmott et al., the amplitude and phase of the harmonics are shown as a vector (Figs. 5 and 6). The length of each vector (arrow) represents the magnitude (note the logarithmic scale) while the direction locates the occurrence in time of the maximum. A complete discussion of harmonic analysis is given by Rayner (1971).

More than 99.0 percent of the variation in mean monthly surface air temperature is accounted for by the first two harmonics. Explained variance (by the two harmonics) only falls below 90.0 percent for a few areas in the mid-latitudes of the southern hemisphere and in the tropics (Fig. 7). Other mid-latitude areas have greater than 99.9 percent of their variance explained. Another way to evaluate the goodness of fit is to consider the average magnitude of the residuals or the standard error. For air temperature, the variation left unaccounted for by the first two harmonics is less than or equal to 1.25 °C for any grid point.

Amplitudes of the first harmonic increase poleward and are larger over the continents than over the oceans at the same latitude (Fig. 5). This reflects the poleward increase in seasonality as well as the moderating influence of the oceans on temperature variation. The phase of the first harmonic approximates the time of maximum monthly air temperature – mid-July in the continental northern hemisphere and mid-January over the southern hemisphere continents. Maxima are delayed for nearly two months over the oceans.

Tropical regions are dissimilarly characterized by a weak double-maxima air temperature cycle. First harmonic maxima, therefore, are small in these areas. Monsoon climates (just poleward of the tropics) exhibit a maximum one or two months before the solstice. This occurs just prior to the onset of the rainy season which cools the air considerably. Equatorial oceans have weak maxima in late March or early April that are pronounced where little precipitation falls (cf., Legates, 1987). During this time, the Peru and Benguela currents are warmest which contributes to atmospheric warming.

The second harmonic explains only about one-quarter as much variance as the first (Fig. 6). In higher latitudes, particularly in the southern hemisphere, the amplitude of the second harmonic is relatively large and the maxima occur about two months prior (and four months later) than the first harmonic maxima. Dominance of the pronounced seasonal cycle and the rapid warming that occurs at the onset of summer are the probable causes. Amplitudes of the second harmonic also are quite large in the tropical deserts owing to the double-maxima air temperature cycle. Monsoon climates as well are characterized by a relatively large second-harmonic amplitude again owing to a double-maxima in the seasonal air temperature cycle.

5. Concluding Remarks

A relatively dense terrestrial network of long-term monthly surface air temperature stations has been compiled from existing sources, screened for coding errors, and redundant station records have been removed. Oceanic (monthly) grid-point averages augmented the terrestrial measurements. Station and grid-point data then were interpolated to a 0.5° of latitude by 0.5° of longitude lattice using a sperhically-based interpolation algorithm. These interpolated data are available on magnetic tape and may be obtained by contacting the authors.

Maps of the interpolated air temperature field confirm and precisely locate the higher temperatures in low latitudes and the gradients toward the poles. The large intra-annual variation in the polar regions as well as small variation in the tropics also is documented. Harmonic analysis (using a 4° of latitude by 5° of longitude subset of the 0.5° by 0.5° grid) reveals the geographic extent and timing of the mid- and high-latitude seasonal air temperature cycle. Terrestrial air temperature maxima occur approximately one month after the summer solstice while maxima are delayed by an average of two months over the oceans. A double-maxima air temperature regime characterizes the continental subtropics.

Acknowledgements

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STATEMENT OF ADAM MARKHAM, EXECUTIVE DIRECTOR, CLEAN AIR-COOL PLANET, PORTSMOUTH, NH

Good morning Mr. Chairman, and members of the committee. My name is Adam Markham and I am the executive director of Clean Air-Cool Planet, a small non-profit working to achieve reductions of greenhouse gas emissions in the Northeast. Thank you for inviting me here today to talk about likely impacts of continued climatic change.

New England is coming to end of what will almost certainly be the warmest winter on record, and much of the region has been in the grip of severe or extreme drought for many months. These individual weather events are not, in themselves, indicators of climate change but they are providing a taste of what climate change might bring. New Hampshire is currently experiencing the second worst drought in more than 100 years and Maine's last 12 months were the driest on record. Lake Winnipesaukee is at its lowest level in a generation, wells are running dry, and concerns are being raised about hydroelectric power shortages, fish populations and forest fire risk.

As with the rest of the country, we are experiencing a long-term warming trend. On average, New England has warmed by 0.7 °F since 1895. Winters have warmed more than summers, and the greatest warming has been in New Hampshire, Vermont and Rhode Island. Annual precipitation for the region as a whole has increased, especially in southern New England where the change has been more than 25 percent over the last century. More rain is falling in intense storms than in the past.

On the other hand, there has been a significant decrease (15 percent) in snowfall in northern New England since 1953. Snow is lying on the ground 7 days less than it was 50 years ago and the ice comes off lakes a few days earlier now than 100 years ago. Other documented indicators of a shorter winter include progressively earlier flowering of lilacs and the fact that frogs have advanced their spring calling by several weeks.

The New England Regional Assessment (NERA), which was carried out under the auspices of the U.S. Global Change Research Program and coordinated by Dr. Barrett Rock of the University of New Hampshire, was published in September 2001. Four years in the making, the report reviewed some of the risks associated with continued global warming. The warming scenarios described in the report suggest a likely 6–10 °F warming over the next century. In crude terms, such a change would result in Boston getting the climate of Richmond, VA in the best case, and that of Atlanta, GA in the worst case. Either way, the climate of New England would be irreversibly transformed with far-reaching and negative, economic and environmental impacts.

SUGAR MAPLE

Let me start by describing the threat to one of the icons of New England culture, and one that I know is close to Chairman Jeffords' heart—the sugar maple. According to all credible forest models, the sugar maple is one of the tree species most sensitive to warming temperatures. Business as usual emissions scenarios are almost certain to eventually drive the sugar maple northwards out of New England entirely. Even before that happens climate change will start to take a toll.

New England and New York produce approximately 75 percent of the maple syrup produced in the U.S. today. U.S. maple syrup production is worth more than $30 million annually. For Vermont, it is a more than $100 million industry with over 2,000 mainly family owned sugar producers. Many of these families have been careful stewards of these forests for generations and they have a strong interest in the legacy that is passed to their children and grandchildren. Maple trees take decades to mature and new stands are planted for the benefit of future generations. According to NERA this heritage and industry "may be irreparably altered under a changing climate". There are indications that sugar production tends to be better in colder years, and it is established that droughts during the growing season adversely affect production in subsequent years. For example, sugarmakers expect to see impacts of the current drought, which started last summer, in production numbers for this current season.

There is a very short time in the year when conditions are right for sugar production. Sap generally flows during late February and early March. Sugar bushes need a prolonged period of temperatures below 25 °F to convert starch to sucrose and to get high sugar content in the sap. A freeze/thaw cycle of cold nights and warm days (above 38–40 °F) is required to get the sap moving. When the nights no longer freeze the season is over.

According to Dr. Tim Perkins, Director of the Proctor Maple Research Center at the University of Vermont, sugarmakers are reporting that the season is starting earlier and earlier. Traditionally, in much of Vermont, tapping coincided with Town Meeting Day (the first Tuesday in March). But this is changing, and during the last decade approximately a quarter of Vermont's sugar production has occurred before Town Meeting Day. This year's warm winter triggered one of the earliest sugaring season starts anyone can remember.

With such a short window of opportunity, the decision on when to tap the trees is critical to successful production. Tap too early and you risk "drying out" the tree too soon, but tap too late and you may miss some of the best sap runs. By making the beginning of the season more unpredictable and increasing temperature fluctuations, global warming will make the decision on when to tap even more difficult.

There is little data available yet with which to predict more accurately the likely impacts of climate change on maple trees or its possible interplay with other threats to the maple industry, including acid rain, land-use change and pests such as the Asian longhorned beetle. The Proctor Maple Research Center plans to begin a vigorous program of research on global warming impacts in the very near future. High quality field data they have been collecting for a number of years will enable them to construct a computer model of sap flow in maple trees under varying conditions. This will then be used to simulate sap flow under various climate change scenarios to predict the effect on production.

SKIING AND WINTER SPORTS

Winter sports are especially vulnerable to global warming. Because of the strong relationship between winter skiing conditions, the number of customers, and subsequent successes or failures in the ski industry, a changing climate may have severe repercussions for New England's winter tourism economy. There are 80 ski resorts now operating in the region.

Although economic analyses for New England have been limited, studies from Canada suggest that global warming could have major economic impacts for the ski industry there. For example, one analysis indicated that an increase of 3.5–3.7 °C could decrease the number of skier days by 50–70 percent at resorts in Southern Quebec. This could mean a loss of up to $1.7 billion in revenue for Quebec.

A recent study by Brian Palm, a Dartmouth College alum and post-graduate student at Oxford University, of the past 19 years of weather data for Vermont and New Hampshire showed an average of 700,000 fewer ski visits in the years with the worst snow conditions.

Vermont and New Hampshire have the most ski-dependent economies in New England. Together, the two states receive approximately 6 million ski visits annually. Skiers generate some of the highest per capita spending of any tourists. In New Hampshire the industry generated $566 million in visitor spending in 2000. This spending is critical to the state government's budget, and in 2000 it accounted for nearly $58 million in tax revenue. The skiing industry also creates more than 10 percent of the winter jobs in New Hampshire.

Capital investment in the region's ski industry is highly significant and would be at risk from shorter winters and a warmer, less snowy climate. Recent single-season improvements at Sugarbush (VT) and Sunapee (NH) cost $28 million and $11 million respectively. Resort operators have increasingly had to make costly improvements to snowmaking technology to smooth out inconsistent winters. Vermont and ski areas increased the area covered by snowmaking by 15 percent in the last 12 years and resorts in New Hampshire spent $24.2 million to increase acres covered by snowmaking by 18 percent during the last decade. At Attitash in New Hampshire, snowmaking costs about $750,000 per year and accounts for approximately 20 percent of total operating costs.

In 2001, the November temperature for the Northeast averaged 43.6 °F, some 5.3 °F higher than the 107-year average. This was the third warmest November on record. In 2001, Killington Ski Resort, the largest area in the east, recorded its latest opening date in more than 15 years.

Downhill skiing is not the only winter recreation to be affected. This year, some cross-country skiing trails have been devoid of snow, and ice-skating and snowshoeing opportunities have been unusually few and far between. Ice fishing has been sparse or non-existent in southern New England and many snowmobiling trails have been closed for much of the season.

FOREST ECOSYSTEMS

Climate models predict that in the longer term global warming will eventually transform the conifer forest of northern New England into the type of forest now found farther south—either the deciduous forest of the Mid-Atlantic States, or the mixed forests characteristic of southern New England.

The conditions that currently support northern hardwood forests will shift up to 300 miles north during the next 100 years, causing the loss of these forests over much of the landscape. The distributions of white spruce, black spruce, red spruce, balsam fir and other species of cool climates will move north and these trees are likely to disappear from most of their current ranges in the Northeastern United States. If disturbances such as fire or storms increase as has been predicted by some scientists, this would hasten the decline and facilitate the northward spread of southern species like oak and hickory.

More than 300,000 people in New England and New York are employed in the forestry and forest products sector. Milder winters will likely increase the vulnerability of commercial forests to insect pests including eastern spruce budworm, gypsy moth and pear thrips. Any economic losses are likely to disproportionately affect smaller, non-industrial private landowners. More than 250,000 private forest landowners are likely to be affected in New England alone.

Global warming will tend to favor opportunistic, fast-moving and adaptable species. It is likely to prove to be a boon for many pests and invasive species that threaten regional biodiversity. Purple loosestrife, garlic mustard, Tartarian honeysuckle and Morrow honeysuckle are some of the troublesome non-native species that are predicted to benefit as others decline or disappear.

Higher summer temperatures and increased pollution from road traffic will likely contribute to greater ground-level ozone formation with the effect of reducing forest productivity and harming commercial tree species like red spruce and white pine. Ozone impacts are expected to be worst in southern New York and central and southern New England.

Changing temperature and precipitation patterns could harm the multi-million dollar fall foliage industry by muting autumn colors. Without sugar maple the autumn experience in New England would be very different. Fall-foliage tourism accounts for 20–25 percent of total annual tourism in Vermont and Maine. NERA estimated that a 50 percent drop in fall foliage tourism could result in approximately 20,000 job losses.

Climate change is a significant threat to the forest and alpine ecosystems of the most important public lands in the region, including Acadia National Park, the Allagash Wilderness Waterway, Baxter State Park, the White Mountains National Forest, and the Mount Washington State Park.

WILDLIFE IMPACTS

For some animals and plants, climate effects could prove to be disastrous. Many species characteristic of the northern forest will be forced to find new habitat as climate changes. Species already living at the southern edges of their ranges—like martens, fishers and snowshoe hares—will be among the most affected. Bird species that live in northern spruce and spruce/fir forests, including the gray jay, boreal chickadee, spruce grouse and the threatened Bicknell's thrush, are particularly vulnerable to diminished habitat in New England.

A modeling study published by The World Wildlife Fund and Clean Air-Cool Planet in 2000, shows the habitats of the Northern Forest of New England and upstate New York to be especially vulnerable to climate change. According to this study up to 44 percent of Maine's, and 35 percent of New Hampshire's, existing terrestrial habitats are likely to be transformed into other ecosystem types under the most credible climate scenarios. In the most heavily impacted areas, the rates at which plant and animal species may be required to shift their ranges in response to global warming in the next 100 years may be as much as ten times faster than at the end of the last ice age.

According to a recent report by the American Bird Conservancy and the National Wildlife Federation, a great many species of birds will be affected by climate change. Birding has become a major recreational activity in recent decades, with far-reaching economic consequences. In New England alone, in 1996, people spent more than $ 1.8 billion feeding and watching birds and other wildlife.

Several species of wood warbler are expected to extend their ranges northwards, perhaps by hundreds of miles, while disappearing at the southern edges of their current ranges. Five species, including the bay-breasted warbler and Cape May warbler are predicted to disappear from New England entirely. These birds help to keep spruce budworm outbreaks in check by consuming millions of larvae during the breeding season. If they are pushed northwards many forests could become much more vulnerable to insect pests. A study of 35 North American warbler species showed that 20 percent of them have already shifted their ranges an average of 65 miles northwards during the last 25 years.

PUBLIC HEALTH

The White Mountains are within a day's drive of 77 million people and receive more visitors (7–8 million) every year than Yellowstone and Yosemite national parks combined. Recreational visitors in some of these areas may suffer increased health risks as a result of global warming. Sixty thousand hikers a year visit Mount Washington and the major peaks for the White Mountains. On hot summer days there are often high levels of ground-level ozone, particulates and acid aerosols. All of these pose a threat to hikers. According to NERA, there is a striking correlation between hot days (warmer than 90 °F, sunny skies and high levels of ozone pollution. Because long-distance transport of air pollutants appears to occur at the boundary between the mixing layer and the stable layer of the troposphere, at around 3,200 feet, hiking at these elevations or higher may expose hikers to damaging concentrations of dangerous air pollutants not experienced lower low down. According to a study by Harvard Medical School, the Harvard School of Public Health and the Appalachian Mountain Club, prolonged exposure to levels of ozone often encountered on trails in the White Mountains can reduce lung function and is especially damaging to people with a history of asthma or other respiratory problems.

Also a risk for people outdoors, even on the golf course or in their backyards is Lyme disease, which is already on the increase in New York and parts of New England. If undetected, the disease can lead to permanent neurological disability. Because it is passed along to humans by ticks, Lyme disease poses a special threat to people who enjoy outdoor pursuits like hiking, birding and fishing. Swedish research on ticks suggests that warmer winters could increase the incidence of the disease and push its potential range further into northern New England.

Heat waves kill more people in the United States than hurricanes, flooding or tornadoes. Dr. Laurence Kalkstein, Associate Director of the Center for Climatic Research at the University of Delaware has suggested that heat-related deaths in the summertime could double under likely U.S. global warming scenarios. Northern cities are especially vulnerable to heat waves because people are not used to, or acclimated to, high temperatures and humidity. Also building design in the north is more oriented toward keeping heat in during the winter than letting it out during the summer. The elderly and low-income households in urban areas are at highest risk.

COASTAL COMMUNITIES & FISHERIES

The costs of climate impacts in the coastal zone may be particularly large. Sea levels are currently rising at about a foot per century. This rate is increasing and New England coastal communities will likely have to deal with sea level rise of around two feet this century. The State of New Hampshire has calculated that this will massively increase the area of the Seacoast vulnerable to flooding and could turn 100-year storms into 10-year storms. According to the U.S. Environmental Protection Agency (EPA) a two-foot sea level rise would inundate about 10,000 square miles of coastline. Costly beach nourishment and shoreline armoring is already transforming the coast of New England. A three-foot sea level rise would result in half of our natural wetlands and beaches being lost and replaced with armored shores. Coastal development is rapidly closing off the option of natural retreat for many wetlands.

Coastal marine ecosystems and fisheries are also at risk. Warmer temperatures are expected to increase the incidence of toxic algal blooms and help the spread of warm water diseases of shellfish such as oysters. Winter seawater temperature in Narragansett Bay have already warmed by more than 5 °F since 1960 and winter flounder populations have been in decline for 25 years. The flounders migrate inshore in the late fall and spawn in early spring. Winter flounders are adapted for low water temperatures in which most fish can't survive and warm winters are hypothesized to be harming populations through reduced hatching rates and increased predation on larvae.

SOLUTIONS & LEADERSHIP IN THE NORTHEAST

The Northeast States have long been leaders in reducing air pollution. The region also is now beginning to lead the way in responding to global warming.

• In 2000, New York was the first state to enact a law promoting environmentally friendly and energy efficient building practices through tax incentives

- In 2001, Massachusetts Governor Jane Swift signed a new multi-pollutant regulation making the state the first to control CO_2 emissions from existing power stations.
- New Hampshire was the first state to create a voluntary registry for greenhouse gas emissions and a bi-partisan 4-pollutant bill was recently passed in the House.
- The Connecticut Clean Energy Fund is at the forefront of efforts to support the development of commercial fuel cell technologies.
- Efficiency Vermont is the Nation's first public utility dedicated solely to achieving energy efficiency improvements.

In August 2001, the New England Governors and Eastern Canadian Premiers signed a Climate Change Action Plan with the long-term goal of reducing greenhouse gases by 75–85 percent from current levels. The Governors and Premiers concluded that global warming's "multiple impacts will have substantial consequences for the cost and quality of life of the region's citizens". They noted that U.S. national CO_2 emissions have been growing more than 1 percent a year and stated "Given these increases in the face of doing nothing, this plan seeks to reverse the trend."

Northeast leadership is not restricted to the states, however. Thirty-five cities and counties in the region have joined the Cities for Climate Protection Program of the International Council for Local Environmental Initiatives. These municipalities have all passed resolutions pledging to reduce greenhouse gas emissions and implement local climate action plans. For example, Burlington Vermont has adopted an ambitious plan—the "10 percent Challenge"—to reduce the city's greenhouse gas emissions by 10 percent from 1990 levels by 2005.

Colleges and universities throughout the region are doing their part too. Tufts University has pledged to meet or beat the Kyoto Target. Clean Air-Cool Planet has worked with the University of New Hampshire to produce the most detailed greenhouse gas emissions inventory carried out for any college in the country—the precursor to a campus-wide climate plan. Similar projects are underway with the University of Vermont and Bates College in Maine. Students at Connecticut College have voted with their pocketbooks and signed the campus up for green electricity.

Many businesses in the Northeast are showing the way for the corporate sector. IBM (NY) and Johnson and Johnson (NJ) were the first to set ambitious greenhouse gas reduction targets as members of the Climate Savers program of World Wildlife Fund and the Center for Energy and Climate Solutions. Pitney Bowes (CT) is a leader in developing corporate markets for green power and Timberland (NH) has partnered with Clean Air-Cool Planet and Vermont-based NativeEnergy to invest in new wind energy and permanently retire the CO_2 credits from tradable renewable energy certificates (T–RECS). Other companies are convincingly demonstrating that common sense investments in energy saving can pay off handsomely.

For example, Massachusetts-based Shaw's Supermarkets has 185 stores and employs nearly 30,000 people in New England. In 2000, Shaw's realized $3.7 million from energy savings alone. Typically, a supermarket would have to sell $150 million worth of groceries to make that much money.

New York-based Verizon is another important leader in energy conservation. Its efforts are now producing $20 million a year in net savings. Verizon's projects range from encouraging employees to turn off personal computers when not in use (saving approximately $50 in energy costs for each PC each year), and removing more than 200,000 unnecessary lights, to carrying out energy audits in more than 500 buildings and developing fuel cell systems.

NEED FOR FEDERAL ACTION TO CONTROL CO_2

These stories are just the tip of the iceberg. All over New England and the Northeast, individuals, institutions and corporations are inventing, exploring and implementing innovative solutions to climate change. But this is not enough. John Donne famously said "no man is an island; entire of itself. Every man is a piece of the continent, a part of the main". No individual, no city, no State and not even a region as big as a middle-sized nation, as the Northeast is, can solve the problem of climate change on its own. As everyone knows by now, the United States is the world's largest single emitter of greenhouse gases. Without action by the United States we cannot hope to stabilize the world's climate. Without national legislation, regional efforts such as those in the Northeast will founder and ultimately fail.

A strong national response to climate change and a modern energy policy are both crucial if we are to continue to grow our economy, strengthen the country's energy security and act as responsible stewards of our environment.

Energy efficiency and alternative fuels are the real routes to energy security, not drilling in pristine wilderness areas. If we are serious about reducing our reliance on foreign oil and about competing in world markets we must produce more efficient automobiles. If we want energy security and more jobs we should aim to be producing 20 percent of our electricity for renewable resources—wind, solar, biomass and geothermal—by the year 2020.

Federal controls on CO_2 are essential and urgently needed. By dealing with all four pollutants at once and promoting energy conservation the Clean Power Act can save us tens of millions of dollars in comparison to three pollutant strategies that focus only on end of pipe solutions and ignore carbon dioxide. Local and regional leadership such as is commonplace in the Northeast is important and groundbreaking. But, there can be no substitute for coordinated national action, and eventually, economy-wide controls on CO_2.

Despite the fact that there is considerable uncertainty about the precise costs of impacts of climate change on New England, there is very little doubt that it will have a transformative effect on many of the attributes that make the region unique. The loss of sugar maples, changes in the northern forest, warmer winters, more frequent heat-waves and destruction of coastal wetlands will radically diminish the New England experience and may ultimately deliver a body blow to elements of the region's economy.

Thank you for inviting me to testify before you today. I would be happy to try to answer any questions you may have.

RESPONSES BY ADAM MARKHAM TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. Your testimony illustrated well the potential environmental and economic impacts facing New England in a warmer climate, and you also enlightened us about current pro-active business projects aimed at lowering greenhouse gas emissions. In your experience, what reasons have these companies given to explain their motivation for early action on energy conservation and climate change mitigation?

Response. In my experience, the prime motivation has been a recognition that by seeking to reduce wasteful energy use, a company can invariably save significant amounts of money. Bottom-line benefits translate to increased shareholder value and confidence and often to increased competitiveness in the market. Other reasons we often hear include:

- Wanting to be seen as an environmentally responsible
- Certain actions, such as increased day-lighting in buildings help with worker productivity and employee retention
- Increasing business efficiency
- Recognition that customers want to buy from environmentally responsible companies
- Getting ahead of potential future legislation
- Taking advantage of available new technologies

Question 2. The findings of the New England Regional Assessment are very disturbing. The assessment describes a significantly changed regional environment. What do people in New England think about it?

Response. It is difficult to answer this question with more than anecdotal information as I know of no recent New England specific public opinion work on this topic. But on the evidence of newspaper articles, letters to the editor and many conversations with people in a variety of sectors, as well as national opinion polls and focus groups, I would say that people are generally convinced that global warming is happening, that it is a serious problem and that we ought to do something about it, sooner rather than later. In New England, there is growing concern about shorter winters and the potential for increased drought and worse snow and ice conditions. In southern New Hampshire, where I live, at least, it is a common topic of conversation that winters are warmer than they used to be and that summers appear hotter and drier, with worse air pollution. People are particularly worried about the threat to coasts, forests and public health. New Englanders appear to feel that there is a lack of commitment to solving this problem in Washington, and in common with people in many parts of the country they lay much of the blame on the oil and auto industries.

Question 3. Has this year's unusual weather and the drought in the Northeast encouraged people to pay closer attention to climate change issues?

Response. I don't think there can be any doubt that the current drought and a series of unusual and extreme weather events over the last few years have made many people think much more seriously about the potential consequences of climate change. Of course, no single weather event can be attributed to global warming, but people see a pattern of change that is beginning to concern them.

Question 4. As you and all the other witnesses indicated, it is not safe to continue increasing greenhouse gas emissions without limit. What needs to be done to assure that we can avert the point of no return or "dangerous levels" of greenhouse gas concentrations?

Response. I believe that we need to take immediate action to reduce greenhouse gas emissions. The current Senate 4-pollutant bill would be a very important step forward if passed into law. Strengthened CAFE standards are also an essential element of a strategy to prevent dangerous levels. We will eventually also need economy-wide measures to reduce greenhouse gases. In the near future we need to see renewable portfolio standards and strong appliance efficiency standards as well as increased incentives for the development and marketing of renewable energy technologies and building energy efficiency.

Question 5. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. The greatest risk is that we fail to act urgently and responsibly to begin reducing greenhouse gas emissions. Failure to act will lock us into accelerating sea-level rise causing massive economic losses in the coastal zone and increased loss of habitat and species extinction. The most feasible way to reduce the risk is to regulate CO_2 first from power stations and then economy-wide, while at the same time giving incentives for energy efficiency and the development and use of renewable technologies and alternate sources of energy.

RESPONSES BY ADAM MARKHAM TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th Century, the atmospheric concentrations of a number of greenhouse gasses have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

Response. I do agree with that statement, based on the conclusions of the Third Assessment Report of the Intergovernmental Panel on Climate Change and the recent review by the National Academy of Sciences.

Question 2. Dr. Pielke testified that "the primary cause for . . . growth in impact[] is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se." Do you agree with this claim? Why or why not?

Response. While it is true that human and environmental systems are increasingly vulnerable to climate change and variability, I do not believe that this is the primary cause of growth in impacts (except perhaps in the particular case of fast developing coastal areas). For example, worldwide glacier recession, melting permafrost and unprecedented bark beetle infestation in Alaska, earlier Northern hemisphere spring and changes in species distribution are entirely independent of human vulnerability.

Question 3. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought. . . ." Do you agree with that proposition? Why or why not?

Response. In general I do not agree with this statement. However, it is certainly true that we need to increase and expand our research efforts to understand the impacts of climate change. Improving the ability of computer models to simulate future potential climate scenarios is an essential part of this effort. I do agree that we are not well served arguing "yes or no" about global warming. There is clear scientific consensus that we are already experiencing human induced global warming.

Question 4. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. Yes, I believe we should fully implement the Kyoto Protocol. As far as I know the 6/100 of a degree figure is not within the generally accepted range of impacts of the Kyoto Protocol, but I have not specifically reviewed the paper in question. Nevertheless, it is generally accepted that the Kyoto Protocol targets are merely first steps toward reaching the levels of atmospheric greenhouse gas concentrations that we need to stabilize at. The Kyoto Protocol contains review mechanisms to allow policymakers to react to new scientific findings.

Question 5. In the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B," that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. I have no expert knowledge on this question.

Question 6. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty; Coping with the risks of climate change" (copy attached). Please explain why you agree or disagree with the following assertions or conclusions from that report:

Response. "There is not one problem but two: natural climate variability and the influence of human activity on the climate system."

This statement is undoubtedly true and it is highly significant that the insurance industry has recognized the addition of the new threat of human-induced climate change.

". . . it is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted."

I agree that under natural climate variability and in the case of increased vulnerability due to global warming, it is not possible to accurately predict the worst case scenario for any individual weather event in a particular place. We can, however, prepare for the likelihood of hanges infrequency and intensity of extreme events in general and should expect to have to deal with worse impacts in the future. Risk minimization can no longer be assessed in the expectation of a continuing stable climate.

"Swiss Reconsiders it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which—if they are not confirmed—will in time turn to carefree relief, and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind."

I agree that we should not over-emphasize worst case scenarios and I agree strongly that short-term expediency should not lead anyone to ignore or play down the potential impacts of climate change. We should provide the best possible information to the public and policymakers about the full range of potential scenarios and impacts.

Question 7. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. Vulnerability to extreme weather seems to be increasing. This is likely because of changes in demographic patterns and, particularly, increased development pressures in sensitive ecosystems and coastal areas.

RESPONSES BY ADAM MARKHAM TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. If such a target was adopted (as I believe it should be in order to safeguard U.S. ecosystems, communities and economic well-being) these caps would be the subject of negotiations among the ratifying parties to the Kyoto Protocol. The United States has given notice of its intent not to participate in such negotiations, nor abide by their results.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis.

Response. I am not personally aware of any recent economic analysis of this sort.

Question 2. Do your projections of impacts on New England depend on foreign models?

Response. Some of the research results outlined in my testimony are based on foreign models, others are not. The New England Regional Assessment was carried out under the auspices of the U.S. Global Change Research Program and at the time of it's initiation, the best available models were Canadian and British. If carried out today, the best available models would certainly include the newest U.S. versions.

Other studies dealing with Impacts of climate change on sugar maple forests, sea level rise and ecosystems outlined in the report use both foreign and U.S. models but rely mainly on U.S. developed climate models.

Question 3. Do your projections of impacts depend on using models to project regional and local climate change?

Response. Most projections of potential climate impacts rely on model scenarios. The computer models provide the best available tools for creating plausible future climate scenarios in order to undertake risk and sensitivity analyses. Model scenarios do not provide predictions of future climate, only potential scenarios, based on best current knowledge and analytical capability.

Question 4. What happens if the climate effects are lower than the lowest scenario in the NERA study?

Response. Presumably there would be a different set of impacts from those analysed in NERA, just as there would be if the climate effects were higher than the highest scenario. NERA assessed a middle range of scenarios, not the highest or lowest.

Question 5. Please provide your most recent filings of Form 990's.

Response. Provided separately by fax. (Copy retained in the committee's file.)

Response by Adam Markham to an Additional Question from Senator Campbell

Question. You have given us multiple examples of the impacts of climate change in New England and I am sure many of these would apply to the rest of the country as well. My question to you is this: if we don't know whether human activity is a direct cause of the global change in climate, how can we make any determination that a change in the energy policy of the United States could effectively prevent it from continuing? Let's assume that we can't. Wouldn't it also be of great value for us to find ways to reduce our vulnerability to climate change?

Response. Current scientific consensus is that emissions released to the atmosphere as a result of human activities are increasing atmospheric concentrations of greenhouse gases and that this is the most likely cause of observed global warming during the last century. The primary source of anthropogenic greenhouse gases is the burning of fossil fuels so it stands to reason that changes in energy policy would impact global warming.

I believe we should attempt to both reduce the source of the problem and reduce our vulnerability to its impacts.

Statement of Dr. Sallie Baliunas, Astrophysicist, Harvard-Smithsonian Center for Astrophysics

Fossil fuels currently provide around 84 percent of energy consumed in the United States, and roughly 80 percent of the energy produced worldwide. Those energy resources are key to improving the human condition and the environment.

Human use of fossil fuels has increased the amount of greenhouse gases, in particular, carbon dioxide, in the atmosphere. Carbon dioxide is essential to life on Earth. Moreover, the greenhouse effect is important to life on Earth in that the greenhouse gases help retain energy near the surface that would otherwise escape to space. Based on ideas about how climate works, the small additional energy resulting from the air's increased carbon dioxide content should warm the planet.

Projections of future energy use, applied to the scientifically most sophisticated computer simulations of climate, have yielded wide-ranging forecasts of future temperature increases from a continued increase of carbon dioxide concentration in the air. These have been compiled by the United Nations' Intergovernmental Panel on Climate Change (IPCC). The middle range forecast of their estimates of future warming, based on expected growth in fossil fuel use without any curbs, is for a 1 degree Celsius increase between now and 2050. A simulation counting in the effect of the as yet unimplemented Kyoto Protocol, negotiated in 1997 and calling for a worldwide 5 percent cut in carbon dioxide emissions from 1990 levels, would reduce that increase to 0.94C—an insignificant 0.06C cut (Figure 1). That means if increased atmospheric concentrations of carbon dioxide are a major problem, then much steeper cuts than those outlined in the Kyoto Protocol are warranted.

One key scientific question is: What has been the response of the climate thus far to the small amount of energy added by humans from increased greenhouse gases in the air? To prove the reliability of their future forecasts, computer simulations need verification by testing past, well-documented temperature fluctuations. New Federal investment in technology, especially that of space-based instrumentation, has helped address the issue of observed response of the climate to the air's increased greenhouse gas concentration. Two capitol tests of the reliability of the computer simulations are the past decades of surface temperature and lower troposphere change.

RECORD OF SURFACE TEMPERATURE

In the 20th century the global average surface temperature (Figure 2) rose about 0.5C, after a 500-year cool period called the Little Ice Age. The uncharacteristic cold had followed a widespread warm interval, called the Medieval Warm Period (ca. 800—1200 C.E.). The 20th century warming trend may have a human component attributable to fossil fuel use, which increased sharply in the 20th century. But a closer look at the 20th century temperature shows three distinct trends:

First, a strong warming trend of about 0.5C began in the late 19th century and peaked around 1940. Next, the temperature decreased from 1940 until the late 1970's. Recently, a third trend has emerged—a modest warming from the late 1970's to the present.

Because about 80 percent of the carbon dioxide from human activities was added to the air after 1940, the early 20th century warming trend had to be largely natural. Human effects from increased concentrations of greenhouse gases amount to at most 0.1C per decade—the maximum amount of the surface warming trend seen since the late 1970's. This surface warming would suggest a temperature trend of about 1C per century, which is less than that predicted by the computer simulations of the air's increased human-made greenhouse gas content. Accumulated over a century, civilization will readily adapt to such a modest warming trend. However, the recent trend in surface warming may not be primarily attributable to human-made greenhouse gases.

RECORD OF LOWER TROPOSPHERE TEMPERATURE

Computer simulations of climate in which the air's greenhouse gas concentrations increase owing to human activities predict detectable warming not only near the surface but also in the layer of air above the surface, the lower troposphere, which rises in altitude from roughly two to eight kilometers. Records from NASA's Microwave Sounder Units aboard satellites extend back 21 years and cover most of the globe (Figure 3). The satellite-derived record is validated independently by measurements from NOAA balloon radiosonde instruments, and those records extend back over 40 years (Figure 4). Those records show that the temperature of the lower troposphere does vary, e.g., the strong El Niño warming pulse of 1997–98 is obvious. However, no meaningful human warming trend, as forecast by the computer simulations, can be found.

The radiosonde record from balloons confirms the results of the satellites. Although the radiosonde record lacks the dense spatial coverage from satellites, the radiosonde record extends back to 1957, a period that includes the recent rapid rise in the air's carbon dioxide concentration. The balloon record shows no warming trend in global average temperature prior to the dramatic shift in 1976–77. That warming, known as the Great Pacific Climate Shift of 1976—1977, is not attributable to human causes but is a natural, shift in the Pacific that occurs every 20 to 30 years, and can affect global average temperatures.

When compared to the observed response of the climate system, the computer simulations all have forecast warming trends much steeper over the last several decades than measured. The forecasts exaggerate to some degree the warming at the surface, and profoundly in the lower troposphere.

The complexity of the computer simulations of climate is one reason the forecasts are unreliable.[1] The simulations must track over 5 million parameters. To simulate climate change for a period of several decades is a computational task that requires 10,000,000,000,000,000,000 degrees of freedom. To improve the forecasts, much better information is required, including accurate understanding of the two major, natural greenhouse gas effects—water vapor and clouds.

NATURAL CLIMATE VARIABILITY: THE SUN'S INFLUENCE

Given the lack of an observed warming trend in the lower troposphere, the result is that most of the surface warming in recent decades cannot owe to a human-

[1] W. Soon, S. Baliunas, S.B. Idso, K. Ya. Kondratyev and E.S. Posmentier, 2001, "Modeling climatec effects of anthropogenic carbon dioxide emissions: unknowns and uncertainties," Climate Research, 18:259–275. See attached.

caused enhanced greenhouse effect. What might cause the surface warming, especially in the early 20th century when greenhouse gases from human activities had not significantly increased in concentration in the atmosphere? The 20th century temperature pattern shows a strong correlation to energy output of the sun (Figure 5). Although the causes of the changing sun's particle, magnetic and energy outputs are uncertain, as are the responses of the climate to the Sun's various changes, the correlation is pronounced. It explains especially well the early 20th century warming trend, which cannot have much human contribution.

Based on the key temperature measurements of the last several decades, the actual response of the climate to the increased concentration of carbon dioxide and other human-made greenhouse gases content in the air has shown no significant man-made global warming trend. The magnitude of expected human change is especially constrained by the observed temperature trends of the lower troposphere.

This means that the human global warming effect, if present, is small and slow to develop. That creates a window of time and opportunity to continue and improve observations and computer simulations of climate to better define the magnitude of human-made warming. Proposals like the Kyoto agreement to sharply cut greenhouse gas emissions are estimated in most economic studies to have enormous economic, social and environmental costs. The cost estimates for the United States alone amount to $100 billion to $400 billion per year. Those costs would fall disproportionately on America's and the world's elderly and poor.

FIGURE CAPTIONS

Figure 1—Forecast of year-to-year temperature rise from years 2000 to 2050 C.E. (thin line) assuming an increase in the air's greenhouse gas concentration from human activities, based on the Hadley Center's model (UKMO HADCM3 IS92A version). The upper line (labeled "Without Kyoto") is the linear trend fit to the model's forecast temperature rise, without implementation of the Kyoto Protocol. The lower line is the estimate of the impact on temperature with the implementation of the Kyoto Protocol. By the year 2050, around 0.06C global warming is averted by the implementation of the Kyoto Protocol.

Figure 2—Surface temperature changes sampled worldwide and analyzed by Cambridge Research Unit (CRU) and NASA-Goddard Institute of Space Studies (GISS). The pattern of 20th century temperature change has three distinct phases: an early 20th-century warming, a mid-century cooling, and a late 20th-century warming.

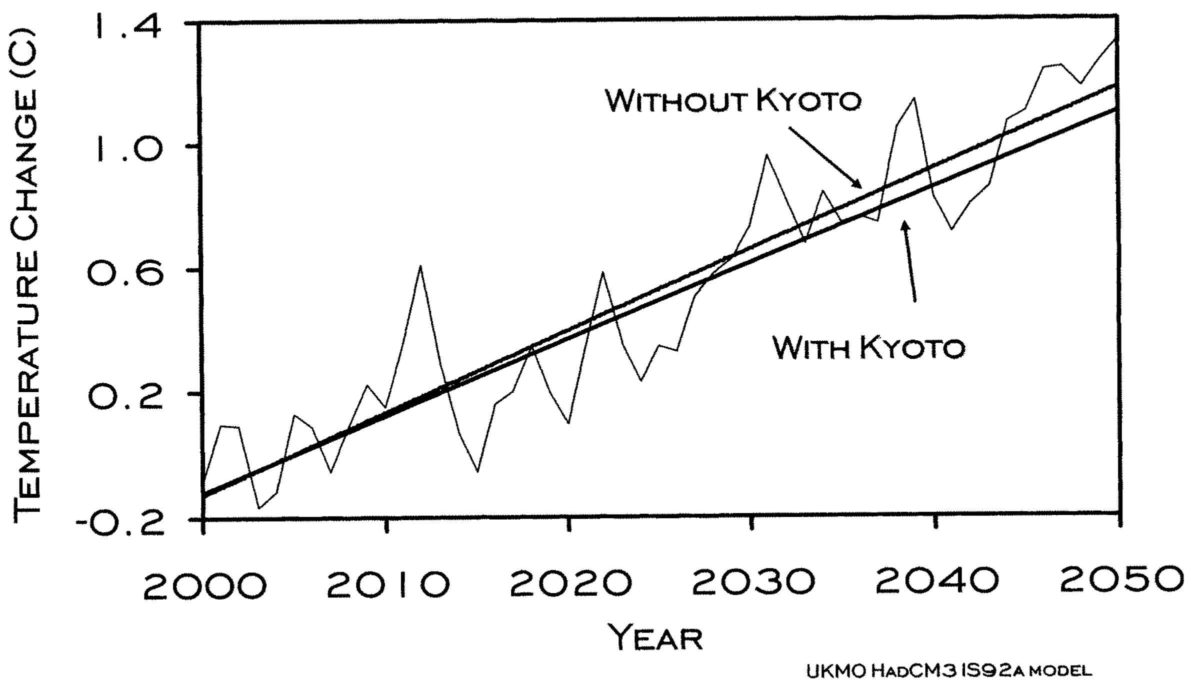
Figure 3—Monthly averaged temperatures sampled nearly globally for the lower troposophere (roughly 5,000 to 28,000 feet altitude) from Microwave Sounder Unit (MSU) instruments onboard NASA satellites. The large spike of warmth resulted from the temporary natural warming of the Pacific Ocean by the 1997—1998 El Niño event. The linear trend is +0.04C per decade (data are from *http://wwwghcc.msfc.nasa.gov/temperature/*)

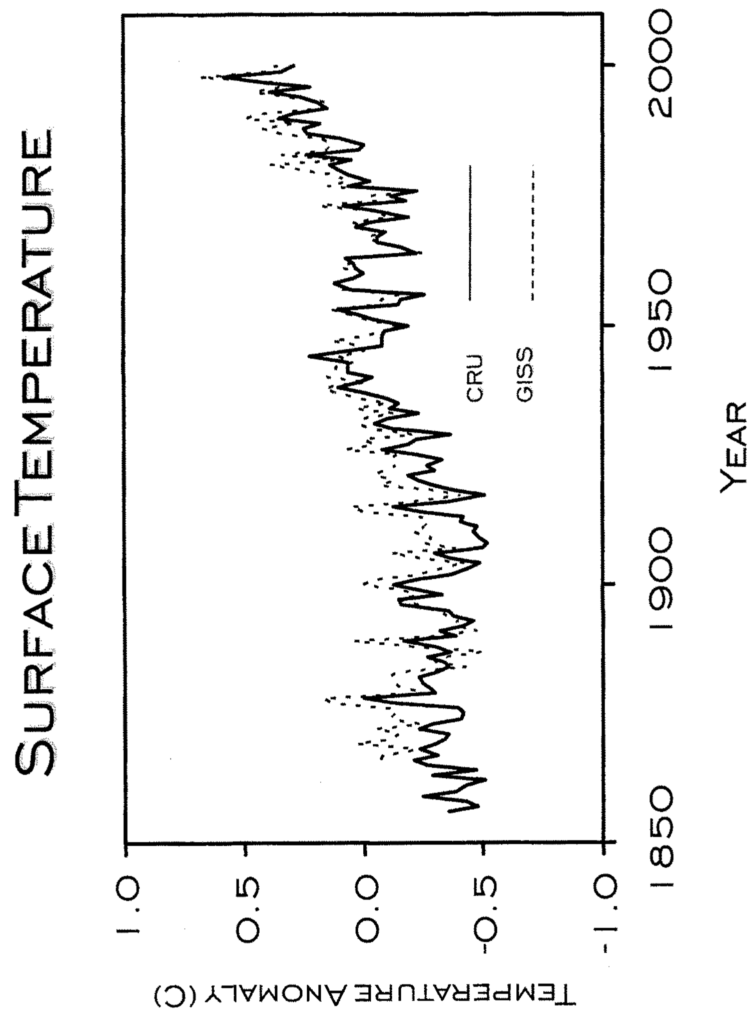
Figure 4—The seasonal average temperature anomaly sampled worldwide for the lower troposphere as measured by radiosonde instruments carried aboard balloons. Although a linear trend of +0.09C per decade is present if fitted across the entire period of the record, that trend is affected by the presence of the abrupt warming that occurred in 1976–1977, owing to the action of the Pacific Decadal Oscillation (PDO). The trends before and after the 1976–1977 Great Pacific Climate Shift indicate no evidence of a significant human-made warming trend (source of data *http://cdiac.esd.ornl.gov/ftp/trends/temp/angell/glob.dat*)

Figure 5—Changes in the sun's magnetism (as evidenced by the changing length of the 22-year, or Hale Polarity Cycle, dotted line) and changes in Northern Hemisphere land temperature (solid line) are closely correlated. The sun's shorter magnetic cycles are more intense, suggesting periods of a brighter sun, then a fainter sun during longer cycles. Lags or leads between the two curves that are shorter than 20 years are not significant, owing to the 22-year timeframe of the proxy for brightness change. The record of reconstructed Northern Hemisphere land temperature substitutes for global temperature, which is unavailable back to 1700 (S. Baliunas and W. Soon, 1995, Astrophysical Journal, 450, 896).

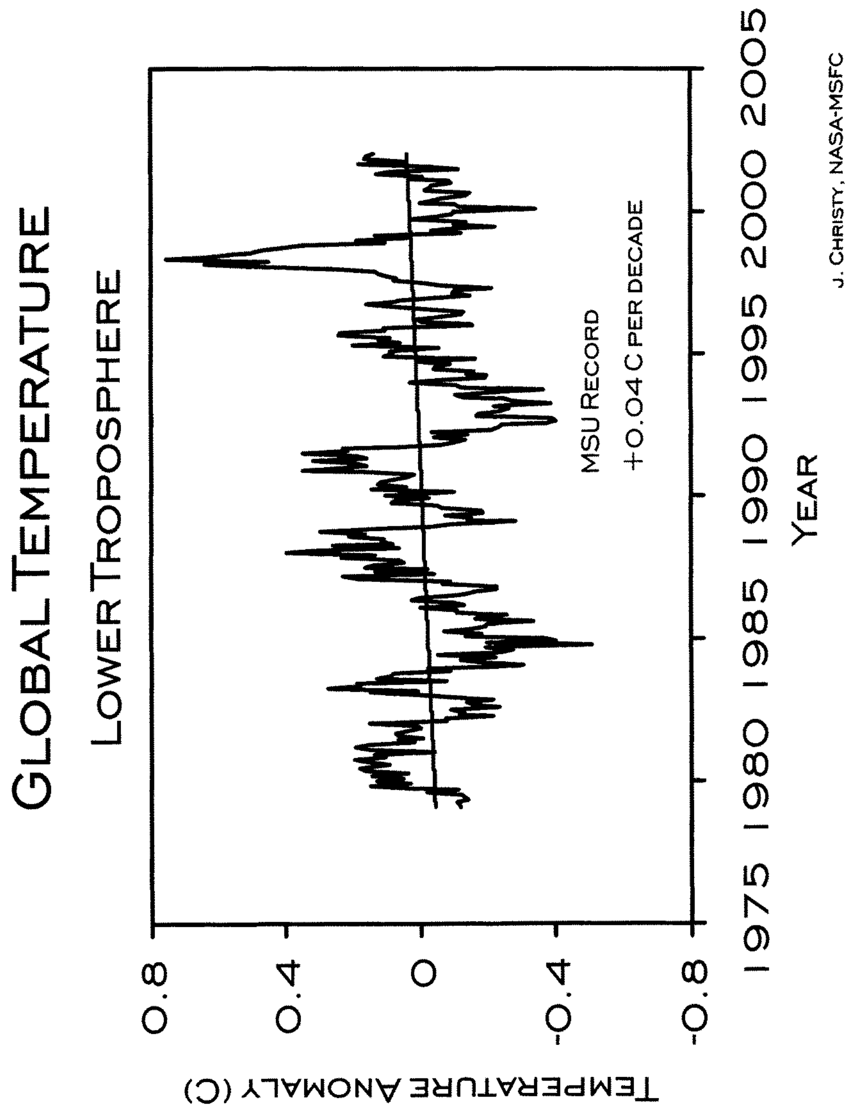
Forecast Amount of Averted Global Warming

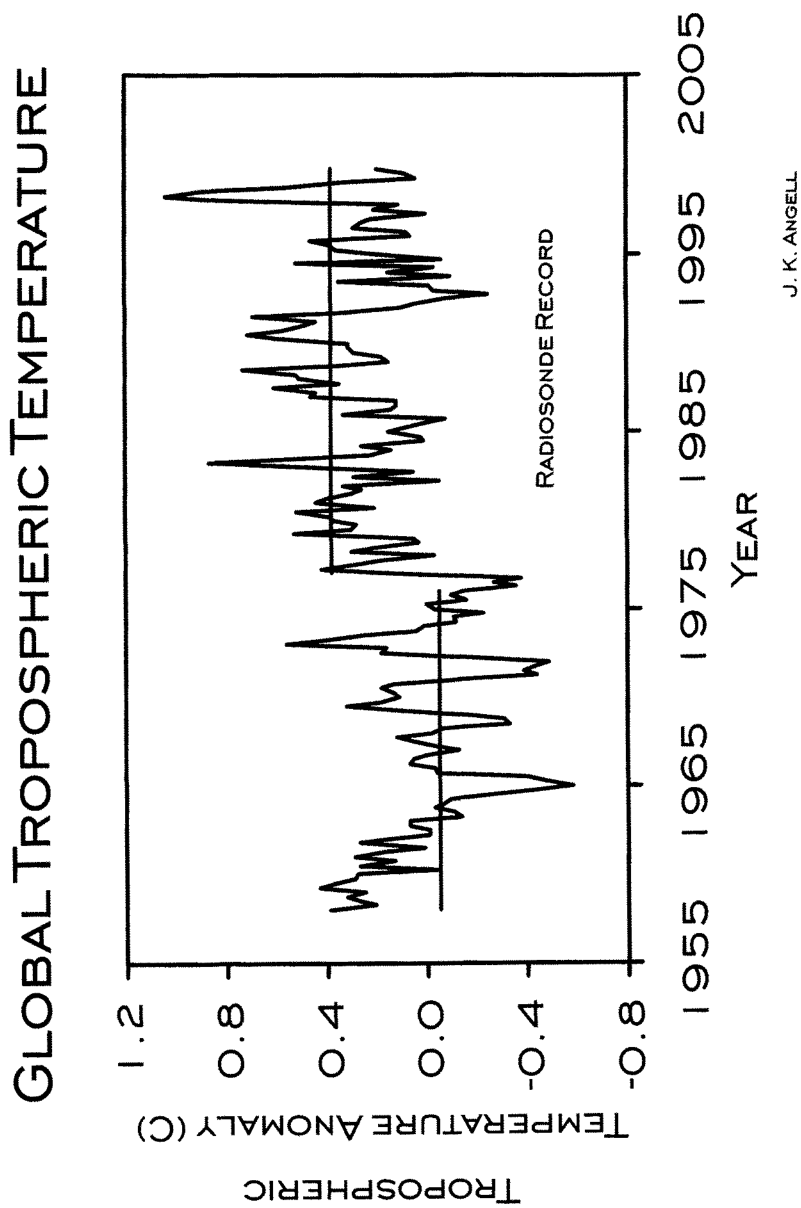
(Temperature difference of 0.06 C)





SURFACE TEMPERATURE
TEMPERATURE ANOMALY (C)
1.0
0.5
0.0
-0.5
-1.0
1850
1900
1950
2000
YEAR
CRU
GISS

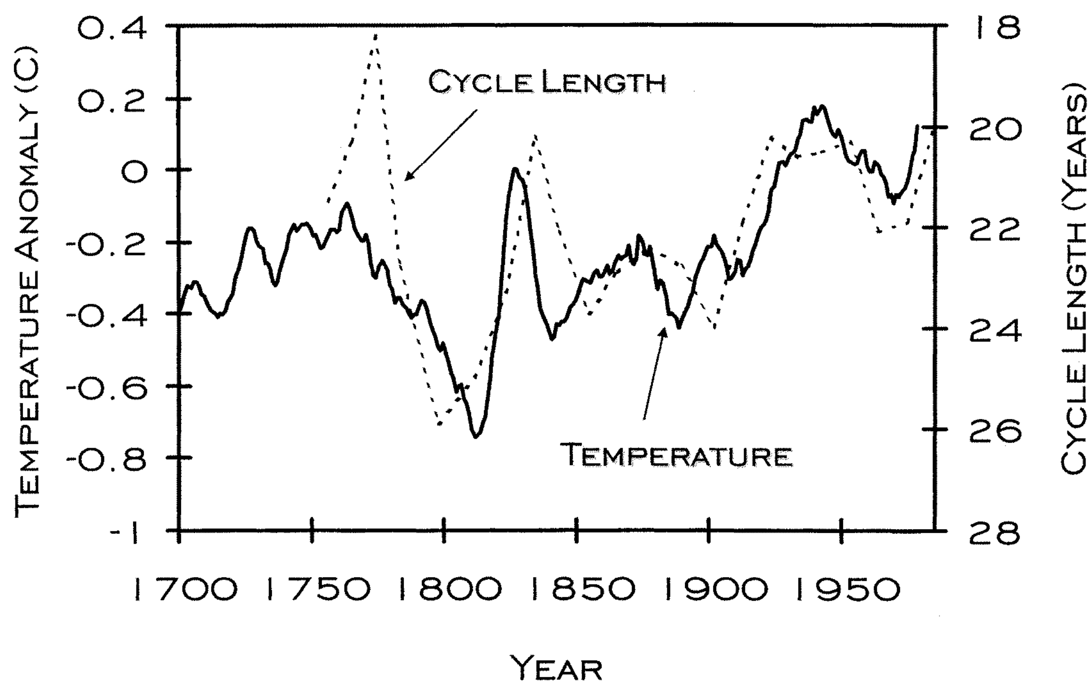

GLOBAL TEMPERATURE
LOWER TROPOSPHERE
MSU RECORD
+0.04 C PER DECADE
TEMPERATURE ANOMALY (C)
0.8
0.4
0
-0.4
-0.8
1975 1980 1985 1990 1995 2000 2005
YEAR
J. CHRISTY, NASA-MSFC



GLOBAL TROPOSPHERIC TEMPERATURE
RADIOSONDE RECORD
TROPOSPHERIC
TEMPERATURE ANOMALY (C)
1.2
0.8
0.4
0.0
-0.4
-0.8
1955
1965
1975
1985
1995
2005
YEAR
J. K. ANGELL

A Sun-Climate Link?

Northern Hemisphere Land Temperature and Solar Cycle



Baliunas and Soon 1995

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REVIEW

Modeling climatic effects of anthropogenic carbon dioxide emissions: unknowns and uncertainties

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ABSTRACT: A likelihood of disastrous global environmental consequences has been surmised as a result of projected increases in anthropogenic greenhouse gas emissions. These estimates are based on computer climate modeling, a branch of science still in its infancy despite recent substantial strides in knowledge. Because the expected anthropogenic climate forcings are relatively small compared to other background and forcing factors (internal and external), the credibility of the modeled global and regional responses rests on the validity of the models. We focus on this important question of climate model validation. Specifically, we review common deficiencies in general circulation model (GCM) calculations of atmospheric temperature, surface temperature, precipitation and their spatial and temporal variability. These deficiencies arise from complex problems associated with parameterization of multiply interacting climate components, forcings and feedbacks, involving especially clouds and oceans. We also review examples of expected climatic impacts from anthropogenic CO_2 forcing. Given the host of uncertainties and unknowns in the difficult but important task of climate modeling, the unique attribution of observed current climate change to increased atmospheric CO_2 concentration, including the relatively well-observed latest 20 yr, is not possible. We further conclude that the incautious use of GCMs to make future climate projections from incomplete or unknown forcing scenarios is antithetical to the intrinsically heuristic value of models. Such uncritical application of climate models has led to the commonly held but erroneous impression that modeling has proven or substantiated the hypothesis that CO_2 added to the air has caused or will cause significant global warming. An assessment of the merits of GCMs and their use in suggesting a discernible human influence on global climate can be found in the joint World Meteorological Organisation and United Nations Environmental Programme's Intergovernmental Panel on Climate Change (IPCC) reports (1990, 1995 and the upcoming 2001 report). Our review highlights only the enormous scientific difficulties facing the calculation of climatic effects of added atmospheric CO_2 in a GCM. The purpose of such a limited review of the deficiencies of climate model physics and the use of GCMs is to illuminate areas for improvement. Our review does not disprove a significant anthropogenic influence on global climate.

KEY WORDS: Climate change · Climate model · Global warming · Carbon dioxide

1. INTRODUCTION

A complete and comprehensive calculation of the effects of increasing atmospheric CO_2 concentration must overcome 3 closely connected problems: (1) calculation of the future trajectory of the air's CO_2 concentration, (2) calculation of its climatic effects, and (3) separation of the CO_2 impacts from other climatic changes.

The first problem involves humanity's impact on the global carbon budget. Anthropogenic emissions of CO_2 are mainly the result of fossil fuel (coal, gas and oil) use, which is related to energy consumption and,

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hence, the world economy. One convenient scheme studies these relationships within the framework of 4 independent variables: CO_2 released per unit energy, energy consumed per unit of economic output, economic output per person and population (Hoffert et al. 1998, Victor 1998).

That perspective raises one major question—Can economy and technology be sufficiently well prescribed that future energy consumption can be reliably predicted?—and leads to a subsequent question—What controls the physical exchanges of CO_2 and how do these factors control the apportionment of anthropogenic CO_2 emissions among various reservoirs of the climate system? With respect to these questions, we note that about one-third of humanity's carbon production has remained in the atmosphere, with a less certain division between the terrestrial biosphere and oceans (Field & Fung 1999, Joos et al. 1999, Rayner et al. 1999, Giardina & Ryan 2000, Schimel et al. 2000, Valentini et al. 2000, Yang & Wang 2000), while economic prediction is a notoriously complex proposition that is even less well defined (Sen 1986, Arthur 1999).

The second and third problems belong to the natural sciences. Here, climate scientists seek a theory capable of describing the thermodynamics, dynamics, chemistry and biology of the Earth's atmosphere, land and oceans. Another fundamental barrier to our understanding and description of the climate system is the inherent unpredictability of even a seemingly deterministic set of equations beyond a certain time horizon (Lighthill 1986, Essex 1991, Tucker 1999). The good news is that attempts to estimate the global weather or climate attractor directly from the primitive equations governing large-scale atmospheric motions yield a finite bound (Lions et al. 1997).

An additional difficulty concerns the logistics of modeling a system with spatial and temporal scales that range from cloud microphysics to global circulation. Fortunately, this difficulty can be circumvented because of empirical 'loopholes' such as the existence of gaps in the energy spectrum of atmospheric and oceanic motions that allow for the separation of various physical and temporal scales. If, for example, climate is viewed as an average over a hypothetical ensemble of atmospheric states that are in equilibrium with a slowly changing external factor, then, under a regular external forcing factor, one may hope to anticipate the change (Houghton 1991, Palmer 1999). Essentially all calculations of anthropogenic CO_2 climatic impacts make this implicit assumption (Palmer 1999). But, in order for such a calculation to have *predictive* value, rather than merely to represent the *sensitivity* of a particular model, a model must be validated specifically for the purpose of its type of prediction. As a case in point, we note that in order to predict climate responses to individual forcings such as the long-lifetime greenhouse gas (GHG) CO_2, the shorter-lifetime GHG CH_4, the inhomogenously distributed tropospheric O_3 and atmospheric aerosols, separate and independent validations are required. A logistically feasible validation for such predictions is essentially inconceivable.

The downside of exploiting the energy gap loophole is that relevant physical processes must be parameterized in simple and usable forms. For example, most general circulation models (GCMs) treat radiation with simple empirical schemes instead of solving the equations for radiative energy transfer (Shutts & Green 1978). Chemical and biological changes in the climate system are also highly parameterized. Clearly some empirical basis and justification for these parameterizations can be made but because the real atmosphere and ocean have many degrees of freedom and connections among processes, there is no guarantee that the package assembled in a GCM is complete or that it can give us a reliable approximation of reality (Essex 1991).

Going beyond the issue of limited computing resources, Goodman & Marshall (1999) and Liu et al. (1999) have elaborated on various schemes of synchronous and asynchronous coupling for the highly complex atmosphere and ocean GCMs, while warning of the extreme difficulty inherent in deciphering the underlying physical processes of the highly tangled and coupled responses. A call to eschew the direction of all efforts into the scale-resolved physical approach in current formulations of GCMs has also been voiced by Kirk-Davidoff & Lindzen (2000).

Another important point has been raised by Oreskes et al. (1994): it is *impossible* to have a verified and validated numerical climate model because natural systems are never closed and model results are always non-unique. It follows from Oreskes et al. that the intrinsic value of a climate model is not predictive but heuristic. Therefore, the proper use of a climate model is to *challenge* existing formulations (i.e., a climate model is built to test proposed mechanisms of climate change) rather than to *predict* unconstrained scenarios of change by adding CO_2 to the atmosphere.

2. SIMULATING CLIMATE VARIABLES

Consider the nominal, globally averaged number of 2.5 W m^{-2} that is associated with the total radiative forcing provided by the increases of all GHGs since the dawn of the Industrial Revolution. Alternatively, consider a doubling of the air's CO_2 concentration that adds about 4 W m^{-2} to the troposphere-surface system. In order to appreciate the difficulties of finding climatic changes associated with these forcings, it is only necessary to consider the energy budget of the entire earth-climate system. Neglecting the nonphysical flux adjustments for freshwater, salinity and wind stress (momentum) that are also applied in many contemporary GCMs (see discussion in Gordon et al. 2000, Mikolajewicz & Voss 2000), there are artificial energy or heat flux adjustments as large as 100 W m^{-2} that are used in some GCMs to minimize unwanted drift in the ocean-atmosphere coupled system (Murphy 1995, Glecker & Weare 1997, Cai & Gordon 1999, Dijkstra & Neelin 1999, Yu & Mechoso 1999).

Models that attempt to avoid artificial heat flux adjustments fare no better because of other substantial biases, including major systematic errors in the computation of sea-surface temperatures and sea ice over many regions, as well as large salinity and deep-ocean temperature drifts (Cai & Gordon 1999, Russell & Rind 1999, Yu & Mechoso 1999, Gordon et al. 2000, Russell et al. 2000). Also, uncertain global energy budgets implicit in all GCMs vary by at least 10 W m^{-2} in empirically deduced fluxes for the shortwave and longwave radiation and latent and sensible heat within the surface-atmosphere system (Kiehl & Trenberth 1997). In addition, Grenier et al. (2000) have called for a simultaneous focus on tropical climate drift caused by heat budget imbalances at the top of the atmosphere while balancing the surface heat budget, because systematic biases in outgoing longwave radiation of as large as 10 to 20 W m^{-2} are not uncommon in coupled ocean-atmosphere GCMs.

Those artificially modified and uncertain energy components of contemporary GCMs place severe constraints on our ability to find the imprint of a mere 4 W m^{-2} radiative perturbation associated with anthropogenic CO_2 forcing over 100 to 200 yr in the climate system. This difficulty explains why all current GCM studies of the climatic impacts of increased atmospheric CO_2 are couched in terms of *relative* changes based on control, or unforced, GCM numerical experiments that are known *a priori* to be incomplete in their forcing and feedback physics. Soon et al. (1999), for example, identified documented problems associated with models' underestimation or incorrect prediction of natural climate change on decade-to-century time scales. Some of those problems may be connected to difficulties in modeling both the natural unforced climate variability and suspected climate forcings from volcanic eruptions, stratospheric ozone variations, tropospheric aerosol changes and variations in the radiant and particle energy outputs of the sun. Another predicament is the inability of short climatic records to reveal the range of natural variability that would allow confident assessment of probability of climatic changes on time scales of decades to centuries. Most importantly, it is premature to conclude on the basis of the magnitude of forcing—4 W m^{-2} for a doubling of CO_2 versus 0.4 W m^{-2} for July insolation changes at 60° N induced by the earth's orbital variations over about 100 yr, a contrast made by Houghton (1991)—that the climatic changes by human-made CO_2 will overwhelm the more *persistent* effects of a positional change in the earth's rotation axis and orbit. The latter form of climate change through gradual insolation change is suspected to be the cause of historical glacial and inter-glacial climate oscillations, while the potential influence of added CO_2 can only be guessed from our experiences in climate modeling. In addition, it would also be premature to conclude on the basis of the magnitude of approximately 0.5 to 1.0 W m^{-2} forcing by the intrinsic solar variation on decade-to-century scale, versus the 0.4 W m^{-2} for July insolation changes at 60° N, that the climatic impact of variable solar irradiance forcing should be less dramatic than that of the Pleistocene glacial cycles.

Historical evidence reveals natural occurrences of large, abrupt climatic changes that are not uncommon (Alley 2000). They occur without any known causal ties to large radiative forcing change. Phase differences between atmospheric CO_2 and proxy temperature in historical records are often unresolved; but atmospheric CO_2 tends to follow rather than lead temperature and biosphere changes (Priem 1997, Dettinger & Ghil 1998, Fischer et al. 1999, Indermühle et al. 1999). In addition, there have been geological times of global cooling with rising CO_2 (during the middle Miocene about 12.5 to 14 Myr BP, for example, with a rapid expansion of the East Antarctic Ice Sheet and with a reduction in chemical weathering rates), while there have been times of global warming with low levels of atmospheric CO_2 (such as during the Miocene Climate Optimum about 14.5 to 17 Myr BP, noted by Panagi et al. 1999). In order to cast the anthropogenic or natural CO_2 forcing as the cause of rapid climate change, various complex climatic feedback and amplification mechanisms must operate. Most of those mechanisms for rapid climatic change are neither sufficiently known nor understood (Marotzke 2000, Stocker & Marchal 2000). (Apparently, a fast trigger such as increased atmospheric methane from rapid release of trapped methane hydrates in permafrosts and on continental margins, through changes in temperature of intermediate-depth (a few hundred meters below sea level) water, may be one example of a key ingredient for amplification or feedback leading to large climatic change [Kennett et al. 2000].)

2.1. Temperature

How well do current GCMs simulate atmospheric temperatures? As noted by Johnson (1997), the appearance of the IPCC (1990) report marks the recognition that all GCMs suffer from the 'general coldness

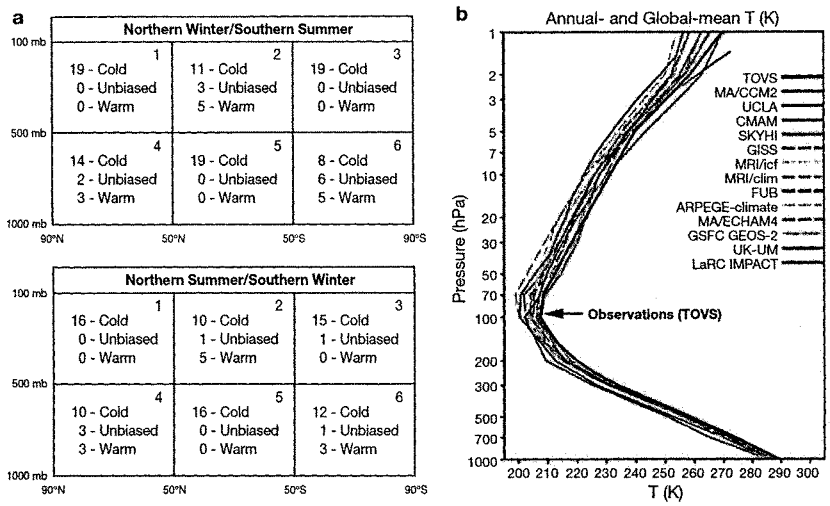
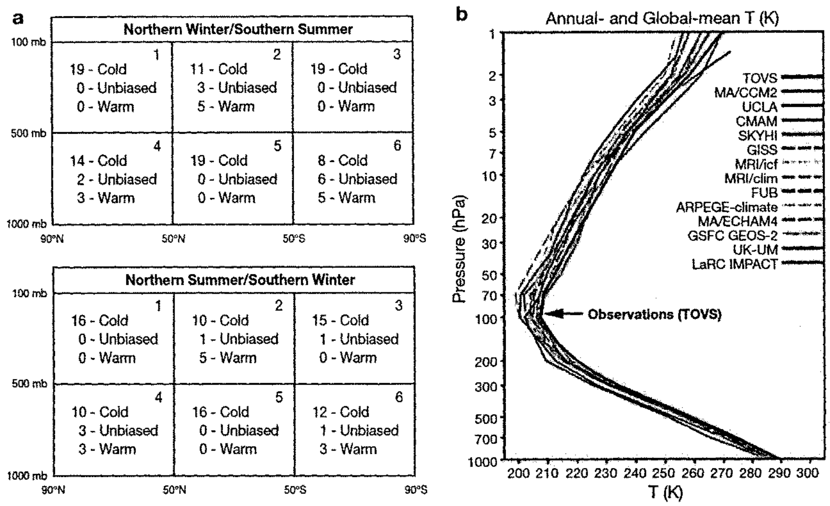


Fig. 1. (a) Illustration of the cold-temperature bias problem in the troposphere in simulations produced by 14 different GCMs. (Note that some GCMs produced more than 1 simulation so that the total number of cases compiled for each of the 6 regions can be more than 14). Indicated in each box are the model temperature biases relative to observations. (From Johnson 1997). In Regions 1, 3 and 5, model results consistently show a cold bias. (b) Note that the cold-bias problem—the fact that most GCM curves lie to the left of the observed temperature line labeled TOVS—extends into the stratosphere. (From Pawson et al. 2000)

problem', particularly in the lower tropical troposphere and upper polar troposphere (Regions 1, 3 and 5 in Fig. 1a, which make a total of 105 simulations). The general coldness problem is seen in 104 out of the 105 outcomes in Regions 1, 3 and 5, from 35 different simulations by 14 climate models.

What is the cause of that ubiquitous error? Johnson (1997) suggests that most GCMs may suffer from extreme sensitivity to systematic physical entropy sources introduced by spurious numerical diffusion, Gibbs oscillations or inadequacies of sub-grid-scale parameterizations. Johnson estimated that a biased temperature of 10°C may be expected from only a 4% error in modeling net heat flux that is linked to any number of a physical entropy sources (including those arising from numerical problems with the transport and change of water substances in forms of vapor, liquid and ice and the spurious mixing of moist static energy). The analysis of Egger (1999) seems to support this result and calls for the evaluation of high-order statistical moments such as entropies to check on the quality of numerical schemes in climate models. A follow-on detailed numerical study by Johnson et al. (2000) sheds further light on how this critical cold-bias difficulty associated with spurious positive definite entropy contaminates the computation of hydrologic and chemical processes (by virtue of their strong inherent dependence on temperature). It is estimated that error in saturation-specific humidity doubles for every 10°C increase in temperature.

The coldness problem also extends to the stratosphere (Fig. 1b), where Pawson et al. (2000) have shown that the cold bias is more uniformly distributed. The range of the cold bias in the globally mean temperatures is about 5 to 10°C in the troposphere and greater than 10°C for the stratosphere. Pawson et al. suggest that the particular coldness problem for the stratosphere is more likely associated with problems in physics such as the underestimation of radiative heating rates, because models have too little absorption of solar radiation by ozone in the near infrared. Alternatively, perhaps there is too much longwave emission in the middle atmosphere so that climate models overcool their stratospheres. Other unresolved problems concern the physical representation of gravity wave momentum deposition in the stratosphere and mesosphere, and the generation of gravity waves in the troposphere (McIntyre 1999).



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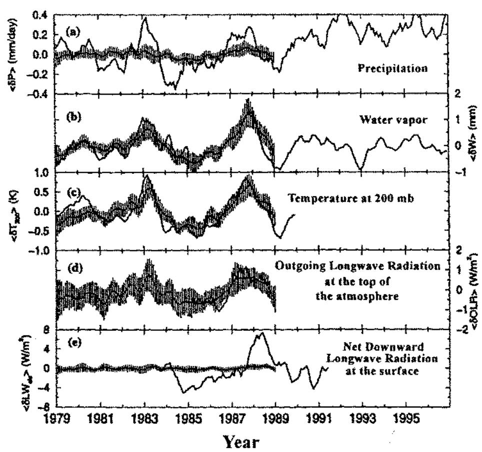

Fig. 3. Comparison of the observed (thick solid line) tropical-mean interannual variations of (a) precipitation (<δP>), (b) total precipitable water vapor (<δW>), (c) temperature at 200 mb (<δT_{200}>), (d) outgoing longwave radiation (OLR) at the top of the atmosphere (<δOLR>), and (e) the net downward longwave radiation at the surface (<δLW_{sfc}>) with the ensemble-mean of 30 AMIP GCM results (the thin solid curve overlaid with vertical lines showing the range of 1 intermodel standard deviation of the ensemble mean). Contrast the good agreement for simulated water vapor, 200 mb temperature and OLR with the internally inconsistent results for precipitation and net surface longwave radiation. (All climate simulations were forced with observed SST.) (From Soden 2000)

agreement between observations and model simulations of precipitation and net downward longwave radiation at the surface. Considering especially the more direct association of latent heat release from precipitation of moist air to the warming and cooling of the atmosphere, Soden (2000) warned that the good agreement between the observed and modeled temperature at 200 mb (Fig. 3c) is surprising in light of the large differences for a simultaneous comparison of the precipitation field (Fig. 3a).

This comparison suggests that the temperature agreement at 200 mb could be fortuitous, since the atmospheric GCMs were forced with *observed* sea-surface temperatures, while the modeled interannual variabilities of the hydrologic cycle are seriously underestimated by a factor of 3 to 4. Based on the models' relatively constant values of downward longwave radiation reaching the surface (Fig. 3e), Soden (2000) points to possible systematic errors in current GCM representations of low-lying boundary layer clouds. However, the study cannot exclude the possibility of errors in algorithms that retrieve precipitation data from observations made by satellites, which would emphasize the need for improved precipitation products.

2.3. Water vapor

Soden (2000) highlighted the positive ability of GCMs to simulate the correct sign and magnitude of the observed water vapor change in Fig. 3b. This conclusion agrees with the extensive review by Held & Soden (2000) on water vapor feedbacks in GCMs. Held & Soden called for a clearer recognition of GCMs' proficiency in calculating the water vapor feedback (which diagnoses model ability to simulate the *residual* between evaporation and precipitation rather than evaporation or precipitation per se) versus GCMs' representation of the more complicated physics related to the cloud forcing and feedback.

However, it is important to add that the latest analyses of the interannual correlation between tropical mean water vapor content of the atmosphere and its surface value continue to show significant differences for the vertical patterns derived from rawinsonde data and outputs of GCMs, including those of the newer AMIP2 study (Sun et al. 2001). Essentially, in comparison with rawinsonde data, GCMs exhibit too strong a coupling between mid-to-upper tropospheric water vapor and surface water vapor. Water vapor in GCMs has also been found to have a stronger dependence on atmospheric temperature than the empirical relation deduced from observations.

Finally, purely numerical problems also exist; they are associated with physically impossible, negative specific humidity in the Northern Hemisphere (NH) extra-tropics caused by problematic parameterization of steep topographical features (Rasch & Williamson 1990, Schneider et al. 1999).

2.4. Clouds

In Fig. 4, we show the sensitivity of the parameterization of the large-scale formation of cloud cover that is used in one state-of-the-art model (Yang et al. 2000). As parameterized, cloud cover is extremely sensitive to relative humidity, U, and to both U_s, the saturated relative humidity within the cloud, and U_{00}, the threshold relative humidity at which condensation begins. The

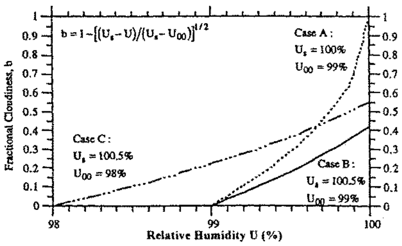

Fig. 4. The parameterized cloud cover is very sensitive (contrasted by cases A, B and C) to relative humidity, U, and to values of U_s, the saturated relative humidity within the cloud, and U_{00}, the threshold relative humidity at which condensation begins. (From Yang et al. 2000)

creators of this GCM discuss how the formula is used to tune the formation of clouds (through large-scale condensation at high latitudes or near-polar regions) by 20 to 30% in order to match what is observed.

Other researchers, such as Grabowski (2000), emphasize the importance of the proper evaluation of the effects of cloud microphysics on tropical climate by using models that directly resolve mesoscale dynamics. Grabowski points out that the main effect of cloud microphysics is on the ocean surface rather than directly on atmospheric processes. Because of the great mismatch between the time scales of oceanic and atmospheric dynamics, Grabowski was pessimistic about quantifying the relation between cloud microphysics and tropical climate. Clearly, the parameterizations of cloud microphysics and cloud formation processes, as well as their interactions with other variables of the ocean and atmosphere, remain major challenges for climate modelers.

3. EXPECTED OUTCOMES OF CO_2 FORCING

Given the range of uncertainties and numerous unknowns associated with parameterizations of important climatic processes and variables, what should one expect from current GCMs for a scenario with an increased CO_2 forcing? The most common difficulty facing the interpretation of many GCMs results is related to confusion arising from imposed natural and anthropogenic forcings that may or may not be internally consistent. This is why Bengtsson et al. (1999) and Covey (2000) have called for more inclusive consideration of all climate forcings, accurately known or otherwise, rather than a piecemeal approach that yields oversimplifications.

Many qualitative outcomes of forcing by anthropogenic GHGs have been postulated, such as changes in standard ocean-atmosphere variables of wind, water vapor, rain, snow, land and sea ice, sea level, and the frequency and intensity of extreme events such as storms and hurricanes (Soon et al. 1999), as well as more exotic phenomena, including large cooling of the mesosphere and thermosphere (Akmaev & Fomichev 2000), increased presence or brightness of noctilucent clouds near the polar summer mesopause (Thomas 1996, but see Gadsden 1998), increases in atmospheric angular momentum and length of day (Abarca del Rio 1999, Huang et al. 2001), and shrinking of surfaces of constant density at operating satellite altitudes (Keating et al. 2000). In these calculations, the benchmark forcing scenario is usually an emission rate of 1% yr^{-1} chosen to represent roughly the CO_2 equivalent of the burden of all anthropogenic GHGs.

Although some of these studies claim an observational detection consistent with modeled CO_2 effects, it is clear that even the theoretical claims, with their strong bias towards accounting for only the effects of GHGs, are neither robust nor internally consistent. A good example is the prediction for the change of the Arctic Oscillation (AO) pattern of atmospheric circulation by the year 2100. The AO is one of the key variability patterns of the wintertime atmospheric circulation over the NH, characterized broadly by a redistribution of air mass between polar regions and midlatitudes. Here, Zorita & González-Rouco (2000) found, using results from 2 different GCMs and a total of 6 simulations with different initial conditions, that *both upward and downward* tendencies in the intensity of the AO circulation pattern are likely under the same scenario of increasing atmospheric CO_2. Apparently, internal model variability dominates those effects from the external forcing of CO_2 and leads to an ambiguous expectation for a CO_2-related signal in the modeled AO variability. This re-emphasis on unforced internal variability is consistent with the recent classification of the observed vertical structures of the AO into distinct perturbations originating in the troposphere versus stratosphere by Kodera & Kuroda (2000). Besides cautioning about the lack of robustness of previous claims for the AO owing to increased CO_2 forcing, Zorita & González-Rouco highlighted the direct impact of that unknown on the calculation of the NH's regional climate change in the extratropics.

Some theoretically predicted CO_2 effects are not detectable unless a very high, or even extreme, level of CO_2 loading is imposed. It is also predicted that a transient GCM experiment forced with the slightly lower CO_2 emission growth rate of 0.25% yr^{-1}, as opposed to the present growth rate of 0.4% yr^{-1}, will ultimately lead to a relatively larger sea-level rise (based only on the thermal expansion of sea water; Stouffer & Manabe 1999). By the time the atmosphere's carbon dioxide content is doubled, an additional 15 cm rise (the calculated global sea level rise for the emission case of 0.4% yr^{-1} is roughly 27 cm) is expected because the atmospheric heating anomaly of a world in which the carbon-dioxide emission rate is slower will have more time to penetrate deep into the ocean, thereby causing a relatively larger thermal expansion of seawater and hence a larger rise in the sea level.

Table 1. Observations and predictions (both unforced GCM and CO_2-forced GCM results) of seasonal and annual Northern Hemisphere (NH) equator-to-pole surface temperature gradients (in °C per 5° latitude; EPG) and ocean-land surface temperature contrasts (in °C; OLC). (From Jain et al. 1999)

	EPG Annual	EPG Summer (JJA)	EPG Winter (DJF)	OLC Annual	OLC Summer (JJA)	OLC Winter (DJF)
NH observations	–3.1	–2.0	–3.9	0.3	–5.5	6.5
GCM unforced	–2.9	–1.7	–3.8	3.8	–3.8	11.4
GCM CO_2-forced	–2.7	–1.6	–3.6	3.3	–4.4	10.9

One example of a problem with estimating the effects of a high level of atmospheric CO_2 loading concerns potential changes in ENSO characteristics, for which no statistically significant change is predicted until the anthropogenic forcing is 4 times the preindustrial value (Collins 2000a). On the other hand, Collins (2000b) subsequently reported a surprising result—no significant change in ENSO characteristics occurred for a similar 4 × CO_2 numerical experiment, based on an updated GCM with improved horizontal ocean resolution and no heat flux adjustment. Collins concluded that calculating ENSO response to increasing GHG forcing can depend sensitively and nonlinearly on subtle changes in model representations of sub-grid processes (rather than depending on gross model parameters such as ocean resolution and heat flux adjustment that are the main differences between the new and old versions of GCM he used). Thus, exploration of the parameter-space of coupled ocean-atmosphere GCMs, Collins concludes, is crucial for improved understanding. As for the statistics of recent ENSO variability, Timmermann (1999) has shown that the observed changes are not inconsistent with the null hypothesis of natural variability of a non-stationary climate. In addition, the careful case study by Landsea & Knaff (2000) confirmed the fact that no current climate model provided both useful and skillful forecasts of the entire 1997–1998 El Niño event.

3.1. Expected changes in seasonal temperatures?

We will consider 3 responses under the typical equivalent CO_2-forcing scenario of 1% yr^{-1}, starting with the seasons. Is the CO_2-forced change expected to alter the character of seasonal cycles? If so, how do predictions compare with what is observed, at least over the last few decades?

Jain et al. (1999) examined this question by considering 3 parameters for the NH surface temperature: the mean temperature's amplitude and phase, the equator-to-pole surface temperature gradient (EPG), and the ocean-land surface temperature contrast (OLC).

A comparison of observed and modeled EPG and OLC climatologies is summarized in Table 1. The results show that expected changes owing to CO_2 forcing are often very small when compared to differences between the unforced GCM and observed values in EPG and OLC. Hence, detecting CO_2 effects in seasonal differences of EPG and OLC may not be feasible.

Jain et al. (1999) did find significant differences between observed interannual and decadal trends of both EPG and OLC and results obtained from CO_2-forced climate experiments. For example, the CO_2-forced run produced a statistically significant increase in amplitude (and delay in phase) for the seasonal cycle of OLC. But no change was observed in the real world. Worse yet, even the unforced experiment yielded a statistically significant increase in the amplitude of the OLC seasonal cycle, which makes the search for a CO_2 signal via this means almost impossible. It was determined, however, that the amplitude of the annual cycle of NH surface temperature decreased in a way consistent with results obtained from the CO_2-forced experiment. On the other hand, the observed trend in *phase* shows an *advance* of the seasons rather than the *delay* derived from the models. Jain et al. offer 3 possible reasons for the disagreement: the use of model flux corrections, the significant impact of low-frequency natural variability, and sampling problems associated with the observations. An obvious fourth possibility is that the model results are incorrect, and the obvious fifth is that CO_2 forcing has not affected those variables.

In light of these difficulties, seasonal cycles are probably not good 'fingerprints' for identifying the impact of anthropogenic CO_2. This conclusion seems consistent with the independent finding by Covey et al. (2000) that showed seasonal cycle amplitude to depend only weakly on equilibrium climate sensitivity (i.e., equivalent to a varying climate forcing in the present comparison), based on the range of results from 17 coupled ocean-atmosphere GCMs from the CMIP. If these results are correct, then it is odd that seasonality in forcing (from geometrical changes in solar insolation by changing tilt angle of the earth's rotation axis and the earth's orbital position around the sun) is believed to cause very large changes in mean climate, but significant changes in mean forcing, e.g., from atmospheric CO_2, cause only insignificant changes in the seasonal climatology.

3.2. Expected changes in clouds?

Next, consider clouds. Given the complexity of representing their relevant processes, can one expect to find a CO_2-forced imprint in clouds?

First, as Yao & Del Gino (1999) have noted, it is misleading to assert that increased cloud cover is evidence of CO_2-produced global warming (i.e., a warming climate with more evaporation and, hence, more clouds). This is so because cloud cover depends more on relative humidity than on specific humidity. For example, under CO_2-doubling experiments with different parameterization schemes, Yao & Del Gino (1999) predicted a *decrease* in global cloud cover, although there was an increase in mid- and high-latitude continental cloudiness. They also cautioned that because a 'physical basis for parameterizing cloud cover does not yet exist,' all predictions about cloud changes in response to rising atmospheric CO_2 concentrations should be viewed carefully.

Others, such as Senior (1999), have emphasized the importance of including parameterizations of interactive cloud radiative properties in GCMs and called for a common diagnostic output such as the water path length within the cloud in control (unforced) experiments. On another research front, Rotstayn (1999) implemented the detailed microphysical processes of a prognostic cloud scheme in a GCM and found a large difference in the climate sensitivity between that experiment and one with a diagnostic treatment of clouds. A stronger water vapor feedback was noted in the run with the prognostic cloud scheme than in the run with the diagnostic scheme, and that stronger water vapor feedback caused a strong upward shift of the tropopause upon warming. Rotstayn found that an artificial restriction on the maximum heights of high clouds in the diagnostic scheme largely explained the differences in climatic response.

At this stage of incremental learning we conclude that no reliable predictions currently exist for the response of clouds to increased atmospheric CO_2. So sensitive are certain cloud feedbacks to cloud microphysics, for example, that a lowering of the radius of low-level stratus-cloud droplet size from 10 to 8 μm would be sufficient to balance the warming from a doubling of the air's CO_2 concentration. Likewise, a 4% increase in the area of stratus clouds over the globe could also potentially compensate for the estimated warming of a doubled atmospheric CO_2 concentration (Miles et al. 2000).

3.3. Expected changes in the oceans?

Finally, consider the oceans. Under an increased atmospheric CO_2 forcing, e.g., of 1% yr^{-1}, one commonly predicted transient response is a weakening of the North Atlantic thermohaline circulation (THC), owing to an increase in freshwater influx (Dixon et al. 1999, Rahmstorf & Ganopolski 1999, Russell & Rind 1999, Wood et al. 1999, Mikolajewicz & Voss 2000: see Fig. 5a). However, with an improved representation of air-sea interactions in the tropics, the significant weakening (or even collapse under stronger and persistent forcing) of the THC predicted by earlier GCMs cannot be reproduced (Latif et al. 2000: see Fig. 5b). (While considering Latif et al.'s results in Fig. 5b, it is useful to note from Fig. 5a that the coarser version of the Max Planck Institut für Meteorologie at Hamburg (MPI) model actually did predict a weakening of thermohaline circulation just like the other models in Fig. 5a.)

In another GCM experiment, Russell & Rind (1999) observed that, despite a global warming of 1.4°C near the time of CO_2 doubling, large regional cooling of up to 4°C occurred in both the North Atlantic Ocean (56–80° N, 35° W–45° E) and South Pacific (near the Ross Sea, 60–72° S, 165° E–115° W) because of reduced meridional poleward heat transfer over the North Atlantic and local convection over the South Pacific. However, Russell et al. (2000) later demonstrated that the predicted regional changes over the Southern Ocean were unreliable because of the model's excessive sea ice variability. Another GCM's high-latitude southern ocean suffered a large drift (Cai & Gordon 1999). For example, within 100 yr after coupling the atmosphere to the ocean, the Antarctic Circumpolar Current was noted to intensify by 30 Sv (from 157 to 187 Sv), despite the use of flux adjustments. Cai & Gordon identified the instability of convection patterns in the Southern Ocean to be the primary cause of this drift problem.

Mikolajewicz & Voss (2000) further caution that there is still significant confusion about what mechanisms are most responsible for the weakening of the THC in various models, since different GCMs give contrasting roles to individual atmospheric and oceanic fluxes of heat, moisture, salinity and momentum.

In addition, several oceanographers (Bryden 1999, Holloway & Saenko 1999) have expressed concern about the lack of both physical understanding and

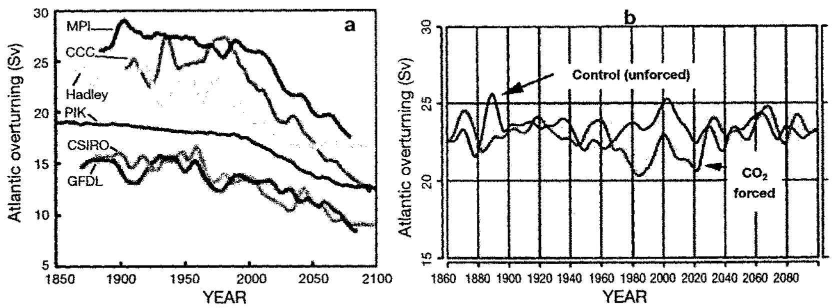

Fig. 5. Predicted (a) large changes (20 to 50% reductions in overturning rate by 2100) in the thermohaline circulation (THC) for 6 different coupled climate models (from Rahmstorf 1999) versus (b) a relatively stable THC response in a state-of-the-art MPI GCM with improved spatial resolution of tropical ocean (from Latif et al. 2000) under a similar CO_2-forced scenario. The quantity shown is the maximum North Atlantic overturning flow rate in sverdrups (10^6 m^3 s^{-1}) at a depth of about 2000 m. Wood et al. (1999) noted, however, that the measure of the THC strength for the meridional overturning adopted here cannot be estimated from observations. They proposed the Greenland-Iceland-Scotland ridge, south of Cape Farewell at the southern tip of Greenland and the trans-Atlantic section at 24° N as 3 locations where more robust observations are available for comparison with GCM results

realistic representation of ocean circulation in global models. Criticisms were especially directed towards the highly schematic representation of the North Atlantic THC as a conveyor belt providing linkages to the world's oceans.

Holloway & Saenko (1999) state that: 'understanding what makes the conveyor work is deficient, drawing mainly on the role of buoyancy loss leading to sinking [is] somewhat like trying to push a string. The missing dynamics are that eddies in the presence of bottom topography tend to set up mean flows that carry major circuits of the conveyors, allowing sunken water masses to 'go for the ride'. Climate models have difficulty in both these regards—to include (if at all!) [sic.] a plausible Arctic Ocean and to deal with eddies either explicitly or by parameterization.'

In spite of those problems, a complete breakdown of the North Atlantic THC is predicted under a sufficiently strong CO_2 forcing (Broecker 1987, Schmittner & Stocker 1999, Rahmstorf 2000, see, e.g., Manabe & Stouffer 1993 for scenarios forced by a quadrupling of atmospheric CO_2). However, as pointed out by Rahmstorf & Ganopolski (1999), Wood et al. (1999) and Mikolajewicz & Voss (2000), the predicted changes of the THC are very sensitive to parameterizations of various components of the hydrologic cycle, including precipitation, evaporation and river runoff. Hence, without a perpetually enhanced influx of freshwater (from any source) or extreme CO_2 forcing, the transient decrease in THC overturning eventually recovers as time progresses in the model (Holland et al. 2000, Mikolajewicz & Voss 2000). In addition, by including a dynamic sea ice module in a coupled atmosphere-ocean model, Holland et al. (2000) report a reduction (rather than an enlargement) in the variance of the THC overturning flow rate, under the doubled CO_2 condition, down to 0.25 Sv^2 (or only 7%) from the high value of 3.6 Sv^2 simulated under the present-day forcing level.

Furthermore, Latif et al. (2000) have just reported a new stabilization mechanism that seems to change previous expectations of a CO_2-induced THC weakening (Fig. 5b, but see also Rahmstorf 2000). In Latif et al.'s case, the state-of-the-art coupled ocean-atmosphere GCM of the MPI resolves the tropical oceans at a meridional scale of 0.5°, rather than the more typical scale of 2 to 6°, and produces no weakening of the THC when forced by increasing CO_2. Latif et al. showed that anomalously high salinities in the tropical Atlantic (produced by excess freshening in the equatorial Pacific) were advected poleward to the sinking region of the THC; and the effect was sufficient to compensate for the local increase in freshwater influx there.

Hence, with the additional stabilizing degree of freedom from the tropical oceans, the THC remains stable under that CO_2-forced experiment, leaving no reliable prediction for change in oceanic circulation in the North Atlantic under an added CO_2 climate. Latif et al. concluded that the response of THC to enhanced greenhouse warming is still an open question. More recently, Delworth & Dixon (2000) added another mechanism that could serve to oppose the THC weakening effect under numerical experiments with increasing CO_2. These authors, using their relatively coarser resolution GCM, found that, given an enhanced forcing owing to an increase in the westerly wind speed over the North Atlantic (as inferred from the observed pattern of the Arctic Oscillation over the last 30 yr), the THC weakening trend from greenhouse warming scenario could be delayed by several decades. Apparently, the stronger winds over the North Atlantic extract more heat from the ocean and hence cool the upper ocean, and they increase its density sufficiently to counteract temporarily some of the effects from net freshening over the North Atlantic because of a global warming. However, Delworth & Dixon noted that the excess freshening over the North Atlantic predicts a significant reduction of the THC eventually.

Rahmstorf (2000) summarized all earlier numerical experiments that proposed a significant (20 to 50%) reduction in the THC overturning rate under global warming scenarios by 2100. We emphasize that our highlighting of the contrasting GCM results by Latif et al. or by Delworth & Dixon, noting the preferable higher spatial resolution of Latif et al.'s GCM, does not undermine all previous model results. The exercise conducted here is meant to note the inconsistency among GCMs for the predicted changes in THC. We conclude that no robust or quantitative prediction of THC is currently possible.

4. DEALING WITH THE ISSUES

Many questions remain open concerning what can be deduced from the current generation of GCMs about potential CO_2-induced modifications of Earth's climate. The climatic impacts of increases in atmospheric CO_2 are not known with practical or measurable degree of certainty. Specific attempts to fingerprint CO_2 forcing by comparing observed and modeled changes in the vertical temperature profiles have yielded new insights related to areas where model physics may be improved. One good example is the unrealistically coherent coupling between the lapse rate and tropospheric mean temperature in the tropics for variability over time scales of 3 to 10 yr (Gillett et al. 2000).

However, even the range of modeled global warming remains large and is not well constrained (Forest et al. 2000). For example, the aggregate of various GCMs gives a global climate sensitivity that ranges from 1.5 to 4.5°C (IPCC 1996) for an equilibrium response to a doubling of the atmospheric CO_2 concentration. Räisänen (1999) more optimistically suggested that many of the qualitative inter-model disagreements in CO_2-forced climate responses (including differing signs of predicted response in some variables, i.e., sea-level pressure, precipitation and soil moisture) could be attributed largely to differences in internal variability in different climate models. On the other hand, Räisänen cautioned that it may be dangerous to rely upon a single GCM for the study of climate change scenarios because 'a good control climate might partly result from skillful tuning rather than from a proper representation of the feedbacks that are important for the simulation of climate change.'

Building partly on that idea, Forest et al. (2000) utilized the Massachusetts Institute of Technology (MIT) statistical-dynamical climate model to quantify the probability of expected outcomes by performing a large number of sensitivity runs, i.e., by varying the cloud feedback and the rate of heat uptake by the deep ocean. It turned out that the IPCC's range of equilibrium climate sensitivity of 1.5 to 4.5°C corresponds roughly to only an 80% confidence interval of possible responses under a particular optimal value of global-mean vertical thermal diffusivity below the ocean's mixed layer. The 95% probability range for the climate sensitivity as quantified by Forest et al. was 0.7 to 5.1°C; and, in the final analysis, Forest et al. determined the more relevant result for transient responses to a doubling of atmospheric CO_2 to be a mean global warming of 0.5 and 3.3°C at the 95% confidence level. Forest et al. concluded, 'climate change projections based on current general circulation models do not span the range of possibilities consistent with the recent climate record.'

There are arguments that the possible range of climate sensitivity and hence climate responses could be narrower. Specifically, both Yao & Del Gino (1999) and Del Gino & Wolf (2000) had proposed to revise this and to raise the value for the minimum climate sensitivity to a doubling of CO_2 from 1.5 to 2.0–2.5°C because most GCMs may have incorrectly overemphasized the negative feedbacks from low clouds. Del Gino & Wolf have found evidence that low clouds get thinner, instead of thicker, with warming (mainly because of the more dominant ascent of the cloud base) in the subtropics and midlatitudes. Thinner low clouds with decreasing liquid water path length means a cloud less capable of reflecting sunlight, which ultimately lessens the impact from the low cloud-temperature cooling feedback carried in most GCMs.

Another scenario that apparently greatly affects climate response is the complex interaction of climate and global carbon cycles. In an extreme case, Cox et al. (2000) proposed a strong positive feedback of global warming that causes a dramatic release of soil organic carbon to the atmosphere. Cox et al. found that the inclusion of such a strong biophysical feedback in a coupled atmosphere-ocean GCM (added with both a dynamic global vegetation and global carbon cycle model) will increase the originally prescribed atmospheric CO_2 from 700 to 980 ppm by the year 2100. This transient numerical experiment predicted a global warming of 5.5 K by 2100, compared to the 4 K scenario without the carbon cycle feedback. The corresponding warming over land is 8 K, instead of 5.5 K without the added atmospheric CO_2 from the strong biophysical feedback. But, these authors acknowledged that their results depend critically on the model assumption of a long-term sensitivity of soil respiration to global warming, which may be contradicted by field and laboratory data (Giardina & Ryan 2000).

In contrast, semi-empirical estimates by Lindzen (1997) and Idso (1998) that included probable negative feedbacks in the climate system yielded a climate sensitivity of about 0.3 to 0.5 K for a doubling of atmospheric CO_2. Furthermore, Hu et al. (2000) noted the tendency for climate model sensitivity, to variation in atmospheric CO_2 concentration, to decrease considerably as the sophistication of parameterizing atmospheric convection increases. In Hu et al.'s study, the change is from a decrease in the averaged tropical surface warming of 3.3 to 1.6 K for a doubling of CO_2 that is primarily associated with the corresponding decrease in the calculated total atmospheric column increase in water vapor from 29 to 14%.

The main point that emerges here is that the range of climate sensitivity remains large and it is not sufficiently well quantified either by empirical or theoretical means.

4.1. Causes of recent climatic change: aerosol forcing

Other recent efforts, such as that of Bengtsson et al. (1999), have highlighted the inconsistency between the differing observed surface and tropospheric temperature trends and simulated GCM trends that try to include forcing factors such as combined anthropogenic GHGs, anthropogenic aerosols (both direct and indirect effects), stratospheric aerosols from the Mount Pinatubo eruption, and changes in the distribution of tropospheric and stratospheric ozone. In addition, Roeckner et al. (1999) have discussed how superposing other forcings, such as direct and indirect aerosol effects, on the GHG forcing has led to an unexpected weakening of the intensity of the global hydrologic cycle. We also wish to add that surface or tropospheric warming in combination with lower stratospheric cooling does not uniquely signify a fingerprint of elevated CO_2 concentration. Such a change in temperature lapse rate is also the natural behavior of the atmosphere associated with potential vorticity anomalies in the upper air's flow structure (Hoskins et al. 1985, Liu & Schuurmans 1990). This ambiguity precludes the detection of anthropogenic CO_2 effects without additional, confirmatory information.

Not all researchers express a forcing by aerosols. For example, Russell et al. (2000) recently cautioned that '[o]ne danger of adding aerosols of unknown strength and location is that they can be tuned to give more accurate comparisons with current observations but cover up model deficiencies.' Such an important caveat may give a better sense of urgency if one recalls that most current GCMs treat the effects of anthropogenic sulphate aerosols by merely rescaling surface albedo according to a precalculated sulphur loading (Räisänen 1999, Roeckner et al. 1999, Covey 2000). Furthermore, at least in the sense of direct radiative forcing, naturally occurring sources such as sea salt and dimethyl sulphide from marine phytoplankton, rather than anthropogenic sources (Haywood et al. 1999, Haywood & Boucher 2000, Jacobson 2001), dominate the variable and inhomogeneous forcing by aerosols. For example, Jacobson (2001) estimated for all sky conditions that the global direct radiative forcing from combined natural and anthropogenic aerosols is about -1.4 W m^{-2}, compared to an anthropogenic-only aerosol forcing (including black carbon component) of -0.1 W m^{-2}. Haywood & Boucher (2000) stressed the fact that the indirect forcing effect of the modification of cloud albedo by aerosols could range from -0.3 to -1.8 W m^{-2}, while the additional aerosol influences on cloud liquid water content (hence, precipitation efficiency), cloud thickness and cloud lifetime are still highly uncertain and difficult to quantify. Therefore, the formulation of an internally consistent approach to determine the climatic effects of CO_2 by including both natural and anthropogenic aerosols in the troposphere remains a critical area of research (Haywood & Boucher 2000, Rodhe et al. 2000, Jacobson 2001).

4.2. Nonlinear dynamical perspective on climate change

A somewhat different interpretation of recent climate change is also possible (Corti et al. 1999, Palmer 1999). In an analysis of NH 500 mb geopotential heights, the authors showed that the record since the 1950s could essentially be projected in terms of the modes of 4 naturally occurring, shorter-term, atmospheric circulation regimes, identified in Corti et al. (1999) as Cold-Ocean-Warm-Land (COWL), Pacific North American Oscillation, North Atlantic Oscillation and Arctic Oscillation patterns. Then, climate variability, viewed as vacillations of these quasi-stationary weather regimes, can be quantified by changes in the probability density function associated with each regime. Palmer and colleagues thus proposed that the impact of anthropogenic CO_2 forcing might be revealed as a projection onto modes of these natural weather regimes. Of course, there is no guarantee that the underlying structure of the weather regimes would remain the same under the perturbation of a different or stronger forcing.

Next, Corti et al. (1999) showed that recent observed changes could be interpreted primarily as an increasing occurrence probability associated with the COWL regime (Wallace et al. 1995), perhaps consistent with the projection of the anthropogenic CO_2 forcing. With this idea in mind, the authors proposed to resolve the contentious discrepancy between the rising trend in surface air temperature versus the relative constancy of the lower tropospheric air temperature, as summarized in the NRC (2000) report, the rationale being that most of the recent hemispheric-mean temperature change is associated with the COWL pattern. Since the COWL pattern is primarily a surface phenomenon, one can expect to find a stronger anthropogenic CO_2-forced temperature imprint at the surface than in the troposphere. Above the surface, the land-sea contrast weakens significantly so that no imprint of anthropogenic thermal forcing anomalies persist there. But such a pattern of climatic change—emphasizing surface response over land—seems also consistent with the heat island effect from urbanization, leaving interpretation of the vertical pattern of temperature trend unresolved.

It is, of course, a curious point that no GCM has yet simulated such a vertical pattern of climate change (Bengtsson et al. 1999). The strongest anthropogenic CO_2 response in GCMs is still expected in the mid-to-high troposphere, simply because of the dominance of direct radiative effects. A further question left unanswered by Corti et al. (1999) is why increased CO_2 should lead to an increase in the residence frequency of the COWL regime. Furthermore, any number of warming influences may contribute to the positive bias of COWL, since the main physical cause of the pattern is the heat capacity contrast between land and sea. In this respect, it is important to point out that the COWL pattern is a robust feature of unforced numerical climate experiments under various air-sea coupling schemes (Broccoli et al. 1998). But as emphasized by these authors, even though a direct comparison of observations with the model-derived unforced patterns and changes 'has implications for the detection of climate change, [they] do not intend to attribute the recent warming of NH land to specific causes.'

Broccoli et al. (1998) conclude that separating forced and unforced changes in observational records is difficult. Hence, they focused strictly on pointing out the problem in the methodology introduced by Wallace et al. (1995) by applying the COWL-pattern variability for climate change detection. In doing so, they utilized a GCM run forced with CO_2 and tropospheric sulphate aerosols to make their points, but they did not elaborate on results with CO_2 forcing alone. Their main conclusion is that the decomposition method of Wallace et al. is not suitable for climate change detection, because it yields ambiguous results when more than 1 radiative forcing pattern (such as CO_2 and tropospheric sulphate aerosols) is present.

The recognition of climatic change as responses of a non-linear dynamical system imposes the strong requirement that GCMs must accurately simulate natural circulation regimes and their associated variabilities down to regional and synoptic scales. This requirement is especially difficult to fulfill because the global radiative forcing of a few W m^{-2} expected from the anthropogenic CO_2 perturbation is quite small compared to the uncertain energy budgets of various components of the climate system, as well as flux errors in model parameterizations of physical processes. For a perspective on the severity of this problem, consider the dynamic phenomenon of midlatitude atmospheric blocking. As part of the AMIP, D'Andrea et al. (1998) have recently confirmed the large differences in blocking behavior produced among the 15 to 16 GCMs that span a wide range of modeling techniques and physical parameterizations. When compared to observed blocking statistics, all GCMs showed systematic errors of underestimating both the blocking frequency and the duration of blocking events (almost all models have problems in producing long-lived blocking episodes over the midlatitude Euro-Atlantic and Pacific sectors). Worse still, there is also no clear evidence that high-spatial-resolution models perform systematically better than low-resolution models. D'Andrea et al. (1998) have thus proposed only ad hoc numerical experiments to study the possible, previously hidden model deficiencies responsible for the large range of GCM performance in simulating atmospheric blocking. Therefore, significant challenges in numerical weather and climate modeling remain.

4.3. New observational scheme

Modeling is but one approach to understanding climate change. To place more confidence in climate modeling by computer, observational capability must advance. Improved precision, accuracy and global coverage are all-important requirements. For example, Schneider (1994) has estimated that a globally averaged accuracy of at least 0.5 W m^{-2} in net solar-IR radiative forcing is required to refine the present unacceptably large range in the estimates of climate sensitivity. In this respect, Goody et al. (1998) have recently proposed the complementary scheme of interferometric measurements of spectrally resolved thermal radiance and radio occultation measurements of refractivity — with help from Global Positioning System (GPS) satellites — that can achieve a global coverage with an absolute accuracy of 1 cm^{-1} in spectral resolution and 0.1 K in thermal brightness temperature. The resolution capability of 0.1 K is needed to quantify the expected warming from increased GHGs in 1 decade, while the accuracy of 1 cm^{-1} is needed to resolve differences in possible spectral radiance fingerprints among several causes. Along with a promised high vertical resolution of about 1 km, the complementary thermal radiances and GPS refractivity measurements should produce a better characterization of clouds, since thermal radiance is cloud sensitive but the refraction of GPS radio signals, while sensitive to water vapor and air molecules, is not affected by clouds. These observational schemes thus offer hope for critical tests of climate model predictions and for the detection of anthropogenic CO_2 forcing before it becomes too large.

5. CONCLUSIONS

Our current lack of understanding of the Earth's climate system does not allow us to determine reliably the magnitude of climate change that will be caused by anthropogenic CO_2 emissions, let alone whether this change will be for better or for worse. We raise a point concerning value judgment here because a value assignment is prerequisite to evaluating the need for human mitigation of adverse consequences of climate change. If natural and largely uncontrollable factors that yield rapid climate change are common, are humans capable of actively modifying climate for the better? Such a question has been posed and cautiously answered in the negative, e.g., by Kellogg & Schneider (1974). Given current concerns about rapid climate change, several geoengineering proposals are being revived and debated in the literature (e.g., Schneider 1996, Betts 2000, Govindasamy & Caldeira 2000). We argue that even if climate is hypersensitive to small perturbations in radiative forcing, the task of understanding climate processes must still be accomplished *before* any effective action can be taken.

Our review of the literature has shown that GCMs are not sufficiently robust to provide an understanding of the potential effects of CO_2 on climate necessary for public discussion. Views differ widely on the plausible theoretical expectations of anthropogenic CO_2 effects, ranging from dominant radiative imprints in the upper and middle troposphere (based on GCM results) to nonlinear dynamical responses. Even if a probability could be assigned to a certain catastrophic aspect of CO_2-induced climatic change, this measure can be objective only if all relevant facts, including those that are still in the future, are considered in the calculation. Therefore, at the current level of understanding, global environmental change resulting from increasing atmospheric CO_2 is not quantifiable.

Systematic problems in our inability to simulate present-day climate change are worrisome. The perspective from nonlinear dynamics that suggests 'confidence in a model used for climate simulation will be increased if the same model is successful when used in a forecasting mode' (IPCC 1990, as quoted in Palmer 1999) also paints a dismal picture of the difficult task ahead. This brief overview shows that we are not ready to tell what the future climate of the Earth will look like. The primary reason for our inability to do so is that, even if we have perfect control over how much CO_2 humans introduce into the air, other variable components of the climate system, both internal and external, are not sufficiently well defined. Also, all future climate scenarios performed in various GCMs must be strictly considered as mere numerical sensitivity experiments, instead of meaningful climate change predictions (Räisänen 1999, Mikolajewicz & Voss 2000). Attempts to integrate the environmental impacts of anthropogenic CO_2 should note limitations in current GCMs and avoid circular logic (Rodhe et al. 2000).

In light of the above, we support a more inclusive and comprehensive treatment of the CO_2 question, stated as an internally consistent scientific hypothesis, as demanded by the rules of science. Climate specialists should continue to urge caution in interpreting GCM results and to acknowledge the incomplete state of our current understanding of climate change. Progress will be made only by formulating and testing a falsifiable hypothesis.

The criticisms in this review are presented with the aim of improving climate model physics and the use of GCMs for climate science research. We recognize that there are alternative arguments and other interpretations of the current state of GCMs and climatic change (Grassl 2000). Furthermore, we are biased in favor of results deduced from observations. For an alternative view, we strongly recommend that the reader consult the IPCC reports (1990, 1995 and the upcoming 2001 report). These provide detailed documentation of the merits of GCMs, including the IPCC's assessment of a discernible human influence on global climate. Our review points out the enormous scientific difficulties facing the calculation of climatic effects of added CO_2 in a GCM, but it does not claim to disprove a significant anthropogenic influence on global climate.

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RESPONSES BY DR. SALLIE BALIUNAS TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. You indicated that a "Kyoto-type cut would avert the temperature rise by the year 2050 by only .06 degrees Centrigrade." Using the same assumptions that brought you to that conclusion, how much warming would occur by 2050, if U.S. emissions continue to grow at the current annual rate (2 percent) until then?

Response. By 2050 one published model (M. Parry et al., 1998, Nature, 395, 741) forecasts a temperature rise of approximately 1.4C with continued U.S. emissions growing at the current rate, and no emission cuts by developing nations.

Question 2. How much warming would be avoided by a "Kyoto-cut" in the year 2100, assuming U.S. participation in the Kyoto timeframe?

Response. By the year 2100 the model cited above should forecast approximately 0.1C of warming averted if the United States implemented a Kyoto-type cut according to the current Kyoto Protocol timeframe.

Question 3. Balloon radiosonde records confirm satellite results, according to your testimony. However, the radiosonde record extends back only to 1957. Why does it make sense to use these records to determine the absence of a significant warming trend, when competing and reliable temperature recordings date back to the pre-industrial era—before humankind began emitting large quantities of greenhouse gases?

Response. No reliable globally averaged surface temperature records date back to the preindustrial period. The present surface temperature record gotten from thermometers that sample locations worldwide reaches back to the mid-19th century. Some of the thermometer readings are prone to warming from local urbanization. That uncertainty, plus the sparse coverage of the surface readings—only about 20 percent of the surface of the Earth, with especially poor coverage of the Southern Hemisphere oceans are sampled in the thermometer record, introduce uncertainty not easily quantified in the surface record. In contrast, the satellite records cover more than 80 percent of the globe, and are validated by the independent records from balloon radiosonde instruments. For a technical discussion, see W. Soon et al., 1999, Climate Research, 13, 149.

Question 4. As you and all the other witnesses indicated, it is not safe to continue increasing greenhouse gas emissions without limit. What needs to be done to assure that we can avert the point of not return or "dangerous levels" of greenhouse gas concentrations?

Response. As a rhetorical question, the statement is philosophically true. However, it is not possible for science to give a reliable, quantitative assessment of "dangerous" in that context.

Question 5. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. According to the key measurements of the lower troposphere, there is little risk of catastrophic global warming risk in the next 30 to 50 years from the expected profile of the atmospheric increase in human-made greenhouse gas emissions. To reduce the uncertainty, an enhanced, targeted program of decisive climate research—both measurements and theory—should be implemented and supported for a decade or longer period.

RESPONSES BY DR. SALLIE BALIUNAS TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th century, the atmospheric concentrations of a number of greenhouse gases have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

Response. I agree that during the 20th century the air's content of certain greenhouse gases, most notably carbon dioxide, have increased owing to human activities. The key question is what has been the response of climate to the increased in the air's concentration of greenhouse gases.

Question 2. Dr. Pielke testified that "the primary cause for . . . growth in impact[] is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se." Do you agree with this claim? Why or why not?

Response. I agree that vulnerability to climate change has increased in some, but by no means all, situations. For example, hurricanes are the most costly destructive natural phenomena in the United States. While hurricane damage and property losses have increased greatly in the last 100 years, loss of life has acutely declined. A powerful, unnamed hurricane struck Galveston in 1900, killing more than 8,000 people. An also powerful hurricane, Andrew, struck a very densely populated area of south Florida in 1991. Hurricane Andrew tragically killed around 50 people, yet thousands of lives were saved by technological advances such as sturdy buildings and satellite imagery that gave early hurricane strike warning. The insurable property damage for Hurricane Andrew hit a record tens of billions of dollars. Expensive development in areas of likely hurricane strike has made society more vulnerable to hurricanes in terms of property loss. On the other hand, Hoover Dam built in the 1930's has reduced environmental, property and human catastrophe that had occurred with the recurrent but unpredictable flooding of the Colorado River.

Question 3. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought . . ." Do you agree with that proposition? Why or why not?

Response. I agree that more attention should be paid to predicting, mitigating and adapting to weather phenomena like hurricanes, hailstorms, blizzards, streamflow flooding, early frosts and tornadoes. To the extent that research funding for those ever-present weather calamities needs to be obtained from study of climate simulations over distant horizons, that is a policy decision I am unequipped to make.

Question 4. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree Celsius? Why or why not?

Response. Implementing the Kyoto Protocol would make no meaningful difference in the averted temperature rise forecast for the next 50 or 100 years, according to the predictions shown by, e.g., the U.N. IPCC TAR.

Question 5. Since the hearing there has been much press attention paid to the breakup of the Anarctic Ice Sheet, especially a 500-billion ton iceberg know as "Larsen B" that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. No reliable evidence posits the calving of the Larsen B iceberg to human-made global warming. The peninsula on which the Larsen Ice Shelf rests has warmed over the last 50 years. However, the climate simulations say the entire region of Antarctica should have shown a warming trend over the last several decades; in the last 50 years the majority of the Antarctic continent has cooled. The calving of the Larsen B iceberg must therefore be a natural phenomenon, caused in part by the local, natural temperature rise and also by changes in, e.g., sea salinity, orography, wind, and sea currents.

Question 6a. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty: Copying with the risks of climate change" (copy attached). Please explain why you agree or disagree with the following assertions or conclusions from that report: A. "There is not one problem but two natural climate variability and the influence of human activity on the climate system."

Response. Because natural climate variability is the backdrop against which human climate effects must be judged, understanding natural variability is prerequisite to detecting human climate effects. The problems are closely interrelated.

Question 6b. ". . . it is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted.

Response. The statement is tantamount to saying that models have no regional credibility for predicting weather events, which is scientifically true.

Question 6c. Swiss Re considers it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which—if they are not confirmed—will in time turn to carefree relief, and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind.

Response. The consequence of Swiss Re's statement is that technology ought to proceed in a timely and sufficiently supported way to understand natural climate variability, as well as adaptation and mitigation to dangerous weather events that have, and will continue, to wreck destruction on humans and the environment.

Question 7. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. Some developing nations have become more vulnerable to extreme weather events, but the events have not been demonstrated to owe to the air's increased content of human-produced greenhouse gases. The United States should continue to lead in mitigating weather vulnerability by committing to elevating those nations from poverty, starvation and lack of education.

RESPONSES BY DR. SALLIE BALIUNAS TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. The United States by the year 2050 would be required to produce zero emissions of carbon dioxide and other human-made greenhouse gases. By the year 2100, U.S. emissions would have to be negative.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis.

Response. In my estimation, no study adequately addresses the enormous economic costs to the United States for such a scenario.

Question 2a. Please provide your assessment of the validity of the various temperature measurements including their coverage of the globe: Satellite.

Response. The satellite Microwave Sounder Unit Measurements, covering about 85 percent of the globe, are validated by several sets of independent balloon radiosonde measurements. Where the measurements overlap, the satellite and balloon records have a nearly perfect correlation—with a 99 percent correlation coefficient. The satellite measurements seem precise to 0.01 C.

Question 2b. Please provide your assessment of the validity of the various temperature measurements including their coverage of the globe: Weather balloon.

Response. The balloon radiosonde measurements are in substantial agreement with the satellite records where they overlap. Both therefore give reliable trends of the temperature of the lower troposphere because they are independent measurements.

Question 2c. Please provide your assessment of the validity of the various temperature measurements including their coverage of the globe: Surface—land.

Response. It is difficult to estimate the global surface temperature to within a tenth of a degree C. Land surface measurements over the United States and parts of Europe are the most reliable going back about a century. The records have been corrected as best as possible for, e.g., the urban heat island effect produced by increased population, urban mechanization, vegetation removal, albedo changes, etc., but the corrections are uncertain. The sea surface records are scarce. It is difficult to estimate the uncertainty owing to the lack of sampling for nearly 80 percent of the globe in the averaged surface temperature, where vast areas of the Southern Hemisphere oceans were not sampled.

Question 2d. Please provide your assessment of the validity of the various temperature measurements including their coverage of the globe: Surface—ocean.

Response. It is difficult to estimate the global surface temperature to within a tenth of a degree C. Land surface measurements over the United States and parts of Europe are the most reliable going back about a century. The records have been corrected as best as possible for, e.g., the urban heat island effect produced by increased population, urban mechanization, vegetation removal, albedo changes, etc., but the corrections are uncertain. The sea surface records are scarce. It is difficult to estimate the uncertainty owing to the lack of sampling for nearly 80 percent of the globe in the averaged surface temperature, where vast areas of the Southern Hemisphere oceans were not sampled.

Question 3. Can you provide documentation that includes temperature proxy indications for at least the last 1,000 years covering the Medieval period?

Response. A very few of the numerous articles documenting climate change going back at least 1,000 years include J. Esper et al., 2002, Science, 295, 2250; J.M. Grove, 2001, Climate Change, 48, 53; C. Pfister et al. 1998, Holocene, 8, 535; and W.S. Broecker, 2001, Science, 291, 1497.

Question 4. What are the effects of removing black soot from the atmosphere? What are the benefits of using U.S. clean coal technology in countries like China and India in terms of removing black soot?

Response. The effect of removing significant amounts of black soot from the atmosphere would be to improve substantially the health of humans and the environment from this pollutant. Efforts should be made to help severe pollution producers like China and India to prevent emission of soot from their coal burning facilities.

Question 5. What are the magnitudes of the various inputs to the climate and what are their contributions (cooling, warming)?

Response. This is the capitol question. The magnitudes of the inputs, and, critically, the responses of the climate system to those agents of climate forcing are inaccurately known. For example, all climate simulations assume water vapor in the upper troposphere produces a large amplification of the small warming that occurs from doubling the air's carbon dioxide concentration. Yet satellite measurements of the amount of water vapor in the upper troposphere suggest that that layer of air is too dry to support the presumed amplification mechanism. Moreover, the lower troposphere should have responded with a significant global warming trend over the last two decades—but the reliable, verified satellite temperature record shows little human-made warming trend. Thus, all models make an assumption that is unsupported by the existing evidence. As Prof. Richard Lindzen of MIT has said of this assumption, it is likely a "computational artifact" that serves to produce exaggerated trends of human-made global warming. Second to water vapor in producing the strongest positive feedback effect is the influence of clouds, whose properties and interactions with the climate system remain highly uncertain.

Question 6. Can you document the uncertainties reflected in the NRC June 2001 "Climate Change Science" underlying report?

Response. Several of the uncertainties have been previously discussed, for example, W. Soon et al., 2001, Climate Research, 18, 259, as attached to my original testimony.

Question 7. Please provide the documentation of how the NRC report (June 2001) addressed the satellite, weather balloon, and surface temperature measurements.

Response. The report largely did not resolve the discrepancy between the satellite and surface discrepancy. For a technical discussion of the underlying issue, please see W. Soon et al., 1999, Climate Research, 13,149.

Question 8. Given your interpretation of gradual change in climate, what is the recommended course of action with regard to scientific modeling?

Response. First, assume that the results of the climate models, whose global warming trends calculated for the last two decades of satellite data are roughly a factor of five too high compared to the validated observations, are, perplexingly, correct. A delay of up to three decades in implementing sharp greenhouse gas emission cuts should produce a negligible additional warming by the year 2100 compared to natural fluctuations in the climate, even in the case of the current climate models that exaggerate the present global warming trends. And, if the human global climate trend is much smaller than the models predict, as the scientific evidence now suggests, then the window of opportunity for improving climate science is longer than three decades. In terms of action, one might consider: getting critical measurements meant improve understanding of natural climate variability, including the physics of water vapor, clouds and important sunclimate interactions.

Question 9. Dr. Baliunas, when Dr. Lindzen testified before this committee last year he made a statement that "no model explains any major feature of the climate." Could you explain this for me. Are our models capable of explaining climate phenomena?

Response. As Prof. Lindzen correctly stated, no general circulation model of global climate change properly simulates any major feature of the climate. That includes natural phenomena like El Niño Southern Oscillation (ENSO), sea ice variability, decadal oscillations such as the North Atlantic Oscillation (NAO) and the Pacific Decadal Oscillation (PDO), the Quasi-Biennial Oscillation (QBO), circulation of energy from the equator to the polar regions, clouds, precipitation patterns and water vapor. The fact that no global model correctly accounts for any of these features of climate means that no global model can possibly account for all of those features.

Current global climate simulations cannot yet make reliable forecasts, especially 100 years into the future.

RESPONSE BY DR. SALLIE BALIUNAS TO AN ADDITIONAL QUESTION FROM SENATOR CAMPBELL

Question. In your testimony, you say that it is "impossible to have a verified and validated climate model" due to the variability of natural systems. It would seem then that predicting climate change would be like predicting chaos. How accurately are you able to make sense of the madness?

Response. Technically speaking, chaos is a deterministic mathematical tool that can yield calculated results that are widely separated even for only slightly different starting points in the calculation. The results are repeatable, but may be extremely sensitive to slightly different starting points. The climate system may be partly or wholly chaotic, but the information is not yet available to determine if climate is so. Some research focuses on chaos calculations in climate simulations. The lack of a reliable global climate forecast of which I spoke depends on having as an essential starting point a verified and validated global simulation, which does not yet exist. One reason why the global simulations lack validity is that the physics of the major, relevant factors in natural variability are simply not known with enough certainty at present. In that regard, it is also not useful to consider as a reliable forecast an average of a suite of forecasts from different climate simulations, each of which fails validation. Improving the reliability of forecasts requires significantly reducing the uncertainty of natural variability—the fluctuations against which human climate effects must be estimated.

STATEMENT OF DR. MARTIN WHITTAKER, INNOVEST STRATEGIC VALUE ADVISORS, INC.

"The greatest challenge facing the world at the beginning of the 21st century is climate change . . . Not only is climate change the world's most pressing problem, it is also the issue where business could most effectively adopt a leadership role." Proceedings of the World Economic Forum Annual General Meeting, Davos, February 2000.

Climate change is rapidly becoming a major issue for U.S. companies and fiduciaries. The increasingly global nature of industrial competition, institutional investment strategies, and legislated disclosure requirements mean that company directors and other fiduciaries in North America should see climate change as a major business risk—and opportunity.

In the private sector, climate change has rapidly developed into a major strategic—and practical—issue for both industrial corporations and their investors. The competitive and financial consequences for individual companies can be huge: Innovest's own research has indicated that the discounted future costs of meeting even 'softened' Kyoto targets correspond to 11.5 percent of total current market value for the most carbon-intensive U.S. electric utility to 0.2 percent in the least; and up to 45 percent of current share value. Increasingly severe climatic events have the potential to stress P&C insurers and reinsurers to the point of impaired profitability and even insolvency; indeed, insurance analysts at one major U.S. investment bank are already known to have lowered their earnings estimates to account for 'what appears to be a higher-than-normal level of catastrophes' during early 2001.

By the same token, recent studies give grounds for optimism that the right blend of market based policies, if skillfully introduced, can substantially reduce the direct and indirect costs of mitigation and perhaps even produce a net economic benefit. Indeed, several leading insurance, fund management and industrial companies are already poised with risk management programs and innovative new solutions that promote both GHG emissions reductions and their own bottom lines. Our research shows that, for a variety of reasons, businesses practicing sound environmental management also enjoy enhanced competitive advantage and superior share price performance.

There is therefore an increasingly compelling need for corporate board members, pension fund trustees, and asset managers to take the climate change issue far more seriously than they have to date as a major and legitimate fiduciary responsibility.

A number of major drivers are currently converging to propel climate change to a much more prominent place on the agendas of company directors and executives, as well as those of a growing number of institutional investors:

STRENGTHENING SCIENTIFIC CONSENSUS

The most recent report by the IPCC (Intergovernmental Panel on Climate Change) actually strengthened warnings from its earlier work regarding the rate, extent and consequences of climate change. The report accelerated climate change time horizons and identified the possibility that at some unknown threshold, sudden and largely irreversible shifts in global climate pattern may occur. Developing countries are predicted to bear the brunt of future climate turbulence.

A new report by the U.S. National Academy of Scientists released in March 2002 corroborated these findings, adding that exceeding the threshold limits could precipitate sudden and abrupt changes which are far more dramatic than anything that preceded them.[1] Simulation modeling indicates that the cost of a single extreme hurricane could reach as much as $100 billion, on the same scale as the accumulated pollution damage in the USA since industrialization began.

IPCC scientists also believe that North America has already experienced challenges posed by changing climates and changing patterns of regional development and will continue to do so. Varying impacts on ecosystems and human settlements will exacerbate differences across the continent in climate-sensitive resource production and vulnerability to extreme events.

GROWING RECOGNITION OF THE GRAVITY OF POTENTIAL FINANCIAL IMPACTS FROM WEATHER EXTREMES

Over the past 15 years alone, the word has already suffered nearly $1 trillion in economic losses due to "natural" disasters, roughly three-quarters of which were directly weather-related.[2]

Munich Re, one of the world's largest reinsurers, recently estimated that climate change will impose costs of several billion dollars each year unless urgent measures are taken to reduce greenhouse gas (GHG) emissions. In the year 2000 alone, global damage reached $100 billion, mostly uninsured, and already simulation modelling shows that the cost a single extreme hurricane could reach $100 billion, on the same scale as the accumulated pollution damage in the USA since industrialisation began.

These concerns have now been echoed by other leading mainstream financial institutions including Swiss Re, Credit Suisse and Deutsche Bank. The costs of continued inaction are potentially astronomical, yet there is growing evidence that aggressive mitigation measures need not cause the economic harm and dislocation initially feared by many conservative economic commentators.[3]

NEW UNDERSTANDING OF THE BREADTH OF SECTORAL IMPACTS

"As we are beginning to appreciate within the reinsurance industry, the effects of climate change can be devastating . . .", Kaj Ahlman, ex-CEO, Employers Re.

Conventional wisdom suggests that the effects of climate change will be limited to sectors directly associated with the energy value chain (including oil and gas, natural gas, pipelines and electric utilities on the downside, and renewable energy) and those industries consuming large amounts of energy (steel manufacturing, smelting and such like).

Recent research makes it clear, however, that the business ramifications relate not just to energy-intensive industries but also sectors such as telecommunications and high-technology (which influence societal resource consumption and provide enabling technologies); forestry (an integral part of the sustainable energy cycle); automotive (the primary users of petroleum products and leaders in fuel cell development); electronics, electrical industries and other equipment suppliers (where fuel cell technologies are already creating whole new markets); agriculture (where industries ranging from animal farming to winegrowing face major potential impacts), tourism and other sectors.

NEW EVIDENCE ON COMPANY-SPECIFIC IMPACTS

In addition to the massive aggregate risk exposures noted above, recent evidence on company-level impacts has revealed:

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[1] U.S. National Academy of Sciences, *Abrupt Climate Change: Inevitable Surprises*, March 2002.

[2] U.S. Department of Energy, *U.S. Insurance Industry Perspectives on Global Climate Change*, February 2001.

[3] See, for example, the IPCC Third Assessment Report 2001.

a. That in some high-impact sectors such as energy and electric utilities, the climate change-driven threat to shareholder value could represent as much as 30 percent of the total market capitalization of major companies; and

b. That even within the same industry sector, firm-specific climate risk can vary by a factor of nearly 60 times.[4]

c. Companies are increasingly finding ways of benefiting from proactive action on tackling greenhouse gases, either through win-win energy savings activities or the development of new products and services based around greater energy efficiency or GHG-reducing technologies[5].

It clearly behooves fiduciaries and investors to know which industry sectors and companies are exposed to the greatest risks and opportunities, and what measures if any are being taken to identify and manage those risks.

THE INTERNATIONALIZATION OF PENSION FUND INVESTMENT

Ten years ago, only 3.3 percent of U.S. pension funds' equity investments were in non-U.S. company securities. Today, that proportion has more than tripled to over 11 percent.[6] A similar internationalization of pension fund investing is occurring in virtually every OECD country. What this means for U.S. fiduciaries is simply this: The competitiveness of their investee companies—and therefore their fiduciary responsibilities—will not permit them to ignore or remain isolated from climate change policy and regulatory developments in other parts of the world.

LEGITIMIZATION BY MAINSTREAM INVESTMENT INSTITUTIONS

Major international investment houses such as AMP Henderson and Friends Ivory & Sime have developed sophisticated guidelines for assessing companies' strategic and operational responses to the climate change threat. What is more, they have begun to communicate the importance of the issue to their clients. This initiative by a mainstream investors will go a considerable distance toward "legitimizing" climate change to conservative investors.

A broad coalition of global institutional investors is already forming to press management at the world's largest companies on shareholder risks associated with climate change via the 'Carbon Disclosure Project' (CDP). The CDP is a non-aligned Special Project within the Philanthropic Collaborative at the Rockefeller Brothers Foundation with the sole purpose of providing a better understanding of risk and opportunities presented to investment portfolios by actions stemming from the perception of climate change. To date, institutions representing over $2 trillion in assets have already joined the initiative.

In the United States, climate change-related shareholder resolutions are anticipated against ExxonMobil, Chevron-Texaco, and Occidental Petroleum during the current (2002) proxy season. Major institutional investors including the city of New York and the State of Connecticut are beginning to flex their financial muscles on the climate change issue.

EXPANDED VIEW OF FIDUCIARY RESPONSIBILITIES

Historically, fiduciary responsibilities have been interpreted rather narrowly in both the United States and Europe. Fiduciaries' principal obligation was the maximization of risk-adjusted financial returns for pension plan beneficiaries, investors, and shareholders. Since environmental performance was widely seen as injurious or at best irrelevant to financial returns, the prevailing ethos held that they were of necessity beyond the legitimate purview of fiduciaries. This ethos has now begun to shift dramatically: A growing body of research is making it clear that companies' environmental performance may well affect financial returns, and is therefore a wholly legitimate concern for fiduciaries. Legislative reforms of pension legislation in a number of European countries, is codifying this new ethos into law[7].

Recent independent back-test evidence indicates that a diversified portfolio of more "sustainable" companies can be expected to out-perform one comprised of their less efficient competitors by anywhere from 150 to 240 basis points or more per annum. In particularly high-risk sectors such as chemicals and petroleum,

[4] See, for example, Innovest Strategic Value Advisors, *Electric Utilities Industry Sector Report*, 2002

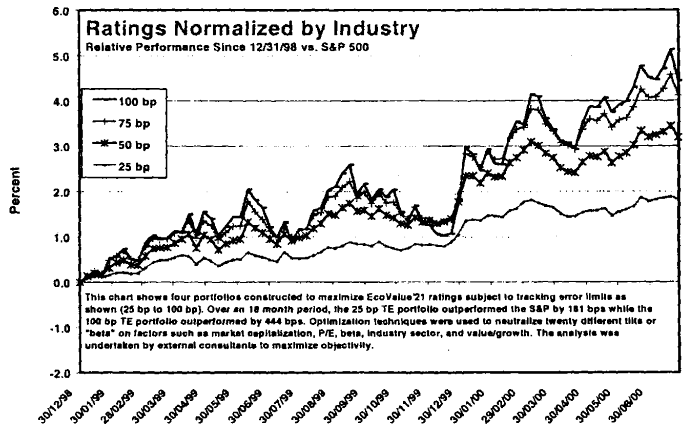
[5] Innovest sector research; Pew Center on Global Climate Change, Corporate GHG Reduction Targets, 2001

[6] R.A.G. Monks, *The New Global Investor*, John Wiley, 2001

[7] See, for example, Baker & McKenzie (Virginia L. Gibson, Bonnie K. Levitt, and Karine H. Cargo), "Overview of Social Investments and Fiduciary Responsibility of County Employee Retirement System Board Members in California," Chicago, 2000

Innovest's own research has revealed that this "out-performance premium" for top-quintile companies can be as great as 500 basis points or even more.

As the chart below illustrates, depending on how much emphasis was given to environmental performance factors, the out-performance margin ranged from 180–440 basis points (1.8—4.4 percent). None of this out-performance can be explained by traditional securities analysis; it appears to be pure "eco-value".



Source: QED International

NEW EMPHASIS ON INTANGIBLE VALUE AND DISCLOSURE

"Reputation is something which, unlike a petrochemical feedstock plant, can disappear overnight. We are increasingly getting firms which are conceptual and Enron being a classic case whose value depends on reputation and trust. And if you breach that, that value goes away very rapidly." Alan Greenspan, Chairman of the U.S. Federal Reserve Bank, Speaking at the Senate Enron Inquiry on Capitol Hill, Washington DC., January 25, 2002.

As recently as the mid-1980's, financial statements captured at least 75 percent on average of the true market value of major corporations; today the figure is closer to only 15 percent[8]. That leaves roughly 85 percent of a company's true market value which CANNOT be explained by traditional financial analysis The yawning disconnect between companies' book value (hard assets) and what they are really worth—their market capitalization—is at an all-time historical high.

This leaves institutional investors and fiduciaries with an enormous information deficit, as the recent implosion of Enron vividly demonstrated. Intangible value drivers are now the strongest determinants of companies' competitiveness and financial performance.

The growing importance of intangibles to company valuations in the United States was underscored in a March 2002 announcement by the U.S. Financial Accounting Standards Board that it will be issuing binding disclosure requirements about companies' intangible assets within the next 12 months. This will clearly accelerate the integration of intangibles into mainstream financial analysis. Internationally, the growing momentum of other major "transparency initiatives" such as the Global Reporting Initiative (GRI) are certain to add climate change as a significant new source of business and investment risk.

INTERNATIONAL LEGISLATIVE MOMENTUM

The European Union has already committed itself to a legally binding timetable for Kyoto implementation, including compulsory taxes on GHG emissions above prescribed limits, starting in 2005. Taxes on greenhouse emissions are either proposed or already in effect in Scandinavia, and the Canadian, Australian and Japanese governments are also in the process of establishing national emissions abatement plans. Japan, the U.K. and Canada have both signaled their intent to ratify the Kyoto Protocol within the coming weeks, probably before the forthcoming Earth Summit in South Africa. The imperatives of global competition will clearly impact

[8] Baruch Lev, *Intangibles: Management, Measurement and Reporting*. Washington, DC. Brookings Institution, 2001

U.S. companies regardless of any tax or other regulatory measures which may or may not be forthcoming in the United States.

DOMESTIC POLITICAL MOMENTUM

In response to both domestic and international pressure for a robust response to Kyoto, President Bush announced his new climate change policy on February 14, 2002. The administration's Clear Skies Initiative commits the United States to reduce it greenhouse gas intensity by 18 percent over the next 10 years, and includes substantial financial incentives for renewables and clean technologies. The President's proposed budget for fiscal year 2003 increases spending on climate change mitigation to $4.5 billion per year.

On February 20, 2002, EPA Administrator Christine Whitman launched one of the key components of the Bush Administration's new climate policy, the Climate Leaders protocol. That initiative encourages companies to report on their emissions of the six major GHG's, using a reporting framework developed by the World Resources Initiative and the World Business Council for Sustainable Development. In concert with similar initiatives elsewhere, this should make a significant contribution to increasing the level of transparency of carbon risk exposures and, as a result, increase accountability for both corporate directors and investment fiduciaries.

In the United States, there are a number of bipartisan bills, resolutions and legislative proposals currently before the 107th Congress, several of which, among other things, propose significantly increased company disclosure of carbon risks, measurement of emissions, and increased research and development.

NEW INSIGHTS INTO THE ECONOMICS OF CLIMATE CHANGE MITIGATION MEASURES

The economics of climate change has been a source of considerable uncertainty and controversy. Several high-profile studies have estimated the costs of mitigation to be extraordinarily high, particularly in the United States. However, these estimates have invariably used worst-case assumptions that necessarily imply high costs, for example, highly limited or none existent emissions trading activity, a need to meet short term targets, or limited use of non-carbon fuels.

Recent studies give grounds for optimism that the right blend of policies, if skillfully introduced, can substantially reduce the direct and indirect costs of mitigation and perhaps even produce a net economic benefit[9].

THE NEED TO LOOK BEYOND THE KYOTO PROTOCOL

Effectively addressing climate change can only be achieved via the adoption of more sustainable development pathways that simultaneously attend to interdependent social, economic and environmental challenges. While the Kyoto Protocol is a crucial first step in managing the problem, focusing entirely on the agreement would encompass too narrow a set of interests and divert attention away from some of the more fundamental social, environmental, technological and economic issues at stake. The broader sustainability context of climate change simply must be appreciated if the issue is to be effectively managed.

Taken separately, few of these trends are sudden or radically new. What is new, however, is their confluence at a single point in time. Taken together, they form a kind of "perfect storm" which has already begun to redefine the responsibilities of fiduciaries in the early 21st century. Together, Innovest believes that they are rapidly moving climate change to a position of growing prominence on both corporate and institutional investor's agendas.

Providing the right blend of regulatory pressure and market mechanisms to allow institutions to incorporate climate-related factors into future underwriting, lending and asset management activities is a critical step. Directing institutional capital toward supporting organic development of new clean energy technologies in their investees is also crucial. The renewables and clean power technology markets are becoming increasingly compelling in the search for 'win-win' outcomes; the nascent GHG, CAT bonds, weather derivatives and microfinance/microinsurance markets also hold substantial promise for strategic finance and insurance companies.

Ultimately, It is Innovest's belief that unleashing the creative instincts of the private sector is by far the most effective way of dealing with environmental pressures. Our research shows that businesses that practice sound environmental management also enjoy enhanced stakeholder and customer capital, operate with reduced costs and less risk, are faster to innovate and generally foster a higher level of manage-

[9] For example, 'Scenarios for a Clean Energy Future', Oak Ridge; Argonne; Pacific North West; Lawrence Berkeley; National Renewable Energy Labs, for U.S. Department of Energy, 2001

ment quality. More importantly, our research also shows that these benefits translate into sustainable competitive advantage and superior share price performance. This linkage between environmental and financial performance therefore creates a virtuous circle, in which proactive firms are rewarded by investors and encouraged to continue in their endeavors. Less proactive firms are also provided with a powerful incentive to adopt more positive responses. In the ensuing battle for best-in-sector leadership, the only surefire winner is the American public, who benefit from a more competitive private sector whose interests are better aligned with the broader tenets of sustainable development, with all the quality-of-life benefits this brings.

INNOVEST STRATEGIC VALUE ADVISORS, INC.

Innovest Strategic Value Advisors is an internationally recognized investment research firm specializing in environmental finance and investment opportunities. Founded in 1995 with the mission of delivering superior investment appreciation by unlocking hidden shareholder value, the firm currently has over US$1-billion under direct sub-advisement and provides custom research and portfolio analysis to leading institutional investors and fund managers throughout the world. Innovest's current and alumni principals include senior executives from several of the world's foremost financial institutions, as well as a former G7 finance minister. The company's flagship product is the Eco Value 21 platform, which was developed in conjunction with strategic partners including PricewaterhouseCoopers and Morgan Stanley Asset Management. Innovest is headquartered in New York, with offices in London and Toronto.

RESPONSES BY DR. MARTIN WHITTAKER TO ADDITIONAL QUESTIONS FROM SENATOR JEFFORDS

Question 1. It is clear that, regardless of the remaining uncertainties concerning exactly when and how climate change will impact our world, perceptions of climate risk have grown to such an extent that companies here and abroad are considering changing their practices to improve their long-term financial stability. How have investors in this and other countries begun to reorganize their financial portfolios to favor more climate-friendly businesses?

Response. From a traditional asset management perspective, few investors have taken steps to adjust investment actions due to climate change considerations alone. The only segment of the asset management universe that has adjusted portfolios on account of climate change issues is the socially responsible investment community (which constitutes anywhere between 3–8 percent of total assets under management in the United States). Mainstream asset managers, regardless of location, have not begun to adjust their portfolios, indeed, our research indicates that many fund managers or analysts do not even recognize that climate change is an issue that would prompt them to consider reorganizing their assets. The overriding feeling on climate change within the non-SRI institutional investment community is that the financial implications of climate change (or, more accurately, the manifestations of climate change on the one hand, and exposure to regulations limiting GHG emissions on the other) are not proven. Unfortunately, this belief is not based upon any rigorous financial analysis of potential impacts to equity or debt valuations. Were such analyses to be conducted, our research indicates that the financial community would be a willing listener.

Rather than adjusting portfolios, there is a small but growing number of pension fund trustees and pension policy professionals (including, for example, the State of Connecticut Treasurer's department) that recognizes climate change as an issue of potential concern, and that is preparing to engage companies to urge them to manage the issue more proactively on account of fiduciary concerns. The Carbon Disclosure Project, which now has backing of over $2 trillion in assets under management, and includes Merrill Lynch Investment Management, the Credit Suisse Group, and Walden Asset Management, is an example of this. We expect that the engagement approach, rather than the asset adjustment approach, will be favored by most pension funds, and that this approach has the potential to exert major influence over corporate management strategies on the climate change issue.

Elsewhere within the broader financial services sector, we know of several commercial banks that are examining whether there is a need to adjust credit risk calculation due to climate change factors. For example, in the hotel and leisure sector, there are reports that financing of winter resorts dependent upon snowy conditions has been affected; Fitch and Standard and Poor's, the credit rating agencies, have begun to examine exposure to potential GHG legislation at the company-specific level in the utilities and power sectors; and private equity and project finance specialists have steered more money toward clean, low carbon technologies on account of the market opportunities being created by actions (regulatory and otherwise) to lower GHG emissions. Finally, in the insurance industry, climate change is exacerbating concerns over weak economic conditions within the insurance industry and forcing companies such as Swiss Re to reexamine their business mix. The P&C business in particular continues to experience weak premium pricing power and increased losses, with catastrophic event (CAT) losses contributing to poor results. The P&C industry has also been plagued by excess underwriting capacity, the effect of which has been to depress prices, shift product mixes into banking and other financial services, and force firms into expanding into overseas markets where climate-related regional impacts may be more acute.

I would be happy to elaborate with specific details on any of the points made above.

Question 2. You work with companies that have started to internalize the risks of emitting greenhouse gases. Why are some companies taking this step, while others hang back? What and why should investors know about a company's carbon risk?

Response. Companies that have taken action to manage climate-change related risks thus far have done so for one or more of the following reasons: (i) to comply with current or anticipated regulations restricting GHG emissions (notably in Europe); (ii) to realize efficiency gains within their operations (notably through energy conservation initiatives); (iii) to reinforce a positive environmental reputation; (iv) to act upon concerns over the effects of future climatic changes on their business; (v) to gain a perceived competitive advantage over peers in technological innovation, particularly in industries with long capital planning cycles (next generation technologies in most industrial settings often confer GHG emissions benefits as a side effect); (vi) in response to concerns expressed by shareholders.

A key determining factor on company stance is its geographic location. For European firms, the primary drivers appear to be reputation (they operate in a marketplace more cognizant of environmental pressures) and regulatory requirements. Companies hang back in this market either because they do not feel exposed to consumer sentiment about climate change or because they do not anticipate being effected by future regulations. In the United States, primary drivers appear to be international competitiveness and operating excellence. U.S.-based multinational companies such as Exxon-Mobil have made it clear that they will act to curtail emissions and internalize risks in those areas of the world where they are required to do so, which may result in different strategies by business units within the same company. In our opinion, U.S. companies hanging back do so primarily because they do not perceive a need to act, either due to lack of regulatory compulsion or because their client base does not require action of them.

At this stage, knowing what we know about potential climate effects and the impacts of emissions regulation, I think it's prudent for financial market investors—particularly those with a long-term investment horizon—to require more information and reliable analysis on how these risks might affect equity valuations or debt quality, so that they can then factor such risks into their own preferred investment style. For investment banking and project finance specialists, there is a more immediate need to understand how the costs of reducing GHG emissions might reduce rates of return and influence capital spending decisions (companies such as BG and Shell are already calculating the sensitivity of project returns to carbon price movements, as they would examine sensitivity to oil price fluctuations or interest rate movement). On the flip side, the World Bank's Prototype Carbon Fund experiences has shown that the generation and sale of carbon credits can augment returns to the point by several percentage points.

In view of on-going post-Enron concerns over off-balance sheet risks, the possibility that climate change may well be a market risk capable of inflicting damage to investor returns has taken on a new significance. The essential point is that company competitiveness and profitability in a wide range of industrial sectors—automotive, chemicals, coal, electric power, manufacturing, oil and gas, refining, water, steel, tourism, food and agriculture, cement—could be seriously affected by climate change. Moreover, there will be substantial differentials in company carbon risk exposure within particular industry segments, differentials that are not currently being picked up by traditional securities analytics.

Question 3. As you know, I'm a cosponsor of legislation to cap carbon dioxide emissions from power plants, S. 556. If there is no cap in the near future, what do you think will be the effect on carbon markets and companies' carbon risk management activities in the United States and abroad?

Response. My chief concern is that without a cap, carbon is unlikely to be assigned a value, and without much of a value, the notion of a carbon market is unlikely to have any legs. Markets function on the basis that something of value is being exchanged. Voluntary or uncapped emissions targets, particularly when applied to the highest emitting sector (and the one most likely to act as buyers of emissions credits/offsets), will not create the conditions necessary for a fully functioning marketplace, with the result that emissions trading is unlikely to prosper except for certain multinational and transnational companies.

Of course, from an environmental emissions perspective, the absence of a cap is unlikely to focus the mind of corporate emitters on mitigation activities. Under an uncapped scenario, carbon risk management is less likely to come down to the simple objective of reducing emissions, and more likely to focus on (i) internal efficiency initiatives, where the prospect of economic gain through enhanced efficiency is the chief driving force, and, (ii) in the long term, clean technology development, where economic gain through new product offerings and process innovation is foremost. These are worthy goals for any firm to pursue but they may not produce the emissions reductions required to combat climate change over the time periods identified by the IPCC.

Question 4. What do you think is the greatest risk, in the next 30–50 years, of continuing to increase human-made greenhouse gas emissions? And, what is the most feasible way to reduce or eliminate that risk?

Response. From a global perspective, to my mind the greatest risk is the potential exacerbation and intensification of poverty-inducing conditions within the developing world. Less developed countries (LDCs) stand to bear the brunt of any disruptions to climate shifts and have less capacity to deal with those disruptions as and when they occur. Aside from broader moral humanitarian concerns, this may also carry an economic penalty for OECD countries, in the form of accelerated immigration from poor regions, lower productivity in basic industries situated in LDCs, stresses on the public purse (due to, for example, health costs and disaster relief) in LDCs with attendant currency woes, requirements for more aid and foreign direct investment from rich countries, and sizable opportunity costs relating to a failure to capture inherent entrepreneurial talents and skills of LDC populations struggling to cope with deteriorating domestic infrastructures.

The most feasible way to reduce that risk is the expedited development, commercialization and transfer of clean power production and transportation technologies. Transportation and stationary power production are the two greatest anthropogenic sources of greenhouse gas emissions; they are also the two areas of civic infrastructure most in need of advancement within poorer countries, primarily in view of their catalytic role in general economic development. India and China play an especially important role in global GHG emissions and international trade, and both present clear market opportunities for U.S. business. The Indian electric power sector is the largest consumer of capital in that country, drawing over one-sixth of all Indian investments. The United States is the largest supplier of foreign direct investment in India, much of it in the power sector. As part of efforts to reduce dependency on coal, India has a significant program to support renewable power, exemplified by wind power capacity that rose from 41 megawatts in 1992 to 1,025 megawatts in 1999, which should present U.S. exporters with appreciable opportunities.

Similarly, in China, which reportedly ranks second in the world in energy consumption and greenhouse gas emissions, power generating capacity and power consumption are expected to nearly triple by 2015 from their values in 1995, requiring some $449 billion in total costs. The China Daily reports that Chinese and U.S. trade ministers agreed in Beijing in April 2002 to set up a new consultation mechanism under which U.S. Trade and Development Agency (U.S. TDA) will provide funding for projects in China in the areas of e-commerce, renewable energy and solid waste treatment. According to Chinese government officials, wind power, solar energy, hydropower and other renewable and new energy resources will account for 0.7 percent of the total annual commercial energy used in China by the end of 2005, and 2 percent by 2015—again, major opportunities for U.S. clean power developers.

All of this is to say that the renewables and clean power technology markets are becoming increasingly attractive for investors and provide a clear possibility for a 'win-win' outcome involving LDCs; the nascent markets for greenhouse gas emissions credits, 'green' power certificates (based on Renewable Portfolio Standards), catastrophic event (CAT) bonds, weather derivatives and microfinance/microinsurance also hold substantial promise for forward-looking finance and insurance companies. Indeed, commercially viable technologies exist today (such as combined heat and power, and cogeneration approaches) whose introduction could go a long way toward reducing GHG emissions in the short term, while more developmental clean technologies are brought to the market.

RESPONSES BY DR. MARTIN WHITTAKER TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th century, the atmospheric concentrations of a number of greenhouse gasses have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

Response. On matters relating to the science of climate change, including the buildup of GHG concentrations and the potential effects on global climate conditions, I take my lead from the Intergovernmental Panel on Climate Change, which I believe to be an authoritative source on the subject. To the extent that Dr. Rowland's statement reflects the opinion of the IPCC, yes, I agree with his statement. A brief point on the issue of scientific discourse: As a scientist by training I realize that uncertainty and debate are fundamental to the process of scientific and technological advancement. While it is clear that uncertainties remain, and that there are scientists whose opinions differ from those of the IPCC, it appears that the balance of probability has shifted toward the view that anthropogenic influences have accelerated the buildup of GHGs in the atmosphere, and that this buildup is likely to be causing changes in the Earth's climate.

Question 2. Dr. Pielke testified that "the primary cause for . . . growth in impact[] is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate, per se." Do you agree with this claim? Why or why not?

Response. As I recall, Dr. Pielke was trying to point out that the heightened economic impact of climate variability was due to more to the increased vulnerability of human systems than to climate change per se (in other-words, modern day society was more exposed to climate variability by virtue of the fact that urban centers, coastal developments, etc., were likely to suffer greater economic impacts from extreme weather events). I agree that human and environmental systems are more vulnerable to climate variability than was previously the case; the recent reports from Swiss Re, Munich Re and the Lawrence Berkeley National Laboratory/U.S. DOE strongly support this view. But the same reports also present compelling evidence that the incidence and severity of extreme weather conditions is also rising, implying that it is not just the economic consequences of climate variability that is worrying, but that the variability is also becoming greater.

Ultimately, however, I am not sure that I recognize a huge distinction between the two points of view in terms of what it means for how we go about addressing the problem. If impacts are growing because of increasing vulnerability of human and environmental systems to climate variability (and if anthropogenic GHG emissions are increasing climate variability) then it is still prudent to adapt more effectively to changing climate conditions and deal with anthropogenic GHG emissions.

Question 3. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought. . ." Do you agree with that proposition? Why or why not?

Response. I believe that Dr. Pielke is right to stress the importance of dealing with more immediate climate-related problems (such as droughts, famines, etc.), which have tended to become forgotten in terms of the overall global warming debate (although not within broader development circles). However, given the possible causal connections that exist between the short-term problems he alludes to and the longer term issue of global warming, I don't believe that we can afford to dismiss the need to better understand future climate conditions altogether. IPCC data presented in the Third Assessment Report and the Special Report on Emissions Scenarios implies that one cannot successfully deal with one issue without tackling the other, and make plain the links between short- and long-term climate issues, and the critical importance of broader demographic, technological and political trends in determining future emissions scenarios. The integrated, interdependent nature of these broader factors, captured within the image of sustainable development, has been overlooked in my opinion within the climate change debate (which has focused more on Kyoto instead). I would certainly concur that less focus on esoteric matters of perceived scientific relevance and more urgency around action to improve the lives of ordinary people and the world in which we live is desirable.

Question 4. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. I believe that the Kyoto Protocol is a valuable first step toward reducing global GHG emissions and that it also has importance as an expression of collective commitment to addressing the climate change issue, and a point around which national efforts to can be coordinated and consolidated. True, as you state in the question, even if fully implemented, the Kyoto targets would have a negligible effect on atmospheric GHG concentrations and expected temperatures. However, I don't believe that this should be used to dismiss the Kyoto Protocol, rather to point out its importance as the precursor to a more comprehensive and ambitious emissions reduction process.

That said, the critical questions to my mind are whether anthropogenic GHG emissions are causing climate variations and, if society believes that to be so, how can we bring about emissions reductions in an optimal fashion. Whether this reduction effort is within the terms of the Kyoto Protocol or not is, in the bigger picture, of secondary importance. In this sense, I concur with the implication of the question, i.e., that Kyoto is not necessarily the answer to the climate problem, and that a longer-term solution needs to be identified.

Question 5. Since the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B," that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. I'm afraid I do not feel qualified enough on the Larsen B issue to offer any insights as to the specific scientific causes. I would only note that the Larsen B story is the latest in a long line of reports of changing environmental conditions in polar regions, the general thrust of which is that global warming is the root cause.

Question 6a. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty; Coping with the risks of climate change" (copy attached). Please explain why you agree or disagree with the following assertions or conclusions from that report: "There is not one problem but two: natural climate variability and the influence of human activity on the climate system."

Response. I agree that distinguishing human-induced climate changes from natural variations is an important issue the resolution of which will clearly help to determine the extent to which efforts to curb climate change through limiting anthropogenic emissions will be successful.

Question 6b. ". . . it is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted."

Response. By protection I assume that Swiss Re is referring to safeguarding the integrity of global human and environmental conditions.

Swiss Re's assertion that the characteristics of extreme weather events at specific locations cannot be predicted with any degree of accuracy is most worrying to me when set against their belief that extreme weather events are generally increasing in frequency and severity (conclusions arrived at from studies of past events). If this is indeed the case, then yes, provisions must be made to manage extreme weather risks particularly in those regions where in a general sense the Capacity to deal with extreme weather is weakest, or the human and economic effects could be greatest. For example, the use of weather derivatives, catastrophe bonds, and other insurance tools could help the industry deal with such varying conditions by improving liquidity and widening insurance coverage. ,

Question 6c. "Swiss Re considers it very dangerous (1) to put the case for a collapse of the climate system, as this will stir up fears which—if they are not confirmed—will in time turn to carefree relief, and (2) to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind."

Response. I absolutely agree with this call for moderation. Indeed, within the financial community Innovest serves, the major barriers to stimulating widespread action to examining climate related risks have been (i) the predictions of catastrophic and unmanageable climate disruptions, which tend to turn off many people who might otherwise be sympathetic, and (ii) a disconnect between short term economic interests and what is perceived to be an exclusively long term climate change issue. Our work has focused on providing robust, reasoned, independent analysis of the business impacts for precisely this reason.

To my mind, the inherent characteristics of climate change as a potential risk issue for ordinary people all work against taking action: it is rather ethereal and therefore doesn't seem 'real' (you can't touch, feel or see it, unlike, say, asbestos); the risk is perceived to be long term, and is therefore instinctively discounted; it is an issue which affects the collective, as opposed to the individual, which again leads people to discount it as a threat to personal well-being; people are generally familiar with it, and therefore don't feel especially worried; and it seems to be out of any one person's control. Long-term, illusory, scattered and unmanageable risks that affect everyone are simply not regarded as matters of any great urgency.

Question 7. Do you believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. On the issue of environmental and economic vulnerability, I believe that the evidence presented by the IPCC (selected passages presented below) and other sources of similar international standing is sufficiently worrying to warrant action and indicates that indeed our vulnerability to extreme weather conditions is increasing:

- According to the IPCC, the Earth's average surface temperature will rise 1.4 to 5.8oC (2.5—10.4 oF) between 1990 and 2100. Sea levels could rise between 9 and 88 cm over the same period. The decade of the 1990's was the hottest of the last century and is warmer than decade in the last 1,000 years in the Northern Hemisphere.
- According to December 2000 World Meteorological Organization (WMO) statistics, 2000 was the 22d consecutive year with global mean surface temperatures above the 1961–1990 normal. 1999 was the 5th warmest year in the past 140 years, bested only by 1998, 1997, 1995 and 1990.
- Severe weather events also continued to increase in size and number. Record rainfall and flooding in Western Europe, severe cold conditions in East Asia and Russia, heat waves and drought in China, Central Asia and the Middle East, and mudslides and typhoons in Southern Africa and Latin America all reached significant proportions over the course of 2000.
- Recent IPCC figures for climate-related influences on healthcare costs, vector borne diseases, coastline erosion, crop yields and other metrics all point toward increasing negative impacts on Earth ecosystems.

RESPONSES BY DR. MARTIN WHITTAKER TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates of the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. Innovest has not prepared forecasts of this nature and I would be reluctant to do so without sufficient background preparation. I can only refer you to the IPCC, which has recommended to UNFCCC signatories that atmospheric GHG concentrations should be stabilized at 550 ppmv of CO_2 equivalent (or twice pre-industrial levels), which would require a 60 percent cut in GHG emissions relative to 1990 levels[1].

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis.

Response. I am not aware of any reliable analysis on this particular subject.

Question 2. What economic analysis is there for the impacts of implementing Kyoto and reductions beyond Kyoto on the Canadian economy?

Response. The Government of Canada does not have an official estimate of the economic impacts of meeting its Kyoto target. That said, the Federal Analysis and Modelling Group has estimated that impacts,on GDP could be (in the worst case) up to 3 percent between now and 2010; over the same period, the country's GDP is expected to grow 30 percent. In other words, Kyoto could shave up to 3 percent

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[1] IPCC Climate Change 2001: Synthesis Report

off GDP growth over the next 8 years and result in 450,000 jobs lost. This, approximates to a reduction of roughly C$11 billion, or C$400 per capita. On the other hand, the best case scenario according to AMG is a 'slight positive' effect on GDP and the net creation of 65,000 jobs.

Cost estimates from other sources (academic and specialist research houses) tend to range from 0.2 percent to 2.5 percent GDP reduction, and a March 2002 Industry Canada report estimates that costs will be in the region of 1.5 percent of GDP, or about C$17 billion in 2010.

In terms of direct costs relating to reducing emissions, AMG describes 2 approaches; in one, expenditures to reduce emissions minus the energy efficiency gains under a carbon 'cost' scenario of C$10–25 per tonne would result in net benefits of about C$3 billion per year. In the other, the additional costs to do with transactions, downtime to adjust business configuration and other anticipated indirect expenditures associated with the shift toward lower carbon fuels are factored in. In this approach, under the same carbon price scenarios, costs are estimated to be in the order of C$1.1 billion per year, or about C$40 per person.

A recent popularly discussed report issued by the Canadian Manufacturers Exporters Association, a group opposed to Kyoto ratification, pegged the costs of Kyoto to the Canadian economy at 450,000 jobs by 2010 and describes a multitude of negative consequences for ordinary Canadians ranging from having to drive in smaller cars and refit their homes with expensive energy conservation equipment to paying more taxes.

Question 3. What are companies doing in other countries to mitigate their business risk?

Response. As you might expect, companies' actions to mitigate business risks depend on their reasons for wanting to act in the first place. We have identified several reasons why businesses feel it necessary to take mitigative action.

(a) Compliance (or Anticipated Compliance) particularly in Canada, Europe and Japan; A recent study among Canadian natural gas utilities showed Enbridge Consumers Gas as the only company to achieve a net greenhouse gas emissions decrease (30 percent) between 1990–7. In 2000, ECG introduced a program to promote energy-efficient equipment in the residential marketplace. Since 1996, the firm's demand-side management program has reduced customers' emissions by 364,000 tonnes of CO_2 equivalent. Dupont Canada, partly in expectation of future emissions constraints, report that CO_2 equivalents (including CFCs) have decreased from 160 billion lbs. in 1998 to 120 billion lbs. 1999, and the company aims to achieve a 65 percent reduction in GHG by 2010 from 1990 base year.

(b) Improved efficiency; Deutsche Telekom, for example, reports that it has saved over DM 8 million in energy costs and reduced carbon dioxide emissions simply by adjusting the output of air-conditioning systems. Pasquale Pistorio, President and CEO of STMicroelectronics (an Innovest 'AAA'-ranked firm), reported returns on energy conservation efforts within 2 years and estimated savings of nearly $1 billion on energy costs between 1994 and 2010 due to use of clean energy alternatives and efficiency measures. And NTT, which will need roughly 4.7-billion kWh of electricity in 2000 and is Japan's largest single purchaser of electric power, is pursuing an energy conservation vision that aims to produce savings of 100 billion yen over 10 years over a business-as-usual scenario, thereby reducing indirect greenhouse gas emissions.

(c) Reputation; In Othello, Shakespeare's Iago notes that 'He that filches my good name . . . makes me poor indeed'. Many leading firms have also recognized the true value of reputation and the importance of climate change to this reputation. ABB, the Swedish engineering and power equipment firm, has already adopted product specifications around greenhouse gas intensity to help distinguish its products in the market place, and Electrolux, BP, Baxter and Suncor have associated their brands very closely with climate friendliness.

(d) Voluntary Targets: The flip side of the reputation issue, many firms are walking the talk and demonstrating their climate credentials by setting themselves voluntary targets. Entergy, which is clearly not yet formally obliged to reduce emissions, purchased 10,000 metric tons of carbon dioxide allowances for under $5 per metric ton as part of its recently announced efforts to voluntarily cut greenhouse gas emissions over the next few years working with Environmental Defense. By virtue of this action, Entergy will be able to lock in relatively cheap emissions reduction credits and take significant steps toward meeting its voluntary targets.

(e) Concerns over exposure to changing weather conditions; Natural gas companies have begun to hedge their exposure to warmer weather (which depresses demand for natural gas used in heating) through the purchase of weather derivatives. Food product firms are also particularly exposed on this front. Due to warm weather and severe storms, Central American farmers harvested their banana crop earlier than normal in late 1997 and early 1998, increasing production by 13 percent. Prices fell as the fruit flooded the North American market, forcing down Dole's margins. In March 1998, Dole's stock price dropped 12 percent in one day. Continued extremes in weather resulting from climate change could also have serious repercussions on food markets due to direct damage to operations. Hurricane Mitch caused massive damage to Honduras, in part because of mudslides exacerbated by deforestation in the region. Both Dole Foods and Chiquita suffered extensive damage to operations in that country which reduced profits and pushed stock prices downwards.

(f) Competitiveness drivers and the need to innovate; In the U.K., Johnson Matthey's "smart" technologies, which contribute to climate. protection by facilitating smaller, lighter and more energy efficient products and processes, typify the kind of innovation opportunities that climate change is creating. In the mining industry, Inco's nickel hydride battery technologies, which contribute to climate protection by facilitating smaller, lighter and more energy efficient hybrid vehicles, are a prime example of how climate change concerns are causing established, 'old-economy' companies to reexamine their business mix.

I would be happy to provide more details of individual company activities and initiatives on climate change, drawn from Innovest's data base on corporate environmental positioning.

STATEMENT OF JACK D. COGEN, PRESIDENT, NATSOURCE LLC

Good morning, Mr. Chairman and members of the committee. Thank you for inviting me to testify. My name is Jack Cogen and I am the president of Natsource LLC, an energy environmental commodity broker headquartered in New York City with offices in Washington, DC, Europe, Japan, Canada, and Australia. My testimony will address the financial risk associated with climate change policy.

At the outset, I want to acknowledge that there are legitimate differences of opinion as to what should be the nature, degree and timing of policy responses to the risk associated with climate change itself. However, the role of Natsource is to work with clients who decide it is in their best interest to evaluate the extent of their financial exposure under possible greenhouse gas policies. Our clients make the threshold decision that they are at risk financially. After that, the next step for them is to analyze the extent of their financial risk and develop strategies that make sense for mitigating that risk. Natsource contributes its policy and market expertise to helping clients assess and manage risk.

The client base of Natsource includes multinational corporations as well as foreign and domestic firms. Natsource assists them in quantifying their financial exposure under different policies that might be adopted to limit greenhouse gas emissions. Our experience indicates that companies consider a variety of factors when they weigh the degree of risk they face and what to do about it. The primary factors are (1) the probability they will be subject to emission limitation policies, and (2) the potential direct and indirect cost of those policies to the company.

Natsource provides analysis, strategic advice, and market intelligence once a company decides to undertake a comprehensive risk assessment. Generally, we help clients assess their financial exposure by identifying policies that might be adopted; assigning probabilities to those policies; quantifying the net emissions "shortfall" or "surplus" the company faces under each policy; and estimating potential compliance costs based on the company's emissions profile, internal reduction opportunities, and our knowledge of various commodities available in the greenhouse gas emission markets. Multinational companies face an especially complicated risk because they operate across multiple jurisdictions with different policies. In addition, many of these companies must evaluate the effect of climate change policies on the market demand for their products in different countries.

If potential compliance costs are substantial and the probability of emission limitations is significant enough, the next step for many companies is to develop a cost-effective risk management strategy. This involves assembling an optimal mix of measures for reducing or offsetting emissions. These include internal and external emission reduction projects, internal emission trading programs, and external trading markets.

Companies choose to undertake emission reduction measures in spite of or because of policy uncertainty for a variety of reasons, including to reduce future compliance costs, gain experience in the greenhouse gas markets, maintain or enhance their environmental image, and place a value on internal reduction opportunities.

Greenhouse gas markets are evolving and will continue to evolve over the next several years. In the future, these markets will function more smoothly and with lower transaction costs as greenhouse gas policies become clearer and markets become more liquid. Even now, more sophisticated financial instruments such as call options are being used as a hedge against risk.

Natsource recently completed the first comprehensive analysis of the greenhouse gas trading market for the World Bank. The analysis identified approximately 60 greenhouse gas transactions involving some 55 million tons of emissions. These numbers actually underestimate the total number of transactions because they do not include internal-only transactions and small volume transactions. Current market prices for greenhouse gas commodities range from less than a dollar to over $9 per ton of carbon dioxide equivalent, depending on the type of commodity and vintage.

In conclusion, Mr. Chairman, a small but growing number of companies are beginning to more carefully analyze their financial risk under possible greenhouse gas policies. For a variety of reasons, some companies have decided to take steps now to reduce emissions even though final policy decisions, in most cases, are still pending. As a consequence, these companies are able to take advantage of the most cost-effective opportunities to reduce their financial exposure. As the markets for sulfur dioxide and nitrogen oxides emissions in the United States have shown, emission markets can provide an efficient way to lower the cost of reducing emissions.

That concludes my remarks, Mr. Chairman. I would be glad to answer any questions you or other Members of the committee might have.

RESPONSES BY JACK D. COGEN TO ADDITIONAL QUESTIONS FROM SENATOR SMITH

Question 1. Dr. Rowland testified that "during the 20th century, the atmospheric concentrations of a number of greenhouse gases have increased, mostly because of the actions of mankind." Do you agree with that statement? Why or why not?

Response. My expertise and that of Natsource lies in providing brokerage services and strategic risk assessment and risk management advice to our clients. Our expertise does not cover scientific or research issues associated with climate change. Consequently, I am not able to provide a response that would be helpful to the committee.

Question 2. Dr. Pielke testified that "the primary cause for . . . growth in impact is the increasing vulnerability of human and environmental systems to climate variability and change, not changes in climate per se." Do you agree with this claim? Why or why not?

Response. My expertise and that of Natsource lies in providing brokerage services and strategic risk assessment and risk management advice to our clients. Our expertise does not cover scientific or research issues associated with climate change. Consequently, I am not able to provide a response that would be helpful to the committee.

Question 3. Dr. Pielke also stated that "the present research agenda is focused . . . improperly on prediction of the distant climate future" and that "instead of arguing about global warming, yes or no . . . we might be better served by addressing things like the present drought . . ." Do you agree with that proposition? Why or why not?

Response. My expertise and that of Natsource lies in providing brokerage services and strategic risk assessment and risk management advice to our clients. Our expertise does not cover scientific or research issues associated with climate change. Consequently, I am not able to provide a response that would be helpful to the committee.

Question 4. Do you believe we should fully implement the Kyoto Protocol? Do you agree with the assertion that full implementation of the Kyoto Protocol would only avert the expected temperature change by 6/100 of a degree, Celsius? Why or why not?

Response. Natsource does not have a position with respect to either the ratification or implementation of the Kyoto Protocol. Natsource's expertise and the services and advice we provide our clients do not include assessing the climatic consequences of implementing the Kyoto Protocol. Therefore, I am unable to provide any opinion on possible temperature changes.

Question 5. Since the hearing there has been much press attention paid to the breakup of the Antarctic Ice Sheet, especially a 500-billion ton iceberg known as "Larsen B" that has been attributed to climate change. What scientific evidence is there that climate change is the sole cause of this phenomenon? Is there any scientific evidence that anthropogenic influences bore any role in the breakup of Larsen B?

Response. My expertise and that of Natsource lies in providing brokerage services and strategic risk assessment and risk management advice to our clients. Our expertise does not cover scientific or research issues associated with climate change. Consequently, I am not able to provide a response that would be helpful to the committee.

Question 6. Included in the hearing record as part of my opening statement was a Swiss Re report titled "Climate research does not remove the uncertainty; Coping with the risks of climate change" (copy attached). Please explain why you agree or disagree with [certain] assertions or conclusions from that report.

Response. The Swiss Re report offers ideas that many people will find useful in the debate over climate change and others will dispute. Natsource's expertise does not include issues associated with science or research, so we are not in a position to either agree or disagree with the conclusions of the report. The Swiss Re report states that the firm "is involved in the political debate about global climate protection . . ." Natsource is not involved in the political debate over climate change. Rather, Natsource works with clients—many of whom are involved in the debate—to help them assess and manage financial risk due to policies to limit greenhouse gas emissions.

Question 7. Do you, believe that our vulnerability to extreme weather conditions is increasing? Why or why not?

Response. My expertise and that of Natsource lies in providing brokerage services and strategic risk assessment and risk management advice to our clients. Our expertise does not cover scientific or research issues associated with climate change. Consequently, I am not able to provide a response that would be helpful to the committee.

RESPONSES BY JACK D. COGEN TO ADDITIONAL QUESTIONS FROM SENATOR VOINOVICH

Question 1a. Advocates for the Kyoto Protocol expect aggressive reductions in emissions beyond 2012. Some advocate a global CO_2 concentration target of 550 ppm CO_2 by 2100 which will require substantial reductions in the emissions of developed countries (including the United States). If a concentration target of 550 ppm by 2100 is adopted, what is your estimate of the caps on emissions for the United States by 2050? By 2100?

Response. Natsource's expertise does not include the ability to evaluate the relationship between atmospheric concentrations of greenhouse gases and emissions caps. Therefore, we are not able to provide any estimate with regard to emission caps.

Question 1b. Are you aware of any economic analysis of the impact of these reductions beyond the initial Kyoto target? If so, can you provide this analysis?

Response. We are aware of general analysis of this issue conducted by preeminent research institutes.

Question 2. What portion of Natsource's business is dependent on the establishment of a trading scheme for CO_2?

Response. Natsource is engaged in brokering transactions involving energy-related commodities. These commodities include electricity, natural gas, coal and emissions. Emissions brokering is provided by dozens of other firms. Natsource has provided emissions brokering services for SO_2 and NOx since the firm's establishment in 1994. These brokerage services contribute to the liquidity of emission markets and, ultimately, to finding the most cost-effective strategies for companies to reduce emissions. Natsource became engaged in the emerging market for greenhouse gas emissions because clients sought our expertise—and the expertise of similar firms—in assessing and managing the risk they face because of the uncertainty of future greenhouse gas policies in the United States and other countries. For some companies, a risk management strategy for greenhouse gases involves taking advantage of past reduction efforts (e.g., sequestration) and obtaining additional reduction credits through various types of market transactions. These market transactions can involve the purchase of various types of reductions, the purchase of call options or the swapping of emission reductions between different jurisdictions, to name a few. As I mentioned in my testimony on March 13, our clients decide they are at risk because of policies to limit greenhouse gas emissions and we help them to develop and implement strategies to mitigate their risk.

As far as Natsource's business with respect to CO_2 trading is concerned, we have been involved in brokering a number of greenhouse gas transactions in the United States and in other countries. Many of these transactions have taken place either to comply in the most cost-effective way with government policies to limit greenhouse gas emissions, or to begin reducing emissions cost-effectively in anticipation of expected policies to limit emissions. This later type of risk mitigation is similar to the purchase of business insurance. While Natsource has been involved in brokering transactions, our main focus has also been on providing strategic counsel on risk assessment and risk management. Currently, a very small portion of Natsource's business is dependent on greenhouse gas trading. It is unlikely that the public policy debate over climate change will be concluded soon. Therefore, Natsource will continue to provide strategic counsel to domestic and international clients.

Question 3. Has Natsource (including any of its staff) ever been involved in advocating the adoption of the Kyoto Protocol?

Response. In order to provide the highest quality strategic counsel to our clients, Natsource is pleased to have staff that have served in senior positions in the U.S. Government under different Presidents. In their official capacity as representatives of the U.S. Government, some of these staff advocated adoption of the Kyoto Protocol. However, Natsource neither supports nor opposes adoption of the Kyoto Protocol, nor do any of Natsource's staff support or oppose adoption. Natsource has clients with a variety of views on the Kyoto Protocol.

Swiss Re

Climate research does not remove the uncertainty
Coping with the risks of climate change

Despite advances in research, climate development is and will remain uncertain. Immediate action must be taken nevertheless, as even natural climatic variability carries risks far greater than generally assumed, and man's influence on the climate system will aggravate these risks still further. Something must and can be done about both these aspects: at regional level by systematically optimising concepts of protection, and at global level by implementing a comprehensive climate protection plan.

In recent years, climate research has brought about a wealth of new knowledge, but it has not provided any certainty about the future of our climate, nor how man's actions will influence the complex climate system. It would have been unrealistic to expect answers to these questions, as there are no scientific methods for reliably predicting the behaviour of complex systems.

To deal with precisely this uncertainty, Swiss Re suggested in its brochure "Global warming: element of risk", published in 1994, that political and administrative measures should be developed in parallel to the necessary and beneficial climate research. New findings from research carried out confirm this approach. This publication is intended to emphasise that, despite the unanswered questions, there is today both the need and the possibility to act.

Swiss Re does not hold the key to the climate problem. However, as a company whose daily work involves dealing with risks, it sees realistic possibilities of at least effectively reducing the risks of climate change.

Status of our knowledge: uncertainty

- The earth's atmosphere has warmed up.
- Natural climatic variability is greater than generally assumed.
- Climatic events are influenced by man.
- What we do not know is how the climate will develop and to what extent it is influenced by man or nature.

The public at large tends to interpret research findings in conflicting ways. Whilst some feel that the collapse of the climate is unavoidable, others see the discussion about climate as media-generated hype which, like the destruction of forests, will soon be forgotten.

Both interpretations reflect hopes and fears, but not the problem itself: the development of the climate is uncertain – and will most probably remain so in the future.

In Swiss Re's opinion, therefore, two approaches are needed to find a solution. We must try to understand the climate system better by means of further research, and we must tackle the existing uncertainty as a risk which can be systematically analysed and overcome.

Risk of climate change

Risk management views the public discussion on climate as a rabbit sitting paralysed in front of a snake – unaware that behind it a fox is poised to strike. There is not one problem but two: natural climate variability *and* the influence of human activity on the climate system.

Natural climate change means a fluctuating climate and the need to constantly adapt to new climatic conditions. Losses occur only where we do not adapt sufficiently.

In addition to the natural climatic factors, there are also man-made ones. This is the anthropogenic influence, which changes the climate system, increases its complexity and makes its behaviour even harder to predict. A full risk analysis therefore requires a systematic analysis of both of these individual phenomena and how they interact. In order to do this, we must fully understand how damage occurs.

There is no such thing as a natural disaster

The primary cause of extreme weather damage is the ill-adaptation of human systems to the possible weather events. To express it more positively, the better suited the system, the fewer losses extreme meteorological situations will cause. That is why Eskimos build igloos and the Pueblo Indians build adobe houses.

The same applies to modern cities with millions of inhabitants: New York is equipped to cope with different extremes of weather than Singapore. If the two cities were swapped, they would be plunged into devastating catastrophes. As they stand today, Singapore could not emerge unscathed from a blizzard and nor could New York survive a tropical cloudburst.

Seen in this way, there are no real natural disasters, or at least not in the sense that disasters are produced by nature. Natural phenomena are just the triggers for processes; the outcome is largely decided by man. How else can we explain that tropical cyclones, for example, cause disproportionately fewer deaths in rich industrialised countries than they do in developing countries, where there are often no efficient early-warning systems, no protective structures and no efficient civil defence and catastrophe management organisations.

Among mankind's great cultural achievements has been the ability to adapt to basic climatic conditions and protect against extreme meteorological weather conditions. We have adapted to such an extent that, within a certain range, weather conditions have little effect on our daily lives.

However, we have done no more than reduce our dependence on average weather conditions. Our vulnerability to extreme weather conditions, in contrast, is increasing. Local weather occurrences are now already being felt at regional level as a result of denser communication, transport, supply and disposal networks, and in the long term their effects may also assume global dimensions. An entire county can be affected by the failure of a satellite communications centre due to a storm, and if a computer chip factory in the Far East is flooded, critical supply bottlenecks may ensue for the information technology sector as a whole.

Climate change is not even a requirement for scenarios such as these to be triggered. Extreme weather occurrences which have been experienced in the past could, if repeated today, lead to substantially higher losses, because our sophisticated technical system networks mean that completely new, indirect consequences and side-effects are possible.

The probability of such losses is another question entirely. In 1935, the conference of the International Meteorological Organisation defined the period from 1901 to 1935 as a "normal climatic period". The scientists of the time assumed that it was enough to observe the weather over a period of a few decades in order to identify not only average weather events but also the possible weather extremes. From this it was concluded that it was possible to make the protection of towns and countryside virtually foolproof – for example, by building flood protection dams large enough to cope with the maximum possible rainfall in a river's catchment area.

A one-hundred-year event every year?

We know today that the climate – the total of all weather events at a given location – can change considerably in the short term solely as a result of natural influences. The fact that a certain intensity of precipitation has only been observed at a certain location once over a 100-year period is insufficient to draw the conclusion that this event will only be repeated on average once every 100 years in the future as well. It could suddenly occur several times within a few years.

However, this does not mean that human-induced effects on the climate are harmless. On the contrary, it is precisely because the natural climate system is extremely sensitive that human intervention can have unforeseeable consequences.

The existence of natural climatic variability means that we cannot predict the maximum possible weather parameters for a given location. Consequently, it is also impossible to provide absolute protection for our systems – be they whole cities and regions or transport facilities and production plants – within the scope of what is economically feasible.

If no-one knows what the maximum rainfall will be, no-one can calculate how low a dam can be whilst still providing absolute protection. Of course, all dams could theoretically be made higher, yet even this would not offer total security but merely a further reduction in the risk.

The phenomenon of climate change – whether natural, man-made or influenced by man – makes reliable probability statements about future meteorological events impossible. This realisation is one of the most important ever made by climatologists. They therefore talk not of *forecasts* but of *projections,* the estimation of possible meteorological events as a result of possible climatic changes.

These projections are extremely valuable in learning to understand the climate. They are, however, not suitable as a basis for planning for security. If probabilities are used to calculate probabilities, the outcome is certain: everything is possible.

The effects of a system collapse

It is generally believed that climate change does not really become threatening until the climate alters dramatically. This point of view is based on the incorrect assumption that storm damage increases in proportion to the severity of an event. This would mean that a slight change in the climate would only lead to a small increase in storm damage – and therefore that there would be sufficient time left to adapt the protective measures to developments.

In reality, however, signs of collapse are typical of damage processes. They derive from the protection limits, different for every system, which indicate how much rain, storm, heat, cold, etc. a system can "take" without collapsing. If the severity of an event exceeds this limit, even only slightly, the protection mechanisms can fail. The system then collapses and the losses accumulate rapidly with each further increase in the event's severity.

Let us take a simple example: provided the sustained wind speeds in a storm area above a town remain below the protection limit, only minor damage occurs. Here and there the wind dislodges slates, blows down scaffolding and hoardings or uproots trees. If, however, the wind speeds are just slightly above the wind loading limit of buildings and other technical installations, it is no longer individual buildings but very large numbers of buildings which are affected or even destroyed, and large-scale damage soon arises.

In view of its complexity, the climate system too may exhibit such signs of collapse. Small increases in the average temperature, for example, can cause low pressure systems to shift from their usual paths and the frequency of heavy rainfall in a particular region to suddenly increase significantly. This also increases the probability of extremely heavy rainfall, which can easily lead to catastrophic events.

It should not, therefore, be assumed that global warming of 2°C in 100 years is harmless. Firstly, the global average value of a typically moderate climate scenario can conceal considerably larger changes in regional averages: in some places it is becoming colder on average, whilst mean temperatures in other places are rising by well over 2°C. Secondly – because of the danger of system collapse – even warming of less than 2°C can lead to serious changes in the typical local weather patterns.

Thirdly, even where there is only a slight increase in the frequency of extreme weather conditions which exceed the protection limit, the collapse of the system can lead to a dramatic increase in storm losses of catastrophic proportions.

The specific risks of climate change

Should extreme weather protection measures fail, the interaction of economic growth and concentration of values, population growth and the increasing settlement of exposed areas, coupled with the system collapse effects described above, will lead to a significant increase in average storm damage worldwide. The only uncertainty is which regions it will affect.

However, the global climate models and underlying damage mechanisms do not offer sufficient material for reliable forecasts for individual areas, let alone predictions of the socio-economic consequences. The estimated global climate model figures say as much about the future climate of a particular town or region as figures for gross domestic products say about the financial situation of an individual family.

As one of the first research projects, Switzerland's National Research Programme 31 (NFP 31) therefore concentrated on the regional effects of climate change. The results were disconcerting: global warming of 2°C within the next 50 years would mean an economic loss to Switzerland (calculated at 1995 prices) of 2.3 to 3.2 billion Swiss francs a year – just under 1% of current GDP. The loss of intangible assets, cultural heritage and scenery is not included in the calculation.

The winter tourist trade would be particularly hard hit if one of its most important competitive advantages, namely the certainty of snow, were to melt. 30 to 40 per cent of the current winter sport industry would be lost in Switzerland – around 2 billion Swiss francs. At the same time, the increase in flood damage would be felt to the tune of 450 million Swiss francs a year. Of course, there would also be winners. An increase in summer trade, for example, could bring in additional profit of 100 million Swiss francs.

These figures overshadow the threat to individual fortunes. Some people would lose their house and home – or even their lives – as a result of natural disasters. Adapting to climatic developments will destroy jobs – but also create new ones. And many a property could become virtually worthless overnight if geologists found that it was at high risk from avalanches or mudflows as a result of the change in climate.

The true-to-life research results are not predictions of actual events but realistic scenarios of possible events. They translate the abstract theories of climate research into local risks, which are then effective because they clearly show that people will be affected by climate change.

Above all, the 50-plus individual projects of NFP 31 show that climate change is not a problem of the distant future but one of the present day. This is impressively highlighted by the massive shrinkage of glaciers in the Alps. Their current length is the shortest for 5 000 years. For those affected, namely those to whom glacier skiing has been their source of income in the past, the causes are of secondary importance. For them the "climate disaster" has long been reality because they have already lost their livelihood.

Twin-track approach: two risks, two strategies

Climatologists show how the climate could develop, but how it will develop remains uncertain. Swiss Re proposed a twin-track approach to the problem in 1994 in its publication "Global warming: element of risk": developing strategies for overcoming this uncertainty in parallel to climate research.

The publication "Global warming: element of risk" showed that we are dealing with two different but related risks: the first is that anthropogenic influences can have an adverse effect on the climate system. The second is that even naturally occurring climate changes could lead to unexpected extreme weather occurrences. And because these are unexpected, the systems are neither adequately protected nor prepared for dealing with such occurrences and losses.

These two risks must be countered with two different strategies:

- global climate protection
- new regional protection concepts.

Global climate protection

The aim of global climate protection is to avoid anthropogenic intervention in the natural climate system when potential consequences cannot be foreseen. This undoubtedly follows from the principle of sustainable development: we do not know exactly what effect the emission of greenhouse gases – above all carbon dioxide – will have on the climate system. However, we do know that, because of the long residence times of these gases in the atmosphere, the effects will not be clearly identifiable for several decades yet. It is not our generation but subsequent ones who will find out what consequences our present actions have had.

The first and most important step towards effective climate protection in Swiss Re's view is therefore to create adequate awareness of the problems, ie tackling the subject seriously and fundamentally, and carefully considering the results of climate research instead of interpreting them too hastily. True, there is still uncertainty about the specific consequences of anthropogenic intervention on the climate. But there is no doubt that man has already altered the climate and that this may have far-reaching consequences in the long term. Ignoring the problem will not make it go away. Nor do we want to fall into the trap of acting too hastily.

Even if business is only indirectly involved in political decision making, it shares the responsibility nevertheless. It must formulate its own opinion on current problems and publish and defend this opinion. Swiss Re urges business and its associations to take a stand, become more aware of the problem and actively contribute towards finding a political solution. The climate problem cannot be ignored, nor will it be solved merely by calls for optimum climate protection. We need to find ways of implementing the necessary climate protection measures in a manner which is both socially and economically acceptable.

New concepts of protection

Besides the implementation of climate protection measures, it is essential that new or at least wider-ranging concepts of protection are developed. These must take into account the fact that the maximum strength and frequency of extreme weather conditions at a given location cannot be predicted. Obviously, technical protection measures continue to make sense because they are suitable for reducing the probability of natural disasters. Even if the intensity of rainfall in a given area rises as a result of climate change, the protection provided by flood dams is basically greater than it would be without them.

It is not the protective structures themselves which are wrong and outdated, but the traditional concepts of protection associated with them, since these are associated with absolute certainty – at least amongst the general public. Yet absolute certainty cannot be provided, as every protective measure can fail or be overwhelmed. A flood protection dam only reduces the probability of a town being flooded but not the possible extent of loss in the event of the dam failing.

Indirectly, the maximum possible extent of the loss is actually even increased by these protective structures. Since more and more coastal areas, riversides and hillside locations are being ever more densely populated and intensively used as a result of the the assumed protection obtained from dikes, dams and avalanche barriers, this means that future natural disasters could occur on an unprecedented scale.

Expressed in risk management terms: it is not enough to reduce probabilities; the possible consequences too must be limited to a manageable size.

There are two ways of achieving this: avoiding risk – for example, by not developing zones which are potentially at risk – or by means of optimum planning for the event of a loss.

Planning starts with effective early-warning systems – so as at least to save human life by prompt evacuation – and ends with the rapid reconstruction of social, economic and cultural structures. Figuratively speaking, a concept is needed for the time before, during and after the storm.

Numerous examples show that in a highly networked world like ours, such a comprehensive response to events can no longer be the sole responsibility of state organisations, such as the fire brigade or army. It must be provided by all parts of society, albeit organised and managed by the state.

An excellent example of this approach is the "Project Impact" concept of the US Federal Emergency Management Agency (FEMA). Its guiding principle: if disasters cannot be ruled out, attempts should at least be made to deal as effectively as possible with their consequences. This gave rise to the idea of the "disaster-resistant community", with community incorporating not just the life and limb of the inhabitants, but also all the economic, social, cultural and technical subsystems. Every individual should learn how he can contribute to dealing with the event and the damage in the event of a disaster.

Project Impact is the practical implementation of the oft-quoted phrase, "There is no such thing as absolute security!". It is the logical development of the relative security achieved in recent decades but which can no longer be increased at will.

The most important requirement for the implementation of such a concept is, however, that the state no longer promises absolute security – and the population no longer expects it.

What can be done?

From a risk management point of view, the following measures need to be taken urgently:
- treat the existing uncertainty as a risk;
- analyse risks at local level, for example according to the approach taken by NFP 31 and similar studies of other regions;
- develop local protection concepts aimed not only at averting dangers but also at developing strategies for dealing with all eventualities, along the lines of Project Impact, for example;
- and, at global level, develop strategies for implementing the necessary climate protection in a way which is socially and economically acceptable.

What shouldn't be done?

Swiss Re considers it very dangerous
- to put the case for a collapse of the climate system, as this will stir up fears which – if they are not confirmed – will in time turn to carefree relief;
- and to play down the climate problem for reasons of short-term expediency, since the demand for sustainable development requires that today's generations take responsible measures to counter a threat of this kind.

What is Swiss Re doing?

As a global player in the reinsurance market, Swiss Re is continually analysing the latest findings of climate research, which it then incorporates into its products as far as technically possible. It is also engaged in developing risk management strategies which exceed the boundaries of traditional insurance cover.

In its capacity as an important commercial enterprise, Swiss Re is involved in the political debate about global climate protection and is committed to developing concepts which will fulfil both the requirements for effective climate protection and the need for economic feasibility. In particular, Swiss Re is involved in the United Nations Environment Programme (UNEP) and plays an active role in international climate convention negotiations.

The 1994 Swiss Re publication "Global warming: element of risk" ends with the following lines: "The answer given by climatologists leaves no doubt whatsoever. We do indeed have a problem and it is far more serious than would appear at first glance. The problem of climatic change is one of an experienced, methodical, political, social, economic, technical and cultural nature. Coping with it cannot be delegated to individual institutions but has to be tackled by joint effort. And not just anytime but now." Today, just under five years later, these words have lost none of their immediacy.

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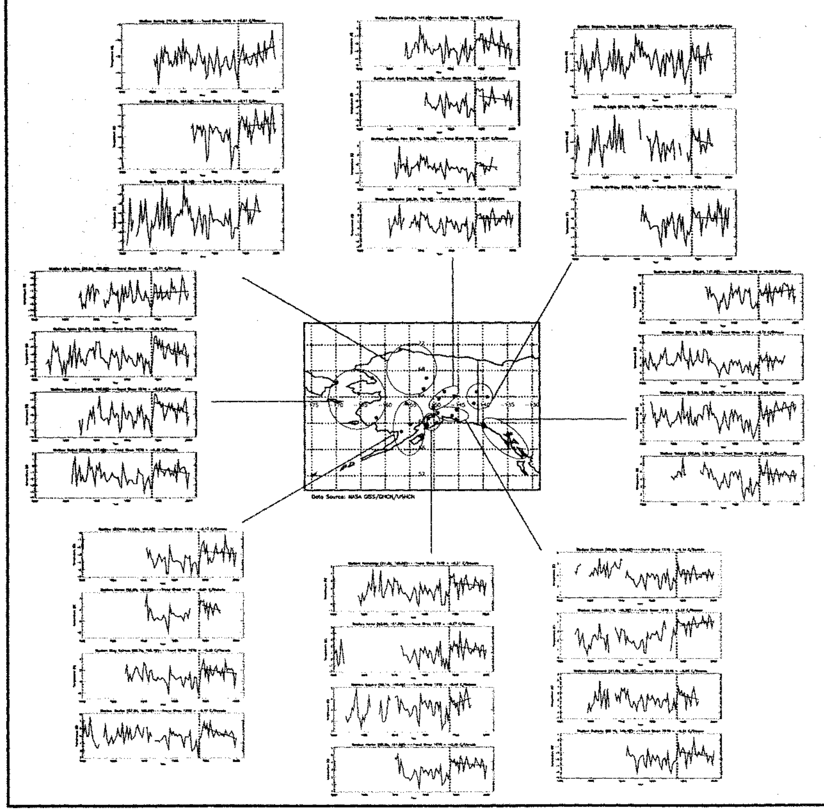
Alaska's Temperature History



EAST-WEST CENTER,
Honolulu, HI, March 28, 2002.

Hon. JAMES JEFFORD,
U.S. Senate,
Washington, DC.

DEAR SENATOR JEFFORDS: Thank you for the kind invitation to share some thoughts on the recently concluded first U.S. National Assessment of the Consequences of Climate Variability and Change. I had privilege of coordinating the Pacific Islands regional contribution to that important endeavor and I am delighted to join my colleagues in the Northeast and the other regional programs in summarizing some of the insights we gained during the process. I have enclosed a copy of the final report of the Pacific Assessment and I hope that you and your staff will find it helpful in your efforts.

The Pacific Assessment explored the consequences of climate variability and change for the American Flag Pacific Islands (Hawaii, Guam, American Samoa and the Commonwealth of the Northern Mariana Islands) and the U.S.-affiliated Pacific Islands that include the Federated States of Micronesia, the Republic of the Marshall Islands and Republic of Palau. The Pacific Assessment was supported through a grant from the National Science Foundation (NSF) with resources from the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the U.S. Department of the Interior (DOI). I was the Principal Investigator and the East-West Center coordinated the Pacific Assessment in collaboration with scientific partners from the University of Hawaii, the University of Guam and NOAA (most notably the National Weather Service Pacific Region and the National Centers for Environmental Prediction of the National Weather Service), and the National Center for Atmospheric Research as well as regional organizations such as the Pacific Islands Development Program, the Pacific Basin Development Council and the South Pacific Regional Environment Programme.

In addition to a scientific program of data analysis, research and modeling aimed at developing a more complete understanding of the regional consequences of climate variability and change, the Pacific Assessment focused on the establishment of a sustained, interactive dialog between scientists and decisionmakers designed to promote the use of climate information to address critical issues in the region. The research and dialog activities supported through the Pacific Assessment have identified a number of specific actions that can be taken to reduce climate-related vulnerability and enhance the resilience of Pacific Islands in the following critical areas:

- Providing access of freshwater resources;
- Protecting public health;
- Ensuring public safety and protecting community infrastructure;
- Sustaining agriculture and sustaining tourism as two particularly significant economic sectors; and
- Promoting the wise use of coastal and marine resources (including coral reefs and fisheries).

More than 200 individuals representing the scientific community, Government Agencies, businesses, NGO's and community leaders contributed their insights and expertise to the Pacific Islands Regional Assessment process and the findings and recommendations reflected in the final report are already being used by each of those stakeholder groups throughout the region.

Perhaps the most important recommendation to emerge from the effort was that the Pacific Assessment should be a continuing process of research and dialog with the overarching goal of nurturing the critical partnerships necessary to develop climate information to support decisionmaking. We have taken this recommendation to heart and are actively seeking resources to address some of the critical research and information gaps identified during the Pacific Assessment process including:

- improving our understanding of climate-related extreme events;
- enhancing Pacific Island efforts to reduce vulnerability to patterns of natural climate variability such as El Niño and, thereby, enhance regional capabilities to adapt to long-term climate change;
- improving our ability to document and model climate processes and consequences on local, island and regional scales;
- developing reliable projections of climate variability and change on various timescales; and
- enhancing our understanding of the consequences of changes in climate on the region's unique ecosystems and natural resources, including the consequences of those changes for critical economic sectors such as tourism, fisheries and agriculture.

Like our colleagues in other regions, we are committed to securing the resources required to help establish a Pacific regional climate information service—an integrated scientific and decision support system that will support the development and application of new scientific insights in response to the information needs identified by the governments, businesses, resource managers, public interest groups and communities that participated in the Pacific Assessment.

We would, of course, like to see a similar commitment on the part of the U.S. Global Change Research Program Agencies that supported the first National Assessment. While we seen promising indications of continued interest in Pacific Assessment activities within individual Agencies such as NOAA and EPA, the absence of a clear national, interagency commitment to sustaining this important regional assessment process discouraging and unfortunate.

In welcoming the regional participants to the Pacific Assessment's November 2000 Workshop on Climate and Island Coastal Communities, East-West Center President Charles Morrison offered the following thought:

> The impacts of the 1997–1998 El Niño are fresh in our minds, and the latest reports of the Intergovernmental Panel on Climate Change confirm what all of you already know—changes in climate matter to individuals, communities, businesses and governments who call islands home. Your valuable natural resources, traditional ways of life, critical economic sectors, community support infrastructure and, to a great extent, your future depend on developing an effective response to the challenges presented by climate variability and change.

Similar statements have emerged from the Northeast and other regional assessments conducted as part of the first National Assessment. Changes in climate matter to this region, this Nation and the world. As the individual and collected programs initiated during the first National Assessment process demonstrated, the scientific community, governments, businesses and communities around this Nation and throughout the world can meet the challenges and capitalize on the opportunities that changes in climate present to us when we combine our individual expertise, insights and assets in a continuing program of shared learning and joint problem solving. The first National Assessment represented a critical step in the emergence of such a new climate partnership. The interest that you and your congressional colleagues have shown in continuing the National Assessment process is encouraging and I'm sure that my regional assessment colleagues join me in expressing our willingness to work with you and the Agencies of the U.S. Global Change Research Program in this important, shared endeavor.

Thank you, again for the opportunity to share some of my thoughts on the National Assessment process. If you or your staff have any questions or would like to discuss this matter further, please do not hesitate to contact me.

Alona pumehana,

EILEEN L. SHEA,
Climate Project Coordinator.

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