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CLIMATE CHANGE IMPACTS TO THE UNITED STATES

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SIXTH CONGRESS

SECOND SESSION

JULY 18, 2000

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED SIXTH CONGRESS

SECOND SESSION

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CLIMATE CHANGE IMPACTS TO THE UNITED STATES

TUESDAY, JULY 18, 2000

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

The Committee met, pursuant to notice, at 9:32 a.m. in room SR–253, Russell Senate Office Building, Hon. John McCain, Chairman of the Committee, presiding.

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

The CHAIRMAN. Good morning. Earlier this year, we examined the science behind global warming as a means of defining the problem. Today we hope to further our efforts to understanding this issue by discussing the climate change impact on the United States, and the National Assessment Report. Because of the fact that at 9:45 a.m. we will begin a series of 11 votes, which will consume the entire morning, we have a problem. We contemplated delaying the rest of the hearing until this afternoon, but unfortunately, a number of our witnesses were not able to remain.

So what I would like to do is begin with opening statements, go as long as we can, and then I will have to adjourn the hearing and reschedule it at a later date. With a vote every 10 minutes, I cannot keep the witnesses here for an extended period of time. It would not be fair to the witnesses, nor would it provide for a productive hearing.

So what I would like to do is begin with our first panel, which is Dr. Thomas Karl, Director of the National Climatic Data Center, National Environmental Satellite, Data, and Information Service of NOAA, Dr. Anthony C. Janetos, Senior Vice President for Program, World Resources Institute, Dr. Raymond Schmitt, Senior Scientist, Woods Hole Oceanographic Institutions, and Dr. Fred Singer, Professor Emeritus of Environmental Sciences, University of Virginia.

I would like to express my deep apology to all of the witnesses, particularly some who have come here from long distances. At this time of year, we affirm Mr. Bismarck's statement that the two things you never want to see made are laws and sausages. These are very important hearings and very important witnesses, and we will reschedule at the earliest date.

Mr. Karl, we will begin with you.

[The prepared statement of Senator McCain follows:]

PREPARED STATEMENT OF JOHN MCCAIN, U.S. SENATOR FROM ARIZONA

Earlier this year, we examined the science behind global warming as a means of defining the problem. Today, we hope to further our efforts to understand this issue by discussing the Climate Change Impact On the United States, the National Assessment Report.

This morning we will examine, as noted in the National Assessment Report, climate change impacts on the United States. Because the report is currently in its 60-day public comment period which ends August 11, we feel that this is an opportune time for the Committee to discuss this very important matter. We hope that today's discussion will spur others to review the document and provide comments to the White House.

I know that some have asked that today's proceeding be postponed until later in the year. I feel this would be a mistake given the timeframe that the Administration has laid out for completing this report. I believe it is important to have this open discussion while the report is still in its draft form thus providing valuable input as it is finalized. Postponing this hearing will not afford the Committee the opportunity to examine the report before finalization.

I look forward to hearing from our witnesses today. Although there are many issues that need to be addressed, I hope the witness will focus on the following: "how can two computer models which give different results be used to reach a consensus conclusion," why federally-funded U.S. models were not selected for the study, and what role does the ocean's dynamics play in these analyses.

As we review this document and other weather predictions, we should keep in mind that these predictions or forecasts have very real meanings to people and the economy. This past Sunday's edition of *The Washington Post* contained an article that demonstrates the importance of accurate weather forecasting.

The article states that the Department of Agriculture and National Weather Service officials predicted that severe drought could cripple the farm economy in much of the Midwest and Deep South. Secretary Glickman warned that the lack of rain could be "catastrophic" to farmers, and Jack Kelley, Director of the National Weather Service, observed that the Midwest drought was the worst since 1955.

Farmers in the agricultural heartland took heed of the warning. Many who were storing their 1999 yields held off putting their crops on the market, reckoning that a drought-induced falloff in production this year would drive up prices.

What happened was just the opposite. Timely rains and cooler-than-predicted temperatures have offered promise of bumper crops in much of the Midwest and other parts of the nation this fall, ensuring that grain and soybean prices will go down for the third straight year due to continuing oversupply.

Last week, the Department of Agriculture lowered its price projections for corn, soybeans and wheat. The point being that a serious, sober examination of the topic is long overdue.

Again, as noted, this is very serious business with real impacts to the American economy and the lives and well-being of our citizens.

I welcome all of our witnesses here today.

[The prepared statement of Senator Snowe follows:]

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

Thank you, Mr. Chairman, for calling this important hearing today to review the public review draft for the National Assessment Report: Climate Change Impacts on the United States, to which the public can respond until August 11. The report is the most comprehensive so far—giving us snapshots specifically for U.S. projections through computer modeling to help us determine potential human impacts on the climate change process. The Report assesses both geographic regions of the country and its socioeconomic sectors. Whether you agree with the different scenarios projected or not, it is a place for us to start.

In 1990, this Committee reported out legislation that was ultimately signed into law by President George Bush, the U.S. Global Change Research Program Act, which, among other programs, called for a National Assessment Report to Congress. The Assessment may be an extremely important tool when we consider the long lifetimes of the buildup of greenhouse gases—particularly carbon dioxide—that have already been put into the atmosphere, both manmade and natural.

Section 106 of the 1990 Public Law calls for a scientific assessment not less frequently than every four years. Quite frankly, I do not believe we should wait for another assessment in four years time, as I understand the United States has made great strides in modeling technologies and capabilities. I would like to think we are capable of pulling on our country's best scientific modeling, as well as the Canadian and United Kingdom models used for the Assessment in a shorter time frame. We need the most updated research information so as to be able to make reasoned environmental and economic policy decisions.

In looking at the potential impacts for my state, I noted projections that gave me great pause. Many in Maine would tell you that if the devastating Ice Storm the Assessment Report mentions that hit across the State in 1998 and paralyzed the state's power infrastructure for over three weeks during bitter cold weather, is a harbinger of what we may expect with climate change, I believe they would want Congress to be paying more attention to the issue.

Also noted in the Report are the possible changes in Northeast forests from conifer to deciduous trees, and the loss of an entire tourist industry if the range of our vibrant sugar maple trees shifts more northward into Canada; and the reduction of cold weather recreation that is vital to the State's winter ski and snowmobile industry.

On the brighter side, there may be the possibility for longer warm weather recreation, already a popular summer pastime in my State, a reduction for heating requirements in the winter—certainly good news considering the State's energy problems last winter both with the supply and the price of home heating oil—and the prediction for increased crop and forest productivity.

One of my biggest concerns is the possible consequences of pest and disease outbreaks if the climate continues to warm, implications for both human health and our economy. According to the report, the Northeast, because of warmer winter weather, may experience increased incidences of diseases such as Lyme disease or West Nile encephalitis—the same disease that was found for the first time in the New York City area last year, which killed 7 people.

The Report says outbreaks are possible because of the increased survival of the reservoirs of infection, such as deer and white-face mice, and the vectors of infections, such as ticks and mosquitoes. If true, this is very disturbing.

Also, there are also some common themes among the regions that are noteworthy. Over 50 percent of the U.S. population resides in the coastal zone. All coastal regions will have to adapt to changes in shoreline characteristics and marine resources as a result of climate change. The models do not clearly predict many of these changes and we need to improve our oceanic databases to strengthen these models.

Even if the models are too high by 50 percent, we still need to know who and what may be affected—both the positive and the negative—so that informed environmental and economic decisions can be made for mitigation and adaptation.

I look forward to the testimony and the discussion this morning, and once again, thank Senator McCain for again bringing focus to the issue of global climate change in this Committee as we have jurisdiction over many of the programs concerned with climate change. I thank the Chair.

STATEMENT OF THOMAS R. KARL, DIRECTOR, NATIONAL CLIMATIC DATA CENTER, NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Mr. KARL. Thank you, Senator. We very much appreciate the opportunity to comment on the National Assessment. I would like to begin with the statement that suggests that the relevant question in this assessment is not whether greenhouse gases are increasing due to human activities and contributing to global warming. Clearly they are.

The CHAIRMAN. Would you pull the microphone a little bit closer?

Mr. KARL. Rather, the question is, what will be the amount and rate of future warming and associated climate change impacts and how will those changes affect human and natural ecosystems?

In this assessment we used climate model simulations with projected changes in greenhouse gases and aerosols comparable to those used in the business-as-usual cases conducted by the Intergovernmental Panel on Climate Change to assess those impacts on a regional basis across the nation.

Our results indicate that climate change will vary widely across the nation, those impacts will vary widely, as will our vulnerability to climate change. What do we mean by vulnerability? Vulnerability is defined as the magnitude of the climate impact after consideration of adaptation measures to lessen those impacts.

We appear to be particularly vulnerable to those impacts affecting natural ecosystems, but less vulnerable to those related to human-managed systems. We expect that the direct economic vulnerability is likely to be modest during the 21st Century for the kinds of climate scenarios we use in this assessment, but this, too, is likely to vary considerably from region to region.

The two principal climate scenarios for the 21st Century in the assessment can be briefly summarized as: one scenario is warm and wet and the other is hot and dry. Some of the gross features include annual average temperature increases of about 5 to 10 degrees Fahrenheit. This is about five to ten times the increase that has occurred during the 20th Century. Changes in total precipitation are less certain.

The CHAIRMAN. Have you ever seen changes like that before?

Mr. KARL. No.

The CHAIRMAN. Increases in temperature?

Mr. KARL. No. This would be an unprecedented change this century. In fact, the temperature increases during the 20th Century we now believe to be larger than anything we have seen in the last thousand years.

Changes in total precipitation are less certain, as indicated. For example, the wetter scenario has substantial increases in precipitation in the Southeast, about a 10- to 30-percent increase in precipitation. The drier scenario has about an equal decrease in precipitation.

There are other aspects of precipitation that we do have more certainty about. For example, all the climate scenarios and the observations suggest that more precipitation will occur in heavy and extreme precipitation events, as opposed to the light and moderate events.

All regions are affected by increases in the ability of the atmosphere to evaporate water from the surface as the temperature increases. This means that areas with marginal increases in precipitation are likely to be more vulnerable to more frequent extreme and severe drought. Other aspects of extreme weather, such as hurricane tracks, local severe weather, tornadoes, hail, et cetera, is still very uncertain.

The CHAIRMAN. I do not understand why an increase in severe weather would be associated with climate change.

Mr. KARL. Regarding the increase in heavy and extreme precipitation events, the best way to think about it is if you can imagine during the winter time in Alaska when you have precipitation, it falls in very light events. It is never very heavy. In converse, think about in the summertime, especially in the southern parts of the U.S., when it rains it rains very heavily, usually in short periods. This is the kind of trend that you will be seeing more frequently. We already see it in the observations. That is, precipitation tends to come in shorter bursts but heavier in magnitude.

With respect to some of the notable regional impacts around the nation, based on scenarios we used, I will just mention a few. In Alaska, sharp increases in temperature during the cold season are very likely to cause continued thawing of the permafrost, further disrupting the forest ecosystem, roads and buildings in that area. There is already considerable evidence in the observations that that has taken place.

In the Pacific Northwest there is likely to be more wintertime flooding and reduced spring flooding as snow pack decreases. Again the observations already show a significant decrease in snow, particularly in the West. This will put added stress on summer water supplies. Rising water temperatures will further complicate needed fish restoration efforts.

In the Midwest, at least for the next few decades, it is likely we will see a continued increase in agricultural production, in large part due to the fertilization effect of carbon dioxide on crops. We expect reductions in lake levels are also likely, increasing the cost of transportation in the lakes and down the rivers, ship and barge transportation. Increased water temperatures are likely to lead to increased eutrophication and reduced oxygen levels in lakes and rivers.

In the Northeast, climate change will very likely interact with many existing stresses in urban areas such as air quality, transportation, especially along the coast, due to rising sea level and storm surges, increased heat-related stresses, and effects on inflexible water supply systems.

Other stresses are likely to be mitigated. For example, snow removal costs and extreme cold winter exposures.

In the Southeast, generally the South does not reap the benefits of increased temperature for agricultural purposes, since temperatures are already quite warm. Along the Southeast gulf coast, inundation of coastal wetland is very likely to increase, threatening fertile areas for marine life, migrating birds, waterfowl.

In the hotter and drier scenario grasslands and savannahs replace the southernmost forests in the Southeast, while the warmer weather scenario expands the range of the southern tree species, and large increases in the heat index (the combination of temperature and humidity) average 10 to over 25 degrees Fahrenheit increases that will make summer outdoor activities quite stressful.

In the Great Plains, similar to the Midwest, higher CO_2 concentrations are likely to offset the effects of rising temperatures, increasing agricultural yields and forest cover for several decades. Again, the southern portions of the Great Plains are not likely to reap these benefits.

In the West, both scenarios project a substantial increase in precipitation, leading to a reduction in desert ecosystems, being replaced by shrublands.

For our island States, more intense cycles of El Niño and la niña are possible, thereby increasing stresses on existing water supplies.

These are just a few of the impacts we discuss in the National Assessment. I just wanted to mention that there are many issues we are uncertain about, especially issues that are interdependent. These could be important, even though we do not understand them.

Further assessments will need to address many of these interdependencies.

Thank you for the opportunity to make an opening statement.

[The joint prepared statement of Mr. Karl, Dr. Melillo, and Dr. Janetos follow:]

JOINT PREPARED STATEMENT OF THOMAS R. KARL, DIRECTOR, NATIONAL CLIMATIC DATA CENTER, NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION; DR. JERRY M. MELILLO, SENIOR SCIENTIST, ECOSYSTEMS CENTER, MARINE BIOLOGICAL LABORATORY; AND ANTHONY C. JANETOS, SENIOR VICE PRESIDENT FOR PROGRAM, WORLD RESOURCES INSTITUTE

We are very pleased to have the opportunity to address the Senate Committee on Commerce, Science, and Transportation on the topic of the potential impacts of climate variability and change on the U.S. Our draft assessment report, *Climate Change Impacts on the United States: the Potential Consequences of Climate Variability and Change* was released for a 60 day public comment period on Monday, June 12. It is an extensive synthesis of the best available scientific information on this important topic.

There are three questions about climate change that dominate discussions of this important topic. How much climate change is going to occur? What will happen as a result? What can countries do about it? There are obviously heated political opinions about each of these, but the issues are real, and it is critical to understand the underlying scientific knowledge about each if sound decisions are to be made. The assessment report focuses on the second of these questions.

A national assessment of the potential impacts of climate change was called for in the 1990 legislation that established the U.S. Global Change Research Program (USGCRP). For several years, the research program focused on developing the basic scientific knowledge that the international scientific assessment process overseen by the Intergovernmental Panel on Climate Change (IPCC) depends on. The IPCC was jointly established by the World Meteorological Organization and the United Nations Environmental Programme in 1988. As scientific research has provided compelling evidence that climate change is in fact occurring, it has become increasingly clear that there is a need to understand what is at stake for natural resources and human well-being in the U.S. In response to this need, in 1998, Dr. John H. Gibbons, then Science Advisor to the President, requested the USGCRP to undertake the national assessment originally called for in the legislation. Dr. Gibbons asked the USGCRP to investigate a series of important questions:

- What are the current environmental stresses and issues for the United States that form a backdrop for additional impacts of climate change?
- How might climate change and variability exacerbate or ameliorate existing problems?
- What are the priority research and information needs that can better prepare policy makers for making wise decisions related to climate change and variability? What information and answers to what key questions could help decision-makers make better-informed decisions about risk, priorities, and responses? What are the potential obstacles to information transfer?
- What research is most important to complete over the short term? Over the long term?
- What coping options exist that can build resilience to current environmental stresses, and also possibly lessen the impacts of climate change? How can we simultaneously build resilience and flexibility for the various sectors considering both the short and long-term implications?
- What natural resource planning and management options make most sense in the face of future uncertainty?

- What choices are available for improving our ability to adapt to climate change and variability and what are the consequences of those choices? How can we improve contingency planning? How can we improve criteria for land acquisition?

A variety of efforts emerged in response to Dr. Gibbons' charge.

Over twenty workshops were held around the country, involving academics, business-people representing a range of industries including manufacturing, power generation and tourism, and people who work closely with land and water ecosystems including resource managers, ranchers, farmers, foresters and fishermen. Each workshop identified a range of issues of concern to stakeholders in those regions, many of them quite unrelated to climate change, per se. Most workshops were followed by the initiation of scientific, university-led regional studies, some of which have finished their work, and others of which are ongoing.

In addition to these kind of "bottom-up" efforts, it was decided that it was also necessary to create a national-level synthesis of what is known about the potential for climate impacts for the U.S. as a whole, addressing the issues identified in the regional workshops and national studies. This synthesis obviously needed to build on the work that had begun to emerge from the subsequent regional and national studies, but also to draw on the existing scientific literature and analyses done with the most up-to-date ecological and hydrological models and data that could be obtained. The National Assessment Synthesis Team (NAST) was established by the National Science Foundation as an independent committee under the Federal Advisory Committee Act (FACA) specifically in order to carry out this second step. This committee is made up of experts from academia, industry, government laboratories, and non-governmental organizations (NGO's) (membership list is Attachment 1). In order to ensure openness and independence, all meetings of the NAST have been open to the public, all documents discussed in its meetings are available through the National Science Foundation, as are all the review comments already received and responses to them. This is perhaps out of the ordinary for a scientific study; but most scientific studies do not focus on issues of such broad and deep implications for American society, and about which there is such heated rhetoric.

The NAST's first action was to publish a plan for the conduct of the national synthesis. In addition, five issues (agriculture, water, forests, health, and coastal and marine systems), out of the many identified, were later selected by the National Synthesis Assessment Team (NAST) to be topics for national studies. Carrying out this plan has been a major undertaking. The end result has been the production of a comprehensive two-volume National Assessment Report, available to the public for a 60-day comment period. The "Foundation" volume is more than 600 pages long, with more than 200 figures and tables, with analyses of the five national sectors, and 9 regions that together cover the entire U.S. It is extensively referenced, and a commitment has been made that all sources used in its preparation are open and publicly available. The "Overview" volume is about 150 pages long, written in a style that is more accessible to the lay public, and summarizes the Foundation in a way that we hope will be understandable and informative, and which we are confident is scientifically sound. Both documents have already been through extensive review. At the end of 1999, two rounds of technical peer review were undertaken, and during the past spring, an additional review by about 20 experts outside the assessment process was undertaken. Over 300 sets of comments have been received from scientists in universities, industry, NGO's, and government laboratories. The responses to all external comments have been described in comprehensive review memorandums. We are now in the final stage of the process, a 60 day public comment period specifically requested by Congress, after which final revisions will be done and the report submitted to the President and Congress, as called for in the original legislation.

In order to ensure that the NAST has undertaken its charge well, an oversight panel was also established through the offices of the President's Council of Advisors on Science and Technology (membership list is Attachment 2). The oversight panel is chaired by Dr. Peter Raven, Director of the Missouri Botanical Garden and recently retired Home Secretary of the National Academy of Sciences, and Dr. Mario Molina, Professor of Atmospheric Chemistry at MIT, and recent Nobel-prize winner for his research on stratospheric ozone depletion. Its membership, like the NAST's, is drawn from academia, industry, and NGO's. It has reviewed and approved of the plans for the assessment, reviewed each draft of the report, and reviewed the response of the NAST to all comments.

What have been the results of this extraordinarily open process? What assumptions drive the analysis? What conclusions have been reached?

It is important to realize that the national assessment does not attempt to predict exactly what the future will hold for the U.S. It has examined the potential implications of two primary climate scenarios, each based on the same assumptions about future "business as usual" global emissions of greenhouse gases that the IPCC has used for many of its analyses. The two climate scenarios were based on output from two different global climate models used in the IPCC assessment. They are clearly within the range of global annual average temperature changes shown by many such models, one near the low and one near the high end of the range. Both exhibit warming trends for the U.S. that are larger than the global average (Attachment 3). This is not surprising. For many years, one of the most robust results of global climate models has been that greater warming is expected in more northerly latitudes, and that land surfaces are expected to warm more than the global average. We have used assumptions that are entirely consistent with those used by the IPCC.

These climate scenarios describe significantly different futures that are all scientifically plausible, given our current understanding of how the climate system operates. As importantly, they describe separate baselines for analysis of how natural ecosystems, agriculture, water supplies, etc. might change as a result. In order to investigate such changes, i.e. the potential impacts of climate changes, the report relies on up-to-date models, on empirical observations from the literature, on investigations of how these systems have responded to climate variability that has been observed over the past century in the U.S., and on the accumulated scientific knowledge that is available about the sensitivities of resources to climate, and about how the regions of the U.S. have and potentially could respond.

One additional important point about the scenarios should be mentioned. The report does not "merge" the results of models that disagree; it explicitly avoids doing so. The best example of this is in the analysis of potential changes in precipitation, where the two models used to create the scenarios give quite different results for some areas of the U.S. We have chosen to highlight these differences and explain that regional-scale precipitation projections are much more uncertain compared with temperature, rather than attempting to merge the results or guess which is more likely. The knowledge that the direction of precipitation change in some areas is quite uncertain is valuable for planning purposes, and clearly represents an important research challenge. There is however, consistency among models and observations on other aspects of precipitation changes. For example, both models and observations show an increase in the proportion of precipitation derived from heavy and extreme events as the climate warms (Attachment 4). So, both types of information are pertinent to help with the identification of potential coping actions. In this respect, the report follows the procedure that the IPCC itself uses for its global impacts reports, each of which examines the potential impacts for entire continents.

The U.S. national assessment presents the results for each scenario clearly, and then takes the important additional step of explicitly describing the NAST's scientific judgment about the uncertainty inherent in each result. Those results that are viewed to be robust are described in more terms; those viewed to be the result of poorly understood or unreconciled differences between models are described in more circumspect language. The lexicon of terms used to denote the NAST's greater or lesser confidence is explicitly described in the beginning of the Overview report. This helps ensure that the report does not mask important results by thoughtlessly merging models, or overstating the scientific capability for assessing potential impacts. Finally, the report begins to identify possible options for adaptation to this changing world. It does not do a complete analysis of the costs, benefits, or feasibility of these options however, which is a necessary next step for developing policies to address these issues.

The report's draft key findings (as more fully described in Attachment 5) present important observations for all Americans:

1. *Increased warming.* Assuming continued growth in world greenhouse gas emissions, the climate models used in this Assessment project that temperatures in the U.S. will rise 5–10°F (3–6°C) on average in the next 100 years.

2. *Differing regional impacts.* Climate change will vary widely across the U.S. Temperature increases will vary somewhat from one region to the next. Heavy and extreme precipitation events are likely to become more frequent, yet some regions will get drier. The potential impacts of climate change will also vary widely across the nation.

3. *Vulnerable ecosystems.* Ecosystems are highly vulnerable to the projected rate and magnitude of climate change. A few, such as alpine meadows in the Rocky Mountains and some barrier islands, are likely to disappear entirely,

while others, such as forests of the Southeast, are likely to experience major species shifts or break up. The goods and services lost through the disappearance or fragmentation of certain ecosystems are likely to be costly or impossible to replace.

4. *Widespread water concerns.* Water is an issue in every region, but the nature of the vulnerabilities varies, with different nuances in each. Drought is an important concern in every region. Floods and water quality are concerns in many regions. Snowpack changes are especially important in the West, Pacific Northwest, and Alaska.
5. *Secure food supply.* At the national level, the agriculture sector is likely to be able to adapt to climate change. Overall, U.S. crop productivity is very likely to increase over the next few decades, but the gains will not be uniform across the nation. Falling prices and competitive pressures are very likely to stress some farmers.
6. *Near-term increase in forest growth.* Forest productivity is likely to increase over the next several decades in some areas as trees respond to higher carbon dioxide levels. Over the longer term, changes in larger-scale processes such as fire, insects, droughts, and disease will possibly decrease forest productivity. In addition, climate change will cause long-term shifts in forest species, such as sugar maples moving north out of the U.S.
7. *Increased damage in coastal and permafrost areas.* Climate change and the resulting rise in sea level are likely to exacerbate threats to buildings, roads, power lines, and other infrastructure in climatically sensitive places, such as low-lying coastlines and the permafrost regions of Alaska.
8. *Other stresses magnified by climate change.* Climate change will very likely magnify the cumulative impacts of other stresses, such as air and water pollution and habitat destruction due to human development patterns. For some systems, such as coral reefs, the combined effects of climate change and other stresses are very likely to exceed a critical threshold, bringing large, possibly irreversible impacts.
9. *Surprises expected.* It is very likely that some aspects and impacts of climate change will be totally unanticipated as complex systems respond to ongoing climate change in unforeseeable ways.
10. *Uncertainties remain.* Significant uncertainties remain in the science underlying climate-change impacts. Further research would improve understanding and predictive ability about societal and ecosystem impacts, and provide the public with useful information about adaptation strategies.

Given these findings it is clear that climate impacts will vary widely across the Nation, as one would expect for a country as large and ecologically diverse as the U.S. Natural ecosystems appear to be highly vulnerable to climate changes of the magnitude and rate which appear to be likely; some ecosystems surprisingly so. The potential impacts on water resources are an important issue in every region examined, although the nature of the concern is very different for the mountainous West than for the East. The potential for drought is a concern across the country. The nation's food supply appears secure, but there are very likely to be regional gains and losses for farmers, leading to a more complex picture on a region-by-region basis. Forests are likely to grow more rapidly for a few decades because of increasing carbon dioxide concentrations in the atmosphere, but it is unclear whether those trends will be maintained as the climate system itself changes, leading to other disturbances such as fire and pest outbreaks. However, the climate change itself will, over time, lead to shifts in the tree species in each region of the country, some of them potentially quite profound. Coastal areas in many parts of the U.S. and the permafrost regions of Alaska are already experiencing disruptions from sea-level rise and recent regional warming; these trends are likely to accelerate. Climate change will very likely magnify the cumulative impacts of other environmental stresses about which people are already concerned, such as air and water pollution, and habitat destruction due to development patterns. There are clearly links between human health, current climate, and air pollution. The future vulnerability of the U.S. population to the health impacts of climate change depends on our capacity to adapt to potential adverse changes. Many of these adaptive responses are desirable from a public health perspective irrespective of climate change. Future assessments need to consider climate change in the context of the suite of environmental stresses that we all face. Perhaps most importantly, the report acknowledges very clearly that scientific uncertainties remain, and that we can expect surprises as this uncontrolled experiment with the Earth's geochemistry plays out over the coming decades.

We hope that the public comment period will indeed result in a broad discussion of this draft report. This is, after all, a topic of immense importance and broad significance for Americans. We invite those with the interest to do so to participate by obtaining the current draft (www.usgcrp.gov), and to submit their comments, concerns, and criticisms. Our interest is in being as open and transparent as possible about what we have concluded, the scientific integrity of the results, and why we think they are important for us all.

Attachment 1

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Benjamin Felzer (National Center for Atmospheric Research)

John Field (University of Washington)

Paul Grabhorn (Grabhorn Studio)

Susan J. Hassol (Aspen Global Change Institute)

Michael MacCracken (National Assessment Coordination Office)

Joel Smith (Stratus Consulting)

Melissa Taylor (National Assessment Coordination Office)

Attachment 2

Independent Review Board of the President's Committee of Advisers on Science and Technology (PCAST)

Peter Raven, Co-chair
Missouri Botanical Garden and PCAST

Mario Molina, Co-chair
MIT and PCAST

Burton Richter
Stanford University

Linda Fisher
Monsanto

Kathryn Fuller
World Wildlife Fund

John Gibbons
National Academy of Engineering

Marcia McNutt
Monterey Bay Aquarium Research Institute

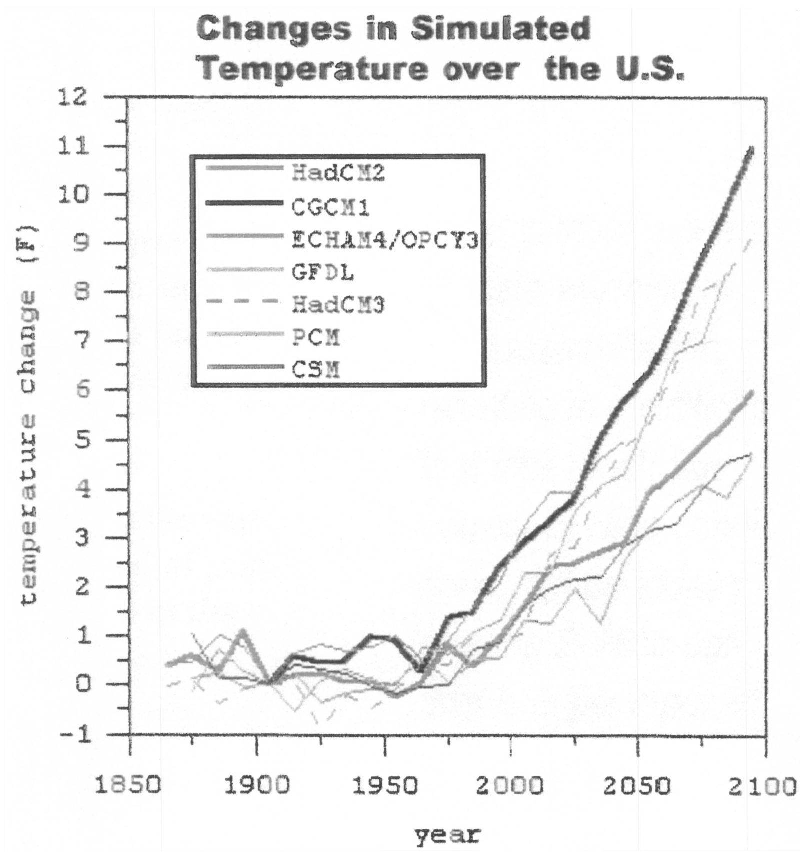
Sally Ride
University of California San Diego and PCAST

William Schlesinger
Duke University

James Gustave Speth
Yale University

Robert White
University Corporation for Atmospheric Research, and Washington, Advisory Group

Attachment 3

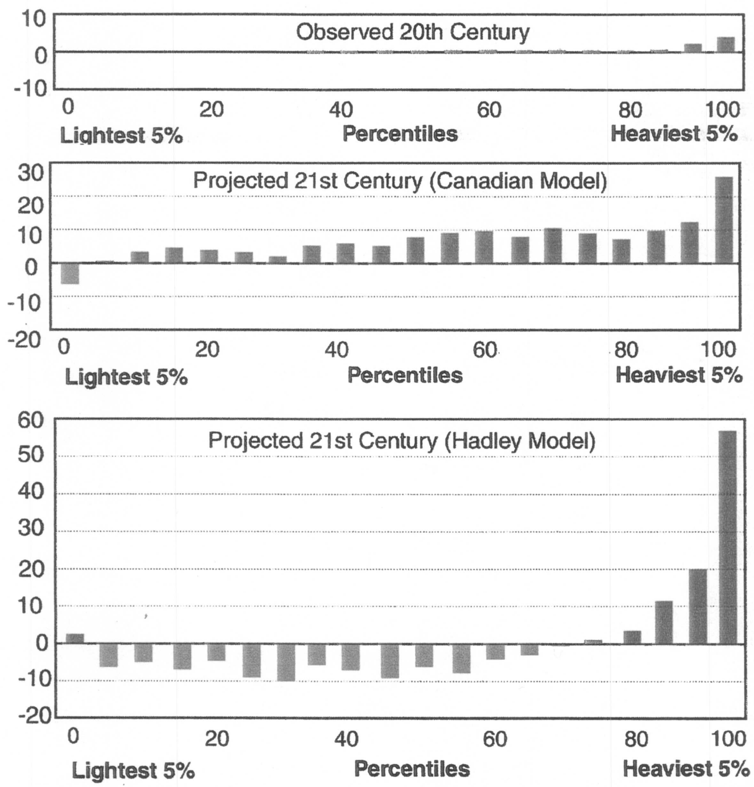


Simulation of decadal average changes in temperature from leading climate models based on historic and projected changes in CO_2 and sulfate atmospheric concentrations. The heavy red and black lines indicate the primary models chosen for use by the National Assessment. For the 21st century the projected global temperature increase for the Hadley model is 4.9°F and 7.4°F for the Canadian model. The model with the smallest projected increase of global temperature is the Climate System Model at 3.6°F. By comparison, the projected increase in temperature for the 21st century over the contiguous U.S. is: Canadian, 9.4°F; Hadley, 5.5°F; and the Climate System Model, 4.0°F.

	Global	USA
Hadley	4.9°F	5.5°F
Canadian	7.4°F	9.4°F
CSM	3.6°F	4.0°F

Attachment 4

Observed and Projected Changes of Precipitation for various categories of daily precipitation events
Annual Precipitation



These graphs of precipitation for the contiguous U.S. show both observed changes during the 20th Century and projected changes for the 21st Century based on the Canadian Global Climate Model (Version 1) and the Hadley Climate Model (Version 2). As the charts demonstrate, the largest increases have been and are projected to be in the heaviest precipitation events, the days already receiving large amounts of precipitation.

Attachment 5

Summary

Large impacts in some places. The impacts of climate change will be significant for Americans. The nature and intensity of impacts will depend on the location, activity, time period, and geographic scale considered. For the nation as a whole, direct economic impacts are likely to be modest. However, the range of both beneficial and harmful impacts grows wider as the focus shifts to smaller regions, individual communities, and specific activities or resources. For example, while wheat yields are likely to increase at the national level, yields in western Kansas, a key U.S. breadbasket region, are projected to decrease substantially under the Canadian climate model scenario. For resources and activities that are not generally assigned an economic value (such as natural ecosystems), substantial disruptions are likely.

Multiple-stresses context. While Americans are concerned about climate change and its impacts, they do not think about these issues in isolation. Rather they consider climate change impacts in the context of many other stresses, including land-use change, consumption of resources, fire, and air and water pollution. This finding has profound implications for the design of research programs and information systems at the national, regional, and local levels. A true partnership must be forged between the natural and social sciences to more adequately conduct assessments and seek solutions that address multiple stresses.

Urban areas. Urban areas provide a good example of the need to address climate change impacts in the context of other stresses. Although large urban areas were not formally addressed as a sector, they did emerge as an issue in most regions. This is clearly important because a large fraction of the U.S. population lives in urban areas, and an even larger fraction will live in them in the future. The compounding influence of future rises in temperature due to global warming, along with increases in temperature due to local urban heat island effects, makes cities more vulnerable to higher temperatures than would be expected due to global warming alone. Existing stresses in urban areas include crime, traffic congestion, compromised air and water quality, and disruptions of personal and business life due to decaying infrastructure. Climate change is likely to amplify some of these stresses, although all the interactions are not well understood.

Impact, adaptation, and vulnerability. As the Assessment teams considered the negative impacts of climate change for regions, sectors, and other issues of concern, they also considered potential adaptation strategies. When considered together, negative impacts along with possible adaptations to these impacts define vulnerability. As a formula, this can be expressed as vulnerability equals negative impact minus adaptation. Thus, in cases where teams identified a negative impact of climate change, but could not identify adaptations that would reduce or neutralize the impact, vulnerability was considered to be high. A general sense emerged that American society would likely be able to adapt to most of the impacts of climate change on human systems but that the particular strategies and costs were not known.

Widespread water concerns. A prime example of the need for and importance of adaptive responses is in the area of water resources. Water is an issue in every region, but the nature of the vulnerabilities varies, with different nuances in each. Drought is an important concern in every region. Snowpack changes are especially important in the West, Pacific Northwest, and Alaska. Reasons for the concerns about water include increased threats to personal safety, further reduction in potable water supplies, more frequent disruptions to transportation, greater damage to infrastructure, further degradation of animal habitat, and increased competition for water currently allocated to agriculture.

Health, an area of uncertainty. Health outcomes in response to climate change are highly uncertain. Currently available information suggests that a range of health impacts is possible. At present, much of the U.S. population is protected against adverse health outcomes associated with weather and/or climate, although certain demographic and geographic populations are at greater risk. Adaptation, primarily through the maintenance and improvement of public health systems and their responsiveness to changing climate conditions and to identified vulnerable subpopulations should help to protect the U.S. population from adverse health outcomes of projected climate change. The costs, benefits, and availability of resources for such adaptation need to be considered, and further research into key knowledge gaps on the relationships between climate/weather and health is needed.

Vulnerable ecosystems. Many U.S. ecosystems, including wetlands, forests, grasslands, rivers, and lakes, face possibly disruptive climate changes. Of everything examined in this Assessment, ecosystems appear to be the most vulnerable to the projected rate and magnitude of climate change, in part because the available adaptation options are very limited. This is important because, in addition to their inherent value, they also supply Americans with vital goods and services, including food, wood, air and water purification, and protection of coastal lands. Ecosystems around the nation are likely to be affected, from the forests of the Northeast to the coral reefs of the islands in the Caribbean and the Pacific.

Agriculture and forestry likely to benefit in the near term. In agriculture and forestry, there are likely to be benefits due to climate change and rising CO_2 levels at the national scale and in the short term under the scenarios analyzed here. At the regional scale and in the longer term, there is much more uncertainty. It must be emphasized that the projected increases in agricultural and forest productivity depend on the particular climate scenarios and assumed CO_2 fertilization effects analyzed in this Assessment. If, for example, climate change resulted in hotter and drier conditions than projected by these scenarios, both agricultural and forest productivity could possibly decline.

Potential for surprises. Some of the greatest concerns emerge not from the most likely future outcomes but rather from possible "surprises." Due to the complexity of Earth systems, it is possible that climate change will evolve quite differently from what we expect. Abrupt or unexpected changes pose great challenges to our ability to adapt and can thus increase our vulnerability to significant impacts.

A vision for the future. Much more information is needed about all of these issues in order to determine appropriate national and local response strategies. The regional and national discussion on climate change that provided a foundation for this first Assessment should continue and be enhanced. This national discourse involved thousands of Americans: farmers, ranchers, engineers, scientists, business people, local government officials, and a wide variety of others. This unique level of stakeholder involvement has been essential to this process, and will be a vital aspect of its continuation. The value of such involvement includes helping scientists understand what information stakeholders want and need. In addition, the problem-solving abilities of stakeholders have been key to identifying potential adaptation strategies and will be important to analyzing such strategies in future phases of the assessment.

The next phase of the assessment should begin immediately and include additional issues of regional and national importance including urban areas, transportation, and energy. The process should be supported through a public-private partnership. Scenarios that explicitly include an international context should guide future assessments. An integrated approach that assesses climate impacts in the context of other stresses is also important. Finally, the next assessment should undertake a more complete analysis of adaptation. In the current Assessment, the adaptation analysis was done in a very preliminary way, and it did not consider feasibility, effectiveness, costs, and side effects. Future assessments should provide ongoing insights and information that can be of direct use to the American public in preparing for and adapting to climate change.

The CHAIRMAN. Thank you for being here.

Dr. Janetos.

STATEMENT OF DR. ANTHONY C. JANETOS, SENIOR VICE PRESIDENT FOR PROGRAM, WORLD RESOURCES INSTITUTE

Dr. JANETOS. Mr. Chairman, thank you for the opportunity to discuss the national assessment of potential impacts of climate change in the U.S.

There are really three questions about climate change that have dominated many of the public and scientific discussions: first, how much climate change is going to occur, second, what might happen as a result, and third, what can countries do about it?

The purpose of the national assessment is to focus only on the second of these questions. That is, to address the question of, so what, with our best understanding of the underlying science, and then to address the questions of major uncertainties in order to make well-reasoned recommendations for future research.

The national assessment was called for in the original enabling legislation in 1990 for the U.S. global change research program. In 1997, Dr. John Gibbons, then Science Advisor to the President, requested the global change research program to undertake the national assessment focusing on understanding other environmental stresses and issues within which climate change impacts might occur, whether climate change and variability might exacerbate or ameliorate existing problems, what options for coping might exist, and what research is most important to complete over both the short and the longer term.

A variety of efforts emerged in response to Dr. Gibbons' charge. First was a substantial bottom-up effort. Over 20 workshops were held around the country, involving a broad range of stakeholders, academics, farmers and ranchers, businesspeople, land managers, people from every walk of life.

Each workshop identified a range of issues of concern within their regions. Many of these were followed by the initiation of scientific studies, some of which have finished their work and have been published, others of which are ongoing.

At the same time, it was thought to be necessary to create a companion but independent effort to create a national level synthesis of what is known for the U.S. as a whole, addressing the issues that were raised in workshops, and addressing issues that have been raised in national studies of several important sectors.

This national study was viewed to build on work that has been done and published, on the published scientific literature, and on analyses that were to be done with the most up-to-date environmental data and models that could be obtained. All sources that were used in the national assessment and the national study were to be documented and to be available so that this study would present the best snapshot at this time of our understanding, using the best available information.

The national assessment synthesis team, which Mr. Karl, Dr. Melillo and I co-chair, was chartered under the Federal Advisory Committee Act specifically to carry out the national study. Its membership is drawn from academic and research institutions from industry, from nongovernmental organizations, and government research laboratories.

The first thing that we did was to publish a plan for the conduct of the national synthesis and select five issues for national analysis in addition to the work which Tom has just described on the different regions of the U.S. This plan was published in 1998 and has been available on the Internet.

The products of our work is now in two volumes. The first of these we call the foundation volume. It is over 600 pages long, with more than 200 figures and tables. It is extensively referenced and, as I mentioned, we have made the commitment that all of the sources, of which there are thousands used in it, are documented and are available. These are basically the same guidelines as the Intergovernmental Panel on Climate Change has used for the accessibility of source material.

The second volume we have called the overview. It is written more in a style for the general public. It is substantially shorter, about 150 pages long and extensively illustrated, and is a summary of the foundation document.

Both of these volumes have already undergone significant review. At the end of 1999 and the beginning of this year we went through two rounds of technical peer review. Subsequent to that, this past spring we went through an additional review by about 20 independent experts. We have received over 300 sets of comments and have made a commitment to document our responses to external comments that we have received.

In addition, we have written an overview memo summarizing our responses to major comments. We are now approximately half-way through a 60-day public comment period that was specifically requested by the Congress. When it ends, we anticipate responding to the additional comments we will have received, as we have done before, and putting the report in final form in order to be submitted to the President and Congress, as called for in the original legislation.

Throughout, the national assessment synthesis team has been the beneficiary of oversight review and guidance from an oversight panel which was established through the offices of the President's Council of Advisors on Science and Technology, chaired by Dr. Peter Raven and Dr. Mario Melina.

One thing I would like to emphasize in closing is that it is important to remember that the national assessment does not attempt to predict exactly what the future will hold for the U.S. It has examined the potential implications of two primary climate scenarios, but has used many other data sets as well. That is, it uses our best scientific understanding of ecosystems, hydrologic systems, agriculture, forestry, and so on, to explore the different consequences of scientifically plausible futures.

We explicitly discuss uncertainty in the underlying science. In fact, throughout the assessment we have consistently used language describing our scientific confidence in the results and findings so that the reader can understand when we are very confident of our findings and when we are less so.

Thank you very much.

The CHAIRMAN. Thank you very much. Dr. Schmitt.

STATEMENT OF DR. RAYMOND W. SCHMITT, SENIOR SCIENTIST, WOODS HOLE OCEANOGRAPHIC INSTITUTIONS

Dr. SCHMITT. Thank you, Mr. Chairman. I am a physical oceanographer. In the past 25 years I have averaged about 1 month a year at sea on research cruises. In the past 10 years I have averaged about 1 month a year working on committees concerned with the role of the oceans in climate.

The thrust of my statement is that the oceans have a very important role to play in climate, and that we are not doing a very good job at either modeling the role of the oceans in climate predictions, nor are we properly monitoring the state of the ocean in order to make these predictions possible.

In the past few years oceanographers have done a large-scale survey of the state of the world ocean. We called it the World Ocean Circulation Experiment. It was funded by the National Science Foundation, and what we found was quite interesting.

In most areas—not all, but in most areas, deep waters had warmed significantly since the last time a major survey had been done in the fifties, so we are seeing global warming in the ocean. It is real, and we are finding it in the ocean and, in fact, the fact that we find it so deep in the ocean has been a surprise for many climate modelers, because the models they use have a very slow responding ocean. It is more like lava or concrete than the water that we know.

So oceanographers have a very different view of the ocean. We see a more active agent of climate change.

The CHAIRMAN. Why would it warm in——

Dr. SCHMITT. So deep?

The CHAIRMAN. Yes.

Dr. SCHMITT. Well, it is quite interesting. The ocean interacts with the atmosphere at high latitudes, and the water can sink quite deeply. Up in the Labrador Sea, up in the seas off Greenland and Iceland, we call this deep convection, and this deep convection is how the ocean changes temperature, how it gives heat to the atmosphere and changes its own internal temperature, and this whole process—we call it the thermohaline circulation—is very important to transporting heat to high latitudes, for keeping Europe warm. The fact that England has a very moderate climate is due to this thermohaline circulation.

Well, one of the very exciting things that the paleoceanographers have found is that this circulation shut off at times in the past, when that water got too fresh. At the end of the last glaciation, about 12,000 years ago, there was a lot of fresh water coming from the melting glaciers. It shut off thermohaline circulation because adding fresh water makes the water lighter and it cannot sink, so then no heat was carried northward, Europe got very cold, and the ice ages came back for about 1,000 years.

The striking thing is that this change happened in a couple of decades, in the data that they have obtained from the ice core and in the sedimentary record at the bottom of the ocean. Some climate models predict an increase in high latitude rainfall due to the global warming. Warm air carries more water than cold air, and they have projected a shutdown in this thermohaline circulation. That would be a very significant change that could occur very rapidly.

Now, the other thing that we found in the last few years is that the ocean has certain temperature patterns that lock in specific climate phenomena. We all know about El Niño and la niña. That is warm water sloshing back and forth in the Pacific. Well, there is another oscillation called the North Atlantic oscillation, that seems to be controlled by the patterns of warm water moving around the North Atlantic.

We are at the stage technologically where we can make better measurements of these deep temperature patterns in the ocean with autonomous probes, floats that are like weather balloons for the ocean. They drift at depth, they inflate a small bladder every 10 days, come to the surface and obtain a profile of temperature and salinity on the way up, send that data to a satellite, and then resubmerge for another 10-day drift.

From this we get the heat content of the ocean, we find out its salt content, and therefore whether it is likely to continue deep convecting in the winter. These things will help us to gain the ability to predict climate for 5 to 10 years in advance. We find this a very exciting research possibility.

The CHAIRMAN. What are you finding out?

Dr. SCHMITT. Well, the hope that we are holding out is that when we have enough data coming in from these new observation systems, and enough understanding of these processes, that we will be able to predict climate with greater confidence than we have now. Right now there is a great deal of uncertainty about all of these modes of operation.

The CHAIRMAN. When will you be able to start making these predictions?

Dr. SCHMITT. Prediction is a dangerous game. There is a program called Argo we are trying to get funded.

The CHAIRMAN. Yes.

Dr. SCHMITT. We hope to have that in place in full operation in about 5 years, and I would think it would really start to have a significant effect on climate predictions 5 years from now.

That is the basic thrust of my statement, and I thank you for the opportunity to present this to the Committee.

[The prepared statement of Dr. Schmitt follows:]

PREPARED STATEMENT OF DR. RAYMOND W. SCHMITT, SENIOR SCIENTIST, WOODS HOLE OCEANOGRAPHIC INSTITUTIONS

The Ocean's Role in Climate

My name is Raymond Schmitt, I am a Senior Scientist in the Department of Physical Oceanography at the Woods Hole Oceanographic Institution. My research interests include the ocean's role in climate, small-scale mixing processes, the global water cycle, and instrumentation for a global ocean observing system. I have served on a number of national and international committees concerned with climate, including the Atlantic Climate Change Program Science Working Group, the Ocean Observing System Development Panel, and the Climate Variability (CLIVAR) Science Steering Group, and am a contributing author to the IPCC Third Assessment Report.

The thrust of my comments today is that the crucial role of the oceans in climate has not been sufficiently acknowledged in most research on climate change to date, including the National Climate Assessment Report under discussion here. It was a tradition of the climate modeling community to treat the ocean as a shallow swamp; a source of moisture but playing no role in heat transport and storage. We now know this to be a significant error, the oceans are an equal partner with the atmosphere in transporting heat from the equator to the poles, and a reservoir of heat and water that overwhelmingly dwarfs the capacity of the atmosphere.

A few facts about

The Oceans:

Cover 70% of the surface of the Earth.

Have 1,100 times the heat capacity of the atmosphere
(99.9% of the heat capacity of the Earth's fluids)

Contain 90,000 times as much water as the atmosphere
(97% of the free water on the planet)

Receive 78% of global precipitation

A quote from Arthur C. Clarke gets it right:

"How inappropriate to call this planet Earth when clearly it is Ocean"—*Nature*, v. 344, p. 102, 1990.

New evidence for the essential role of the oceans in climate is coming out of the recent World Ocean Circulation Experiment (WOCE), supported by the National Science Foundation. A globe-spanning set of ship-based observations in the '90s revealed that the depths of the ocean had warmed significantly since previous observations in the '50s. In fact, about half the "missing" greenhouse warming has been found in the ocean. It was missing because models had projected a larger increase than had been observed. It now appears this was because they had not properly accounted for the capacity of the oceans to store large quantities of heat on short timescales. In fact, it is easy to calculate that if all of the extra heat due to the greenhouse change in the radiation balance were to be deposited in the deep ocean, it would take 240 years for it to rise 1°C. Thus, monitoring the ocean's patterns of heat storage is absolutely essential for understanding global warming, yet we have no system for such observations.

But the oceans do more than simply delay global warming. Research over the past twenty years has brought a growing appreciation of how the slow movement of warm and cold patches of ocean water can affect our weather for months at a time. The alternating influence of El Niño and la niña are now well known to the public and are rashly blamed for any type of unusual weather. These 3–5 year period disruptions in weather patterns are caused by the movement of warm water in the tropical Pacific, and are now predictable up to a year in advance because of a special monitoring network of ocean buoys maintained there. The influence of El Niño on U.S. weather is well publicized, but it actually explains only a small part of the variation in temperature and rainfall over the United States. Some other natural ocean climate cycles known as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) can explain much more of the variability in winter-time weather than El Niño. (Figure 1.). The NAO in particular has much more impact on the eastern half of the United States than El Niño.

Exciting new findings suggest that the ocean controls the timescale of the NAO, thus holding out the hope that these weather patterns will be predictable when sufficient ocean observations become available.

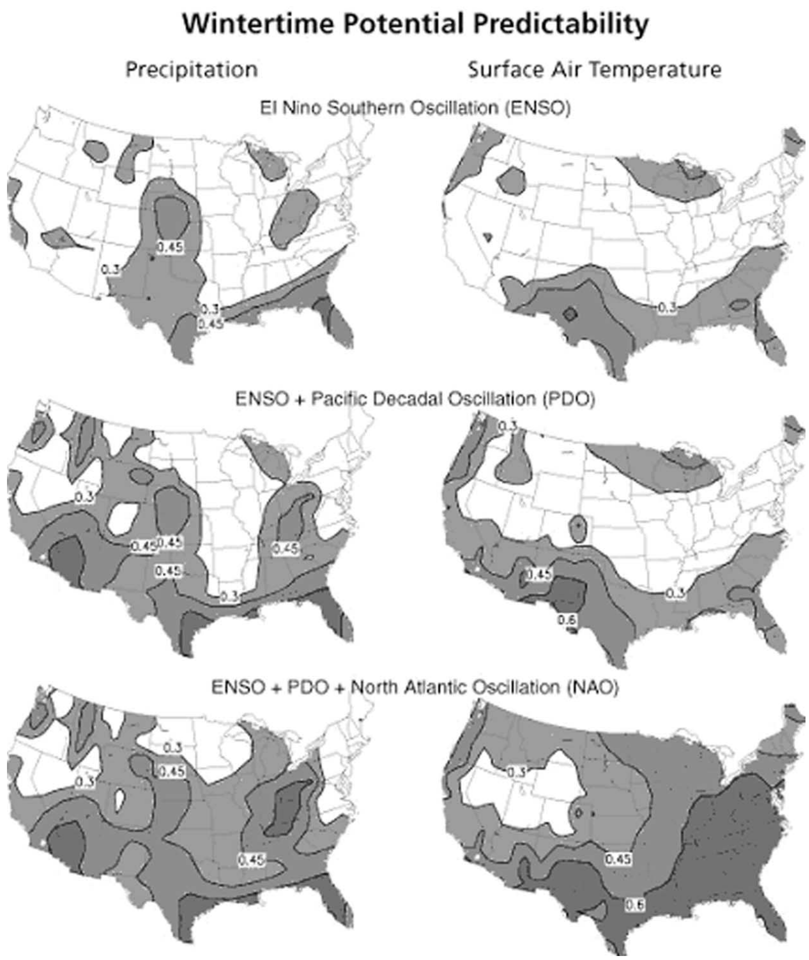


Figure 1. The correlation of U.S. winter-time climate with El Niño, PDO and NAO over a 35 year period. If we could predict these phenomena in advance, then the square of the numbers represented by the colors gives the winter climate variability that is potentially predictable. That is, white areas would have no predictability, but in the brown areas 36% or more of winter climate changes could be predicted. However, we do not yet have predictive capabilities for PDO or NAO. If predictions are to be made we will require a greatly expanded ocean observing system.

Recent research indicates that the NAO's changes in atmospheric pressure patterns over the Atlantic are linked to the slow variation in water temperatures, as the ocean currents rearrange the warm and cold ocean patterns that serve to guide the atmosphere in its preferred modes of oscillation. Only the ocean has the long-term memory to provide the decadal time scales observed in the NAO. An understanding of these natural modes of climate variation is essential for accurate predictions of the regional trends in U.S. climate. That the two models examined in the Climate Assessment report should differ so widely in prediction of future U.S. precipitation is no surprise. Models are only a repository for what we think we know, and an understanding of the important oceanic phenomena such as PDO and NAO has not yet been achieved. In order to understand these phenomena we need to observe the motion of the deep warm and cold patches that give the ocean its multi-decadal memory, and we need to sustain those observations through a few cycles of the oscillations. In contrast to the 1,200 records of U.S. land temperature used to examine climate trends in the report, we have only three sites with anything like a continuous deep record in all of the North Atlantic! For these few sites with rather short records, an observation once a month is often the best we have. This observation system is woefully inadequate. It is obvious that the ocean is the long-term memory of the Earth's climate system yet we persist in ignoring it. Some think it sufficient to look at the surface of the ocean with a satellite and try to model the interior. However, satellites can tell us nothing about the deep interior temperatures that influence winter-time climate.

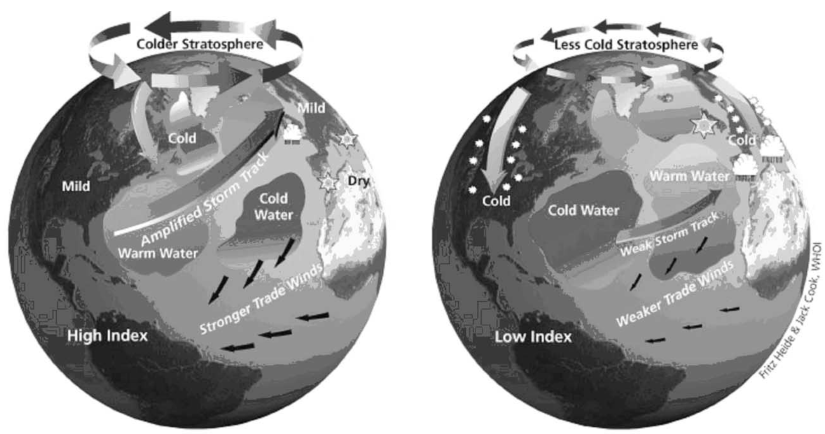


Figure 2. The North Atlantic Oscillation (NAO). Its "high index" state is shown on the left, this corresponds to particularly high atmospheric pressure over the Azores, an intense low over Iceland. Ocean winds are stronger and winters milder in the eastern U.S. When the NAO index is low, ocean winds are weaker and the U.S. winter more severe. Changes in ocean temperature distributions are also observed.

The Water Cycle and Thermohaline circulation

Also, satellites can tell us nothing about the salt content of the ocean, which reflects the workings of the water cycle. There is an increasing attention to the importance of the water cycle in global change; for most communities drought or flood are more pressing challenges than a few degrees of warming. However, there has been little recognition that most of the water cycle occurs over the oceans. It would take a diversion of only 1% of the rainfall falling on the Atlantic to double the discharge of the Mississippi River. Water travels quickly through the atmosphere, spending only about 10 days on a short ride from one spot to another. Water molecules spend thousands of years on the slow return flow in the ocean. But the process of water leaving the surface of the ocean, and thereby changing its salt content and density, drives an interior flow many times larger than the flux of water due to evaporation and precipitation alone. This "thermohaline circulation" is a key element of the climate system, as it is responsible for most of the ocean's heat transport from equator to pole. When salty water gives up its heat to the atmosphere, it can become dense enough to sink to the bottom of the ocean, thereby keeping making room for more warm water to come north for cooling. The North Atlantic is the saltiest ocean and the most active site for such "deep convection". However, if it becomes too fresh from rainfall the surface waters cannot sink and the flow of warm water stops.

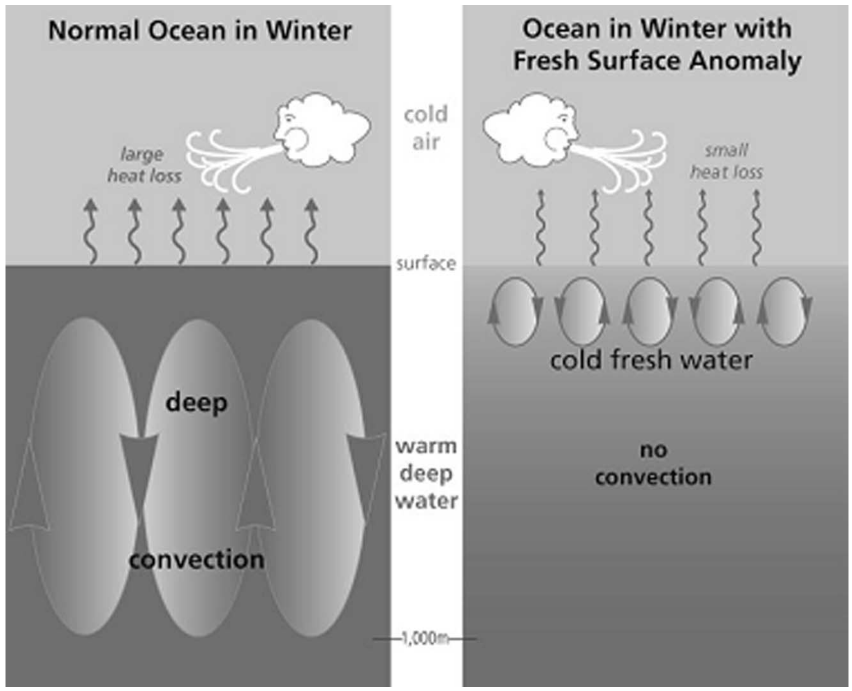


Figure 3. The influence of salt content (salinity) on the process of deep convection. Normally, winter cooling at the surface causes deep vertical mixing which releases much heat to the atmosphere (left). When fresher water lies at the surface because of rain fall or ice melt, the deep convection is prevented and only a shallow surface layer provides heat to the air above (right). Thus, salinity is now considered a key variable for climate studies.

Records from ocean sediments of the fossils of marine life indicate that this has happened many times in the past, with dramatic consequences for climate over a large area. The most recent event was about 12,000 years ago, when the freshwater from melting glaciers shut down the thermohaline circulation in the North Atlantic. This had dramatic consequences for the North Hemisphere, returning much of it to glacial conditions for 1000 years. The data indicate that this happened rapidly, in only a decade or two. Some models predict that such abrupt climate change could happen again as the water cycle intensifies with future global warming. However, such transitions in the thermohaline circulation have been shown to depend on the rate of interior mixing in the ocean, and we know that this is incorrectly treated in the present generation of climate models.

Model Deficiencies

In fact, oceanographers have many complaints about how poorly climate models simulate the ocean. Because of computer limitations, they must treat it as a very viscous fluid, more like lava or concrete than water. Such models fail to simulate the real ocean's changes in deep temperatures. We know that the "sub-grid-scale" parameterizations for mixing processes are incorrect, reflecting none of the observed spatial variations or differences between heat and salt. This mixing drives the interior flows in the ocean. We know that the processes by which ocean currents give up their momentum are incorrectly treated. And these are not problems that will quickly yield to increased spatial and temporal resolution in the computer models. Even if computer power continues to increase by an order of magnitude every 6 years, it will be over 160 years [1] before models have the resolution necessary to simulate the smallest ocean mixing processes! Society cannot afford to wait that long. We will not come to an understanding of climate by more computational cycles of models with incorrect physics. We require a systematic study of the sub-grid-scale processes in the ocean. This is noticeably lacking in our current Global Change Research Program.

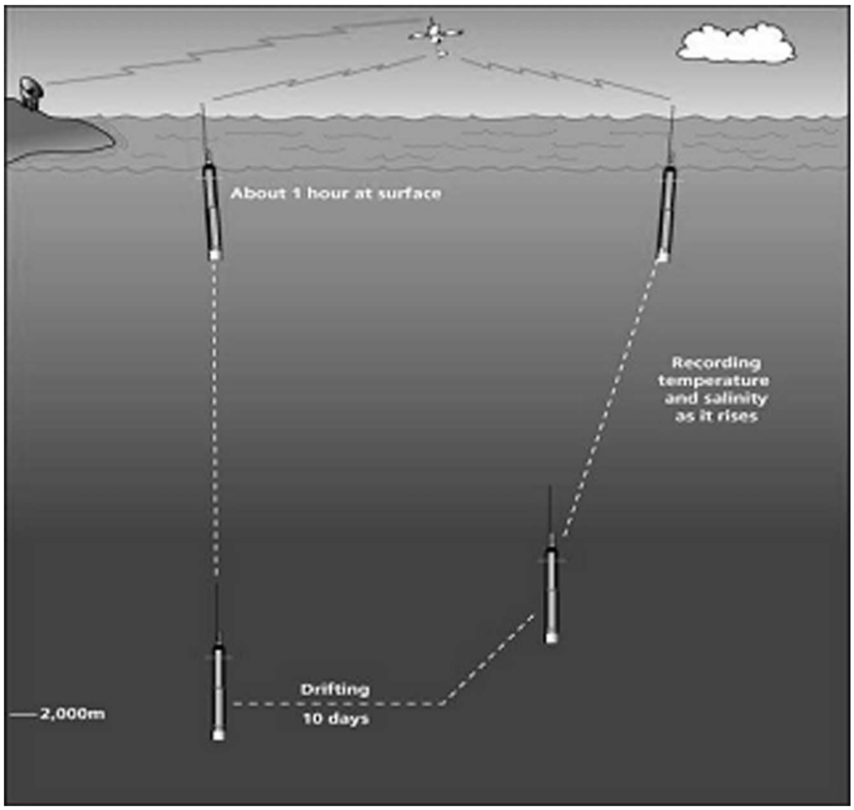


Figure 4. The operation of a profiling float for the ARGO program. These autonomous probes can provide unprecedented amounts of data from the interior ocean at a modest cost. Knowledge of the interior ocean temperature is necessary because these waters interact with the atmosphere every winter through the process of deep convection.

Observing Deficiencies

While we have in place a system for monitoring El Niño, we have no such ability to observe the motions of thermal anomalies in the mid- and high-latitude oceans. Nor do we monitor the salt content of ocean currents, to determine the potential for deep convection or to help understand the vast water cycle over the oceans. But new technology, the vertically profiling ARGO float (Figure 4.), promises to give us the data we need to begin to understand this largest component of the global water cycle. These are like weather balloons for the ocean, drifting at depth for 10 days then rising to the surface to report profiles of temperature and salinity to a satellite.

[1] It will take a factor of 10^8 improvement in 2 horizontal dimensions (100 km to 1 mm, the salt dissipation scale), a factor of 10^6 in the vertical dimension (~10 levels to 10^7) and ~10^5 in time (fraction of a day to fraction of a second); an overall need for an increase in computational power of ~10^{27}. With an order of magnitude increase in computer speed every 6 years, it will take 162 years to get adequate resolution in computer models of the ocean.

They then resubmerge for another 10 day drift, a cycle to be repeated 150 times or more. The distance traveled between surfacings provides a measure of the currents at the depth of the drift. The ARGO program (http://www.argo.ucsd.edu/) is an international plan to maintain a global distribution of ~3000 floats as a core element of a Global Ocean Observing System (Figure 5.). Other parts of the system involve fixed sites with moored buoys and underwater profilers that record temperature and salinity all the way to the bottom of the ocean. These new technologies will give us the data we need to begin to decipher the complex climate phenomena we know to be operating in the ocean. Science is the process of testing ideas against observations, and failure to make the observations is an abandonment of the scientific process.

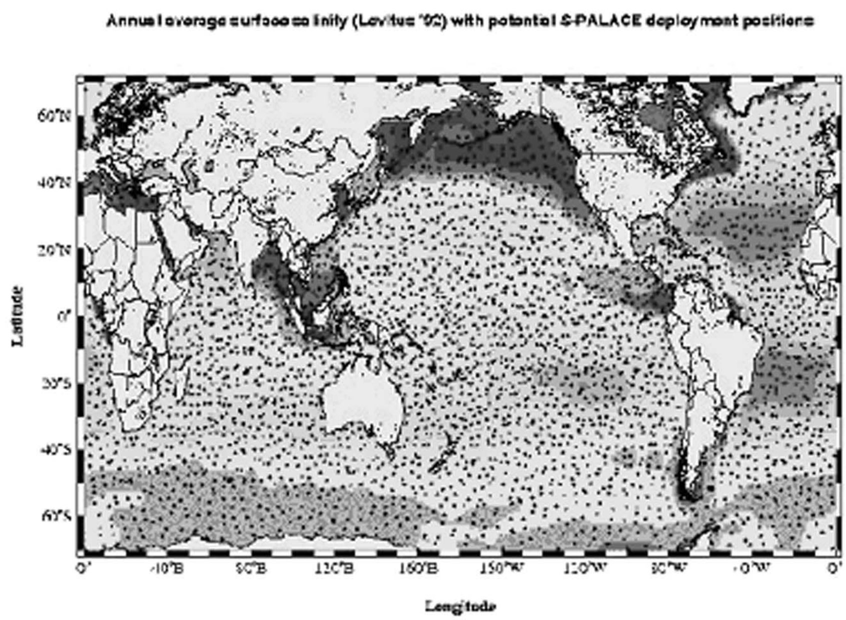


Figure 5. The surface salinity of the global ocean is represented by the colors, with red being the saltiest and blue/purple the freshest. 3000 random dots, representing possible ARGO float positions, are seen to provide good sampling of the large-scale patterns of salinity variation. The Atlantic Ocean is seen to be saltiest, which helps explain why deep convection is especially likely there, and its important role in the thermohaline circulation.

What Can Congress Do?

1. Support fundamental research into the processes that govern the ocean's role in climate. This includes the basic oceanic research programs at NSF and ONR, and international programs like CLIVAR.
2. Make a substantial and long-term commitment to the creation of a Global Ocean Observing System. Fund the ARGO program at NOAA (Ocean Observations component of Climate Observations and Services) and the ocean observing satellites of NASA.

Summary:

Policy makers would like climate scientists to produce firm predictions. However, they must always remember that science is the process of testing ideas against facts and access to quantitative data is essential to the process. The ocean is a crucial element of the climate system, yet its "subgrid-scale" processes are too poorly understood and its basic structure too poorly monitored, to provide much confidence in the details of present day predictions. The National Climate Assessment Report is a good faith effort to assess the effects of global warming on U.S. climate; the regional disagreements of the two available models are to be expected, given our poor

understanding of the ocean. Global warming due to the effect of greenhouse gases on the radiation balance is as certain as the law of gravity, but the issues of how rapidly heat is sequestered in the oceans, its impact on the water cycle, and the important regional variations in climate, remain very challenging research questions.

Climate prediction is a hard problem, but appears to be tractable. An abundance of evidence indicates that the key to long-term prediction is in the workings of the ocean, which has 99.9% of the heat capacity of Earth's fluids. It is the heart of the climate "beast," the atmosphere its rapidly waving tail, with only 0.1% of the heat capacity. Let us get to the heart of the matter, with an unprecedented new look at the ocean. We have the technical capabilities. The cost is modest. The payoff is large. The society that understands long-term climate variations will realize tremendous economic benefits with improved predictions of energy demand, water resources and natural hazards, and it will make wiser decisions on issues affecting the habitability of the planet, such as greenhouse gas abatement.

The CHAIRMAN. Thank you very much. Dr. Singer.

STATEMENT OF DR. S. FRED SINGER, PROFESSOR EMERITUS OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VIRGINIA, AND FORMER DIRECTOR OF U.S. WEATHER SATELLITE SERVICE

Dr. SINGER. Mr. Chairman, I have researched and published mainly in atmospheric and space physics over the last years.

I am professor emeritus of environmental sciences at the University of Virginia, and president of the Science and Environmental Policy Project, which is a nonprofit, nonpartisan research group of scientists. We all work pro bono, without salary, and we do not solicit money from industry or government, so we are fairly independent. We speak our minds on many issues as we see fit. We are mainly interested in making sure that the science underlying the various policies, environmental policies is correct and sound.

The reason I have a skeptical view on the climate science underlying the assessment is because it does not fit with the evidence. My testimony concerns just three pieces of evidence, which I will briefly outline.

The first statement I make is that there is no appreciable climate warming today. I repeat, there is no appreciable climate warming. This puts me at odds with many of my colleagues, I realize that, including my distinguished colleague, Tom Karl, but I hope that I can convince him and others that the evidence supports what I have to say.

I think the evidence that the climate has not warmed in the last 2 decades is overwhelming. I have four pieces of evidence. The weather satellites, with which I am very familiar, do not show any appreciable warming of the atmosphere in the last 20 years. In fact, if you take out 1998, the El Niño year, there is even a slight cooling of the atmosphere in the last 20 years.

There has been long debate about this, but fortunately the National Research Council of the National Academy of Sciences has published a report this year in which they essentially endorse the satellite data, and the fact that the atmosphere has not warmed in the last 20 years.

Weather balloons carrying radios get exactly the same result, and these are independent measurements of the atmosphere. They also show no appreciable warming in the last 20 years.

The third piece of evidence is the temperature record for the United States as produced by NOAA and also published by NASA.

The temperature record for the United States shows that the temperature has not warmed appreciably since about 1940.

Now, the thermometers do show a *global* warming. It means that there must be warming going on somewhere outside of the United States, and outside of Western Europe, because neither one of those two networks shows any appreciable warming.

This is very puzzling, and it is possible that the thermometers are not giving correct readings, or that they are contaminated in some way. The warming seems to occur mainly in Northwestern Siberia and in subpolar regions of Alaska and Canada. But when one checks proxy data, like tree rings, ice cores, and things of that sort, which also are a way of measuring temperature, they show no warming since 1940, so the thermometer data that do show a warming are the odd man out, and we need to do the necessary research to find out why that is.

As of now, I would say that there is no appreciable warming in the last 20 years and, by the way, if there is no warming in the last 20 years, this means that this is not the warmest century in the last 1,000 years. In fact, we believe it was warmer 1,000 years ago than it is today. And this is not the warmest decade in the last 1,000 years, either.

So you see, we have a chance here to have a good debate on these issues, but this is probably more appropriate for the American Meteorological Society meetings that we are going to be attending soon.

My second point relates to the regional changes in temperature, precipitation, and soil moisture. After all, this is the important thing, because all of the impacts of climate change are based on what is actually happening in the region. My belief is, and I believe everyone would agree, that to predict regional changes is beyond the state-of-the-art of climate models.

Climate models cannot even predict properly the global changes, but to predict regional changes is practically impossible, and we have proof of that. The proof is actually in the report itself, the report that Dr. Janetos has just referred to. The two climate models that are used in the report give opposite results in 9 of the 18 regions that have been studied.

For example, when it comes to rainfall the report shows the Dakotas losing 85 percent of their current rainfall in one model, while the second model shows a gain of 75 percent. These opposite results occur in 9 cases out of 18, and in some other cases the results show a huge difference.

The same is also true with soil moisture. The Canadian model that was used predicts a drier Eastern United States. The British model that was used predicts a wetter Eastern United States.

So we conclude that the model results are not credible, and therefore we believe that the conclusions that are drawn about the impact of these climate changes are interesting exercises but should not be taken too seriously.

My third point: I want to discuss sea level rise. Sea level rise is widely feared, but also very much misunderstood. Most people think the sea level rose in the last century because temperatures rose in the last century. That is not so. Sea level has been rising for about 15,000 years. Sea level rose by 400 feet in the last 15,000, and the reason it rose is because the ice melted at the end of the last Ice Age.

First, the ice melted in North America and Northern Europe, and that caused a very rapid rise in sea level. We can actually measure it. It is about 80 inches per century, as measured.

Once that ice was gone, the melting slowed down. But the melting still continues, though, in the Antarctic, but now it is the West Antarctic ice sheet that is melting slowly, and has been melting for 15,000 years, and this slow melting of the West Antarctic ice sheet amounts to about 7 inches per century of sea level rise.

This is the sea level rise that is going on right now. This will continue for another 6,000 years, unless another Ice Age intervenes. But assuming that we do not get another Ice Age, we will have sea level rise going on for another 6,000 years no matter what we do.

We cannot affect this in any way. We cannot stop the tides, we cannot stop continental drift, we cannot stop the Antarctic ice sheet from melting. It is just going to continue its slow-melting process. It has to do with the fact that it is warmer now than it was 15,000 years ago.

Finally: The bottom line of all of this is that the scientific evidence does not support the results of the National Assessment. It also tells us that we should be doing serious research on both atmospheric and oceanic processes, and that this research needs to be carried out much further before we can have confidence in any assessment report.

My conclusion: The National Assessment should definitely not be used to justify any irrational or unscientific energy and environmental policies, and that advice I think is particularly relevant to the forthcoming Presidential debates and campaigns.

Thank you very much.

[The prepared statement of Dr. Singer follows:]

PREPARED STATEMENT OF DR. S. FRED SINGER, PROFESSOR EMERITUS OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VIRGINIA, AND FORMER DIRECTOR OF U.S. WEATHER SATELLITE SERVICE

Mr. Chairman, Ladies and Gentlemen,

My name is Fred Singer. I am Professor Emeritus of Environmental Sciences at the University of Virginia and the founder and president of The Science & Environmental Policy Project (SEPP) in Fairfax, Virginia, a non-partisan, non-profit research group of independent scientists. We work without salaries and are not beholden to anyone or any organization. SEPP does not solicit support from either government or industry but relies on contributions from individuals and foundations.

We hold a skeptical view on the climate science that forms the basis of the National Assessment because we see no evidence to back its findings; climate model exercises are NOT evidence. Vice President Al Gore keeps referring to scientific skeptics as a "tiny minority outside the mainstream." This position is hard to maintain when more than 17,000 scientists have signed the Oregon Petition against the Kyoto Protocol because they see "no compelling evidence that humans are causing discernible climate change."

Others try to discredit scientific skeptics by lumping them together with fringe political groups. Such ad hominem attacks are deplorable and have no place in a scientific debate. To counter such misrepresentations, I list here qualifications relevant to today's hearing.

Relevant Background

I hold a degree in engineering from Ohio State and a Ph.D. in physics from Princeton University. For more than 40 years I have researched and published in atmospheric and space physics. I received a Special Commendation from President Eisenhower for the early design of satellites. In 1962, I established the U.S. Weather Satellite Service, served as its first director, and received a Gold Medal award from the Department of Commerce for this contribution.

Early in my career, I devised instruments to measure atmospheric parameters from satellites. In 1971, I proposed that human production of the greenhouse gas methane, through cattle raising and rice growing, could affect the climate system. This was also the first publication to discuss an anthropogenic influence on stratospheric ozone. In the late 1980s, I served as Chief Scientist of the Department of Transportation and also provided expert advice to the White House on climate issues.

Today, by presenting evidence from published peer-reviewed work, I will try to rectify some erroneous claims advanced at the May 17 NACC hearing.

1. There Is No Appreciable Climate Warming

Contrary to the conventional wisdom and the predictions of computer models, the Earth's climate has not warmed appreciably in the past two decades, and probably not since about 1940. The evidence is abundant.

a) Satellite data show no appreciable warming of the global atmosphere since 1979. In fact, if one ignores the unusual El Niño year of 1998, one sees a cooling trend.

b) Radiosonde data from balloons released regularly around the world confirm the satellite data in every respect. This fact has been confirmed in a recent report of the National Research Council/National Academy of Sciences.[1]

c) The well-controlled and reliable thermometer record of surface temperatures for the continental United States shows no appreciable warming since about 1940. The same is true for Western Europe. These results are in sharp contrast to the GLOBAL instrumental surface record, which shows substantial warming, mainly in NW Siberia and subpolar Alaska and Canada.

d) But tree-ring records for Siberia and Alaska and published ice-core records that I have examined show NO warming since 1940. In fact, many show a cooling trend.

Conclusion: The post-1980 global warming trend from surface thermometers is not credible. The absence of such warming would do away with the widely touted "hockey stick" graph (with its "unusual" temperature rise in the past 100 years); it was shown here on May 17 as purported proof that the 20th century is the warmest in 1000 years.

2. Regional Changes in Temperature, Precipitation, and Soil Moisture?

The absence of a current global warming trend should serve to discredit any predictions from current climate models, including the extreme warming from the two models (Canadian and British) selected for the NACC.

Furthermore, the two NACC models give conflicting predictions, most often for precipitation and soil moisture.[2,3] For example, the Dakotas lose 85% of their current average rainfall by 2100 in one model, while the other shows a 75% gain. Half of the 18 regions studied show such opposite results; several others show huge differences.

The soil moisture predictions also differ. The Canadian model shows a drier Eastern U.S. in summer, the UK Hadley model a wetter one.

Conclusion: We must conclude that regional forecasts from climate models are even less reliable than those for the global average. Since the NACC scenarios are based on such forecasts, the NACC projections are not credible.

3. Sea Level Rise: Controlled by Nature not Humans

The most widely feared and also most misunderstood consequence of a hypothetical greenhouse warming is an accelerated rise in sea levels. But several facts contradict this conventional view:

a) Global average sea level has risen about 400 feet (120 meters) in the past 15,000 years, as a result of the end of the Ice Age. The initial rapid rise of about 200 cm (80 inches) per century gradually changed to a slower rise of 15–20 cm (6–8 in)/cy about 7500 years ago, once the large ice masses covering North America and North Europe had melted away. But the slow melting of the West Antarctic Ice Sheet continued and will continue, barring another ice age, until it has melted away in about 6000 years.

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[1] National Research Council. "Reconciling Temperature Trends." *National Academy Press*, Washington, DC. January 2000.

[2] R. Kerr. "Dueling Models: Future U.S. Climate Uncertain." *Science* 288, 2113, 2000.

[3] P.H. Stone. "Forecast Cloudy: The Limits of Global Climate Models." *Technology Review* (MIT), Feb/March 1992. pp. 32–40.

b) This means that the world is stuck with a sea level rise of about 18 cm (7 in)/yr, just what was observed during the past century. And there is nothing we can do about it, any more than we can stop the ocean tides.

c) Careful analysis shows that the warming of the early 1900s actually slowed this ongoing SL rise,[4] likely because of increased ice accumulation in the Antarctic.

The bottom line: Currently available scientific evidence does not support any of the results of the NACC, which should therefore be viewed merely as a "what if" exercise, similar to the one conducted by the Office of Technology Assessment in 1993.[5] Such exercises deserve only a modest amount of effort and money; one should not shortchange the serious research required for atmospheric and ocean observations, and for developing better climate models.

The NACC should definitely NOT be used to justify irrational and unscientific energy and environmental policies, including the economically damaging Kyoto Protocol. These policy recommendations are especially appropriate during the coming presidential campaigns and debates. I respectfully request that an expanded exposition[6] be made part of my written record. [The Executive Summary is in the appendix, the whole document can be found at: *//www hoover.stanford.edu/publications/epp/102/102complete.pdf*]

The CHAIRMAN. Thank you, Dr. Singer. In other words, you reject the findings of the Assessment practically in its entirety.

Dr. SINGER. I think these are interesting exercises, what-if exercises, but I do not think they should be taken seriously.

The CHAIRMAN. Dr. Schmitt, in the climate change you have noted in your findings, what is the impact on the ecology of the oceans, such as the effect on reef life, et cetera?

Dr. SCHMITT. Well, I am hardly an expert, but there are very significant impacts on fisheries. I know the cod fishery in New England has changed a lot. It is difficult to sort out whether it is due to overfishing or just changes in the North Atlantic Oscillation, because the water off Labrador is so much colder now than it was 10, 15 years ago.

In other areas warming in tropical areas has a great impact on the life of corals. There is a phenomenon called coral bleaching, which basically kills a coral reef, and I believe that occurs if the water gets too warm. In other areas the stocks of salmon have been correlated with these climate phenomenon such as the North Atlantic Oscillation and the Pacific Decadal Oscillation.

These phenomena, with their long time scales—they are 5, 10, 15 year cycles—hold out the hope of predictability because the ocean has this long memory of the heat content. It has enormous heat content. It has 99.9 percent of the heat content of the climate system, and we need to be doing a much better job on monitoring that heat content.

The CHAIRMAN. Mr. Karl, do you have a response to Dr. Singer's views?

Mr. KARL. Yes. I have—I do not know where to begin, to be quite honest.

Dr. SINGER. Just start anywhere.

Mr. KARL. I guess I would first point out that what we did in the assessment was draw on the published referenced literature. In fact, I think if you look at the references in the assessment there is—probably over 95 percent are from papers that have been peer-

[4] S.F. Singer. Hot Talk, Cold Science: Global Warming's Unfinished Debate. (The Independent Institute, Oakland, CA. (second edition, p. 18)).

[5] Office of Technology Assessment. "Preparing for an Uncertain Climate." Govt. Printing Office, Washington, DC. 1993.

[6] S.F. Singer. "Climate Policy—From Rio to Kyoto: A Political Issue for 2000—and Beyond." Hoover Institution Essay in Public Policy No. 102. Stanford, CA, 2000.

reviewed. The other 5 percent are reports that often were used because we needed to obtain the data from those reports.

What I would just want to point out is that the position of Dr. Singer, although I very much respect his opinions, is quite at odds with the scientific published literature. I would just point out a few egregious examples of what I have heard.

50 percent of the rise, or more than half of the rise in sea level is due to the expansion of ocean waters. As temperatures increase, the ocean density increases, and it has nothing to do with the melting of ice glaciers.

The other aspects that I heard which I would completely disagree with, and that is the warming in the U.S. record. It is very clear, in fact, especially in the last decade or two, the U.S. was lagging behind global temperature increases up till the early 1980's, and since the mid-1980's, and particularly during the 1990's, the U.S. has virtually captured the rest of the globe.

That is not to be unexpected. In fact, if you look at one area in the country, the Southeast part of the U.S., it is where we have not seen much of an increase in temperature. In fact, there have been very small changes in temperature, but again if you look at the 1990's in the Southeast, we are almost now as warm as we were back in the 1930's.

And again, I might point out that in the Arctic we have had record low ice extents in the Arctic. In fact, if you look at the latest IPCC report that is up for review, it is documented that we also see reduced snow cover extending across the northern hemisphere.

So it is not just the temperature records that we use to deduce the fact that the globe is warming. There are many, many other ancillary pieces of information that are used as well.

So those are just a few of the things I would like to point out.

The CHAIRMAN. Dr. Janetos, can you comment on the *Science* Magazine article which claims that the two models used in the report, the Hadley Center and the Canadian, are not intended, or capable of predicting future impacts of climate change on a regional basis?

Dr. JANETOS. Mr. Chairman, in the assessment we tried to be very careful to say what we have not done is try to predict exactly what the future will be like. Each of these models, each of these general circulation models was selected after a careful review of the criteria that we set a priori in order to understand the potential consequences.

They had to have saved the right data, they had to have used an emissions scenario that was already well understood, and they had to be documented in the scientific review literature.

What we have tried to do is essentially ask the question, what if the models are correct? Since we cannot distinguish between them on scientific bases, we need to be able to understand the implications of the different plausible futures that they hold for the U.S.

The CHAIRMAN. Thank you. We will be submitting written questions that we hope you will be able to respond to. I apologize for the short-circuiting of this hearing. We will be asking the second panel to come back. We thank you for taking your time to come before the Committee.

You have added a lot to this very important discussion, and I want everyone to be very aware that we will continue to pursue this with further hearings. I think that it is an issue that is extremely important for us to seriously consider, and I thank you for being here. I thank you for your continued efforts, and I hope I have the opportunity to personally visit with all the members of the panel as we explore this very complex and difficult situation. I thank you.

Unfortunately, this hearing is adjourned.

[Whereupon, at 10:10 a.m., the Committee adjourned.]

APPENDIX

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO THOMAS R. KARL

Question 1. Can you explain the process used in the report to address the differences between the results of the two computer models and how this process is used to identify new research areas?

Answer. A lexicon was developed to communicate scientific uncertainty related to the scenarios from the two climate models used in the National Assessment as well as other models, data, information, and state of knowledge. This lexicon conveyed areas of uncertainty by linking words with probabilities. For example, if the National Assessment Synthesis Team (NAST) assessed the about even odds for an event the word 'possible' was used. On the other hand, if the NAST was fairly certain about an event, then words like "very likely" or "very probable" were used to indicate that there was more than 90% chance of occurrence. Where both models agreed, projections were seen as more certain. In cases where model results differed, both possible future scenarios were examined and results were characterized as less certain. Model results were not merged.

Whenever the NAST encountered instances where there was considerable uncertainty about the outcome these areas were then identified in a 'Research Needs' section of the report. In our Research Needs section we recommend a number of measures that are required to improve our confidence in modeling future climates.

Question 2. If the report explicitly does not "merge" the results of models that disagree, can this assessment be considered a fair analysis of climate change? Furthermore, when the two models diverged, where these results downplayed in the report versus when they concurred?

Answer. In response to the first question, it is difficult to understand why the assessment would not be considered fair if the two primary models were not merged. As indicated above, the NAST did not merge the scenarios from the models, but rather the NAST reflected the uncertainty related to several different possible outcomes and expressed this lack of confidence through use of the lexicon.

In response to the second question, the answer is no. Again, the NAST painstakingly used the lexicon to express its confidence in any projected changes for the 21st Century. Projected scenarios from all relevant models were discussed. This included both of the two primary models as well as the secondary models used in the Assessment.

Question 3. Dr. Schmitt has raised several issues concerning the impact of the oceans on the climate modeling results. How sensitive are the climate change impacts on the U.S. to changes within the ocean water temperatures?

Answer. Dr. Schmitt's remarks refers to improving climate forecasts from climate models that are dependent upon initial conditions. These deterministic climate model forecasts require information about the current state of the oceans. Clearly, it is very important to have comprehensive high-quality real-time ocean observations available to properly initialize these models.

The Global Climate Models used in the National Assessment do not require real-time initial conditions. They are self-contained models and generate their own ocean climate. Changes in ocean temperatures can have a large impact on the climate of the U.S. An obvious example relates to the changes of ocean temperatures in the tropical Pacific related to the El Niño southern oscillation and its effect on the temperature and precipitation in the U.S. Another example relates to hurricane formation. Water temperatures significantly less than 80 degrees Fahrenheit do not provide enough energy to the atmosphere to spawn powerful hurricanes. And as a result, hurricane formation is highly seasonal dependent.

Question 4. In the past few years, the U.S. experienced some distinctive weather patterns, namely El Niño and la niña. Can you discuss how these and other warm ocean water related weather patterns factors into your modeling efforts?

Answer. First, it is important to understand that El Niño and la niña are the opposite phases of an oscillation that is atmospheric and oceanic based. As such, la niña reflects cold ocean waters in the tropical Pacific while El Niño reflects the opposite conditions, warm waters. Present-day Global Circulation Models are only now beginning to show success in simulating important ocean-atmosphere oscillations such as the El Niño/Southern Oscillation. Neither of the models used in the National Assessment has a fully satisfactory representation of the El Niño/la niña oscillation, and it is likely that this has lead to some of the differences between model projections. The Global Climate Model that has been most successful in reproducing the El Niño/la niña events, primarily because of its higher resolution, is the Max Planck Model from Germany. Unfortunately, based on the NAST's selection criteria, we could not use this model as a primary model, but the NAST was able to point out that this model projects a major increase in the intensity of both El Niño and la niña events as the globe warms. This could be very important, and in our Research Needs section of the National Assessment the NAST points out the importance of more research related to climate model inter-comparisons, representation of important ocean processes, and analysis of possible influence of climate change on existing patterns of climate variability.

Question 5. Do you anticipate that any of the ongoing university regional studies will contradict the findings of the current draft report?

Answer. I do not anticipate that the any of the ongoing studies will contradict the current National Assessment Draft Report, but I would be surprised if they did not add additional insight into important issues and uncertainties. In assessing such a broad range of science, economics, and sociology, it was very clear to us that new understanding and insights were occurring continuously. Most often however, these insights made incremental additions to our understanding. A good example of this are the incremental advances in our understanding about global change as reflected in the series of Inter-governmental Panel on Climate Change Assessments completed during the 1990s. It is rare in science, that a discovery or theory completely displaces the old paradigm. We acknowledge that such things can occur however, such as the discovery of the "Ozone Hole" or Einstein's Theory of Relativity.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. ANTHONY C. JANETOS

Question 1. Some critics of this report charge that the Administration has ignored scientific and analytical procedures, and instead produced an advocacy-driven document. Given that most scientific studies are not open to the public, do you believe that "value" was added to the process by involving the public in this manner?

Answer. The public has been involved in two ways throughout the assessment process. First, during the workshop phase of the process, in which more than twenty workshops were held around the country, broad public participation was sought. The role of the workshop participants was primarily to identify environmental issues of concern to people in the different regions of the U.S. This input was then used to help decide which issues of importance within each region would be followed up in scientific studies.

The second way in which the public was involved was opening the Synthesis reports up to a public comment period, at the specific request of the Congress. We received many comments from people who otherwise might not have had the opportunity to read such a report at this stage in its development. Some of these comments have been quite insightful and helped us improve the document as a method of communication with a broad readership.

It is correct that most national scientific processes have not been so open to soliciting input from the public. I argue that our process has been enhanced by the public participation that we received, without resulting in an advocacy-driven document. We have focused on issues that people perceived to be important to them, and not just on issues of interest to the scientific community. At the same time, we were able to bring up-to-date scientific knowledge and methods to bear on the issues that had been identified. Objective scientific and analytical procedures and methods have been used throughout. Our objectivity has been ensured by extensive peer review.

Would you also discuss the level of participation from the private sector?

Answer. The private sector has been involved in several different ways. Our oversight panel is broadly representative of several different sectors, including academia, the for-profit private sector, and non-governmental organizations (NGO's). The National Assessment Synthesis Team and other contributors to the national reports include individuals from all these sectors as well, plus experts from government research laboratories. Many individuals in the private sector have reviewed all or part of the reports, and have offered their comments to us. Finally, many of the regional workshops included participants from the private sector, who were important contributors to the process of identifying issues for scientific analysis.

Question 2. Can you describe the peer review process that the assessment team incorporated into its findings?

Answer. The peer review process had several steps. First was a round of technical peer review on the initial drafts of the national reports, which began in November of 1999, and continued into January of this year. We received more than 300 comments from individuals who identified themselves as technical experts in the many different aspects of the report. This technical peer review included experts in the government agencies, as well as academia, the private sector, and NGO's. The second step was submitting the entire report to a list of about 20 experts identified by our oversight panel, who were charged with evaluating the entire structure of the report, its responsiveness to its original intent, and the strength of the findings and conclusions. Throughout, we have had the benefit of comments from our oversight panel.

The National Assessment Synthesis Team has considered every written comment that it has received. We have responded to comments in writing, documenting either how the comment has been taken into account, or why we have decided not to do so. These responses to comments have also been shared with our oversight panel.

Question 3. How did your "bottom up" approach to the assessment report impact the findings or scope of your work?

Answer. I believe that the approach of identifying issues through involvement of the public in the series of workshops did affect the scope of the work. Specifically, it enabled us to focus on the issues viewed as most important by the participants of the workshops. However, the analysis of those issues was done by experts, so that the actual findings themselves are the result of objective analysis.

Question 4. Did the oversight panel for the National Assessment Synthesis Team offer any cautious or contradictory statements throughout the reporting process?

Answer. The oversight panel has been cautious throughout, and has been especially helpful to us in ensuring that we have described accurately the scientific basis for our findings, and been open about the degree of uncertainty that remains. They have not provided contradictory statements.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. RAYMOND W. SCHMITT

Question 1. Your written statement mentions that the ocean is the long term memory of the climate system. Would you discuss what methods are available to retrieve that long-term memory?

Answer. Most of the heat energy reaching Earth is absorbed into the upper ocean at low to middle latitudes. A significant fraction of this is used to heat and moisten the atmosphere on a daily basis, causing the winds and rain we experience as weather. But over the course of the seasons, large amounts of heat are stored within the ocean during spring and summer for release in the winter. This is the basic moderating influence of the oceans on climate; the vast heat capacity of the oceans prevents the winter from becoming too cold, and the summer from becoming too hot, especially in areas near the coast. But we have also found that ocean currents are capable of moving tremendous quantities of heat around the planet. This has an essential role in the climate system, fully half of the transport of heat from equator to pole is accomplished by the slow-moving, high heat-capacity ocean, with the other half of the heat transport carried by the fast-moving, low heat-capacity atmosphere. The atmosphere cycles its water vapor and heat within two weeks, so it has only a short-term memory of past conditions. However, the ocean's heat-content is so large its memory time is decades to centuries, when the deep ocean is considered.

The way to retrieve and interpret the long term climate memory of the oceans is to measure the temperature at depth. Satellites provide an estimate of the temperature of the ocean in a thin surface layer but tell us nothing about the deep-reaching temperature signals necessary to help predict the climate a season or even a decade ahead. New technology of profiling floats (the ARGO program), new profiling moorings that measure temperature and salinity and maintenance of traditional ship-based observations will all help to acquire data on the deep temperature and salinity of the ocean. We will never decipher the mysteries of the climate system without measuring the dominant portion of its heat content that resides in the ocean.

Question 2. Would you briefly discuss the importance of ocean salinity (or salt content) to climate studies?

Answer. Salinity variations have nearly as much influence on seawater density as temperature changes. This means that in the high latitude ocean salinity plays a very important role in determining whether the surface waters will be dense enough to sink and become deep water. Salinity can be decreased there by rain fall, river runoff and ice melt. If deep water ceases to form then the "thermohaline" circulation is disrupted and the warming influence of the North Atlantic on American and European weather is much reduced. Increased rainfall in high latitudes and subsequent collapse of the thermohaline circulation is a prediction of global warming models, with dramatic consequences for climate. However, the ocean models and measurements are presently inadequate to say whether thermohaline collapse is probable or even possible with global warming. In the tropics, high rainfall rates can cause low salinity water to collect at the ocean surface and modify the ocean's transfer of solar heat to the atmosphere. Salinity variations in the ocean reflect the workings of the greater part of the global water cycle; a mere 1% of the rainfall on the Atlantic ocean would double the discharge of the Mississippi River. Yet salinity is a very poorly monitored variable; for many areas of the ocean, there has never been a salinity measurement. Thus, it is very important that we begin to make much greater use of new technology such as ARGO floats, moored and drifting buoys and ships to better define the patterns of salinity variation in the ocean. Only then will we achieve an adequate understanding of the global water cycle and its variations which are so important to society.

Question 3. You mentioned that because of computer limitations, many models must treat the ocean as a very viscous fluid, more like lava or concrete than water. What are the implications of this assumption?

Answer. The models that are run for climate predictions cannot resolve or represent the smaller scales of variability in the ocean. This means that the many eddies and fronts we find in the real ocean (100 km in size and smaller) are not in the models. This introduces a number of defects in the models even for the large scales which are well resolved. For instance, some currents are driven by eddies, and without eddies such currents are not found in the models. Also, the ocean's interior mixing processes are known to be caused by internal waves, yet there are no internal waves in the models. Mixing controls the patterns of the deep currents, which are notoriously wrong in the models. The problem gets worse for climate projections of decades or centuries, with many ocean phenomena missing or seriously misrepresented. Without an accurate portrayal of ocean dynamics, prediction of future climate states is fundamentally impossible.

Question 4. Your written testimony states that it is unlikely that we will have the necessary computer power over the next 160 years, even with an increased order of magnitude every 6 years, to simulate the smallest ocean mixing processes. What are our alternatives to gain a better understanding of these processes?

Answer. Study the real ocean. We can develop a better understanding only through dedicated "process" studies focussed on these different phenomena. This allows the development of "parameterizations" of the small scale processes that can be used in the numerical models. The United States had a significant research effort on small-scale ocean processes during the cold war through support of the Office of Naval Research, but funds from that source are now much diminished. There is a great need for a revitalization of such work in order to bring the ocean climate models toward some semblance of reality.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. S. FRED SINGER

Question 1. The report states that by using the two selected computer models, a plausible range of future actions are captured, with one model being near the lower end and the other near the upper end of projected temperature changes over the U.S. Do you agree with this statement?

Answer. The National Assessment Report chose two climate models (out of perhaps two dozen) to provide scenarios for the 21st century. The selection criteria are not readily apparent. One model came from the Canadian Climate Center; it predicts extreme temperature rises over the U.S. (of 11°F by 2100). The other model chosen was produced by the Hadley Center in Britain; it predicts less extreme temperatures.

The main point, however, is that BOTH models are already too high and therefore proven wrong by the temperatures observed in recent years. As shown in my testimony, there has been no appreciable warming over the U.S. since about 1935, according to the analysis by Dr. James Hansen of NASA–GISS. Notwithstanding the oral response by Tom Karl, virtually the same is true for the analysis published by NOAA–NCDC.

To verify this, it is only necessary to view the disparity between the observed temperatures (see my written testimony) and the calculated temperatures (see written testimony of Karl/Melillo/Janetos).

Question 2. What are your thoughts as to why regional forecasts from the climate models disagree so strongly in some areas and not as much in others?

Answer. At the present state-of-the-art of climate models, regional forecasts are even worse than those for global averages. No reliance whatever should be placed on them. The strong disagreements between the model predictions themselves provide adequate confirmation for my statement.

Question 3. Your written statement mentions that a careful analysis shows that the warming of the early 1990's actually slows ongoing sea level rise. Can you explain this finding?

Answer. Sea levels have been rising for about 15,000 years, since the peak of the last ice age. The total rise has been about 400 feet. Sea levels are continuing to rise at a rate of about 7 inches per century, and will continue at about that rate for several millennia more as slow melting continues in the Antarctic.

As global temperatures fluctuate (no matter whether from natural causes or possible human causes), the ongoing sea level rise may be expected to show slight modulations; it may slow down for some decades or it may accelerate. It all depends on whether a warming of the oceans produces a greater or lesser effect than an accumulation of ice in the Antarctic from increased ocean evaporation and subsequent precipitation. (These two effects on sea level oppose and nearly cancel each other.)

When we investigated what happened during the major warming between 1920 and 1940, we found empirically that the rise in sea level slowed down. We therefore expect that any future warming, unless extreme and sustained over many centuries, will likewise reduce the rate of sea level rise rather than accelerate it. The existing fears about rising seas from greenhouse warming have no scientific foundation whatsoever. They are based on hype rather than observed facts.

Question 4. Do you accept the claim that the 20th century was the warmest of the past 1000 years?

Answer. The claim that the present century is the warmest of the past 1000 years relies on the "hockey-stick" temperature graph (Mann, Bradley, and Hughes, Geophysical Research Letters 1999). It is derived from various proxy data rather than thermometer records; yet it has been widely cited. It forms the cornerstone of the claimed "discernible human influence" in the Summary for Policymakers of the IPCC-Third Assessment Report.

The graph is actually a composite of two records: (i) temperatures from "proxy" data (tree rings, etc.) going back to 1000AD; and (ii) a superimposed global instrumental (thermometer) record of the past century.

Close examination reveals that the proxy record stops in 1980 and therefore does not independently support the post-1980 temperature increase suggested by the thermometer data. Thus there is no evidence for a substantial warming since 1980 (or even since 1940). There is no evidence for the claim that the present century is the warmest of the past 1000 years. And there is no evidence to back the claim of a "discernible human influence" on global climate.

Prepared Statement of Hon. Larry E. Craig, U.S. Senator from Idaho

Mr. Chairman, thank you for inviting me to testify at this very important hearing. On June 16, 2000, I spoke on the Senate Floor about the Administration's recently released draft National Assessment Synthesis Report. I ask that a copy of that Statement be included in the record of this hearing.*

Mr. Chairman, the potential of global climate change is one of the most important environmental issues of this new century. The stakes are high. Worst-case scenarios involving rising temperatures and sea levels scare many people. On the other hand, premature government action to cut back energy use to levels lower than those in the growth-oriented nineties could cool the economy faster than it cools the climate.

What is required at this time, Mr. Chairman, is steady and thoughtful leadership. Responsible government includes environmental stewardship. However, the ultimate

* The information referred to was not available at the time this hearing went to press.

obligation of government is to protect freedom. By freedom I mean the opportunity to achieve one's true potential as an individual, a community, or a nation: the freedom to grow!

Freedom spawns discovery and innovation. Discovery and innovation solve problems and create opportunities. This is the true spirit of America.

Mr. Chairman, today you will have the co-chairs of the National Assessment before you. These are accomplished men with impressive scientific backgrounds. The Committee will have the opportunity to question them on a document that I believe is long on fear and short on conclusive science.

Let me lay-out some of the reasons why I am so concerned about this document.

The National Assessment process was authorized under the Global Change Research Act of 1990 but did not officially begin until January, 1998—one month after the Kyoto Protocol. The *final* report was expected in January, 2000, but was delayed.

Last year, in the Fiscal Year 2000 appropriations, Congress directed that *all* research used in the National Assessment must be subjected to peer review and made available to the public prior to use in the Assessment, and the Assessment must be made available to the public through the *Federal Register* for a 60 day public comment period. This was not challenged by the Administration.

The Administration released a "draft" summary report on June 12th of this year by posting it on a website and publishing a notice in the *Federal Register* that it was available for comment until August 11th. This action is clearly at odds with Congressional intent. The underlying regional (geographic) and sector (health, agriculture, forests, water, coastal) work that was to have served as the basis for the summary report has not been completed or made available for review.

In a June 30th letter to Congressman James Sensenbrenner, Chairman of the House Committee on Science, Neal Lane, who testified before this Committee on May 17th Mr. Chairman, stretched credibility in defending this action. Although taxpayer funds were provided to support the work, he claimed the underlying reports were not "federal" reports and therefore not covered by the earlier Congressional guidance. The underlying reports are to be completed over the next year or so and published by the respective teams working on them.

Mr. Chairman, a question that begs an answer is: Why the rush to release the National Assessment? The premature release of this document allows for more polarizing advocacy. Although supposedly a "draft" report published for technical review and comment, it was trumpeted by President Clinton on the day of its release and served as a basis for repeating tired claims:

"It suggests that changes in climate could mean more extreme weather, more floods, more droughts, disrupted water supplies, loss of species, dangerously rising sea levels."

It's easy to miss (or ignore) the qualifications to these predictions and simply report that the Assessment forecasts dire changes in climate in the future. For example, a page one story in *The New York Times* on June 12th carried the headline: "Report Forecasts Warming's Effects—Significant Climate Changes Predicted for the Country."

In Texas, a July 4th story by the environmental reporter at the *Dallas Morning News* reported on action by five environmental groups asking Governor Bush—"to launch a Texas assault on global warming, which scientists say could heat up North Texas in the next century." The story went on to discuss the draft National Assessment including the comment—"Two computer simulations of the future of Texas climate show sharp rises in the July heat index, with the worst impact in North Texas."

Not everyone has been misled. *The Wall Street Journal* published an article entitled: "U.S. Study on Global Warming May Overplay Dire Side" on May 26th, in anticipation of the impending release. A similar story ran in *The Detroit News* on May 28th. Numerous Op-eds and Letters to the Editor have also run.

However, Mr. Chairman, the early release of this document raises more intriguing political questions than helpful probative scientific ones. For example, it puts the Assessment on a timetable for inclusion in the UN's Intergovernmental Panel on Climate Change's "Third Assessment Report" on climate change which is due to be finalized next year. In fact, Mr. Chairman, I have been informed by staff that drafts are already circulating for comment and these drafts include references to the U.S. National Assessment.

It is becoming clear that the June 12th release of the Assessment is serving as support for campaign claims by Al Gore to support his views on climate and energy use. Indeed, his release on environment and energy policy occurred just two weeks later on June 26th.

Mr. Chairman, the Administration could have avoided seeding these concerns if it had followed the common sense approach requested by Congress and taken the time to get it right:

First, complete the underlying regional and sector work, peer review the science used as its basis, and make the results available for public comment;

Second, write the synthesis overview report based on this work, not independently, peer review the results and make a complete draft easily available for all interested citizens to review with enough time to gather complete comments and expose them to the public.

In addition, Mr. Chairman, the independent National Research Council should have a strong role in the drafting process, not just White House allies as implied in some critiques.

Lastly, but importantly, one must question the use of foreign computer models in this study. Was this in our best interest? The National Assessment used a Canadian and a British Large Scale General Circulation Model (GCM's) to make climate change predictions at a *regional* level. According to a June 23rd *Science Magazine* article entitled "Dueling Models: Future U.S. Climate Uncertain," there is a clear consensus of opinion in the scientific community that these models are not intended, or capable of, predicting future impacts of climate change on a regional basis. Even the EPA web site makes this point.

The mere use of the foreign computer models in the National Assessment once again, begs an answer to an obvious question: What needs to be done to improve U.S. modeling capability? Other questions that need answers are: How well has the current Administration been spending our money in the climate arena? Do we have our scientific priorities in order?

These, along with many other questions, I hope will be asked of those testifying before you and the Committee this morning. We must pursue a more consensus building approach to the climate change issue. Senator Frank Murkowski and I have introduced legislation that we believe provides a framework for national consensus—making continued stalemate on this issue unnecessary and intolerable. We have the vehicle to move forward. We should do so expeditiously, and with the constructive support of the Administration.

Thank you, Mr. Chairman.

PREPARED STATEMENT OF HON. FRANK H. MURKOWSKI, U.S. SENATOR FROM ALASKA

I want to thank Chairman McCain and the members of the Committee for holding this hearing today to review the recent National Assessment Report on climate change and its impacts on the United States.

The report estimates effects of climate change on various regions of the country, and various sectors of our economy, such as agriculture and water resources. At the heart of this report are "potential scenarios" of climate change over the next 100 years predicted by two climate models—one from Canada, and the other from the United Kingdom. These two climate models were "state of the art" three years ago when work began on this report, but it's important to note that significant advances in our ability to model climate on regional scales have been made since then.

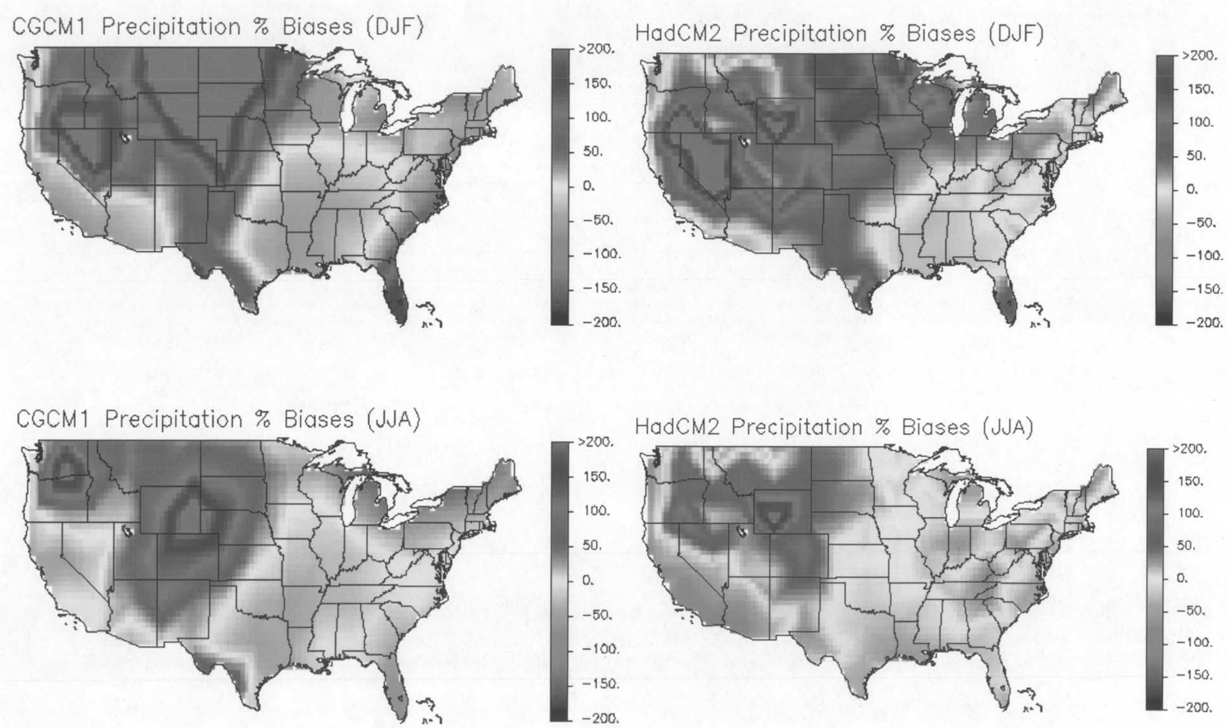
These "scenarios" of climate change were then used to drive other models for vegetation, river flow, and agriculture—each of these models have their own set of assumptions and limitations reflecting incomplete understanding of the Earth system and its component parts.

The end result of the three-year study is a 600 page report that paints a rather grim picture of 21st Century climate. Now the environmentalists and others in favor of the Kyoto Protocol are shouting from the rooftops—saying that these "potential scenarios" mean that we should go forward with drastic and costly measures to limit greenhouse gases.

As the Committee considers the National Assessment Report today, I encourage you to look beyond the rhetoric to the science that underlies this assessment—we are only just now beginning to conduct the kind of scientific research that will allow us to determine impacts of climate change on the regional and local scales that are most relevant to our constituents.

For example, a reasonable test of a climate model is whether or not it accurately simulates today's climate—the National Assessment's own science web site displays a chart that compares rain and snowfall predicted by the two climate models to actual measured precipitation (see attached Figure). The areas in blue and purple reflect areas where the model predicts more than TWICE as much rainfall as observed—if you live in an area with 10 inches of rain, the model would predict that you get 20 or more. Similarly, the areas in red reflect areas where the model predicts less than HALF as much rainfall as observed—if you actually get 10 inches of rain, the model would predict that you get 5 or less.

Comparison of Climate Model Rainfall Predictions vs. Observed



Source: http://www.cgd.ucar.edu/naco/gcm/biasdet.html

Now, we know that the amount of rain and snow falling within a river basin determines river flow—which determines:

- the amount of water for irrigation of crops
- the health of fish species
- the generation of hydroelectric power
- and the water available for human use

So depending on what the climate models say, you can imagine very different impacts—and if the models are off by 50 or 100% in either direction, so too could be the estimates of impacts from climate change on these sensitive areas of the environment and our economy. This is just one example of the need for continued scientific research to understand the entire Earth system and how it responds to changes in atmospheric trace gas concentrations.

Nonetheless, the National Assessment has been a very useful exercise: it shows the difficulty of estimating regional impacts of climate change; it highlights the need for additional scientific research (namely improved climate models and observing systems); and it reminds us of the potential risk of climate change—a risk that we should responsibly address through the construction of a national energy strategy that includes consideration of climate change and its potential risks.

The Committee on Energy and Natural Resources, which I chair, has held a number of hearings on climate change and its economic consequences for the United States—and the findings are not encouraging. If we heed the environmentalists' call and ratify the Kyoto Protocol, American consumers would see gasoline prices above $2.50 per gallon and watch their electricity bills increase by over 85%, according to the Energy Information Administration. These projections have withstood scrutiny and have been confirmed by numerous other studies of Kyoto and its economic impacts.

Furthermore, the Kyoto Protocol will not lead to stabilization of greenhouse gas concentrations in the atmosphere—the principal goal of the Framework Convention on Climate Change signed by the U.S. in 1992. Without developing country participation in the Protocol, greenhouse gas emissions would continue to rise as a result of industrialization and increased energy needs of China and India—nearly one-third of the world's population. No matter what kinds of cuts in emissions we make, Kyoto will not result in any meaningful difference in the climate.

As the Senate stated when it passed S. Res. 98, the "Byrd-Hagel Resolution" regarding climate change, a climate treaty must include meaningful developing country participation and must not come at economic cost to the United States. Neither of these conditions have been met in the current Kyoto Protocol, and it is clear to me that we need an alternative approach to addressing the risk of climate change—one that recognizes the global, long-term nature of the problem.

To this end, I have sponsored, with Chairman McCain and 19 other Senators, the Energy and Climate Policy Act (S. 882) which provides a technology-based alternative to the Kyoto Protocol. Our bill:

- Creates a new $2 billion effort over the next ten years to cost share technology development with the private sector;
- Creates an Office of Climate Change within the Department of Energy to coordinate research and development activities across a wide range of energy technologies; and
- Promotes voluntary reductions by improving the government's system of tracking voluntary emissions reductions.

Senator Craig has also introduced a bill (S. 1776) that I have cosponsored which complements S. 882—it addresses some issues such as strengthening coordination between elements of the U.S. Global Change Research Program. We anticipate including elements of Senator Craig's bill in an amended version of S. 882 when we consider it later in the year. I welcome interest from members of the Committee if they wish to review our legislation and offer comments or amendments.

In summary, I believe that we should take prudent steps to address the possible risks of climate change, but we should recognize the global, long-term nature of the problem and respond accordingly. A balanced portfolio of energy options, including expanded use of natural gas and continued reliance on emissions-free nuclear and hydro power, would produce fewer greenhouse gases than the Administration's current energy plan. We should expand existing emissions-free technology, including nuclear, hydropower, solar, wind and biomass, but we should also promote new technology to trap and store greenhouse gas emissions from the atmosphere and encourage voluntary actions to reduce greenhouse gases and use energy more efficiently. We should also invest in a new generation of energy technologies that can be deployed in developing countries, preventing greenhouse gas emissions before they occur.

The risk of human-induced climate change is a risk we should responsibly address, and a balanced, technology-driven energy strategy offers us the means to do so. As we consider our future national energy strategy (which drives our greenhouse gas emissions), we now have an excellent opportunity to address our environmental concerns at the same time that we address our growing dependence on foreign oil.

I thank Chairman McCain and the members of this Committee for their interest in these issues, and look forward to working with you on establishing a balanced energy portfolio that makes good sense for our economy, our environment, and our national security.

PREPARED STATEMENT OF THE ANNAPOLIS CENTER

Global Climate Modeling: Helping to Understand Strengths and Weaknesses

Introduction

The public's and decision-makers' understanding of the strengths and weaknesses of computer modeling of global climate is essential to the formulation of long-term policies related to global climate change. In the hope of facilitating better understanding of the status of climate modeling, the Annapolis Center gathered a diverse group of experts for discussion of the status of climate modeling and to prepare this report.

The majority of the group's views on this general subject were as follows:

- There are a number of "greenhouse" gases in the earth's atmosphere, including water, in the form of vapor, CO_2, and methane. (Water vapor is a much stronger contributor to the natural [non-anthropogenic] greenhouse effect than CO_2.)
- Atmospheric carbon dioxide (CO_2) has been increasing for more than 100 years, almost certainly in large part because of human activity.
- There are growing indications that global near-surface temperatures have increased over the past century by about 1°F (0.6°C). Temperatures in the lower five miles of the atmosphere, the lower-to-mid troposphere, have increased only slightly, if at all, in the past several decades of instrumental monitoring.
- Natural increases in atmospheric CO_2 in the Earth's past have been well documented, however, the cause-and-effect relationships with past climate change are not clear.
- The rate of increase of CO_2 in the atmosphere in the past century is greater than any previously recorded historic rate.
- How much of the observed warming is caused by human activities and by natural climate variations is uncertain.

Climate Modeling and Simulation

How can we understand the earth's climate system and the possible consequences of increased concentrations of greenhouse-gases in the atmosphere? We can do some things in the laboratory, but because the earth's climate system is so large and incredibly complex, we can recreate only small pieces of it in the lab for extensive study. So scientists develop computer models based on the governing physical principles as expressed by mathematical equations that describe many of the processes that may affect climate. Such models act as simulation laboratories in which experiments can be performed that test various assumptions and combinations of events. These experiments not only can expand our knowledge, they can also develop insights into possible climate futures.

Although there are a variety of increasingly complex climate models, only the "general circulation model" (GCM, sometimes also referred to as a global climate model) determines the horizontal (geographical) and vertical (atmospheric and oceanic) distributions of a group of climatic quantities, including (1) temperature, wind, water vapor, clouds and precipitation in the atmosphere; (2) soil moisture, soil temperature and evaporation on the land; and (3) temperature, currents, salinity and sea ice in the ocean. The related equations are so complex, however, that they can only be solved for specific geographical and vertical locations, and only over specific time intervals. For example, a typical GCM subdivides the atmosphere into thousands of three-dimensional volumes, each having linear dimensions of about 250 miles in the north-south and east-west directions, and a mile in the vertical direction. The task of making these boxes smaller is severely limited by the speed of even present-day supercomputers. For example, decreasing the horizontal size of a GCM from 250 to 25 miles would increase the required computer running time by a thousand fold—from about 2 weeks to more than 30 years of run-time to compute the resulting change in the equilibrium climate of the model!

The Uses of Climate Models

Until the advent of supercomputers, our attempts at climate modeling were rudimentary. That situation changed roughly 25 years ago. Much of the recent attention by the public and decision-makers on climate change has been due to measurements indicating that warming has been occurring near the Earth's surface over the last century and to relatively recent projections from GCMs.

Climate varies naturally over both short and long time scales, sometimes rather dramatically over a few years or decades. This rapid variability was experienced in Europe during the Little Ice Age of 1400–1850. To understand climate change, scientists must understand the detailed nature of the extremely complex climate system. While we have learned a great deal, there is still much we do not know. Climate models today can give us insights into what might happen under various assumed situations.

Currently, there are about 30 GCMs being developed and/or used by research groups around the world. Many of these models are related, with the differences among the models lying in the natural processes they include and how they integrate and treat these processes within a specific model.

As discussed above, computer models are necessary in the study of climate change because of the extraordinary complexity and number of the physical processes that are embodied in the climate system. Some of the factors that affect climate include:

- the concentrations of gases and aerosols;
- interactions between the atmosphere, the biosphere, and oceans;
- volcanic activity; and
- interactions of components within the atmosphere and ocean themselves.

The growth of computing capacity has allowed scientists to integrate complex climate-system processes into single computational frameworks. These frameworks can be used to develop an increasingly more comprehensive, but still incomplete, overall picture of the global climate system.

The Roles of GCMs

The general uses of GCMs are:

First, the building and running of a model is a process by which theory and observations are mathematically evaluated, codified and integrated in a computer program. Models can thereby be used to identify needed refinements in theory and observation. Model building is a long process of back and forth comparisons between analytical description ("theory") and field studies ("observational data"). These comparisons include end-to-end efforts to correlate observational findings with improvements in model representations.

Second, climate models are used to identify and then assimilate observational measurements that are initially incomplete. These measurements can then be used to derive more consistent, spatially specific estimates of meteorological quantities. Such model-assimilated data have proven to be of great utility to the research community in better understanding the observed and potential variability of the climate system.

Third, models can be used to focus observational activities. In regions where data are sparse, models can be used to define the frequency, coverage, and type of measurements that may shed the most light on the physics, chemistry and the composition of the atmosphere.

Fourth, climate models have recently predicted a few climate anomalies up to a year in advance. These model predictions, which are increasing in accuracy, incorporate information on the current state of the oceans and atmosphere. Predictions of El Niño and La Niña events and climate anomaly patterns associated with these phenomena have proven reasonably accurate and there is potential for this type of model prediction to be extended out beyond a year.

Fifth, climate models can be used to develop scenarios of possible future states of the climate system, given a specified set of assumptions (e.g., the future quantities of greenhouse gases, including ozone trends and aerosols). Such climate scenarios can then be used to develop projections of possible climate-related impacts on human and natural systems. Models currently show large-scale climatic response to increased greenhouse gas levels: for instance, (1) there may be some warming at the surface, warming of the troposphere, and some cooling in the stratosphere; (2) there may be greater warming at high latitudes than at low latitudes; and (3) there may be an increase in low level humidity over the oceans. Such fingerprints of human-induced climate change have been compared with the observed climate to help detect its changes and attribute its causes.

From the GCM-based projections of climate change, analysts can begin to evaluate the potential impacts on market and non-market sectors of society. As these impact models become more sophisticated, increasingly better pictures of what might happen under different scenarios will develop. More research on impacts will help countries identify the seriousness of possible climate change and allow them to study the cost-benefits of various response options.

In addition, models can be used to facilitate an understanding of the lag time between causes and effects associated with human as well as natural causes of climate change. It is essential to keep in mind that model projections depend on the sophistication of the model: the estimates in the model, the assumptions used by the model, and what in nature is not yet understood and therefore not covered in the model. This is why the climate research community generally places so much emphasis on verifying model results with actual data. By exploring sets of these model projections, the policy community can begin to discuss the effects that policies, aimed at reducing greenhouse gases, might have on climate, humans, and economies.

Models & Decision-Making

Existing GCMs can make "what if" projections of future global climate possibilities because they are the best available tools, even though they are currently limited in resolution and completeness. Regionally specific information is ultimately needed because, for example, while U.S. citizens have interest in what happens to the planet as a whole, they are especially interested in what happens to the U.S. and to their own neighborhood. Global climate projections from different models show a range of effects. The range of effects is largest for smaller regions. Partly, this is due to the natural local variability of climate and partly this is due to scientific uncertainties.

Just as global climate models have advanced, so have global economic impact models for estimating costs and benefits. Integrated assessment models, which take into account chains of events (if "A" happens, then results "B" could occur, but if "A" does not happen, then "C" will occur), are a tool to help understand long-term costs and benefits.

Limitations of Models

Having discussed the uses and strengths of GCMs, one should not assume that they do not have weaknesses—in fact, some scientists would state that the weaknesses are so great as to question their value in near-term decision-making. Some of the features of the GCMs are less robust than others, partly because there is disagreement between the models about predicted climate changes. Furthermore, even if the models agreed, it does not necessarily make them correct.

Phenomenological Feedbacks

Much of the uncertainty in current climate models is associated with "feedbacks"—how various phenomena interact with one another. Feedback mechanisms are clearly important. Climatologists agree that, without these feedbacks, a doubling of CO_2 would give about a 1.8°F (1°C) rise in global-average temperature. Many phenomena have large impacts on others, some amplifying and some dampening effects. Some extremely important phenomena, the feedback consequences of which we do not fully understand, are the following:

- Clouds;
- Ice;
- Land surface processes;
- Ocean effects;
- Biological processes;
- Physical and chemical reactions in the atmosphere;
- Particulates;
- Solar cycle effects; and,

- Tropical convection and rainfall.

These phenomena are not yet adequately understood in isolation, let alone in combination with other factors. Thus, scientists must utilize approximations, estimates of aggregate regional effects, or ignore some phenomena all together for the time being. Other suspected feedback mechanisms are yet to be described or modeled.

For example, the role of clouds and water vapor in climate models is not well understood; yet water vapor is the most significant greenhouse gas in the natural (unperturbed) atmosphere and dramatically affects cloud cover and the transfer of radiant energy to and from the Earth's surface.

Also, modeling the impact of clouds is difficult because of their complexity and compensatory effects on both weather and climate. Clouds can reflect incoming sunlight and therefore contribute to cooling, but they also absorb infrared radiation that would otherwise leave the earth, thereby contributing to warming.

Parameters

Models utilize observational data to adjust various model parameters to help make such parameters more realistic. "Tuned" models, however, cannot be validated by the data for which they were adjusted and must be validated by independent means.

As previously mentioned, the equations related to the climate to be modeled are so complex that they can only be solved at specific geographical and vertical locations, and only over specific time intervals. The limit on horizontal size imposed by present-day supercomputers also limits the physical processes that can be explicitly included in a GCM. As discussed above, GCMs using today's supercomputers explicitly include physical processes having horizontal sizes of approximately 250 miles and larger. Worse yet, the physical processes smaller than 250 miles cannot be ignored because their effects can significantly impact climate and climate change. Thus, climate modelers face the dilemma that their models cannot resolve the small-scale physical processes and they cannot ignore their effects. This is one, if not the major difficulty in modeling the Earth's climate. The approach taken to overcome this problem is to determine the effects of the small-scale physical processes on the larger scales that can be included in a GCM using information on those larger scales and statistical relationships. This approach is called "parameterization." The principal differences among GCMs lie in their approaches to parameterization, particularly in the case of cloud and precipitation processes. These parameterization differences have a significant influence on differences in climate sensitivity—the change in the equilibrium global-mean surface temperature resulting from a doubling of the CO_2 concentration—between various GCMs.

Testing Models

One way that models are tested is to use them to reproduce past events and variations. The earth's climate has been changing for millions of years but we do not have detailed data on those changes because humankind was not acquiring relevant data until relatively recently. As such, we cannot accurately truth test climate models over past periods of time beyond much more than a hundred years. Thus, we are asking these models to assist us in decision-making in an environment of considerable scientific uncertainty. There is, however, significant effort underway to compare the general nature of model simulations of pre-historic time periods against data from proxies (e.g., tree-ring widths, borehole temperatures, and oxygen isotopes in sediments) of past climates.

Human Resources

Compared to intermediate and smaller modeling efforts, such as those aimed at understanding the behavior of a particular climate process over a single locality, insufficient U.S. and international resources for research and computer hardware are being devoted to high-resolution global climate modeling.

Data

Instrumental temperature measurements of varying quality exist for about 135 years. Relatively crude but useful information before then has been obtained from proxy data such as the width of tree rings and the abundance of certain isotopes trapped in ice cores taken from the ice caps and glaciers and in sediment cores taken from the deep sea and lakes.

Climate data are routinely collected for weather prediction. Much of this data gathering was not designed to detect subtle trends that occur on decadal or longer time scales. For climate modeling, we need more accurate and extensive data than even currently used in weather prediction. There is also a need for better organization and long-term archiving of climate data.

Advancement of Models

Model development has progressed considerably in the past decade. However, though there have been downward modifications in estimates of future climate change (e.g., through the inclusion in models of the effects of aerosol cooling), the limits of uncertainty in possible global-average warming for a future doubling of CO_2 have not been narrowed; that uncertainty has been in the 2.7–8.1°F (1.5–4.5°C) range for the past 20 years for most GCMs.

While the capacities and speed of supercomputers have progressed dramatically in recent years, climate models remain constrained by current computational capacity. In fact, the leading climate models are no longer in the United States because U.S. researchers do not have access to the more powerful Japanese computers that other nations (*i.e.,* Canada, Japan, United Kingdom) are using. Current computer capabilities applied to climate modeling are modest compared to what is needed to run high-resolution simulations using GCMs. Current computer limitations require that we settle for grid sizes that are much larger than needed to model some important phenomena such as tropical convection and precipitation.

The participants in the discussion agreed with the National Research Council's Report "Capacity of U.S. Climate Modeling (1998)" statement of the Council's "summary results", if not all the details of its Report.

Conclusions

There are significant uncertainties in predicting future climates as a consequence of (a) natural climate variability; (b) the potential for uncertain or unrecognized climatic forcing factors (e.g., explosive volcanism, new or unknown anthropogenic influences, etc.); and (c) inadequate understanding of the climate system. We must expect that new observations or results from studies of global climate processes may yield information that causes us to re-evaluate and improve the capability of climate models. Our estimates of the credibility of climate system models can be, of necessity, consistent only with known facts and only based on the "best" current knowledge.

Projections vs. Predictions

Thus, it was the consensus of the experts convened by the Annapolis Center that climate models may never be able to make greenhouse-warming PREDICTIONS with certainty because of the enormous number of variables involved and the uncertainty inherent in the future. On the other hand, models of greenhouse warming are essential in the learning process. Climate models can be used for making PROJECTIONS based on various assumptions that in turn may be useful in understanding the consequences of various human activities and policy alternatives. When such projections will represent possible real climate futures is difficult to judge because of the enormous scientific uncertainties involved.

CLIMATE PROJECTIONS are "what-if" scenarios about what might happen under a set of ASSUMED conditions. Projections may change as more knowledge is acquired.

When weather forecasters make predictions one day or a week in advance, they can verify their predictions soon thereafter. Climate projections for the next century cannot be verified so easily.

Continued climate warming year after year is not likely to occur. Periods of apparent cooling, however, would not necessarily mean that the Earth was not slowly warming over the long term. Similarly, if we were to experience warming year after year, we should not assume that man-made climate change was the primary or only cause.

Though Better Understood, We Still Have A Long Way To Go

Global climate science has progressed significantly in recent years but our lack of knowledge is still great. A major vehicle for understanding the enormously complex global climate system has been computer modeling. Today's GCMs have developed rapidly relative to earlier models and provide improved estimates of what may happen in the future. Many believe that such models are still in a relatively early stage of development. Nevertheless, GCMs are important research tools that can help to focus the research and measurements needed to better understand climate change. Climate modeling will be increasingly more valuable as models and our understanding of basic processes are improved.

Models of climate changes are still evolving because we do not yet completely understand or model everything that can or will affect climate. Scientific uncertainty will always be a component of modeling climate change. Our challenge is to reduce this uncertainty.

Because of the Uncertainty, Care Must Be Used in Decision-Making

Care must be taken when using the results of climate models for major public policy decisions because of the existing uncertainty, as well as our lack of knowledge about important physical and chemical reactions in the atmosphere and oceans.

Adapt Via "Act-Learn-Act"

Because man-made greenhouse gas emissions are likely to continue to increase in the future, the workshop participants endorse adaptive and affordable management strategies, such as "act-learn-act," that are robust against what we do no yet know. We will surely be learning more about climate change over time. As we learn more, we must revisit greenhouse-related policies and adjust them accordingly.

PREPARED STATEMENT OF DR. PETER B. RHINES, PROFESSOR, UNIVERSITY OF WASHINGTON

Climate change takes on real force when it combines with human activity. It produces multiple and compounded changes of the physical environment, and of ecosystems. The U.S. feels these impacts from beyond national boundaries, from the global atmosphere and ocean.

There are many points of contention: between modification of our environment and accommodation to it; between natural and human-induced climate change; within the scientific debate, between the need for prediction and the need for diagnosis. Improved observation and understanding of the current and past states of the environment (the atmosphere, ocean and land surface) may be just as important as attempts to predict its future.

As Dr. Schmitt has earlier this morning described, the ocean plays a particularly interesting role in climate: it dominates the storage of heat and carbon and water; it also contains a significant fraction of global biological activity: photosynthesis and respiration. It is a well-spring of diversity, harbors newly discovered forms of life, and in the search for natural pharmaceuticals it is richer than the land.

Large-scale oscillations of climate. El Niño/Southern Oscillation (ENSO), centered in the tropics, is an 'argument' between ocean and atmosphere which radiates across N. America. With enormous impact on temperature, rainfall, storms, flooding, drought, there is some good news in an el niño winter, and much bad news.

In the far northern Atlantic Ocean, the paths followed by intense storms over the ocean have moved north since the early 1970s. These storms intensify as they suck heat from the ocean. This is a part of the so-called North Atlantic Oscillation (NAO), which can switch regimes from one month to the next, or from one 30 year period to the next: it has an element of unpredictability. It is intimately related to the jet stream and polar vortex, a 'tall' mode that reaches to the stratosphere. The NAO is one of several important patterns of oscillation of the atmosphere outside of the tropics (others include north-south 'annular oscillation' of the jet-stream system in the Southern Hemisphere, and a great wave round Antarctica that appears to be coupled between ocean and atmosphere).

In addition to its many impacts on weather, drought and flooding, the NAO is involved in the great, deep overturning circulation of the ocean. The temperature and salinity of the oceans both condition its fluid density . . . its ability to sink. It is at high latitude that the ocean is chilled by the atmosphere, and in rare and small regions, water sinks to the abyss. This global system fulfills the need for heat to be transported from the warm latitudes to the cold, where it radiates to space.

Nearly horizontal layering of the oceans, with dense waters sinking beneath buoyant surface waters, is the result of this 'heat engine' and it is of great consequence to the distribution of ocean life. Photosynthetic life needs sunlight and nutrients. By controlling the flow of nutrients from their rich store at depth, upward to the sunlit surface, life of the ocean is determined by its patterns of its up/down, north/south circulation. This 'meridional overturning circulation' provides a severe challenge to computer models, because of the small yet essential features and the complex shape of the solid Earth. While current computer models have many inaccuracies, they are increasingly being subjected to the acid test of focused, small scale seagoing observational programs.

ENSO and NAO are examples of the possible expression of global warming in 'modes' . . . that is patterns of ocean and atmosphere response with warm and cold, wet and dry. The Titantic sank in 1912, during a cold period that encouraged icebergs to reach southward into shipping lanes. There followed two major periods of global warming this century, the 1930s–40s and 1970s–90s, which in fact correlate with phases of the NAO. These modes are good tests of computer models of climate, and indeed are the subject of intense simulation work at present.

Northern Asia and Canada experienced some of the most intense warming in the 1990s, dominating the global average: we in the U.S. have not yet seen the full force of warming. The northern Atlantic actually has cooled for many years, as cold, Arctic air blew from Canada with increased vigor. Greenhouse warming is expected on average to be initially severe in the Arctic, and to increase the water vapor in the atmosphere. In N. America, increased precipitation and streamflow out into the ocean has developed. Together with the long feared, and now observed, thinning and meltback of the Arctic sea ice, these events are portentous.

Abrupt climate change. The paleoclimate observations, both from sea-floor sediment cores, glacial ice cores, record remarkable periods of rapid change in the distant past, particularly during ice-age glaciation and the transition out of it. Both the increasing input of fresh water on top of the ocean, and the warming itself, can resist the sinking and global deep circulation described above. Communication between land surface, Arctic, and Atlantic ocean is important to the distribution of low-salinity water, and it is correlated with the NAO. Mathematical models and computer models of climate predict a slowdown, by up to 50%, of this global circulation in the coming decades. Such changes can be called *abrupt* in the great scheme of things. A new National Research Council study on abrupt climate change is underway this summer.

The ocean ecosystem represents an important, in some ways dominant, part of global photosynthesis and respiration. Ocean circulation and its layering into dense deep waters and buoyant surface waters largely control the distribution of life in the sea. Disappearance of cod from Atlantic fisheries has a strong relation to over-fishing, yet these fish are very sensitive to temperature. Recovery of cod stocks has been slow, even when fishing grounds closed down. Salmon fisheries in the north Pacific have seen very long (~50 year) cycles, under a multitude of pressures from declining quality of rivers and streams, and climate change (the so-called Pacific Decadal Oscillation, or PDO). This summer Coho salmon returned to Lake Washington in great numbers, for the first time in a decade, yet other salmon species are now on the endangered list. Overall, 11 of the 15 most important global fisheries are in trouble, and the world fish catch has begun to decline after rising six-fold between 1950 and 1996. It is a classic case of compounding of causes: over-fishing puts stress on fish populations, making them sensitive to modest climate change.

Storms. Severe storms, hurricanes, tornados, the super-novae of weather, are of particular importance. Loss of life in underdeveloped countries and economic loss in the U.S. are both striking. A tropical cyclone (dynamically similar to a hurricane) in the Indian Ocean hit land in Bangladesh in November 1971; its 30 foot-high storm surge inundated the low-lying river delta, causing between 250,000 and 500,000 fatalities. In the U.S. Hurricane Andrew, in 1992, was one of the most costly natural disasters in history. A direct hit of a major hurricane on Miami could cost more than $70B in property damage, owing to the intense coastal population increase and development of coastal real estate. Hurricane Mitch, in 1998, showed the world how capricious and destructive these storms are in the less-developed world. Following an unexpected path southward, then sitting over the mountains of Honduras and Nicaragua, Mitch destroyed villages and cost more than 10,000 lives through endless rainfall, flooding, and erosion. It nearly destroyed the economies and social infrastructure of these countries.

Hurricane paths and their intensity are correlated with el niño cycles, and with another key tropical oscillation, the Madden-Julian Oscillation. Hurricanes (and tropical cyclones) take their energy from the heat of the tropical ocean. They do so surprisingly rapidly, and have been observed to intensify in passing over the Gulf Stream and warm eddies (only 50 miles wide) in the Gulf of Mexico. Long lasting effects are inland flooding, pollution and sedimentation, which destroy habitats in estuaries and marshes. Their connection with global warming is less clear. Model studies suggest a 5%–12% increase in hurricane wind-speed for a 2 degree C rise in sea-surface temperature, but this is very uncertain.

Changes in normal weather, for example, more intense rainstorms, have been linked to ENSO, NAO and other global climate modes. Possible links exist back to global warming through these modes of oscillation, as well as more directly, through the changing levels of cloudiness.

At every turn in this discussion we must weigh the relative advantages of prevention, protection, and treatment in the aftermath. Amartya Sen, an economist at Cambridge University, argues that destruction from climate and storms is most severe in the aftermath: that stockpiling of food and creation of jobs programs for the poor are important in preserving human life . . . as much so as protection from the storm on the day, itself.

Coastal Ocean. The coastal ocean, the water on the continental shelves and in estuaries, is a small part of the global ocean, yet is the home of roughly one half of oceanic biological productivity (roughly 25% of global primary biological productivity). It is the site of much diversity, and close involvement with human populations, which are increasingly concentrated near the seacoast. It is also the site of 80 to 90 percent of the global fish catch. Estuaries, where rivers meet the sea, are a sort of pumping machine in which river-flow and tidal stirring combine to suck water in from the deep ocean, supplying the region with nutrients: to their benefit, estuaries flow in and out at rates much greater than (as much as 50 times) the river-flow that drives them. Nutrient sources from rivers are often a small contribution, yet in some estuaries, agricultural practices are loading the estuaries with nitrogen and phosphorus, as well as viruses and bacteria. Chesapeake Bay seasonally teeters on the edge of hypoxia, a reduction of oxygen to the point where fish can no longer live, when stratification, layering of the water by density, and nutrient inflow are both high.

The coasts are what we call 'potential vorticity guideways' along which climate change can be signaled rapidly (for example, from an el niño event on the Equator, poleward along the North and South American Pacific coasts). With a complex of local influences, human and natural, the coastal ocean is undergoing rapid change. Yet, at the same time, global climate change is strongly felt in this region. A third, severe effect is the colonization of the coastal ocean (and lakes and rivers) by new species introduced by ship traffic. Ships carry ballast water from one continent to another, discharging it and its biological cargo near the coast. The highly diverse coastal ecosystem, after evolving in relative isolation, is suddenly invaded.

It is hard to say in detail what is the time- and space-variability of ocean biology and its impacts on the health of humans, fish and algae. This is because we have not yet invested in baseline observations of the coastal ocean. But we observe numerous regional hot-spots, as with the dinoflagellate *gymnodinium catenatum* transported to Australia from Asia, and the Asian clams that have taken over San Francisco Bay.

Both river- and deep-sea inputs to estuaries change with climate. For example, during El Niño, riverflow decreases in some regions, thus decreasing the nutrient supply from this source. At the same time coastal winds change and this change can alter the supply of nutrients to the estuary as more or less nutrient rich water is pulled up from the deep ocean to the estuary mouth. Variation of the health of fisheries, such as oysters in the Pacific Northwest, has been shown to depend on the frequency and strength of El Niño. Because of the link to offshore waters, estuaries can also be expected to show evidence of longer term climate change such as the PDO.

Major rivers can exhibit these sensitivities strongly. In the Pacific Northwest the largest river is the Columbia. The plume from the Columbia can stretch several hundred kilometers from the river mouth—to the Strait of Juan de Fuca in the north and to San Francisco in the south. The size of the plume is controlled in spring by the amount of snow pack received by the region in the preceding winter. For example, snowpack was high in 1999 during la niña. In such years, the plume floods other nearby estuaries, substantially reducing the salinity and nutrients in those estuaries, dramatically altering the environment encountered by emerging salmon smolts and entering juvenile crab larvae. In years with lesser snowpack, the Columbia plume likely has a more southwestward orientation and may have much less effect on local estuaries. Long term effects on the fisheries might be expected due to these and other such climate effects and are the subject of current research.

Human health. Along with colonization of the coastal ocean by new species there are increasing problems involving toxins. Harmful algal blooms are occurring more frequently. They involve both local human causes (nutrient loading, turbid water), and physical ocean changes (temperature, stratification, upwelling, rainfall). While mortality is not often widespread, illness and economic loss from closure of shellfish beds is. Estimates of the loss to the fishing industry from a single *Pfiesteria* outbreak, in Chesapeake Bay in 1996, were $20M. The degree to which global climate change is involved, is not yet known.

An example of a pressing public health and economic problem is the diatom in the genus *Pseudonitzschia* that cause domoic acid poisoning (DAP), also known as amnesic shellfish poisoning (ASP), and dinoflagellates in the genus Alexandrium that are the source of paralytic shellfish poisoning (PSP). Toxic outbreaks along the U.S. coast can be highly localized or can extend over several hundred miles and last for several months. Both the occurrence of such toxic algal blooms in the offshore coastal waters and the delivery of the toxic algae to coastal beaches and to coastal estuaries is thought to depend on wind speed and direction as well as coastal water properties and hence have a direct link to climate changes along the U.S. coast. Near the Strait of Juan de Fuca, the physical oceanography of the coastal circulation has been linked with the appearance of HABs at the coast. A detailed study of the toxic dinoflagelate *gymnodinium breve* shows its development in the warm, broad shallows of the Gulf of Mexico, and its transport in the Gulf Stream system as far as North Carolina, where it has come to shore.

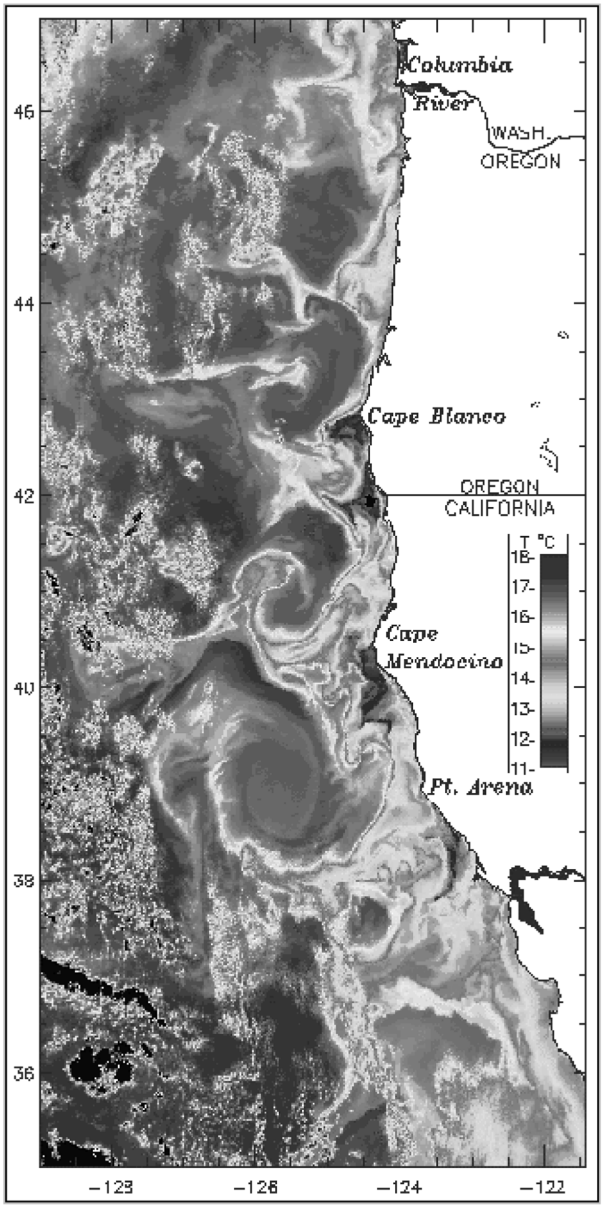
A major outbreak of cholera developed in coastal Peru, during an extended el niño event in 1991, and thereafter quickly appeared to neighboring countries. In the first 3 weeks, 30,000 cases and 114 deaths were reported. Cholera lives dormant in the sea as *vibrio cholerae,* associating itself with mucous membranes of the copepod. There is an apparent relationship between warm sea-surface temperature and cholera there and in Bangladesh. The association of climate with disease is thus plausible, yet there are several possible routes, for el niño rainfall alters sanitation on shore as well as disturbing and warming the coastal ocean.

Cholera is a disease that may illustrate the association of virulence with transmission rate. In evolutionary biology, Paul Ewald of Amherst College argues that cholera and many slowly developing human diseases have evolved so as to maximize their own transmission. Thus, with poor sanitation in the under-developed world, cholera is rapidly transmitted and very virulent. In countries with good sanitation cholera exists in a much more benign strain, adapted to very slow transmission. This message suggests that global climate change and human activity (like introduction of 'exotic' species by ship traffic) both could conspire to increase the virulence of toxic viruses and bacteria in the environment.

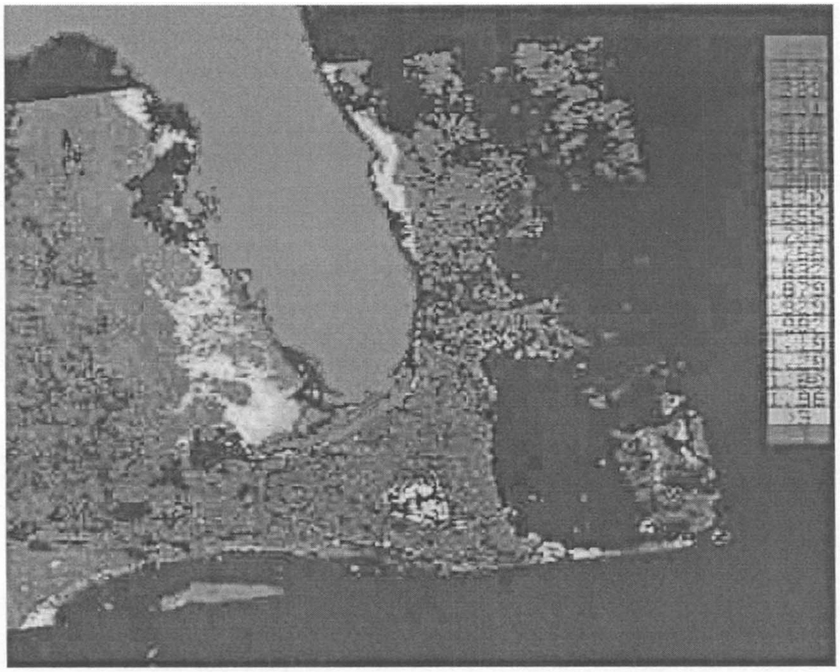
There is a tension throughout this debate on global change, between advocates of public health, social infrastructure, economics of the recovery on the one hand, and advocates of mitigation of climate change (and its role in disease), and environmental science, on the other. Regardless of the balance struck in resolution of this debate, there is value in observing our environment, predicting its future, AND assessing its current behavior.

New technologies. A remarkable chain of technological discovery has focused on observations of the global environment. These are moored and drifting and self-propelled vehicles in the ocean, with a range of sensors for physical, biological and chemical substances; orbiting satellites that probe both oceans and atmosphere; seafloor and moored 'observatories' that allow us to 'explore in time' as well as space. The importance of establishing long-term measurement sites for climate studies cannot be overstated (the TAO array of moorings in the Pacific, perhaps the largest scientific instrument ever built, has shown us the inner workings of el niño). Molecular biology gives a remarkable tool for studying the function and evolution of ecosystems. Computer models of the climate system have become the centerpiece for ideas and observations, and computing power continues to increase steadily (though sometimes delayed by political constraints).

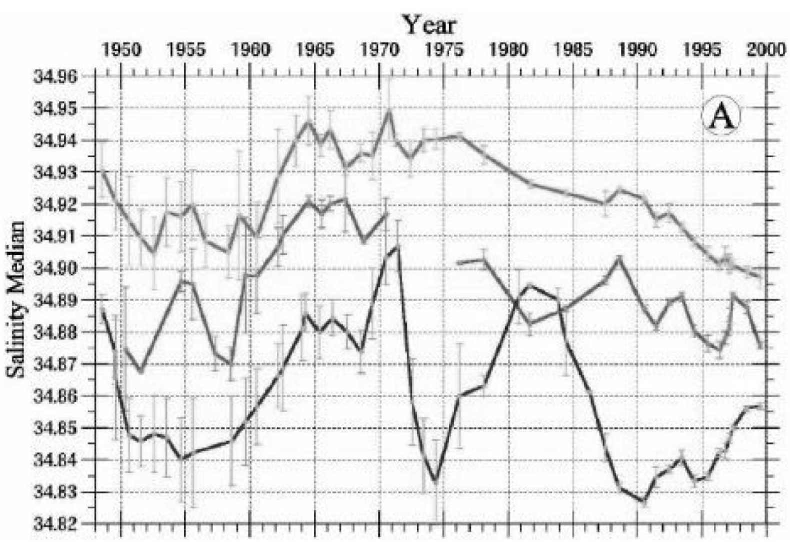
These new sensors and platforms give us eyes for viewing climate, computers and the internet give us a global central nervous system, but we also need the will to observe and understand the environment as it is assaulted by accelerating natural and human-induced change.



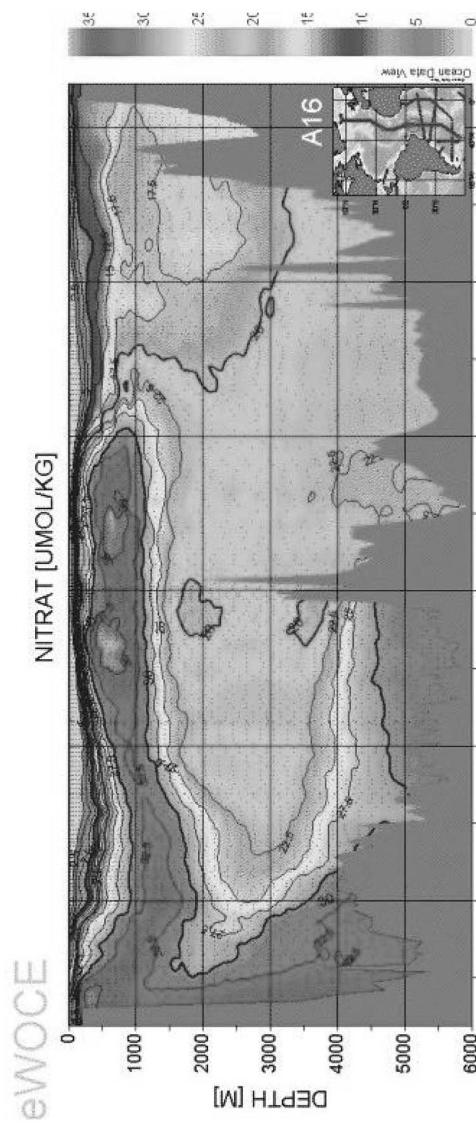
Currents and upwelling of cold, nutrient rich water along the U.S. west coast Sea-surface temperature (Oregon State University)



Evidence of a red tide on the West Florida Shelf: Nov 1978, red = chlorophyll a > 3 μg/l (Florida Marine Inst.)



Northern Atlantic (Labrador Sea) salinity at three depths (2000m, 3500m, 1500m top to bottom). Salinity declines as fresh water input at the surface has increased with intense, cold forcing by the North Atlantic Oscillation. I. Yashayaev, J. Lazier Bedford Inst. of Oceanography, P. Rhines (Univ. of Washington)



Dissolved nitrate in the Atlantic Ocean, along a section from Antarctica (left) to Iceland. High concentrations of this nutrient occur deep in the ocean, and in the Southern Ocean. Near the surface nitrate is almost absent, evidence of active ecosystem growth at the top of the ocean. The global ocean circulation must bring nitrate up to the surface, and controls the distribution of life (WOCE program).

CLIMATE POLICY—FROM RIO TO KYOTO: A POLITICAL ISSUE FOR 2000—AND BEYOND
Hoover Institution Essay by S. Fred Singer

Executive Summary

Within the United States, global warming and related policy issues are becoming increasingly contentious, surfacing in the presidential contests of the year 2000 and beyond. They enter into controversies involving international trade agreements, questions of national sovereignty versus global governance, and ideological debates about the nature of future economic growth and development. On a more detailed level, determined efforts are under way by environmental groups and their sympathizers in foundations and in the federal government to restrict and phase out the use of fossil fuels (and even nuclear reactors) as sources of energy. Such measures would reduce greenhouse-gas emissions into the atmosphere but also effectively deindustrialize the United States.

International climate policy is based on the 1997 Kyoto Protocol, which calls on industrialized nations to carry out, within one decade, drastic cuts in the emission of greenhouse gases (GHG) that stem mainly from the burning of fossil fuels. The Protocol is ultimately based on the 1996 Scientific Assessment Report issued by the Intergovernmental Panel on Climate Change (IPCC), a U.N. advisory body. The IPCC's main conclusion, featured in its Summary for Policymakers (SPM), states that "the balance of evidence suggests a discernible human influence on global climate." This widely quoted, innocuous-sounding but ambiguous phrase has been misinterpreted by many to mean that climate disasters will befall the world unless strong action is taken immediately to cut GHG emissions.

This essay documents the inadequate science underlying the IPCC conclusions, traces how these conclusions were misinterpreted in 1996, and how this led to the Kyoto Protocol. I also discuss some fatal shortcomings of the Protocol and the political and ideological forces driving it.

The IPCC conclusion is in many ways a truism. There certainly must be a human influence on some features of the climate, locally if not globally. The important question—the focus of scientific debate—is whether the available evidence supports the results of calculations from the current General Circulation Models (GCMs). Unless validated by the climate record, the predictions of future warming based on theoretical models cannot be relied on. As demonstrated in this essay, GCMs are not able to account for observed climate variations, which are presumably of natural origin, for the following reasons:

1. To begin with, GCMs assume that the atmospheric level of carbon dioxide will continue its increase (at a greater rate than is actually observed) and will more than double in the next century. Many experts doubt that this will ever happen, as the world proceeds on a path of ever-greater energy efficiency and as low-cost fossil fuels become depleted and therefore more costly.
2. Next, one must assume that global temperatures will really rise to the extent calculated by the conventional theoretical climate models used by the IPCC. Observations suggest that any warming will be minute, will occur mainly at night and in winter, and will therefore be inconsequential. The failure of the present climate models is likely due to their inadequate treatment of atmospheric processes, such as cloud formation and the distribution of water vapor (which is the most important greenhouse gas in the atmosphere).
3. The putative warming has been labeled as greater and more rapid than anything experienced in human history. But a variety of historical data contradicts this apocalyptic statement. As recently as 1,000 years ago, during the "Medieval climate optimum," Vikings were able to settle Greenland. Even higher temperatures were experienced about 7,000 years ago during the much-studied "climate optimum."

The IPCC's Summary for Policymakers tries hard to minimize the inadequacy of the GCMs to model atmospheric processes and reproduce the observed climate variations. For example, the SPM does not reveal the fact that weather satellite data, the only truly global data we have, do not show the expected atmospheric warming trend; the existence of satellites is not even mentioned.

The scientific evidence for a presumed "human influence" is spurious and based mostly on the selective use of data and choice of particular time periods. Phrases that stress the uncertainties of identifying human influences were edited out of the approved final draft before the IPCC report was printed in May 1996.

A further misrepresentation occurred in July 1996 when politicians, intent on establishing a Kyoto-like regime of mandatory emission controls, took the deceptively worded phrase about "discernible human influence" and linked it to a catastrophic future warming—something the IPCC report itself specifically denies. The IPCC presents no evidence to support a substantial warming such as calculated from theoretical climate models.

The essay also demonstrates that global warming (GW), if it were to take place, is generally beneficial for the following reasons:

1. One of the most feared consequences of global warming is a rise in sea level that could flood low-lying areas and damage the economy of coastal nations. But actual evidence suggests just the opposite: a modest warming will reduce somewhat the steady rise of sea level, which has been ongoing since the end of the last Ice Age—and will continue no matter what we do as long as the millennia-old melting of Antarctic ice continues.
2. A detailed reevaluation of the impact of climate warming on the national economy was published in 1999 by a prestigious group of specialists, led by a Yale University resource economist. They conclude that agriculture and timber resources would benefit greatly from a warmer climate and higher levels of carbon dioxide and would not be negatively affected as had previously been thought. Contrary to the general wisdom expressed in the IPCC report, higher CO_2 levels and temperatures would increase the GNP of the United States and put more money in the pockets of the average family.

But even if the consequences of a GW were harmful, there is little that can be done to stop it. "No-regrets" policies of conservation and adaptation to change are the most effective measures available. Despite its huge cost to the economy and consumers, the emission cuts envisioned by the Kyoto Protocol would be quite ineffective. Even if it were observed punctiliously, its impact on future temperatures would be negligible, only 0.05°C by 2050 according to IPCC data. It is generally agreed that achieving a stable level of GHGs would require much more drastic emission reductions, including also by developing nations. To stabilize at the 1990 level, the IPCC report calls for a 60 to 80 percent reduction—about twelve Kyotos on a *worldwide* basis!

Finally, the essay attempts to trace the various motivations that led to the Kyoto Protocol. It concludes that U.S. domestic politics rather than science or economics will decide the fate of the Protocol; in particular, the presidential elections of 2000 will determine whether the United States ultimately ratifies the Protocol, which would be essential for its global enactment. Conversely, informed debate about the Protocol can influence the outcome of the elections.

YALE UNIVERSITY, SCHOOL OF FORESTRY AND ENVIRONMENTAL STUDIES,
New Haven, Connecticut, July 12, 2000.

Senator JOHN MCCAIN
Committee on Commerce, Science, and Transportation
United States Senate
Washington, D.C.

Dear Senator McCain:

In response to your invitation to speak to the Senate Committee on Commerce, Science, and Transportation, I would like to submit the following material as part of the written record. Over the last five years, I have been working with a distinguished group of researchers from across the United States measuring the impacts of climate change on the U.S. economy. The initial study, edited by Robert Mendelsohn and James Neumann and published in 1999 by Cambridge University Press, was entitled "The Impact of Climate Change on the United States Economy." A subsequent book entitled "Global Warming and the American Economy: A Regional Assessment of Climate Change" is being prepared for publication at present. Following is the introduction and the synthesis of results of this new book.*

The critical insight of both of these new books is that adaptation matters. Empirical research indicates that households and firms will respond to climate change and reduce damages and enhance benefits. Coupled with more careful modeling of dynamic effects, carbon fertilization, and ecosystem change, the new results are far more optimistic than the old studies. These estimates do not include nonmarket effects in health, ecosystem change, and aesthetics, but it is not clear that these nonmarket effects will be large in the United States.

*The information referred to has been retained in the Committee files.

Climate change is likely to result in small net benefits for the United States over the next century. The primary sector that will benefit is agriculture. The large gains in this sector will more than compensate for damages expected in the coastal, energy, and water sectors, unless warming is unexpectedly severe. Forestry is also expected to enjoy small gains. Added together, the United States will likely enjoy small benefits of between $14 and $23 billion a year and will only suffer damages in the neighborhood of $13 billion if warming reaches 5C over the next century. Recent predictions of warming by 2100 suggest temperature increases of between 1.5 and 4C, suggesting that impacts are likely to be beneficial in the U.S.

The impact of warming depends upon the initial temperature of each region. With mild warming of 1.5 C, every region benefits from warming. The average American would enjoy benefits of about $100/yr. However, with 2.5C warming, the cooler northern regions of the country benefit far more than the warmer southern regions. The average citizen in the north would enjoy benefits of about $80/yr whereas southern citizens would enjoy average benefits of only about $6/yr. If warming rises to 5C, the benefits in the north shrink to about $40 per person, but citizens in the south may suffer damages from $120 to $370 per person.

In summary, climate change does not appear to be a major threat to the United States for the century to come. There is little motivation for expensive crash programs to curb short term emissions of greenhouse gases. The focus of mitigation policy should remain on inexpensive ways to control global emissions over the next century.

Sincerely,

ROBERT MENDELSOHN,
Edwin Weyerhaeuser Davis Professor.

TABLE 1
National Impacts

Sector	Old Results	New Results
Agriculture	–17.5 to –1.1	19.6
Forestry	–3.3 to –0.7	3.7
Water	–7.0 to –15.6	–2.2
Coastal	–7.0 to –12.2	–0.2
Energy	–9.9 to –0.5	–5.8
TOTAL	–44.7 to –13.8	15.1

Sources: Nordhaus [1991], Cline [1992], Fankhauser [1995], Tol [1995], Mendelsohn [2000].

Regional Impacts

(Billions of USD/yr)
2.5C, 7% Precipitation Scenario

Region	Sector					
	Agr	For	Ene	Coa	Wat	Total
Northeast	2.6	1.9	–0.4	–0.1	0.0	4.0
Midwest	5.4	1.1	–0.1	–0.0	–0.0	6.4
N. Plains	2.8	0.6	–0.1	–0.0	–0.1	3.2
Northwest	1.1	–0.1	1.4	–0.0	–1.7	0.7
Southeast	4.2	–0.8	–3.0	–0.1	–0.0	0.3
S. Plains	2.1	0.6	–2.4	–0.0	–0.2	0.1
Southwest	1.4	0.4	–1.2	–0.0	–0.2	0.4
National	19.6	3.7	–5.8	–0.2	–2.2	15.1

Regional Impacts

(USD/per capita/yr)

Region	Climate Scenario		
	1.5C 15%P	2.5C 7%P	5.0C 0%P
Northeast	28	52	19
Midwest	84	84	36
N Plains	539	359	75
Northwest	410	80	–369
Southeast	91	6	–122
S. Plains	129	5	–266
Southwest	80	11	–134
National	97	52	–56

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