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# GLOBAL CLIMATE CHANGE

## HEARING

BEFORE THE

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## UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

**SPECIAL HEARING**

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# GLOBAL CLIMATE CHANGE

**TUESDAY, MAY 29, 2001**

U.S. SENATE,
COMMITTEE ON APPROPRIATIONS,
*Fairbanks, AK.*

The committee met at 9:30 a.m., in Fairbanks, AK, Hon. Ted Stevens (chairman) presiding.

Present: Senators Stevens.

OPENING STATEMENT OF CHAIRMAN TED STEVENS

Chairman STEVENS. Let me thank you all for being here and I don't apologize because change in Washington is welcome in many ways. This one may not be so welcome. But we have lost the other members of the Senate who would have been with me today because of the delay and the cancellation of portions of our trip. So I do appreciate the fact that the rest of you have agreed to appear here today for this hearing which I consider to be very important for the future of our country and, particularly, for Alaska. We're meeting to review the scientific research on global climate change issues related to the Arctic Region. I'm pleased to be able to hold this hearing here in Fairbanks on the campus of our University to discuss this important subject and I thank our hosts for helping us put the hearing together. As a matter of fact this will be the last hearing I conduct as Chairman of the Appropriations Committee as, when we return to Washington, the control of the Senate will change, as you all know. Before all of this change came about I chose the University as the site for this hearing because of the important scientific research that's being conducted here on climate change. And I want to point out the work being conducted under the leadership of Dr. Syun Akasofu at the International Arctic Research Center. IARC has become one of the leading institutes of research on Arctic climate change issues and currently performs a number of important scientific studies for our Federal Government.

Today, we have assembled a very distinguished group of scientists and government officials to present to us facts and predictions on the Arctic climate change issue and the impact it is having on the Arctic Region. I'm really sad my colleagues are not here to be able to hear what climate change observations the scientists are seeing in the Arctic Region, particularly here in our State, and what the potential causes of these changes may be and how it is affecting the lives of people in our region and the environment of our State and Nation. Further, we need to learn about the future projections of climate change in the Arctic Region.

The first two panels, which comprise the morning session, will be distinguished scientists who are on the cutting edge of climate change research. After we hear from these scientists, we will hear in the afternoon from the main Federal research agencies involved in climate change research. The Federal Government plays a vital role in supporting climate change research. The U.S. Global Climate Change Research Program, which is made up of several Federal agencies, is coordinating the Federal Government's efforts to improve our scientific understanding of changes in climate and how it affects our economy and our lives. We'll hear from representatives of this interagency group this afternoon.

I recognize that there's been a lot of attention recently to the President's approach on climate change policy but I want to emphasize that we're here today to gather facts related to climate change and to discuss the underlying scientific research being conducted. It's important for us to understand what we know, what we do not know and what we need to know in order for us to have a reasonable level of confidence in what will really occur in our environment.

I'm especially interested in establishing a record of what is happening in the arctic region of our State. Much of what is happening here will have a significant impact on the Nation, in my opinion, as well as the world, perhaps. In particular, we need to develop practical responses to address the impact of climate change. For example, some parts of Alaska, Native villages along the coastline are losing land because of the increased inundation of the sea, the encroachment of the ocean on the small villages. This is a slow-moving disaster that may require more than a slow-moving response as far as the Federal and State governments are concerned.

Our first panel includes Dr. Akasofu and Orson Smith of the University of Alaska; Caleb Pungowiyi, an Alaskan Native who has observed the impact of climate change along the coastline of Alaska; Norbert Untersteiner of the University of Washington; and John Walsh of the University of Illinois. We'll then have a second panel of scientists and climate change experts. The second panel includes Glen MacDonald from UCLA, Douglas Martinson representing the National Academy of Scientists and a professor at Columbia University, and George Newton of the Arctic Research Commission who is accompanied by Gary Brass.

In the afternoon, we'll hear from the key agency representatives involved in climate change research. We have Margaret Leinen of the U.S. Global Climate Research Program; Dan Goldin, the Administrator of the National Aeronautics and Space Administration; Rita Colwell, the Director of the National Science Foundation; Scott Gudes, the Acting Administrator of the National Oceanic and Atmospheric Administration who is joined by Tom Karl, Director of the NOAA National Climate Data Center, and John Calder, Director of the Arctic Research Office of NOAA. We also have Charles Groat, Director of the U.S. Geological Survey.

And I'm really pleased to have all of you here and I thank you very much for your courtesy in coming and we'll proceed with the first witness. The first panel is Dr. Akasofu, Orson Smith, Caleb, Norbert Untersteiner and John Walsh. If you gentlemen would come forward, please.

I want to say, for the audience, that we will terminate just before noon and Dan Goldin is the speaker at the Chamber of Commerce this noon and we'll resume at 2 o'clock for the afternoon session.

Dr. Akasofu, we'll call on you first, please.

**STATEMENT OF SYUN AKASOFU, DIRECTOR, INTERNATIONAL ARCTIC RESEARCH CENTER, UNIVERSITY OF ALASKA, FAIRBANKS, AK**

Dr. AKASOFU. My name is Syun Akasofu. I'm the Director of the International Arctic Research Center, IARC, of the University of Alaska. I'd like to make an introductory remark on Panel I of the morning session. I would like to thank Chairman Stevens for having this particular hearing on global climate change in the Arctic.

Now, there is no longer any doubt that climate has changed substantially in the Arctic over the last few decades. The effects of the climate change can be clearly recognized: (a) Warming of the atmosphere, particularly in the continental area, is several times faster than the global average. (b) The second is the receding glaciers. Practically all the glaciers—most of the glaciers in Alaska, Canada, Greenland are receding with 30, 40 meters per year. (c) Next one we see is the warming of permafrost down to 100 feet, 30 meters; and (d) Shrinking of Arctic Ocean sea ice coverage and the thickness, too.

Further, without exception, all computer simulations indicate that the Arctic is a region most sensitive to climate change on Earth. There is no exception. All the computer models show that, when you double the $CO_2$ amount, the Arctic will be most warmed by this effect.

Next slide, please. There are many simulation results. So at this point, our understanding of climate change is well-represented in a recent paper entitled "Observational Evidence of Recent Change in the Northern High-Latitude Environment" by distinguished Arctic researchers.

Next. From the other (indiscernible) in part, state.

> Taken together, these results paint a reasonable picture of change . . ."—and so on—". . . but their interpretation as a signal of enhanced greenhouse warming is open to debate. Nevertheless, the general pattern of change broadly agree with the model predictions.

And Dr. Norbert Untersteiner will discuss this issue in more detail in the morning session.

Therefore, in this particular situation, we have four fundamental climate change questions: (1) Are we seeing climate changes due to greenhouse effect as predicted by global climate models? (2) Are the changes in climate due to natural or manmade causes? And so on.

A large number of individual research projects on these issues have been conducted by researchers all over the world. However, it is quite obvious, first of all, that it is not possible to work on these four questions without a close international cooperation/ coordination. Second, what we need now is an integration/ synthesis effort based on results from the individual research projects. This is because the immediate causes of the permafrost warming, receding glaciers and shrinking of sea ice coverage could be quite different.

Okay. Go back.

In this situation the IARC has considered carefully the roles it can play by considering "What are the most crucial integration/synthesis projects the IARC can coordinate and facilitate on an international scale?" Under this consideration, the first project we have taken up is the Arctic Climate Impact Assessment. It is an Arctic version of the IPCC report.

The second project is a cross-calibration of computer models that were used for the IPCC report. This is the only quantitative tool we can use to predict the future changes so it's very important to make this tool better. Dr. John Walsh will describe this project in the morning session.

In Alaska, we are experiencing several significant changes in both marine and terrestrial ecosystems and an increase in coastline erosion during the last few decades, although the direct relation of these changes to global warming is not certain. Dr. Orson Smith and Mr. Caleb Pungowiyi will report on those changes.

Thank you.

Chairman STEVENS. Thank you very much. For the information of all the witnesses, this is being immediately put on to the web. It goes out to the internet live. Our next witness is Orson Smith.

**STATEMENT OF ORSON P. SMITH, PE, PH.D., ASSOCIATE PROFESSOR, SCHOOL OF ENGINEERING, UNIVERSITY OF ALASKA, ANCHORAGE, AK**

Dr. SMITH. Senator Stevens

Chairman STEVENS. Could you pull that mike in towards you a little bit, please?

Dr. SMITH. Sure. Thank you. Senator, fellow panelists and guests. My name is Orson Smith. I'm Chair of the Arctic Engineering Program for the School of Engineering at the University of Alaska Anchorage.

Chairman STEVENS. And I left out, Mr. Smith, we will put into the record the complete statements that each of you have filed and, also, your presentation you've made as to your biography so those who read the record will understand it. But we'll also go out on the web.

Dr. SMITH. My testimony today follows a series of workshops and meetings in the last year-and-a-half on the subject of climate change impacts. These productive meetings involved discussions between research scientists and practicing engineers about the tangible impacts of global warming on Alaska's people and its economy. I will first mention consensus views related to coastal resources and finish with remarks about infrastructure across the State.

Conditions of Alaska's coastal oceans are changing with global warming. Thinner, less extensive sea ice will generally improve navigation conditions along most northern shipping routes, such as the Northwest Passage offshore of Canada's Arctic coast and the Northern Sea Route offshore of Russia. The GIS-based Alaska Sea Ice Atlas, now in preparation by the University of Alaska and the U.S. Army Cold Regions Research and Engineering Laboratory, reveals these trends.

More open water allows wave generation by winds over longer fetches and durations. Wave energy is constrained by wind speed, duration of winds, fetch, or the distance over water which the wind blows, and water depth. Wave-induced coastal erosion is expected to increase with global warming.

One measured effect of global warming is sea level rise, due to melting glaciers and thermodynamic expansion of ocean water. Rising sea level inundates marshes and coastal plains, accelerates beach erosion, exacerbates coastal flooding and forces salinity into bays, rivers and groundwater.

Some northern regions, including areas of Southeast and Southcentral Alaska, have sea level trends complicated by tectonic rebound of landforms from the retreat of continental glaciers. At Sitka, in Southeast Alaska, the net effect is falling sea level.

Coastal areas of Alaska have a wide variation of tectonic trends, however. The Aleutian Chain has volcanic geology not subject to glacial rebound. The net trend at Adak is for sea level rise, as it also appears along Alaska's western and northern coasts.

Global sea level rise will allow more wave energy to reach the coast and induce erosion as waves break at the shore. Higher sea levels at the mouths of rivers and estuaries will allow salt to travel further inland, changing water quality and habitats. Global warming is predicted to involve more frequent and more intense atmospheric storms with stronger winds. These winds will induce even higher water levels at the coasts, accompanied by higher waves.

Permafrost coasts are especially vulnerable to erosive processes as ice beneath the seabed and shoreline melts from contact with warmer air and water. Thaw subsidence at the shore allows even more wave energy to reach these unconsolidated, erodible materials. Alaska's permafrost coasts along the Beaufort and Chukchi Seas are most vulnerable to thaw subsidence and subsequent wave-induced erosion.

Coastal erosion problems around the State are an extraordinary challenge to communities such as Barrow, Wainwright, Kivalina and Shishmaref. More communities on coasts and riverbanks will be in jeopardy from higher water levels. Changing depths offshore will also change coastal vulnerability to tsunamis.

Contingency planning should begin now. Coastal survey data is often inadequate to reliably judge changes. A baseline survey of coastal characteristics and associated coastal processes would help assessment of erosion rates and for planning future responses.

The Arctic Coastal Dynamics Program is a recent international initiative to address coastal change in the Arctic. The program plan, developed by specialists of the International Arctic Science Commission and the International Permafrost Association, involves systematic cataloging of coastal characteristics and establishment of a cooperative network of coastal monitoring stations. Uniform coastal classification and improved predictive models are also proposed. The program includes many opportunities for participation by coastal residents. The Arctic Coastal Dynamics Program needs government sponsorship and funding for implementation.

Lesser ice extent and thickness will provide an opportunity for export of natural resources and other waterborne commerce over new northern shipping routes. Marine transportation remains critical to Alaska's economy so early attention to these opportunities will save time and money getting valuable products to market. Ice-capable commercial cargo vessels suited for Alaska service have not yet been developed, though ice-class commercial ships of all types are in service elsewhere around the Arctic.

Global warming is also changing Alaska's rivers as transportation routes, water sources and habitants. Predicted increased precipitation will induce higher stream flows and more flooding. Erosion of thawing permafrost banks will accelerate, threatening hard-won infrastructure of rural Alaska river communities such as Bethel and Noatak. River ice breakup will occur earlier and be more difficult to predict in terms of ice jam flooding. Prediction and prevention of ice jam flooding in Alaska warrants further study.

Conditions for commercial river navigation may improve for transport of minerals and bulk exports to tidewater. Since no State or Federal agency is presently responsible for either charting or marking river channels, this prospect will be difficult to measure. A program to survey river navigation routes would provide a baseline from which to monitor change and evaluate improvements for waterborne commerce.

A warming climate inland will affect infrastructure of all types as ground and hydrological conditions are changed. Engineers have a toolkit of proven means to deal with these changes but often lack adequate site information for optimum site or transportation route selection.

Global warming will bring more erratic winter weather, increasing the frequency of freeze/thaw cycles across the State. Roads and railways will suffer attendant problems and maintenance costs are likely to increase as a result. Improvement of bridges and culverts may prove to be a particularly expensive impact of global warming on northern transportation infrastructure.

Thawing permafrost and freeze/thaw cycle changes in the active layer of soils across Alaska will bring potential adverse impacts to existing foundations of all types. New foundations may be designed accordingly if site conditions are known and predictions are accurate. Hydrological changes in streams and ground water will bring both problems and opportunities for water supply. Safe waste disposal in low-lying tundra areas will generally become more difficult and expensive.

Climate change began some time ago and problems of warming permafrost and other environmental changes have occurred throughout the careers of cold regions engineers in practice today. The fears for northern infrastructure relate to lack of site information and reliable prediction of future change.

Storage and accessibility of engineering site data is improving but more old data can be saved and new data must be measured. The World Wide Web provides means for quick access to 21st century GIS-based atlases of linked environmental databases, complete with common engineering applications. One such effort is the Engineering Atlas of Alaska, in its first stage of development at the U.S. Army Cold Regions Research and Engineering Laboratory in cooperation with the University of Alaska.

Monitoring is difficult to fund and instituting a "1 percent for monitoring" public works policy can follow the lead of arts advocates.

This concludes my testimony. I appreciate this opportunity to speak today.

Chairman STEVENS. Thank you very much, Dr. Smith. Our next witness is Caleb Pungowiyi. He is a member of the Robert Newlin Senior Memorial Trust. Caleb, nice to see you here.

**STATEMENT OF CALEB PUNGOWIYI, PRESIDENT, ROBERT AQQALUK NEWLIN SR. MEMORIAL TRUST**

Mr. PUNGOWIYI. Thank you, Senator. Honorable Chairman, Members of the Committee and distinguished visitors and guests, I am honored and humbled to be included among the distinguished scientists and learned men that were invited to testify on the effects of the current warming trend. In my testimony I will not present any scientific proofs or any silver bullets that puts the finger on the cause of the warming. I will tell you that there are effects and changes that are occurring that are undeniable and, rather than some vague possibility, is already affecting and changing people's lives.

My name's Caleb Pungowiyi. I am currently the President of Robert Aqqaluk Newlin Senior Memorial Trust, the non-profit foundation established by NANA Regional Corporation. My testimony today does not represent nor speak on their behalf or that of the NANA Regional Corporation.

First of all, I must say, Senator, that I am extremely delighted that the U.S. Congress is concerned enough to hold hearings such as this. While there are uncertainties and no clear solutions to the risks and threats that face our communities, the need to assess and perhaps identify the actions that can be taken to minimize the impacts are necessary and I appreciate your concern and your presence at these hearings.

A year and a half ago, we held a workshop in Girdwood on "Impacts of Changes in the Sea Ice and Other Environmental Factors in the Arctic," convened by the Marine Mammal Commission. This workshop was not only to look at the impacts but also to highlight the research on the impacts on the Native people from climate change is scarce and virtually nonexistent. And Senator, I purposefully elected not to present any overheads or show data on the slide presentation because I wanted to highlight the lack of information that exists currently or is nonexistent because there is no research currently being done on the effects in the coastal communities or the people. This workshop—or, I had hoped to bring a copy of that report but, unfortunately, I forgot to bring a copy with me but I will make sure that a copy is available to you and the members of your committee. We, including the U.S. Government, must understand that the social and economic impact on the local economies and subsistence practices, however minimal they may seem, causes enormous hardship, social chaos and, as you well know, will cause population disbursement. And it is currently causing population disbursement. I mean by people relocating or moving to other places that have more opportunities for easier living.

It is very evident now that the sea ice in the Bering Sea and the Arctic Ocean is thinning. To us living on the Arctic coastline, sea ice is our lifeline. It supports the majority of the resources from which we depend upon. In fact, in 1972 the U.S. Congress, recognizing the dependence of Alaska Native people on marine mammals, exempted the Alaska Natives from the Marine Mammal Protection Act. Today that dependence continues but, if the warming trends continue, many of those resources are at risk. The ice-dependent marine mammals such as polar bear, walrus, bowhead whale, beluga and ice breeding seals that are—that's like the (indiscernible) seal, the ring seal, the spotted seal and the ribbon seal—are all dependent on the sea ice for their survival. We see the ice forming later and disappearing earlier. If it were not for the cold springs that we've had in the last few years, our spring marine mammal hunting would be a disaster. These are all long-lived species and [it's] hard to judge the current impact on them but we do know that there are impacts on the productivity of the species.

And Senator, at this time I would like to say that, while the impact from the lack of sea ice is perhaps because of the gradual change, the impact has been fairly minimal. The long-term trend is very scary, especially when we think about the immediate impact, if there are changes in their food resources, especially the fish and the shrimp and the other (indiscernible) that depend on production in the sea ice, that this problem from starvation and lack of a stable platform for them to reproduce on will have a tremendous and immediate impact on these species.

I was talking to Dr. Roswell Schaeffer, the Mayor of Northwest Arctic Borough, the other day. Ross is an experienced and respected hunter and he also is a very astute observer. We both mentioned, as we were talking, that we had caught seals but that the female seals that we had caught had shown signs of giving birth but were not nursing. There's no milk in the mammary glands which means that the seal gave birth and for some reason the fetus must have died or aborted so that the seal is not nursing at the time. We both feel that this is because of the very late freeze up this year—Kotzebue Sound did not freeze until February—and they didn't have the opportunity to make dens and therefore aborted their fetuses. We also know that impacts are not just on the marine animals but other species such as fish and sea birds.

Is it just the warming of the ocean temperatures that are causing the thinning of the ice? I don't think so. We are seeing some real changes in the atmosphere as well. The sky is not blue anymore. It is more hazy and whiter and we see lot more wind, winds that are strong enough to affect hunting and fishing in the marine waters. We see our hunters taking greater chances by going out in weather conditions that put their lives at risk. There are also economic costs as the hunters travel greater distances to harvest game, expending more fuel and time. The success rate is also being affected. There are times when hunters will go out and return empty handed because the game was not there or out of reach. These are the effects that have gone unnoticed by the policy makers and scientists. If we didn't have public assistance, Native stores and food stamps, many village people would be in extreme hardship, if not starving. We are resilient people and we adjust readily to change but if that change is too rapid, too disruptive, it causes social chaos, hardship and suffering.

I want to also State at this point, Senator, that there is currently no research on the effects on the people. We are not doing any data gathering on what the people are expending to try to hunt, on harvesting game, and also the success rate or lack of success on how they are being impacted at this stage. I would like to ask that the Arctic Research Commission or others who are involved in Arctic research will recommend more social studies to study the impacts from the climate change.

More wind causes wave action and wave action along the rising waters causes erosion. In the past 20 years we have lost much land to beach and soil erosion. Many subsistence camps have lost land to erosion, especially in areas like Cape Espenberg and Cape Krusenstern. In the decades before where the beaches built up—we've had scientific evidence of beach buildup over the years, thousand of years on some of these capes. We're now seeing loss of land and fairly rapidly.

The other day you mentioned, Senator, that some of the communities like Shishmaref and Kivalina will have no choice but to relocate. While the economic costs of such relocation will be expensive, there are also social costs that will be born by the people for years to come. It is a cost that we cannot measure in dollars and cents. Most people take change too lightly and do not think that people are being affected directly. It is not the severe events such as the hurricane, the floods, the droughts and the unseasonal snowfall that are the major effects of climate change but small changes that will and are having dramatic effects. It seems that we must experience wholesale disaster or economic chaos before the policymakers will take notice. Alexander Akeya, an elderly man from Savoonga said to me in 1996.

> "That is my garden out there. My life depends upon it. If something bad happens to it, we will suffer greatly but the Government will not help us because we are not farmers or fishermen."

And I think that really speaks, Senator, of how the people will be affected if the changes continue the way they are, especially in the last few years where we've seen the rate of ice conditions declining—or receding more rapidly.

What would I recommend? The air that is around us and above us and the waters of the sea are two things that give life to this Earth but yet we abuse them mercilessly. I don't think we really, really understand how thin that life support is. One, we as human beings need to have greater willingness to examine how we are affecting the climate change and minimize the actions that are leading to greater climate change. Second, we need to document and record the economic and other effects of warming on the coastal residents of Western and Northern Alaska. Three, little is being done to observe the effects of the retreating sea ice on the ice-dependent marine mammals and the sea birds. Four, there is little known about the ice-dependent species such as Arctic Cod, Saffron Cod and krill. These are the species that are major food sources for the millions of marine mammals and birds and yet we virtually know nothing about their bio-mass and their status. And, Senator, starvation is a much greater threat to these species than the thinning of the ice because it's quicker and it's more massive and we need to know what potential effects that—the food source may have on these marine mammals. Five, there are changes occurring on the land as well. Beavers are moving in. Large herds of caribou that have been increasing, like the Western Arctic caribou. And it's probably only a matter of time before we see some of these herds crashing. The treeline is moving west and northward. We see more insects, wetter summers and late, late freeze-up.

We must take steps to truly understand the impacts that are occurring and will occur. As leaders, you must give us hope and opportunity to address the problems that will have profound and adverse effects on the lives of individuals and families in the small communities that are so dependent on the natural resources.

I thank you for this opportunity. May God bless you and give you wisdom as you ponder what must be done to address these extremely difficult problems. Thank you, Senator.

Chairman STEVENS. Thank you, Caleb. Dr. Untersteiner. Thank you.

**STATEMENT OF NORBERT UNTERSTEINER, UNIVERSITY OF WASHINGTON AND UNIVERSITY OF ALASKA**

Dr. UNTERSTEINER. Senator Stevens, ladies and gentlemen, thank you for the opportunity to present my testimony here. As we hope to confirm here there is no longer any doubt that significant changes are occurring in the Arctic environment and, especially since the last testimony, there is no need to enumerate the many events.

Without suggesting that greenhouse gases alone are the only cause of all these changes, it still seems appropriate to note the extreme anomaly of our present situation. The first picture shows carbon dioxide, methane and air temperature during the past four major glacial cycles. These four peaks represent 100,000 year cycle of the global atmosphere. These numbers were derived from a many-thousand-meter-deep ice core on the Antarctic Continent. As you can see from the top curve—that shows carbon dioxide loading in the atmosphere—that dot on the upper left is where we are now. It is about 50 percent more carbon dioxide in the atmosphere now than there has been in the last 400,000 years. Well, we're clearly in an anomalous situation and there is no indication that this sharp increase is going to stop anytime soon.

There was a time not long ago when we had to argue that the Arctic is important because most of the North Atlantic deep water is formed east of Greenland and because the boreal forests are a huge carbon reserve and because some of the richest fisheries and marine ecosystems live in the cold nutrient-rich waters of the North. This is all true but, as in so many other fields of human endeavor, we have learned to view the world as one large, complex, interdependent system in which all regions and components are important in their mutual interactions and dependence. The effects of El Niño travel over the whole hemisphere, the dust of volcanic eruptions circumnavigates the Earth, and pollutants and dangerous wastes from human activities travel from the middle of continents to the middle of ocean basins. The Arctic is simply important as an integral part of the Earth that sustains us. It is important because we live here, we need its resources and we are responsible for its well-being. The impressive development of the research done here at the University of Alaska is tangible proof.

The fact that our global environment, especially climate, are changing has created a multi-faceted controversy in which, according to latest polls, about half of the Nation thinks that the environment poses problems that are commensurate with health care and education. Some questions of particular sensitivity are these:

—How much of the observed changes are due to the intrinsic evolution of the climate system and how much is caused by human activities?

—What is the value of international treaties that try to curb the emission of climatically-active agents and pollutants?

—And, third, what are proven countermeasures to climate change and, if they can be identified, what do they cost?

A natural consequence of all this is an increased demand for predictions. The only devices we have to make predictions are mathematical models of the Earth system including the atmosphere, the ocean, the ice and, if at all possible, the vegetation in the biosphere. Before we can trust such models to yield meaningful predictions, we demand that they are able to reproduce with some degree of accuracy the state that we are in today. For the purpose of illustration, we choose one part of that complex entity called climate that is of particular interest to us, that is, the extent of the Arctic sea ice.

Now, climate models have been developed in several countries and the results have been compared to a myriad of direct observations taken during the past two centuries or so and derived from measurements that allow us to deduce past climates. Hundreds of scientists, called the Intergovernmental Panel on Climate Change or IPCC, have issued two comprehensive reports at 5-year intervals, and the third one is about to be issued. For the time being, only a "Summary for Policymakers" is publicly available on the web. We cannot hope to delve into the content of this very extensive report but we would like to illustrate the use of climate models by means of one specific example taken from that IPCC draft.

This figure shows the actually observed maximum and minimum extent of Arctic sea ice on the two bars on the left, for different time periods. The top of the blue bar is the maximum ice extent; the bottom is the minimum ice extent. Across the bottom are acronyms; they represent different institutions at which these models have been developed. And you can see that these predictions are pretty much all wrong and they are all wrong in different ways. You might say that, if we cannot compute current conditions correctly, how can we expect to model meaningful results for future scenarios in which, for instance, the atmosphere contains twice as much greenhouse gas as it does today?

There's a curious aspect to this ensemble of results shown in this figure. The truth reproduced by any individual model is pretty bad but the average result comes much closer to the observed truth than any of the individual models. We know that simple averages are not always meaningful and it remains to be seen if they are in this case.

What the experts do with this kind of information is called "ensemble forecasting." The argument goes as follows: the ensemble forecast is better than each individual because all the models employ the same fundamental physics but they all must take different shortcuts and simplifications and no one models can compute everything to unlimited resolution in space and time. So the differences are, to some degree, comparable to random errors, which implies that their average is some improved approximation to the truth. In other words, there is reason to expect that predictions generated by future climate models will gradually gain in content and reliability, and they will provide an increasingly firm basis for policy decisions.

The basic dilemma of trying to make perfectly correct policy decisions on the basis of imperfect information is, of course, not unique to matters of the environment. Consider, for instance, the stock market: There are many economic models and formulas to predict business and the stock market. To apply the notion of an "ensemble forecast" one could be assured that the individual forecasts are made by comparably rational basis, which seems hardly to be possible when the human psyche is involved.

Yet, despite our minimal ability to predict the economy, government and society as a whole are not afraid to take measures: The Federal Reserve manipulates the cost of credit, large investors have hedge funds and they shift their money from one field to the other in accordance with some probabilistic considerations designed to strike a balance between purpose and risk, and we are all saving money in the assumption that at some distant future the imaginary value printed on it will still be convertible to bread and gasoline. If we are not afraid of attempting to manipulate our gigantic, multi-trillion-dollar economy on the basis of very tenuous principles, why are we so timid about taking measures with regard to our environment?

One can, of course, take the view that we need not worry about the environment. Throughout Earth's history, adaptation has been the operative concept: Organisms that were able to adapt survived and the others became extinct. It was recently pointed out by Richard Lindzen in testimony to the Senate's Environmental and Public Works Committee on the 2nd of May of this year—I quote—". . . a large part of the response to a climate change, natural or anthropogenic, will be adaptation, and adaptation is best served by wealth . . ." This is another way of saying that, if you are an affluent urban-dweller, you don't have much need to worry about it. This is true, but the same message may not play so well in the ears of my esteemed colleague here or a subsistence fisherman in Nome or, for that matter, a rice farmer in Cambodia.

Until we get better understanding of why these changes are occurring and what will happen in the future, there are a number of things we can do and that are, in fact, a win/win approach:

We can turn down our thermostats, down in winter and up in summer and we can build houses with thicker walls and we can install heat pumps, solar panels and wind generators and, most of all, we can drive smaller cars. These changes require no profound political, economic or philosophical reasoning. They are at the expense of no one and benefit everyone.

Thank you.

Chairman STEVENS. Thank you very much, Dr. Untersteiner. Our next witness is John Walsh. Mr. Walsh. I noted your name at the top of that one statement. You were one of the authors of the statement that Dr. Akasofu referred to?

Dr. WALSH. Yes.

Chairman STEVENS. Thank you.

**STATEMENT OF JOHN E. WALSH, UNIVERSITY OF ILLINOIS, URBANA, IL**

Dr. WALSH. I'm presently visiting at IARC. Senator Stevens, ladies and gentlemen, I appreciate the chance to speak to you today. With an eye towards the changes that we have already heard about, I will summarize the projections for coming decades from state-of-the-art global climate models.

First figure. I will show a consensus or an ensemble projection based on eight models from around the world and I will highlight the geographical pattern of the projected changes, the seasonality, and perhaps most importantly the consistency among the models.

Next figure shows the changes in the annual mean temperature projected for the late 21st century by this ensemble of models. The yellow color represents a warming of two or three degrees celsius; the orange, five or six degrees celsius, or nine to ten degrees fahrenheit. This warming is strongest over the Arctic Ocean and the northern land areas and it's stronger there than anywhere else in the Northern Hemisphere. And the warming is generally consistent with the observed trends that Dr. Akasofu showed earlier.

The next figure shows that this warming is not distributed evenly throughout the year. In fact, it's considerable stronger in the autumn and winter. It's smallest in the summer.

The next figure shows an example of the seasonal cycle of the warming projected for the late 21st century. It's for the North Slope of Alaska. January's on the left, December is on the right. The vertical bars represent the ranges among these eight models. The general pattern of a weaker warming in summer and a stronger warming in winter is apparent. But perhaps most importantly all models project the warming. So even though there are large ranges in the rates, all models are consistent in the warming.

The next figure shows the pattern of precipitation changes that are projected by these same models for the late 21st century. The map on the left is for winter; the map on the right is for summer. The green and blue represent increases of precipitation. The amounts in the blue areas are five to six centimeters water equivalent, per season. The largest increases in the winter are projected to occur in Southeastern Alaska. In the summer the largest increases are projected for the northern land areas, especially Central Alaska. This figure, incidentally, on the right shows that the contiguous United States is projected to experience drying. The yellow and the red represent drying. The same is true for Western Europe. So these models in general are projecting a northward shift of the major precipitation belts.

The next figure shows one scenario of precipitation through the 21st century. This is from one of the models. It's fairly typical of the set of eight. The general increase is apparent although there is quite a bit of interannual variability but the interesting feature of this figure is the tendency towards greater positive extremes as one goes through the next century. So the implication is that there will be occasional severe periods with more extensive rains than have occurred in the earlier periods, not only in this model but in the observational data. And these changes in the extreme events are a potentially serious part of climate change and my impression is that they are generally under-researched and especially in the Arctic.

The next figure shows projected changes in the coverage of sea ice from two models. The left panel is for the Arctic; the right panel is for the Antarctic. These are simulations that span two centuries, the past century and the coming century. They were (indiscernible) by observed carbon dioxide concentrations in the past century, projected changes in the future. Both models show a substantial decline of sea ice through the next century in both hemispheres. The decline in the Arctic begins in the last third of the 20th century. By the end of the 21st century the projected changes range from 30 to 70 percent of the current sea ice coverage in the Arctic. The losses in the Antarctic are comparable. These two models generally correspond to the other six that are not shown in the figure.

In connection with the simulation on the left which shows the decline beginning in the late 20th century, it may be worthwhile to look at the observed record in the next figure. This figure shows the yearly sea ice coverage in the Arctic for each season. Each season is in a different color. Summer is green, winter is blue. The annual average is black. There are indications in the observational record that this decrease of sea ice coverage began in the 1950's or 1960's. The decrease is largest in summer. This is consistent with the experience of Arctic residents and it's a message that comes through in every sea ice data set that's been looked at for the last 20 to 30 years, a decrease of sea ice coverage that's larger in the summer and smaller in the winter.

In summary—next—All the models in this ensemble agree that the Arctic will warm. They agree that the strongest warming will occur over the Central Arctic. The warming will be strongest in winter. They agree that Arctic precipitation will increase and that sea ice coverage will decrease substantially during the next century. And, in general, the changes that are projected are consistent with recent observational data. There have been circulation changes that have contributed, at least a portion of the changes, in some variables like air temperature.

Next figure. Finally, the models show less agreement but still some agreement on the rates of change, on details of the changes in precipitation and on the responses of the land surface and the ocean.

Thank you.

Chairman STEVENS. Very interesting, gentlemen. I do thank you all. This is a very provocative panel, as a matter of fact.

The Canadians have been collaborative in some of these efforts of research. Have any of you been working with the Canadians on this subject, the changes in the Arctic brought about by global climate change? Any of you involved with—the Canadians at all?

Dr. WALSH. The Canadian model is one of the most prominent ones and, in fact, some of those sea ice results were directly from the Canadian group in Victoria.

Chairman STEVENS. In terms of our portion of the Arctic, Alaska, in particular, do you feel we have the data and tools available now to reliably predict what's going to happen in the future? You have several different models and have presented a synthesis of those, as I understand it. Tell me, do you think we have the tools available and, if we don't, what could we do to improve them? Yes, Mr. Smith.

Dr. SMITH. Senator, I feel there's room for improvement, particularly in monitoring in support of the predictive models. The difficulties of ground (indiscernible) in Alaska are widely spaced data points, measurements, to confirm the predictions. And monitoring is so tough to fund. The constructing agencies are project-oriented and they're reluctant to invest for the long-term when they build. But I think that you can, perhaps, encourage them to invest in monitoring and expand a network of monitoring stations.

Chairman STEVENS. Any other comments? Mr. Untersteiner.

Dr. UNTERSTEINER. Well, let me choose the example of the ice. It's not a single or two or three kinds of observations that will give us the clue for predicting the ice. This is an extremely complicated question that is all focused on the heat balance of the surface of the ocean and involved in that is the transmisivity (ph) of the atmosphere to infrared radiation, the cloudiness, what types of clouds, at what elevation do most of the clouds occur. These are all things that act together in a very complicated way in order to control what the heat balance is of the surface which then controls whether that ocean is going to freeze a little sooner or a little later so the physics of the entire atmosphere and ocean collaborate to produce this one phenomenon. So this is obviously a thing that requires much more study.

And I couldn't agree more with the point of Dr. Smith, that monitoring is not glamorous and it's extremely valuable and will be needed to a much greater extent than we do now.

And I should say, perhaps especially in the ocean, the technology to make long-term observations have improved—has improved dramatically in the past decade and monitoring the ocean that was once an issue of making many trips with the research vessels is now a matter of buoys that have an enormous capacity to store and transmit data and I think that is a very hopeful direction for future application of technology.

Chairman STEVENS. Dr. Akasofu.

Dr. AKASOFU. You asked us about the computer modeling because IPCC uses many computer models and the computer models is the only way we can predict quantitatively the future and so this is the most important tool and we're trying to improve the computer models by putting the people working on this together. This is the only way we can improve that, working together. So we have been proceeding on this project.

Chairman STEVENS. Well, thank you very much. And I particularly thank Dr. Untersteiner and Dr. Walsh for coming so far to be part of the panel. I look forward to working with you hopefully in Washington some time in the future. I think we're going to continue to pursue this subject and find out how we can start relying on some of these projections and get some basic understanding in Washington of the problem and some of the issues that—some of the solutions we might try to test as to deal with them. Caleb, thank you for coming. Those are tremendous personal observations and we're indebted to you for coming and presenting them. Very clear and very understandable. So we thank you very much.

Dr. SMITH. Thank you, Senator.

Chairman STEVENS. Thank you all, gentlemen. We'll take a 5 minute recess and have a change. The next panel is Dr. Glen MacDonald, Dr. Douglas Martinson and George Newton from the Arctic Research Commission.

Dan Goldin has told me that one of these cameras is a NASA camera and this will be given to the cable industry at a later date, this hearing. We now have a panel composed of Dr. Glen MacDonald from UCLA; Dr. Douglas Martinson from Columbia University who's also the National Academy of Sciences; and George Newton, of the Arctic Research Commission, accompanied by Dr. Gary Brass. Gentlemen, start with Dr. MacDonald, please. Good morning.

**STATEMENT OF GLEN M. MacDONALD, PROFESSOR AND VICE CHAIR OF GEOGRAPHY, UNIVERSITY OF CALIFORNIA, LOS ANGELES**

Dr. MACDONALD. Thank you. Good morning, Senator, and thank you for inviting me to speak here today.

Today I'd like to address two issues. I would like to explain to you the importance, I think, crucial role of paleoclimatic research in understanding natural variability in the Arctic climate system and environment and detecting the impact of climactic warming and, finally, hoping in helping in mitigating the impacts of climactic warming. The second item which I'd like to address today is to share with you some of the results of our research.

I come here today not only representing UCLA but I'm also a Cochair of the Paleoenvironment of the Arctic Sciences Program. This is part—supported by NSF through the Arctic Systems Science and Earth Systems History Programs. And I will be presenting research, then, by my fellow scientists within the PARCS (ph) Program, some working in Alaska and some elsewhere.

We all know that, if we've lived in the Arctic, that the climate here is variable. From one year to the next we may see relatively large differences in summer temperature, winter temperature, precipitation. If you've been in the Arctic a long time or worked in the Arctic a long time you also know that there are differences from decade to decade. For example, in many parts of the North American Arctic the 1960's was relatively cold. The 1980's and 1990's have been extremely warm. So with that background of natural variability we then must ask how can we detect the beginnings of climactic warming caused by greenhouse gasses, increasing methane, $CO_2$, et cetera. How can we know if that warming will exceed the natural variability? And, finally, we might ask, if the Arctic system is prone to natural variability and we must manage, then, an environment and human infrastructure in the Arctic in the face of climate warming, we really have two concerns. One is the warming caused by increasing greenhouse gasses but, second, the natural variability of the Arctic climate which may affect our efforts both on annual, decadal and even century time scales.

So I'd like to illustrate then some of the findings that we have obtained using paleoclimatological approaches. These are approaches in which we reconstruct climate and environment over the past few hundred years back to about 150,000 years for the PARCS community which I represent. We use things like tree-ring records, ice cores, lake sediments, marine sediments, bore-hole temperatures. All of these techniques have been worked on, carefully calibrated, verified, cross-verified by scientists in the United States and elsewhere. We feel that they have reasonably high precision and a reason to be reliable.

Why are they so crucial in the Arctic? Most Arctic climate stations extend back only maybe 50 to 100 years. Their records are short. In addition, their geographic distribution is very sparse. We simply don't have a data base of observational records in which we can look at climactic change over periods of decades or centuries to tell what the natural variability is or to see if we have indeed warmed beyond the natural variability.

Can I have the first overhead, please.

This is a record taken from tree-rings from far-eastern Siberia, just across the pond from us here. What the record shows you at the top is the reconstruction of June temperatures extending back to 1450 AD. What's notable about the reconstruction, of course, is the high amount of variability, both on a decadal and an annual time scale. In addition, what we can see is the 20th century may not have experienced all the warmest years but it is the longest period of prolonged warming when years are above the mean temperature since 1450. It is the longest sustained warm period in our record. This very typical of Arctic tree-ring records. They mainly show us summer warmth and they mainly show us that the 20th century is warmer than the last 400 to 1,000 years.

Below we see that this warming is reflected in the pulse of establishment of trees starting at about 1900. Most of the northern treeline forests in large portions of Siberia, parts of Alaska and northern Canada established in the 20th century as temperatures began to warm. We can also see that between about 1800 and 1850 there was a period of pronounced cooling. We see that this caused the mortality and death of a lot of trees. This is also seen in most treering records that we have from the circum-Arctic region. It shows us that there's natural variability which produced cooling, not on the order or 1 year or 2 years, but on the order of decades.

May I have the next overhead, please.

When we take records like this and we put them together—and this is a paper which I was a coauthor on with a number of other scientists led by Jonathan Overpeck (ph) of NOAA—we can reconstruct, then, a kind of circum-Arctic temperature index. This reconstruction required the use of tree-rings, lake sediments, ice cores, marine sediments and other forms of paleoclimatological data, all carefully cross-checked, verified. The paper was published in Science Magazine. You can see the geographic distribution of the sites below and they include sites from Alaska.

What you see at the top is the record of Arctic climate warming. The black line is temperature and you can see—and the units it gives are sigma units—but it basically shows the 20th century had a 1 to 1.5 degree warming compared to earlier centuries. You can see the record is then compared to $CO_2$, methane, natural variability and solar output and, finally, volcanic eruptions.

And what we see from this record are two very important factors. First of all, long-term variability and evidence that the 20th century has been warmer than any of the preceding four centuries. Second, we see the impact not only of $CO_2$ and methane but in the natural variability. The decrease in temperatures, for example, following the 1950's was coincidental with the decrease in the output from the sun. So there is natural variability on top of this record as well as the greenhouse warming. In the future we will have to be able to anticipate both that natural variability and the increased warming due to greenhouse gasses.

How does that compare, then, with other studies? Is this just a one-off? May I have the next overhead, please.

PREPARED STATEMENT

This is a comparison published this year by Keith Briffin (ph) and a number of scientists from throughout the world. It compares the record I just showed you, which is the Overpeck, et al., record, with a number of similar records taken from Arctic regions and from areas of the Northern Hemisphere north of 20 degrees North. And it provides a broad overview of Northern Hemisphere temperatures over about the last 1,000 years, including the Arctic. And there are two salient features that I want to draw your attention to. First of all, the 20th century is warmer, particularly the last two decades of the 20th century, than any of the preceding 1,000 years. This is an exceptional event. Second, we can see that there's considerable long-term variability in the climate as well as short-term variability, a period of cold, for instance in the 1600's, the period of cold in the early 1800's that I told you about, as well as warm periods around 1200 years ago. The causes of these natural long-term climactic variations are still poorly understood. Their geographic expression is still poorly understood. But what we do understand is they are there in the past; they will be there in the future. And paleoclimatology, particularly in the Arctic, provides us, really, the only tool that we have to find these long-term changes in climate and address them.

Chairman STEVENS. Thank you.

Dr. MACDONALD. Thank you.

[The statement follows:]

PREPARED STATEMENT OF GLEN M. MACDONALD

I thank Senator Stevens and the members of the Committee for this opportunity to testify today. My name is Glen MacDonald and I am a Professor and Vice Chair of the Geography Department at UCLA. I am also a Professor of Organismic Biology, Ecology and Evolution at UCLA and a member of the UCLA Institute of the Environment. I have recently been named as a co-chair of the Paleoenvironmental Arctic Sciences Program (PARCS) sponsored by the National Science Foundation (NSF). PARCS is supported by both the Arctic Systems Science (ARCSS) and Earth Systems History (ESH) Programs of the NSF. I am here today to present testimony regarding my own research on past, present and future patterns of climate change in the Arctic and the findings of allied research by members of the PARCS community and others. I will also present a synopsis of research imperatives for Arctic climatic change that have been identified by the PARCS scientific community.

THE IMPORTANCE OF PALEOCLIMATIC RESEARCH FOR UNDERSTANDING FUTURE ARCTIC CLIMATE CHANGE

I do not need to inform the Committee about the importance of understanding if Alaska and the Arctic are warming due to increased atmospheric concentrations of greenhouse gasses such as carbon dioxide and methane. That atmospheric concentrations of such gasses have increased significantly over the past 150 years because of human activity is indisputable. Analyses of climate model experiments indicates that the Arctic is particularly prone to warming related to increased atmospheric concentrations of greenhouse gasses. Warming by a few degrees in temperature in Alaska could lead to changes in plant and animal distributions, vegetation structure, permafrost conditions and sea-ice conditions. Such changes would require significant adjustments in subsistence practices of native peoples, engineering for large scale resource development and conservation planning. In addition, computer models of global climate indicate that changes in the Arctic, such as northward shifts in the geographic position of treeline, degradation of organic soils, and decreases in sea-ice cover, have the potential to enhance global climatic changes. How can paleoclimatolgy (the study of past climates) help us to detect it the Arctic has begun to warm due to increased greenhouse gasses, and help us to anticipate and mitigate the impacts of global climate warming in Alaska and other areas of the Arctic?

Paleoclimatic studies provide records of past climatic changes and the impact of those changes on the environment. The Arctic paleoclimatic research I am speaking of today examines climatic changes over the last several hundred years and as far back as about 150,000 years ago. We all know that weather varies from year to year. Some years are typified by very cold conditions, other years may be unusually warm. We also know from our own experiences, and from instrumental meteorological records, that climate can vary from decade to decade. For example the 1960's were a period of relatively cold temperatures in the North American Arctic. Finally, we can observe that a year of warm or cold temperatures in the Alaskan Arctic may correspond to a period of average or even warmer temperatures in some other regions. The inherent variability that we can observe in the climate system raises two important questions. First, what are the causes of such inherent variability in climate and how might they influence future climatic conditions in the Arctic? Second, if the Arctic climate is prone to significant natural variability from year to year or decade to decade how can we determine if there is a pattern of Arctic warming that can be attributed to increases in greenhouse gasses?

In order to detect the influence of increased greenhouse gasses on climate today and in the future we require very long records of temperature so that we can perceive general trends of warming despite the natural variability in climate. Long records of climate also allow us to determine if the rates and magnitudes of current or future warming exceed the natural variability that existed prior to the increase in greenhouse gasses. Unfortunately, there are few weather stations in the Arctic that have been in existence for more than fifty years and a relative handful that have existed for even 100 years. The geographic network of weather stations in the arctic is sparse and the records that are available are relatively short. Thus, we cannot determine from weather stations records the full range of natural variability in Arctic climate or assess if the climate has become unnaturally warmer due to increased concentrations of greenhouse gasses in the atmosphere.

Given the short duration and geographically sparse nature of weather stations in the Arctic, how can we reliably detect if the region is warming? A number of paleoclimatic techniques can provide detailed records of past Arctic temperatures that extend back hundreds to thousands of years. Sources of such records include tree-rings, fossils and geochemical evidence from lake, ocean and peatland sediments, and evidence from cores of glacial ice from places such as Greenland. The paleontological and geochemical techniques used to analyze these records and obtain estimates of past climatic conditions have been carefully developed over decades, continuously cross-checked, and then verified against reliable meteorological records. I take pleasure in saying that scientists from Alaska and throughout the United States have been at the forefront of this work. The paleoclimate records we have obtained allow us to place recent climate changes into the context of natural variations in climate that have occurred for hundreds to thousands of years.

There now exists a number of individual studies and syntheses of Arctic paleoclimate research that bear directly upon the questions of natural variability in Arctic climate and the detection of present and future warming due to increased greenhouse gasses. My own paleoclimatic work has focused upon analysis of tree-rings and the analysis of fossils and geochemical evidence from lake and peatland sediments. Our sampling network extends from western and central Canada to northern Eurasia where we have sites from the Finnish-Russian border to far eastern Siberia. I have also been involved in syntheses that incorporate data from other researchers working across the Arctic, and include sites from Alaska. I will review the findings from my own work and relevant work of others below.

NATURAL VARIABILITY IN CLIMATE AND EVIDENCE OF RECENT ARCTIC WARMING

From my own work in Canada and Russia we have developed a circumpolar geographic network of climatic records that extend back in time from 200 years in some cases to over 13,000 years in other cases. Many of these records provide information on past summer temperatures. Summer temperatures are particularly crucial for plant and animal life in the Arctic, permafrost development and the state of organic soils. Here I will concentrate on the evidence from our tree-ring studies.

Our analyses of tree-ring records, some of which extend back approximately 1,000 years, shows that the Arctic climate of the past few centuries has been typified by a high range of natural variability in summer temperatures on annual, decadal and centennial bases. In many cases, annual variability is relatively localized. A cold summer in Alaska does not always correspond to a cold summer in northeastern Canada or Northern Finland for example. In addition, the tree-ring records show that decadal variability in temperatures has been a persistent feature of the Arctic climate. The tree-ring records, and evidence from analysis of lake and peatland sediments, also show that there have been long-term fluctuations in Arctic climate. Some of these periods of warmer or cooler conditions persisted for several decades, some for several centuries. Some of these long-term fluctuations are apparent for much of the Arctic, others are apparent only in some regions and not in others. In some cases the onset of long-term changes in climate have been very rapid, occurring over a period of years to decades. These long-term variations in temperature have had a significant impact on the Arctic environment. For example, most of the North American and Eurasian Arctic experienced colder summer temperatures during the period AD 1800 to about 1850 than the preceding several centuries or during the subsequent 20th Century. In general, average summer temperatures during this period were 1° to 2° C cooler than the long term average over the past 500 years. This long, multi-decadal, period of cooling resulted in increased mortality and decreased regeneration of treeline spruce and larch populations at high latitude and high elevations sites in both North America and Eurasia. Determining the cause of such long-term fluctuations in climate requires further evidence of their timing and geographic occurrence.

The tree-ring records provide clear evidence of the natural variability of Arctic climate at a number of time scales. What do they tell us about warming during the period of dramatic increases in atmospheric greenhouse gasses in the 20th Century? Our tree-ring records, from sites located in the Yukon, the Northwest Territories, northern Russian and northern Siberia, all indicate that the 20th Century has experienced the highest sustained high summer temperatures and/or the longest period of sustained high summer temperatures for the last 200 to 1,000 years (some sites have records that only extend back 200 years while others extend back about 1,000 years). In general, the average summer temperature of the 20th Century has been 0.5° C to 1.5° C higher than the long-term mean temperatures recorded by our Arctic tree-ring records. More significantly perhaps, we often find that the high summer temperatures measured at many Arctic weather stations for the 1980's and 1990's are unprecedented. In summary, our tree-ring records indicate that the 20th Century, and particularly the last two decades of the 20th Century, have experienced summer temperatures that are anomalously warm. Our records also show that the warming over the 20th Century has resulted in increased tree regeneration at treeline sites.

How do the results and conclusions reached by my research group compare with other independent studies? There are now a number of synthetic studies that combine tree-ring data, and in many cases data from lake sediments, marine sediments and glacial ice cores, in order to produce long and robust records of Arctic temperature changes over the past 400 to 1,000 years. These records are drawn from many regions of the Arctic, including Alaska, and furnished by many independent scientists from the United States, Canada, Great Britain, the Fennoscandian countries and Russia. These studies may use different combinations of data and different analytic techniques, but they have arrived at a common conclusion—large scale syntheses of Arctic paleoclimatic data indicate that for the Arctic as a whole the 20th Century was the warmest period in the past 400 to 1,000 years. The various estimates provided by these studies suggest that during the 20th Century the Arctic has experienced average summer temperatures that are about 0.5° to 1.0° C higher than the long term mean for the past 400 to 1,000 years. Similar synthetic studies have been produced for northern hemisphere temperatures and global temperatures and produce roughly similar results.

Although the evidence of Arctic warming over the 20th Century is pervasive and to my mind convincing, we must ask if this recent warming can be attributed to increasing concentrations of greenhouse gasses? A number of studies, using paleoclimatic data and coupling such data with computer models of climate have tackled this question. Some of these studies, including one I have been involved in, have focused on the Arctic, others have been more global in extent. The consensus from such studies appears to be that the high temperatures of the 20th Century represent a combination of natural and human caused factors. Part of the warming can be attributed to natural increases in solar radiation. Part of the warming can be attributed to decreased volcanic activity and subsequent decreased concentrations of volcanic aerosols in the atmosphere. However, a significant proportion of the warming over the 20th Century (perhaps 20 percent to 40 percent) appears to be attributable to human caused increases in greenhouse gasses. The impact of these gasses on warming appears to have increased as the 20th Century progressed and concentrations of such gasses has increased.

It is my conclusion that the evidence for greenhouse warming in the Arctic is substantial and convincing. The questions that now arise are: (1) how will natural short-term and long-term variability of climate interact with this warming to affect the Arctic environment over the next century, (2) will this warming exceed the natural maximum rates and magnitudes of warming that are apparent in the geologic record covering the last 150,000 years (the last time the earth was as warm as today was about 125,000 years ago), and (3) how will the warming of the Arctic in turn influence global climate in the future?

RESEARCH PRIORITIES ON ARCTIC PALEOCLIMATE

The research reported above, and most of the associated work done by other U.S. scientists, has been supported by the NSF. In particular, the Arctic Systems Science Program (ARCSS) of the Office of Polar Programs and the multidisciplinary Earth System History Program (ESH) have been crucial in promoting American research and scientific leadership on issues of Arctic climate change and its impact on Alaska and beyond. Despite relatively modest budgets these programs have led to the generation of scientific information that has had profound national and international impact. The Paleoenvironmental Arctic Sciences Program (PARCS) that is sponsored jointly by ARCSS and ESH has identified a set of research imperatives aimed at applying paleoclimate research to answering some of the most significant and difficult to address questions confronting us regarding global warming and the Arctic. These questions revolve around the timing, rate, geographic extent, impact and causes of past climate changes. The research imperatives we have identified reflect the fact that future climatic changes in Alaska and the Arctic will combine both natural variations in climate with changes caused by humans such as increased concentrations of atmospheric greenhouse gasses. By understanding these past changes and their causes we can better anticipate and manage the impact of future natural and human caused climate change in Alaska and the Arctic in general.

*Imperative 1.*—We need to further document the temporal and geographic patterns of multi-decadal to centennial fluctuations in the Arctic climate. Such long term fluctuations can have a profound impact on the physical, biological and human systems of the Arctic. Without knowing their periodicity and geographic extent we cannot know their causes or anticipate their future occurrence.

*Imperative 2.*—We need to determine how fast climatic changes can occur in the Arctic. We also need to evaluate what natural climatic forces cause rapid changes in Arctic climate so that we can anticipate such 'climatic surprises' and their impact on nature and people.

*Imperative 3.*—We need to evaluate how sensitive the biological and physical environment of the Arctic has been to past long-term climatic fluctuations and to rapid changes in past climate. By knowing this we can anticipate and mitigate the impact of future climatic variations.

*Imperative 4.*—We need to understand how those elements of the Arctic environment that are important to global climate, such as the location of treeline, the rate and amount of carbon storage or methane release for Arctic soils, and the extent of sea-ice, have responded to past climatic change, particularly earlier warm episodes, and those elements have influenced climatic change at a global scale.

The research imperatives listed above can all be addressed using carefully analyzed networks of tree-rings, lake and peatland sediments, marine cores and ice cores from Alaska and the rest of the Arctic. The United States possesses unique expertise in Arctic paleoclimatic research that has been developed over several generations. We have led the way in collaborative research with other Arctic nations, particularly Russia. However, we face significant challenges in our attempts to meet these imperatives and maintain our leadership in Arctic paleoclimatological research. The costs of logistics for work in Alaska and the Arctic have increased, the costs of supporting graduate students, post-doctoral students and research assistants have increased, and as research techniques have become more refined the costs of equipment and analyses have increased. The research funding for Arctic paleoclimatology has not kept pace with these increases and our level of research activity in Alaska and throughout the Arctic has suffered. Our relative leadership in international paleoclimate research in the Arctic has also suffered. As I hope I have demonstrated, U.S. Arctic paleoclimatology researchers have developed sophisticated techniques and made crucial contributions to detecting and anticipating the impact of climate warming that could not be made by any other scientific approach. They have identified crucial areas of research that need to be undertaken to understand future climate change and manage and conserve the resources of Alaska and the Arctic. I hope that these important efforts can be maintained though increased support to the NSF and to the ARCSS, ESH and PARCS programs in particular. I thank you for your consideration.

**STATEMENT OF DR. DOUGLAS G. MARTINSON, LAMONT-DOHERTY EARTH OBSERVATORY OF COLUMBIA UNIVERSITY, PALISADES, NY**

Chairman STEVENS. Dr. Martinson.

Dr. MARTINSON. Thank you, Mr. Chairman, for allowing me this opportunity to speak to you about this very important and often overlooked topic.

What I'd like to do is describe characteristics of the Arctic that make it so important in—actually, in global climate. You've heard a lot of the change that's going on in the Arctic and we know it's important but I'd like to put it in to some of the broader context, though I think the comments by Caleb, Mr. Pungowiyi, were probably the comments that put it in the most relevant context.

Before I go into those details, I'd like to make a comment that—this business about getting an observing system. We are in desperate need of a climate-observing system, of which the Arctic needs to be at the very heart of this observing system for reasons I hope to explain in a moment. But we are desperate for such an observing system. We need good solid records. This is an entire game of detecting signal from noise, ultimately finding subtleties in climate variations that might lead to fingerprints that help us identify natural from anthropogenic warming. This is certainly one of the goals of all these studies. And there are a number of national and international efforts underway to outline what are the issues we need to study, what are the observations we need to make on a regular, coherent, consistent basis and what sort of field programs do we need to conduct in order to understand the processes to represent them in the models better. And I would hope an outcome of some of this would be a very strong U.S. leadership in these efforts. We have an excellent polar program in the United States here and we work well with the other countries and these various international efforts are putting a lot of effort to try to establish what needs to be done. Scientists from around the world—and we're all speaking with one voice. It's actually very rewarding to attend these meetings and hear around the table, around the various Nations, "Yes, this needs to be done." It's not in that Nation's backyard but everyone recognizes this as an important characteristic. And so anyway, with that.

Let me talk a little bit about the Arctic and why is the Arctic so important to studies of global climate. If I can have that next.

Well, one obvious thing—you may be aware that the Arctic sea ice cover has long been identified as a potential early warning indicator of greenhouse warming. All right. And the reason for that is three-fold. One reason is because the sea ice is so highly visible and easy to observe from space and, as a consequence, presumably—and this has been borne out, shown to be true—we can monitor it from space and see how it varies and use that as an indication of whether or not we have warming.

But there's a couple of other reasons. This—next slide, please. This highly visible ice cover, which is typically three to four meters thick—or used to be—and is very extensive—an area on the right panel, the winter sea ice coverage, that's an area about the size of the United States, maybe just a tad bigger—and in the summer it melts back to just over half that size—that this highly visible sea ice cover is also very, very sensitive to warming. One thing we have in the Arctic that is quite different from the Antarctic—the Antarctic has the ice gross and the case cycle is strongly modulated by its interaction with the ocean. And the Arctic, because we have so much fresh water entering from the Siberian side and the various rivers that flow into this enclosed basin, the ocean stratification is such so that the interaction with the ice is minimal. And as a consequence one might presume that changes in the ice cover are more or less a direct consequence of changes in the atmospheric forcing, the air temperature, the winds—winds play a tremendous in the ice distribution.

If I can have the next. But in addition to the fact that we expect the sea ice to be sort of a sensitive indicator of atmospheric warming, there's another reason why we point to the Arctic for an early warning indicator and that's something we call polar amplification. Now, you saw this earlier in the morning's panel, the very strong amplification or projected amplification of atmospheric temperatures in the polar regions of the models. These models show over and over and over again a tremendous amplification in the polar regions. However, it's not just a model effect. This also shows up in the observations. And, here, I've taken the global data set, put together from Jones, et al., that shows the distribution of air temperature, surface air temperature around the globe. And if you separate out the air temperature south of 65 degrees North, which is plotted in the blue line—so that represents sort of the non-polar regions of the world. And you look at the change in annual average air temperature around the world outside the Arctic region and, then, you do the same thing with the temperatures from 65 degrees North and higher—and that's the red curve. And what you see is these two curves show more or less the same pattern. But the polar region tends to exacerbate anything that's going on elsewhere in the world. It's just done stronger in the Arctic. So when we have warming up here, as you can see in the last century, we have even more warming in the Arctic. And when we have cooling, we have even more cooling in the Arctic.

Now the interesting thing about this is that, as Dr. MacDonald said, one of the things we're trying to do is an issue of detecting signal from noise. We have a tremendous amount of natural variability and we're trying to find a very small signal of climate change emerge from that. And one of the reasons for targeting the Arctic is with polar amplification hopefully we'd start to see a warming signal emerge in the Arctic regions before we see them elsewhere. That's another reason why we've targeted the Arctic as an early warning indicator. Of course, what I'm saying—nothing I'm saying leads to distinguishing early warming in the Arctic as being differentiated from natural from anthropogenic. And, in fact, the results, the Overpeck, et al., results that Dr. MacDonald showed up there, show that this polar amplification clearly goes back in time during natural variability as well. So it's not just an artifact of anthropogenic warming, though people are certainly putting a lot of effort into determining "Is there a unique Arctic signature to anthropogenic warming that doesn't show up in natural warming?" And there had been some tantalizing finds that that was the case but further studies suggested that they weren't the most robust indicators of diagnosing this problem.

So for those reasons there's been a certain amount of—a lot of attention and excitement over changes in the Arctic by the global climate community, not just the polar scientists, though it's always encouraging to us that there's so much change going on in the Arctic. It certainly makes it interesting, though, of course, people's lives are disrupted. "Interesting" might not be the appropriate euphemism.

Now, with that polar amplification and sort of the role of the Arctic, let me give a little background information, if you don't mind, as to why we might even expect the Arctic to play a role in global climate.

May I have the next. First of all, I'm going to grossly oversimplify the Earth's climate system with just this visual and the next one. And, essentially, what it shows is in the Equatorial regions, as people that live up here in Alaska are aware, at least as we go farther north, you have the incoming solar radiation from the sun, the primary source of heating to this Earth, certainly for our climate. That's just directed dead on to the Equator, a very intense beam, just like taking a flashlight and aiming it straight down at a table. You get a very concentrated beam of solar radiation and it's very effective at heating the planet down there. As you go farther up on the spherical Earth those same incoming beams of solar radiation get spread out. They're hitting the Earth at an oblique angle and they get spread over broader area and, as a consequence, the heating is less efficient. And, of course, when you finally get to the polar latitudes, it's spread very thin and, in the wintertime, of course there's no solar radiation at all except at the fringe of the Arctic region.

Now, what the consequence of this is, as you all learned in high school we get an excess amount of heat at the Equator and a deficit of heat at the Poles. This leads to a very strong temperature contrast between the Equator and the Pole and, in the most simplistic—I apologize to my distinguished colleagues here—in the most simplistic presentation of what climate is: Climate is nothing more than the Earth's attempt at distributing the excess of heat at the Equator to the heat-starved polar regions. That's it. And the broader this great (indiscernible) qualifiers at the mid-latitudes, of course, play a role in this, too. The stronger the gradient the more energetic the system can become and excess transfer of heat from the Equator towards the Poles and the rotation of the Earth, that's what drives the climate system and the circulation and all the interesting varieties of climate that we have. So for this reason one might expect that changes in the polar regions which change the Equator to Pole temperature gradient may, in fact, lead to changes in global climate. Taking into account this oversimplification but people are aware of the impact of that.

Now, if I can have the next one. Another thing. What about the sea ice? What role does this sea ice play in this regulation of the polar temperatures? Well, the sea ice plays a very important and interesting role in the physics of the system. One, as any of you know that have spent any time walking outside on a bright sunny day in the snow, the sea ice and the snow cover is highly reflective surface, very reflective. Therefore, what little sunlight is getting in, a huge fraction of it, 80 to 90 percent of it, is reflected back into space because of this highly reflective surface. And, as a consequence, the solar radiation is less effective in warming the polar regions because of this albedo effect. That's the reflectivity of the ice, known as the albedo. Twenty to 80 percent—I'm sorry—80 to 90 percent of it's reflected back but the ice actually very often has cracks in between the flows, as you can see in the photograph there which was from an Arctic experiment we had called SHEBA. A couple of years ago we occupied a site for a year up in the Central Arctic near the North Pole. And these cracks, which are known as leads where the open ocean appears—and the open ocean is a dark surface. It is as effective in absorbing solar radiation as the ice is in reflecting it. So wherever there's water suddenly about 80 percent of that incoming solar radiation is absorbed. So we get tremendous amount of change in the ability to heat the surface when there's water instead of ice. And you can imagine, because of this extreme contrast in the reflectivity between those two surfaces, if you displace a little bit of ice with water, you'll have a tremendous difference in the amount of absorbed solar radiation, therefore, the warming.

Another important aspect of the ice is it serves to insulate the relatively warm ocean water from the frigidly cold atmosphere. It's like having a well triple-glazed glass windows to your house. The ocean water, of course, cannot be colder than the freezing point which is a couple of degrees, minus two degrees centigrade, say, on average. And the atmosphere can be minus 30, minus 40, up there, degrees centigrade. And effectively this ice prevents a direct contact of that warm water from the atmosphere and, if you remove the ice, like opening the windows to your house in the wintertime, the heat would leave the water, go into the atmosphere, immediately warm the atmosphere, and you're talking something like a 40 to 70 degree temperature warming. Because thermal capacity to water is so much, it would overwhelm the atmosphere and it would dominate the temperatures. And as long as we have that ice there that's what permits the temperatures to be so frigid in the Arctic. As far as the atmosphere is concerned, the Arctic looks like an ice-covered continent, except for these small amount of leads which maybe occupy a half to 1 percent of the entire Arctic ice cover. So the distribution between ice and water plays a tremendous role in the atmospheric temperature over the Arctic and, of course, the circum-Arctic region surrounded by this ice cover.

Can I have the next. Now, I'm not going to go through this in detail because Professor Walsh already showed the composite curves that go into this but, of course, you have seen that the sea ice extent is undergoing fairly dramatic changes. I'd say in the last two decades on average the NASA scientists have shown that on the last two decades it's disappearing at a rate of about 3 percent per decade relative to the 1970 values. And Professor Walsh and his team have reconstructed or attempted to reconstruct ice extent all the way back to the beginning of the last century and you can see, as he said, that since the middle of the last century this decrease in the ice cover seems to have been taking place.

Next one, please. So, of course, we're dramatically changing the balance between water and ice and that's one of the reasons why we expect to see a polar amplification in this region and enhanced warming, particularly in winter. In the winter the only source of heat to the polar atmosphere is from the ocean. In the summer it's the sunlight. In the winter it's the ocean. And that insulating cover of the ice serves very well to keep the heat in the ocean.

Now, in addition to a retreat of the ice cover, we also have indications from a lot of good studies that have recently been done that the ice is also being reduced in its thickness. And their best estimates, which are a little tenuous, but the best estimates show that it's being decreased on the average of maybe 40 percent over the last several decades. So it's getting thinner and it's getting less extensive. Some of the modeling results, and as is pointed out—Dr. Untersteiner pointed out that the models have a lot of problems, which is true and that's why we're trying to understand the system better to improve the models among other things—but one of the things is the good modelers know how to take advantage of the model strengths while circumventing their weaknesses. And when they do that and do a comparison between some of the better model results and the observations, it looks like the ice that is disappearing is the thicker, multier (ph) ice. And the interesting thing there is there's been a number of studies, theoretical studies on energetics of the system and modeling studies. And these both agree, these different approaches agree, that there's an interesting phenomenon here in the Arctic. And that is the system seems to be able to exist in one of two stable States. One stable State is the current one where we have a perennial year-round thick ice cover. The other stable State is where the winter ice cover is gone and we essentially only have ice in the summer. That's a seasonal sea ice cover which is typical of the Antarctic region. And according to these studies what happens is, because of the energetics of the system, as you start to melt the perennial ice cover and make it thinner and less extensive because of these feedback mechanisms I just mentioned about the—you start to absorb more heat in the ocean and that starts to warm up the regional atmosphere which melts more ice, absorbs more heat, melts more ice, et cetera—Well, because of that what happens is, once the perennial ice starts to retreat, these studies suggest that you'll hit a threshold and that will—retreat will continue on much faster and the system will tend to transition to the other State which, in this case, would be transition from the perennial ice cover to a seasonal ice cover. Obviously, the implications of that to the native people and the wildlife is fairly severe but I don't want to just sit here and do as it's often tempting to do and yell that the sky is falling. But presumably, as Dr. Smith said, that, "Yes, accompanying climate change, as well as there being negative effects, there is a very strong potential of having benefits." But in order to reap those benefits, we need to anticipate the changes and, if we have to make infrastructure changes, put those in place in order to take advantage of the beneficial changes that accompany this change.

So—if I can have the next slide—in addition to the changes in the sea ice cover, which are most obvious and they're the easiest to document and observe, there have also been a great number of other changes going on in the Arctic Region. And these have been documented by a number of scientists who have been studying Arctic change. There's a new program called SEARCH, the search for Environmental.

Mr. NEWTON. Environmental Arctic Change.

Dr. MARTINSON [continuing]. Thank you. Yeah. It's called "SEARCH." Anyway, this program has gotten a collection of people together in an effort to identify the various changes that have been documented so far, with this sort of poor sporadic data set, and to work out what are the remaining issues that we have to resolve in order to improve our understanding of this system and where it might go in the future. And these changes are very tantalizing. Some of them are listed there on the right. The expansion of what we call the "Atlantic layer," warm salty water from the Atlantic, the subtropical Atlantic, works its way up into the Norwegian Sea and eventually works its way into the Arctic. And as it cools, it sinks down and makes a layer that is below the surface layer of the Arctic Ocean and that helps set the stratification of the ocean and it's the stratification that allows it to form an ice cover. Absolutely—the ice cover is absolutely intimately coupled to the stratification of the ocean. You change the stratification of the ocean and you change the ability of the Arctic to support an ice cover. And we've seen that this Atlantic layer has gotten warmer. It's gotten saltier. Loss of cold halocline layer, I'm sorry I didn't decode that one. That is a special insulating layer that lays above the Atlantic layer and below the surface layer, that layer that's in direct communication with the atmosphere. And that cold halocline layer is a very effective insulator that keeps the warmth of the Atlantic layer away from the sea ice that sits on the very top of the ocean. That cold halocline layer, that insulating layer, has disappeared in the 1990's in the vicinity of the North Pole. And our estimates are that, with the loss of that layer, we would expect the ocean to contribute a considerable amount of ocean heat to the ice such that the ice growth will be reduced by something like 80 percent in the wintertime. I'm not saying the entire net thickness will change but the ice that normally would grow in that region near the North Pole, 80 percent of that will not grow because of this ocean heat flux. All right. And we also, of course, I've already mentioned the decrease of the sea ice cover of 3 percent per decade. Another interesting observation is that the snow cover in the circum-Arctic, the continental region surrounding the Arctic—the snow cover's also disappearing at a rate comparable to the sea ice. It's going at about 4 percent per decade. That number's not as well known because the snow is a little harder to interpret. There's been a tremendous difference in the storm tracks. The storms are now originating in different locations. They're becoming more intense and they're more frequent. And the ocean circulation is changing with the overlying atmosphere and it's doing it in such a way that the fresh water input from the rivers, particularly the Siberian rivers, is being rerouted to different parts of the Arctic and this is having a very important influence on the stratification of the ocean, again. And as I said, that'll impact the sea ice and the circulation of the system.

So the interesting thing about having an ensemble of observations like this, even if they're a little tenuous because we don't have the most solid long-term coherent data base, is these observations add all sorts of texture to the problem. It's like diagnosing an illness. It's one thing to say you have a rash. It's another thing to say you have a rash, your white blood cell count's through the roof, et cetera. The same thing with this. When we get all these things, they seriously constrain the hypotheses we can advance to explain what's going on in the Arctic and how it's responding to this global warming. And these things are invaluable in adding these different insights. They give us all sorts of different—well, they keep us honest because, if we understand it—well, we hope we're honest anyway but we—if we understand the system properly, we should be able to predict or at least anticipate all of these changes with our interpretations that we put forth.

If I can have the next one. Now, Dr. Untersteiner mentioned the shutdown in the North Atlantic deep water. The North Atlantic deep water originates where that big green X is. And, essentially, what happens is water from the North Atlantic that drifts up there and cools, as it cools, it becomes denser and it sinks. And from there, it starts to follow that blue path. It travels around the world and, when it sinks, it takes up $CO_2$. It takes up nutrients, all sorts of various quantities. And it more or less stores those in the deep ocean reservoir where that reservoir is not exposed to the atmosphere for sometimes thousands of years. The water makes its way into the Pacific where eventually it's up-welled to the surface and it slowly makes its way back to that starting point following the red arrows. Now, my fellow oceanographers are fairly loathe to sometimes show this figure because it's felt that it grossly oversimplifies a very complex system but it certainly conveys the essence of the system. And one of the—well, as Dr. Broker has called it the Achilles Heels of climate, is the thought that, if we change the sea ice that's exported from the Arctic into the North Atlantic, that sea ice, when it enters the North Atlantic or the regions where North Atlantic deep water is produced, it tends to melt. That freshens the surface and the fresher the surface is the less likely it is to sink. And there's the possibility that if we altar the Arctic climate system that ice will change, the fresh water at the surface will change and we have the possibility of shutting down what this conveyor belt, which is called the thermal hyaline circulation. Now, the implication there is that it's—warm water's the Gulf Stream which you all know of or have heard of. The Gulf Stream is subtropical waters that flow along the eastern seaboard of the United States, break away and, then, continues across the ocean up into the Norwegian Seas there and it's relatively warm subtropical waters and it's been long assumed that it's that heat from the subtropics that's what keeps the United Kingdom and Northwestern Europe so anomalously warm during the wintertimes. And if we shut down the North Atlantic circulation, the North Atlantic deep water circulation, we're not going to be pulling that warm water up there. And as a consequence, there's the potential of abruptly sending some of those regions into colder climates because you won't be having this warm water bringing the heat up. That theory, actually, is being called into question just recently by a number of scientists that are saying actually the United Kingdom and Northwestern Europe are not anomalously warm; in fact, it's the Northeastern United States that are anomalously cold. So they're saying that what keeps the United Kingdom and Europe warm is the presence of ocean water. And whether it's a couple of degrees warmer because it comes from the south, from the subtropics, or whether it's just sort of resident temperatures up there, it still contributes a lot of heat to those regions and would not necessarily have a big impact. Of course, this hypothesis stems from some of the paleoclimate records Dr. MacDonald referred to. Those records, indeed, show dramatic what we call abrupt warming events through time and people have ultimately tracked it back and assumed or have worked out that the cause of those abrupt warming events were due to the shut down of the thermal hyaline circulation that I've just referred to. And that's why this has often been targeted as something that we're sort of nervous about.

PREPARED STATEMENT

So that, with that—if I can have the next one—getting on to projections for the Arctic as you were interested in—and Dr. Walsh covered this, I thought, very nicely. In fact, we're more or less dependent upon the models. And the models have a lot of flaws but the models also have a lot of strengths. There you can see some of the model trends. This is actually from a paper that Dr. Walsh was one of the coauthors on. And you can see some of the observations and dots and certain trends that Dr. Walsh and others have computed are straight lines on there, like that straight blue line. And effectively what all of the models show more or less across the board is that, if we continue to have global warming, the ice will continue to melt. And most of them, as I said, because of this polar amplification, the ice will start to melt even at a faster rate. And in order to, I would say, flesh that out with more detail and better estimates, we need to be able to represent the detailed processes, these feedbacks between the ocean and the ice better. The clouds, they're a constant source of trouble. And we need to understand the feedbacks. If you remove ice, you expose the ocean and the water of the ocean to the atmosphere and you can evaporate it up and make more clouds. And the clouds, they come in and they serve as an umbrella; they shade the surface and they make it cooler but, at the same time, they absorb heat and they tend to radiate this heat downward like a warm thermal blanket. And the polar regions, which are rather unique, seem to have a different response to the clouds than some of the other areas on the Earth. The results of our SHEBA study a couple of years ago seem to suggest at this early stage that the insulating blanket wins. It seems to have more of an effect than the umbrella effect of the clouds.

So, with that, I will close.

Senator STEVENS. Thank you very much. Mr. Newton.

[The statement follows:]

PREPARED STATEMENT OF DOUGLAS G. MARTINSON

Mr. Chairman, Thank you for giving me this opportunity to present my impressions on Climate Change in the Arctic at this hearing. My name is Doug Martinson. I received a Ph.D. in 1981 from Columbia University on paleoclimate (studying the Ice Age cycles, and considering the role of the Arctic and Antarctic polar oceans in these cycles). I am an Adjunct Professor in the Department of Earth and Environmental Sciences at Columbia University and a Senior Research Scientist at Columbia's Lamont-Doherty Earth Observatory. I am a physical oceanographer, specializing in air-sea-ice interaction in high latitude oceans, and the role of this interaction, as well as the role of the sea ice fields in global climate. I do both modeling studies and fieldwork, and have been to the Arctic and Antarctic polar oceans numerous times. I am a member of a number of national and international committees dealing with global climate change, and the role of Polar Regions in climate. I am not a member of the National Academy of Sciences (NAS) though I was asked to be their representative for this hearing. I was chairman of the National Academy of Sciences Panel on Climate Variability over Decade to Century Time Scales, and have been a member of the NAS Global Change Research Committee and am currently (since 1990) a member of the NAS Climate Research Committee. I have just completed a 5-year term as the on the Science Steering Group for the WCRP (World Climate Research Programme, a program of the UN's WMO) CLIVAR project (Climate Variability and Prediction), am a member of the Science Steering Group for the WCRP ACSYS (Arctic Climate System) project and was a member of the WCRP Task Force defining the new CLIC (Climate and Cryosphere) project, among others. I have also served as chairman or member of a number of advisory committees to NSF and NASA, as well as to the American Meteorological Society. I teach a graduate level course on statistical methods for data analysis (focusing on the mathematical techniques, their proper use and interpretation) and have taught this course since 1985 in the Department of Earth and Environmental Sciences at Columbia University.

POLAR CLIMATE PRIMER

I intend to explicitly address each of the points articulated in the invitation letter for the hearing, but would like to start by presenting a few fundamental facts regarding the Arctic and its role in the Earth's climate system to put some of my comments into a broader (global) perspective.

Sea ice has covered the majority of the Arctic Ocean, year-round, with a 9-foot thick blanket of ice as expansive as the United States, for as long as civilization has been aware of it. In sunlight, this vast area is blindingly radiant; a reflective surface remarkably efficient in reflecting sunlight back into space, before its warming rays can heat the region. Likewise, the presence of sea ice serves to insulate the frigid atmosphere from the relatively warm ocean water (which cannot be colder than the freezing point). This prevents the ocean from warming the atmosphere to more moderate levels.

Sea ice is such an efficient insulator, that the exposed ocean water in its absence would warm the overlying air by some 20 to 40 degrees in winter. Moreover, the exposed ocean is nearly as impressive in its ability to absorb the warming sunlight as the ice is in reflecting it. Consequently, the presence or absence of ice leads to considerable differences in the temperature (and with that, circulation) of the overlying atmosphere. This dramatic contrast makes polar climate highly sensitive to changes in sea ice—even small changes in the sea ice can result in large changes in the polar climate. On a grander scale, these same characteristics that constrain the polar temperatures help define the temperature contrast between the tropics and the poles. Since climate is nothing more than the Earth's attempt to eliminate this contrast, that is, redistribute excess heat received in the tropics to the heat-starved Polar Regions, anything that influences polar temperatures can influence global climate.

Though we have been aware of the potential sensitivity of the climate system to changes in sea ice cover for many years, only since the early 1970s have we finally been able to obtain regular observations of the sea ice fields through constant monitoring via satellites. Since then, we have observed a clear and steady decline in the extent of the Arctic sea ice cover, showing it to be disappearing at a rate of approximately 3 percent of the early 1970 coverage each decade. There have also been a number of recent exceptional years, even in light of the steady decline: in the 1990s we experienced the four smallest summer ice extents ever observed. Furthermore, other, less complete records of the sea ice suggest that the decline has been continuous over this entire century. While the reduction in ice extent is unequivocal, changes in thickness are also apparent. Recently, during a year long experiment in the Arctic, the thickest ice floe we could find to establish our SHEBA (Surface Heat Balance of the Arctic) ice station on was only 60 percent of the mean thickness we expected to find. Conditions in the upper ocean showed an excess of freshwater consistent with the interpretation that the thin ice was a result of excess melting the previous year. Likewise, we have recently documented changes in other parts of the Arctic Ocean that are strongly suggestive of additional ice thinning. Results from submarine surveys under the ice suggest considerable thinning (of the order of 40 percent) in recent decades.

The causes for these changes are still uncertain, though we have some candidates, such as global warming that has been documented over the majority of the last century. Relative to mean global temperatures, temperatures in the Polar Regions show the same general trends, but are amplified relative to the changes observed in lower latitudes. Therefore, warming of a degree or two averaged around the globe is equivalent to a warming of approximately twice that much in the polar regions as seen in the figure. The changes in the sea ice do indeed correspond to changes in polar temperature though whether this is a cause or effect is unclear. Furthermore, changes in the polar upper ocean observed in some regions strongly suggest that the winter ice growth will be reduced by 70–80 percent in those regions, since the changes serve to introduce considerable heat from the ocean to the ice, preventing strong ice formation in winter. Because the observations of change are so new, we have not yet had time to test, or formulate the potential mechanisms and impacts associated with such changes (our current research is focused on determining the spatial and temporal characteristics of this upper ocean change). While we have an idea of what might be driving the immediate changes observed, the bigger, unanswered question at this time is whether the changes are part of a long-term trend, or part of a cycle, in which case the trends can be expected to reverse themselves in the future. At present there is evidence that may support both viewpoints, in which case the most likely future projection would involve a long term decline, tempered in some years by an expanding phase of the cycle, and enhanced in other years by coinciding with the retreating phase of the cycle.

## ARCTIC CHANGE

In addition to the changes in the Arctic upper ocean, it is interesting to note all of the other recently documented changes taking place in the Arctic and surrounding regions. These include changes in ocean characteristics that reflect differences in the nature of the circulation and the nature of the ocean-ice interaction (i.e., an insulating layer that separates the warm deep Atlantic water from the frigid surface layer disappeared in the vicinity of the North Pole); differences in sea ice and snow extent and thickness (i.e., the sea ice coverage has been decreasing by nearly 3 percent/decade over the last couple of decades, and has shown considerable thinning, by 40 percent on average; the circumArctic snow fields appear to be decreasing at a comparable, or slightly faster rate, nearly 4 percent/decade); differences in surface air temperature and permafrost distribution show dramatic trends in air temperature (most of which show warming, though some isolated cooling regions are also apparent). The details of these changes are still being evaluated, since our documentation of the region over the last 50 years has been rather sporadic in both time and space. Fortunately, serious international efforts to combine all existing data working toward a coherent picture of the change has afforded us significant new insights. These changes seem to be accompanying changes in the nature of the overlying atmosphere that appears to reflect a change in its fundamental mode of circulation. The Arctic changes appear to track those in global climate (particularly global warming), and the circulation changes are such that we expect the river runoff from the Siberian rivers to be distributed differently in the Arctic Ocean. This has major implications for the sea ice distribution, since the freshwater from rivers plays an important role in establishing ocean conditions favorable for sea ice formation. Recent modeling work and observational analysis suggests that the river water is now injected farther eastward in the Arctic relative to the Siberian shelves, and this can explain much of the changes in sea ice distribution, though we are not positive that this is the explanation.

## ARCTIC CHANGE RESEARCH

In an effort to better document and understand the extent of the changes, and deduce their implications and broader scale impacts a major interagency (NSF/ONR/NOAA/NASA/DOE) study has recently been initiated (championed by scientists at the University of Washington's Polar Science Center, with contributors from Alaska's IARC and other universities as well), called the Search for Environmental Arctic Change (SEARCH). The program has focused, to date on articulating the key outstanding questions that must be answered in order to most efficiently advance our understanding of Arctic change, and in identifying those issues that must be resolved in order to answer the questions. Key findings are that we need more comprehensive and systematic Arctic observations, focused modeling efforts, as well as a number of specific process studies needed to help improve the manner in which key polar processes are represented in the climate models. These will complement the findings from the recently completed NSF/ONR SHEBA field program, which provided the most comprehensive documentation of the various processes involved in regulating the surface energy balance of the Arctic. Results from this field program should greatly improve our ability to represent the Arctic region in global climate models, though even as thorough as this program was, the complexity of the polar climate system demands further such studies, as each one will incrementally advance our understanding and allow model improvements and diagnosis that will ultimately allow us to make reasonable projections of Arctic response to changes in the atmospheric forcing (e.g., greenhouse warming or the injection of sulfate aerosols associated with volcanic eruptions, which have been shown to lead to significant warming events in the Arctic region).

Our analyses suggest that changes in sea ice just north of Alaska covary with changes in the surface air temperature in the western tropical Pacific Ocean, perhaps reflecting a connection between the El Niño phenomenon and northern Alaska. In particular, anomalous air temperatures in the western tropical Pacific appear to portend to some extent the upcoming winter ice conditions north of Alaska in the upcoming winter. We also find that southwestern Alaska covaries with the sea ice concentration near the northeastern tip of Greenland, and oppositely with the ice concentration in the Labrador Sea (of the northwest Atlantic Ocean) as seen in the figure.

Because of the complexity of the climate problem, it requires coordinated international efforts. In this respect, the WCRP has formed a project that focuses international attention on the cryosphere (cold regions) and climate. Part of our needs outlined in the initial CLIC science plan suggest that a coherent observational network be established to better document changes taking place in the highest latitudes. Canada is contributing significantly to this effort with their extensive network, though the network is threatened by recent budget cuts to the Meteorological Services of Canada (MSC). This has led to the closing of some stations, including some that have already been shown to be critical to recent analyses of Arctic change. Further cuts may lead to additional closings by the Canadians have requested additional funds to keep the stations operating. At present, U.S. contributions to the MSC have proven critical in helping to maintain the observational network (continuing talks between MSC and U.S. NOAA would probably prove useful in helping the Canadians optimize their resources). The Canadians are also formulating a plan to contribute to the international (WMP) Global Climate Observing System (GCOS), which is designed to provide a global observing network that will address a large fraction of our climate observational needs. The Canadians are also in the process of switching over, like many countries, to automated weather observing instruments, though this leads to problems of data quality continuity, while helping open new frontiers to observation.

## OBSERVATIONAL NEEDS

At present, our best estimates of what mechanisms are responsible for these changes, and how sensitive the mechanisms are to future change, what their net influence is, and how a change in the earth's climate may influence the ice cover and thus the climate itself, is gauged through model studies. This reflects the fact that it is extremely difficult to collect data in the hostile Polar Regions so we are hindered in our ability to fully address these issues through observations themselves (as is sometimes possible, and most desirable, in other regions). Regardless, consistent observations over periods of time long enough to document the climate variations of interest are essential for initializing, diagnosing and improving the models. Unfortunately, such observations, and their regular maintenance is expensive and labor intensive, and existing subArctic observational networks are in danger of being undermined because of budgetary and sometimes safety issues. This is currently the problem faced by the Meteorological Service of Canada (MSC) which maintains an extensive subArctic observing network, though a number of stations, including ones that have been shown to play an important role in recent assessments of past circumArctic change, have been eliminated (some of the network is being preserved by critical U.S. agency contributions; and talks between MSC and U.S. NOAA have proven very helpful). The models, while still crude in a number of respects, help us determine which observations are most critically needed, and which processes should be targeted for more detailed study. Even at their present level though, models provide strong support to the notion that changes in the Polar Regions may significantly influence global climate. For example, a recent study using NASA's Goddard Institute of Space Studies (GISS) global climate model suggests that reasonably sized changes in the ice albedo, or other surface polar conditions have consequences that are ultimately felt globally. Most dramatically, greenhouse warming scenarios with that model given a doubling of the atmospheric $CO_2$ content, suggests that 38 percent of the greenhouse warming that results from this doubling is due to the melting of sea ice in the polar regions.

FUTURE PROJECTIONS OF CLIMATE CHANGE IN THE ARCTIC (THE "DEC-CEN" PROBLEM)

Climate prediction is a difficult proposition, but climate research and dedicated observational networks have led to tremendous advances over the last couple of decades, most notably seen in the successful prediction of the largest climate phenomenon existing (El Niño) and its various regional impacts around the globe. Unfortunately, the fact that the background climate state appears to be changing continuously implies that we will have to keep studying even this well known phenomenon in order to preserve our excellent predictive capabilities that we have already achieved. Furthermore, we need to identify and evaluate more climate patterns (undoubtedly of smaller significance in the overall scheme of climate), in an attempt to eventually achieve predictive capabilities for other regions of the Earth. While El Niño does indeed drive considerable variability in the Antarctic, its influence on the Arctic region is much less clear. The Arctic is subjected to another large scale climate pattern whose state also has considerable implications to regional climate in the North Atlantic and surrounding environs; this pattern is known as the Arctic Oscillation (AO), or alternatively, the North Atlantic Oscillation (NAO). While we can make some climate predictions for the Arctic according to the diagnosed state of the AO (e.g., a high state is often accompanied by an increase in the number and strength of Arctic storms; cyclones), we are not clear what drives the state of the AO, though the state of the sea ice fields is likely to play a role, and models suggest that the AO tends towards a high state with global warming (though there is considerable uncertainty in this).

For Arctic climate predictions on long time scales, we currently rely on climate models; most of which seem to agree that continued global warming (whether natural or anthropogenic) will lead to further retreat of the Arctic winter sea ice cover. Numerical models as well as theoretical studies suggest that the Arctic sea ice fields can exist in only one of two stable configurations: (1) perennial sea ice cover, as we currently have; or (2) seasonal sea ice cover with little to no summer sea ice as is typical of the Antarctic polar oceans. These studies also suggest that once the perennial ice fields start to thin and the winter cover decreases (as is currently happening), eventually, the sea ice field will reach an unstable state and make the transition rather rapidly to the other stable state (i.e., the perennial ice pack will begin to disappear at an accelerated rate and quickly transition to a seasonal sea ice cover). Recent predictions, though highly uncertain, suggest that the transition to seasonal sea ice state could occur in as little as 50 years given the current melting rate. Much of this acceleration reflects the fact that we appear to be melting away the thickest ice first, so the surviving ice is thinner, and easier to eliminate with a comparable amount of melting. Once the winter ice cover is eliminated or significantly reduced, presumably the winter conditions would be considerably moderated, as the winter air would now be warmed by direct contact with the relatively warm ocean waters (this positive feedback mechanism is part of what is known as the ice-albedo feedback mechanism—it suggests that once ice begins to melt, the melt itself will contribute to additional changes that will lead to more warming, and thus more melting). The impact to polar wildlife and native people relying on regular natural seasonal cycles of climate and ice conditions presumably would also be considerable, as seasonal cycles would be greatly altered.

While this is a worse case scenario, some of the future change, if properly anticipated could prove beneficial. The anticipation of change occurring over relatively long time scales, as we are dealing with in the Arctic (and much of the rest of the globe) has associated with it particular problems that are not apparent in the study of more rapid and short time scale change (this is best summarized from one of our recent National Academy Reports dealing with climate variability, excerpted here from my contribution to the report).

Climate research on decade to century ("dec-cen") time scales is relatively new. We have only recently obtained sufficient high-resolution paleoclimate records allowing examination of past change on these long time scales, and acquired faster computers and improved models allowing long simulations for studying such change.

From this it has become clear that the heretofore-implicit assumption of a relatively stable mean climate state over dec-cen time scales since the last deglaciation, about which considerable seasonal and interannual variations occur, is no longer a viable tenet. The paleo records reveal considerable variability occurring over all time scales, while model and theoretical studies indicate modes of internal and coupled variability driving variations over dec-cen time scales as well.

A significant fraction of these insights have only become apparent in the last decade. Consequently we are on the steep end of the learning curve with new results and dramatic insights arising at an impressive rate. The fundamental scientific issues requiring our primary attention are thus evolving rapidly. Flexibility and adaptability to new directions and opportunities is thus imperative to optimally advance our understanding of climate variability and change on these time scales.

Furthermore, the paradigm developed to successfully study climate change on seasonal to interannual time scales cannot be applied to the study of dec-cen climate problems. That is, we have realized considerable success studying short time-scale climate problems by generating hypotheses and models that are quickly diagnosed and improved based on analysis of the amply long historical records or quickly realized future records. For dec-cen problems, the paleoclimate records are still too sparse and the historical records too short. Future records will require multiple decades before even a nominal comparison to model predictions is possible. Compounding the problem, the change in atmospheric composition as a consequence of anthropogenic emissions represents a forcing whose future trends can only be estimated with considerable uncertainty. As a result, progress requires considerable dependence on improved and faster models, an expanded paleoclimate data base, and imposed anthropogenic emission scenarios. Heavy reliance on these methods and assumed forcing curves, without the benefit of real-time observations for constant model validation and improvement, implies a considerable effort toward model validation through alternate means, improved understanding of the limits and implications of proxy indicators constituting the paleoclimate records, and detailed monitoring of emissions to help track actual rates. As for future observations, we can only now begin collection of these data that will ultimately aid future generations of scientists in their understanding of dec-cen climate variability and change.

Thus it is fundamental that we have support to gather the necessary observations, build, test and improve climate models including detailed representation of the Polar Regions, and continue field programs to improve our understanding of the processes underlying the interactions and changes taking place.

I would welcome any questions that you might have.

**STATEMENT OF HON. GEORGE B. NEWTON, JR., CHAIR, U.S. ARCTIC RESEARCH COMMISSION**

**ACCOMPANIED BY DR. GARY BRASS**

Mr. NEWTON. Thank you, Senator Stevens. I appreciate this opportunity to discuss the needs for climate change research in the Arctic.

As you know, the Arctic Research Commission was established in 1984 by the Arctic Research and Policy Act. Under the Act we have a number of responsibilities but our chief product is our biennial Report on Goals and Objectives for Arctic Research. We call it the Goals Report. I have included several copies of it in my testimony.

One of the principal purposes of the Goals Report is to provide guidance to the Federal agencies with research programs in whole or in part in the Arctic.

I might insert at this point, Senator, as you prepare for testimony—you probably are familiar with this—when you prepare, you write in a vacuum and when you're late in the agenda, many of your pearls have been put on the table. But I think, if you hear them again, I think it will serve as added emphasis for the importance that we collectively feel for this particular problem.

It is appropriate I believe that I precede your agenda for the afternoon for it is the Commission's responsibility to recommend research, policies and priorities to both the President and Congress and to oversee the coordination of the Arctic research activities of the Federal agencies.

Climate change in the Arctic is already upon us. Warm and salty Atlantic water has increased its penetration into the Arctic Ocean. There is enough heat in this Atlantic water to melt at this time all the ice in the Arctic Ocean. The surface layer of colder fresher water which insulates the ice is being eroded by this warming from below. Additionally, Arctic sea ice is thinned by about 40 percent and the extent of the summer sea ice has decreased by 5 to 10 percent over the last 30 years or so. These changes will have major impacts on fisheries and transportation through the Northern Sea Route and Northwest Passage. Deep ocean convection in the Greenland Sea drives the ocean's conveyor belt and draws warm, Gulf Stream water north to maintain the reasonably comfortable climate of Scandinavia, Great Britain and the rest of Northern Europe. Changes in the Arctic may cause a slowing of this conveyor belt with major climactic consequences and reduce the climate of Northern Europe and Great Britain to somewhat akin to Northern Quebec and Southern Nunavuk.

Fisheries have already changed in the Bering Sea. The species of crab caught today are different from those caught in abundance a decade or two ago. Herring are scarcer and salmon are found in places where they had not been found before while other salmon fisheries such as in Bristol Bay have suffered serious declines. Marine mammals and sea birds have undergone substantial change in recent years as well, a regime shift occurring in the Bering Sea in the 1970's causing major changes in fish populations. Recently, a new phenomena has occurred. Sea ice is melting earlier in the Bering Sea changing the composition of spring plankton bloom which is causing changes in fish-feeding success.

Long-term observations in permafrost also show the temperatures are increasing. The date of snow-melt in Barrow now comes 40 days earlier than it did 30 years ago. Plants and animals are shifting their distribution pattern, routes of travel, nesting and birthing sites and other aspects of their ecology and behavior. And changes in temperature are causing changes in plant growth. This warming will have serious effects on roads, forests, bridges, ports, buildings, pipelines and airports. I note that Caleb mentioned the change in the treeline in the Nome vicinity. A friend of Caleb's recently shared with me that the treeline has grown from 6 miles east of Nome to 40 miles west of Nome in his life time. That's probably around 40 years, a significant change.

In 1947 a Navy evaluation board reviewed the 1931 expedition to the Arctic by the submarine Nautilus under the direction of Sir Hubert Wilkens. The review states that.

> Very little is known about the real Arctic and, in view of its strategic military importance, it is necessary that basic information and scientific data be collected upon which to formulate future plans in all phases of global warfare.

True then and just as true today but its impact has expanded for all aspects of the Arctic, including climate change.

In the Commission's Goals Report we have made four principal recommendations for research initiatives. These are studies of the Arctic region and global change, studies of the Bering Sea region, health of the Arctic residents and applied research. Each of these recommendations address climate change issues. Now let me discuss these recommended research programs contained therein.

The Interagency Arctic Research Policy Committee, called IARPC, has constructed a new program for the Study of Environmental Arctic Change called SEARCH. SEARCH is an interdisciplinary, interagency program for the study of rapid environmental change ongoing in the Arctic. The Commission recommends support of the SEARCH Program when it comes before Congress in fiscal year 2003. Dr. Colwell, who is Chair of the IARPC, and other agency heads in your afternoon panel will no doubt have more to say about the SEARCH Program.

The SEARCH Program currently contains a section on rapid change in the Bering Sea. The Commission recommends that this section of the SEARCH Program be developed into a new interagency program for an intensive study of the Bering Sea with a comprehensive research approach aimed at continuous improvements in our ability to predict the behavior of the Bering Sea system and, thus, enable management of the ecosystem through foresight and understanding.

The North Pacific Research Board will conduct an organizing meeting in Anchorage tomorrow and Thursday of this month. The Commission is a member of the NPRB and we expect that it will play a vital role in the study of the Bering Sea.

The BERPAC Program is a collaborative U.S.-Russian program for the study of the Bering Sea and its surroundings supported through the Department of the Interior. The Commission strongly recommends that the tempo of this program be increased to annual cruises and that funds be appropriated to allow this increase in program activity.

Climate change is also affecting the healths of Arctic residents in subtle ways. We have recommended a third interagency program in Arctic health. We recommend to the Committee the section on Arctic health in the Goals Report. The Commission also recommends support of the Alaska Traditional Food Safety Program proposed by the State of Alaska as an important first initiative in that area.

The Commission has supported two workshops on Arctic ports done by Dr. Smith who spoke earlier. We are aware of the proposals by the National Ocean Service of NOAA for a program of improvements and upgrades in the maritime transport system. Climate change will play a major role in changing maritime transportation. We support this program with a special emphasis on Alaskan ports and transportation facilities.

The Commission also has an interest in research into the problems of the oil on ice-covered seas. Clearly it would be better for us all if research into these questions were conducted before a serious spill in the Arctic occurs rather than after the fact and in the face of legal difficulties which might arise. The Commission supports the proposal for the Center for Advancing Marine Spill Response from NOAA–NOS as an excellent venue for such studies.

The U.S. Navy is considering their response to climate change in the Arctic as well. The Commission hopes that opportunities to improve these capabilities will receive your support, particularly through increased research by the High-Latitude Program of the

Office of Naval Research which, for your information, has—the budget for which has declined 87 percent in the last decade.

Because of the unique nature of the Arctic, research facility requirements are every bit as important as the research itself. NSF has made great progress in recent years in the support of Arctic research logistics. The Commission supports their planning efforts for new facilities at Toolik Lake and at Barrow.

The University of Alaska Institute for Marine Science and the Woodshole Oceanographic Institution are engaged in design studies for new research vessels capable of operating in high latitudes and in the marginal sea ice zone. The Commission supports these efforts of these two outstanding institutions to design and build new marginal ice zone ships.

The SCICEX Program has ended and the Commission is searching for new opportunities to gather data on climate change in the Arctic Ocean. The Commission remains in contact with the Navy Submarine Force to find creative ways to continue the SCICEX Program in some form.

Autonomous Underwater Vehicles capable of taking over where the SCICEX submarine cruises ended are not currently available. A substantial design and development effort is called for which the Commission supports and recommends to you as well.

For the long future, the Navy is considering the potential needs for a replacement of submarine NR–1, the Nation's only nuclear-powered research submarine. The SEARCH committee, in a separate workshop, has indicated an overwhelming importance of Arctic capability in the design of such a replacement. The Commission supports these efforts.

I wish to leave you with some important points. I call them my Arctic one-liners in that they describe what I believe is the urgency of this problem. The Arctic drives the world's weather engine. The Greenland Sea drive-wheel of the conveyor belt is of critical importance. And it's the most poorly understood area of the planet, that being the Arctic. And 9 out of 10 people in this world live on continents that border the Arctic Ocean. Additionally, 80 percent of this State of Alaska is underlain in permafrost. The infrastructure impacts are considerable should that permafrost erode. We talked earlier about ice albedo and, certainly, as this ice pact disappears, it sets up positive feedback for further and accelerated dissipation of Arctic Sea ice on an annual long-term basis.

Climate change most likely is a combination of a long natural cycle and man-induced change will affect each and everyone of us in this room. In this century the world will see great changes in the land and its freeze/thaw cycle and the resulting impact on our infrastructure. There will be changes, as well, in terrestrial vegetation and marine life and there will be changes in our presence in the Arctic Seas, commercial use of the Northern Sea Route and the Northwest Passage as short routes between markets, a quicker way to get a car made in Japan to a market in Hamburg, Germany. And it's not just a little change. That's a 40 percent difference in distance if that route is viable for commercial interests. There will be easier transportation of Arctic-based resources out of Alaska, out of Russia, out of Europe. And concurrently another ocean for our military to protect, a thought that has not really sunk in yet in what the Navy is doing in their long-term planning.

PREPARED STATEMENT

To counter and properly exploit these changes we, as a Nation, must be ready. We must correctly identify and anticipate the magnitude of environmental changes. We can't tell where we're going until the models tell us where we are now and where we will go in the future. That means continued support for basic and applied research, support for all means of data collection, land, sea, air and space, and support for the logistics necessary to perform that research properly. To understand the Arctic we must go and work there.

Thank you very much.

[The statement follows:]

PREPARED STATEMENT OF GEORGE B. NEWTON, JR.

Thank you Senator Stevens for this opportunity to discuss Arctic research needs with the Committee. As you know, the Arctic Research Commission was established in 1984 by the Arctic Research and Policy Act (ARPA). Under the ARPA we have a number of responsibilities but our chief product is our biennial Report on Goals and Objectives for Arctic Research (the Goals Report). I have included several copies with my testimony and the Commission office can supply more if you need them.

One of the principal purposes of the Goals Report is to provide guidance to the Federal Agencies with research programs in whole or in part in the Arctic. These agencies make up the Interagency Arctic Research Policy Committee (IARPC). IARPC uses the guidance in the Goals Report to conduct the biennial revision of the National Arctic Research Plan, a five year plan for Arctic research. This plan is submitted to the President for approval and to the Congress as the nation's established plan for research activities in the Arctic. In what follows I will describe the major recommendations of the Goals Report and their implementation in the National Arctic Research Plan.

CLIMATE CHANGE IMPACTS IN THE ARCTIC

Climate change in the Arctic is already upon us. For example, in the last decade scientists have observed substantial changes in the Arctic Ocean. Oceanographic studies have shown that warm and salty water from the Atlantic Ocean enters the Arctic Ocean through the Fram Strait between Svalbard and Greenland. This water mass has increased in volume and penetration into the Arctic Ocean and the temperature at its core has increased by as much as 2 degrees Celsius. There is enough heat in the Atlantic water to melt all of the ice in the Arctic Ocean but it is trapped below a surface layer of colder fresher water above the "cold halocline." This cold halocline is being eroded by warming from below and may, in fact, be gone for parts of the Arctic Ocean near Svalbard.

At the same time, measurements made from US and British nuclear submarines have shown that Arctic sea ice is thinning and that the reduction has been about 40 percent over the last thirty years or so. During the same time the extent of sea ice in the Arctic summer has decrease by 5–10 percent. These changes in sea ice cover, if they continue at their current pace, will have major impacts on the Arctic Ocean. Transportation through the Northern Sea Route and the Northwest Passage along the northern coasts of Russia and Canada may be substantially increased. Fisheries may expand into regions no longer covered by ice while marine mammals and sea birds dependent on the ice edge environment may find their lives more difficult.

The world ocean circulation is fed from the Arctic. Deep convection in the Greenland Sea north of Iceland produces cold, dense water which sinks into the abyss to circulate around the globe in what has become known as the "Conveyor Belt." Changes in temperature and salinity of Arctic waters are occurring which may have major effects on the "Conveyor Belt." The deep convection in the Greenland Sea draws new, warm, Gulf Stream water into the region which maintains the anomalously warm climate of Scandinavia, Great Britain and the rest of Northern Europe. A decrease in deep Arctic convection due to climate induced freshening of surface seawater in the region would threaten the economies of this important part of the developed world.

In a similar way, climate change is affecting the Bering Sea. Study of climatological and oceanographic records indicate that a "regime shift" occurred in the Bering Sea sometime in the 1970s. Major changes in fish populations occurred during this regime shift including a notable expansion of walleyed pollock populations along with declines in some other fish stocks.

More recently, a new phenomenon has occurred in the Bering Sea. Changes in the time when sea ice recedes in the Bering Sea change the composition of the spring plankton bloom. Massive blooms of coccolithophorid algae occur when sea ice leaves the Bering Sea early, replacing the diatoms which prevail in more normal years. The small animals which feed on these single celled plants do poorly when attempting to feed on coccolithophorids and the pollock which eat these small animals suffer as a consequence. As climate change continues we may see further changes in Bering Sea ice cover.

Fisheries are changing in the Bering Sea. The species of crab which constitute the majority of the catch today are different from those caught in abundance a decade or two ago. Herring are scarcer and salmon are found in abundance in places where they had not been found before while other salmon fisheries such as in Bristol Bay have suffered serious declines. Some marine mammals and sea birds have undergone substantial changes in recent years. The relationships of these phenomena to climate change are only poorly understood but they are so important to the State and the Nation that they deserve intensive study.

Similar changes are observed on land. Long term observations of the temperature in wells drilled to study permafrost show that subsurface temperatures are increasing. Native communities have remarked on permafrost destabilization in their villages. Evidence has accumulated showing a change in the date of snowmelt at Barrow which is now 40 days earlier than it was 30 years ago. When the snow melts, the ability of the ground surface to absorb solar radiation increases eight fold with the consequence that the ground warms more as well as earlier. to As climate change continues changes in permafrost distribution and stability will affect much of the Arctic.

Plants and animals are shifting their distribution patterns, routes of travel, nesting and birthing sites and other aspects of their ecology and behavior in the Arctic. Satellite studies at the University of Alaska have shown that the date of "greenup," when the tundra plants begin to grow in the spring, has profound effects on the success of caribou calving and calf survival. Experiments at the University's research site at Toolik Lake in the Brooks Range show that even minor changes is thermal regime cause substantial changes in plant growth and nutrient cycling.

In the Goals Report we have made four principal recommendations for research initiatives. These are:

—Studies of the Arctic Region and Global Change,
—Studies of the Bering Sea Region,
—Health of Arctic Residents and
—Applied Research.

I will discuss briefly each of these recommendations and how we see them carried out.

RECOMMENDED RESEARCH PROGRAMS

The Interagency Arctic Research Policy Committee (IARPC) has constructed a new program for the Study of Environmental Arctic Change (SEARCH). The SEARCH Program is an interdisciplinary, interagency program for the study of rapid environmental change which is already occurring in the Arctic region. This program is composed of elements from many Federal Agencies. Current activities are based upon current (FY 2001) and planned (FY 2002) budgets and are aimed at a combined, interagency budget proposal in fiscal year 2003. The purpose of the program is to bring the powers of those agencies conducting research in the Arctic to bear on the problems and promises of change in the region. The Arctic Research Commission is charged with the responsibility to work towards integration and the reduction of redundancy and overlap in Federal Arctic research programs. For this and many other reasons the Commission recommends the support of the SEARCH program when it comes before the Congress in fiscal year 2003. Dr. Colwell, Chair of IARPC, will, no doubt have more to say about SEARCH in her testimony.

The SEARCH Program currently contains a section on rapid change in the Bering Sea. The Commission has recommended in the Goals Report that this section of the SEARCH Program be developed into a new program for an intensive study of the Bering Sea to be organized on the same interdisciplinary, interagency lines as the

SEARCH Program. Because changes in the Bering Sea include changes in exploitation, technology and population which are independent of environmental change, this program will be broader in research scope but narrower in regional focus than SEARCH. The goals of this program are to develop an integrated program which brings together all of the disciplinary studies on individual aspects of the Bering Sea into a coordinated whole which emphasizes the connections between such diverse studies as the physical circulation of Bering Sea water masses and the changes in the populations of such top predator species as the Steller Sea Lion. In addition, the Commission recommends that this program focus on continuous improvements in our predictive capacity through model development and data assimilation programs. Every improvement in our ability to predict the behavior of the Bering Sea system takes us farther away from management by crisis and closer to management of the ecosystem through foresight and understanding with the concomitant reduction in stresses not only on the environment but also on the people who take their livelihood from the Bering Sea. In many ways this approach mimics the successful "Nowcast/Forecast" model followed by the Oil Spill Research Institute and the Prince William Sound Research Center—a project which the Commission has followed for some time and which has had great success in the study of Prince William Sound.

In this regard we place high hopes on two other research programs for the region: the North Pacific Research Board (NPRB) and BERPAC. The NPRB is beginning to organize its research activities. It will, in fact, conduct an organizing meeting in Anchorage on the 30th and 31st of this month. The resources established for the NPRB place it in a strong position to guide and focus the formation of the comprehensive Bering Sea research program which the Commission has recommended. We are hopeful that the NPRB can play this important role.

The second program which the Commission has recommended is the BERPAC Program, a collaborative U.S.-Russian program for the study of the Bering Sea and its surroundings. This study is supported through the Department of the Interior and has conducted field studies in the Bering Sea on a schedule of roughly one research cruise every three or so years. The Commission strongly recommends that the tempo of this program be increased to annual cruises and that funds be appropriated to allow this increase in program activity. Occasional cruises make for difficulties in planning for the home agency. Funds for these exercises must be found in the face of the demands of ongoing, base programs. The incorporation into the Department's budget of annual field and research activities for the BERPAC program will assure that this vitally needed information on the Russian side of the Bering Sea will continue to flow into the U.S. research and management community.

Past BERPAC cruises have employed Russian research vessels and have, as a consequence, been able to operate in the Russian Exclusive Economic Zone without the bureaucratic difficulties which have made expeditions on U.S. vessels rare and difficult. In addition, participation by Russian scientists in the BERPAC Program has forged ties between U.S. and Russian colleagues which, in turn, lead to fruitful exchanges of data and information, especially about the western part of the Bering Sea where there is little U.S. presence.

The Arctic Research Commission has recommended a third interagency program on Arctic Health. While some of the concerns of this program are affected by climate change, the program is largely devoted to understanding current and potential causes of ill health in Arctic populations and finding ways to prevent or ameliorate them. I recommend to the Committee the section on Arctic Health in the Commission's Report on Goals and Objectives.

One of the aspects of climate change which the Commission has focussed on for some time is the effect of climate change on civil infrastructure. Changes in climate will result in major effects on roads, bridges, buildings, airports and other structures. The degradation of permafrost in the extensive areas of discontinuous permafrost and the increase in the thickness of the seasonally thawed active layer in regions of deep, continuous permafrost will result in destabilization of structures. In other regions, the final loss of permafrost will simplify civil engineering practice and increase the durability of structures. Similar benefits and problems will affect basic infrastructure requirements for water, waste water and housing. While these appear as practical problems, there is much that research can do to assist Arctic residents. Research into climate change and permafrost changes are part of the basic research activities already mentioned but research into appropriate materials, building technologies, coatings, corrosion and thousands of other applied topics are similarly required.

Coastal erosion is another facet of climate change needing applied research. Much has been spent on projects to moderate or prevent coastal erosion but the research base necessary to understand such climate change effects as sea level rises and changes in the frequency and severity of storms along with the deterioration of coastal permafrost which underlies and supports much of the Alaskan coast line is clearly insufficient to meet Alaska's needs.

The Commission recognizes these research needs but finding the appropriate Federal Agencies to take on these research tasks is difficult and progress is piecemeal with small programs here and there throughout the government. The foundation of the Denali Commission is a giant step forward in addressing these questions. In addition, the Commission has recommended and supported the conclusion of a new arrangement for cooperation between the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the University of Alaska. CRREL is a world class center of excellence in civil engineering in cold climates. Their agreement with the University of Alaska assures the U.S. Arctic of the resources and expertise necessary to deal with infrastructure problems associated with climate change.

In a similar vein, the Commission has supported two workshops on Arctic Ports as a result of our field studies of maritime facilities in Alaska. Climate change may bring major changes to the activities of the maritime transport system in the Alaska region. These workshops have outlined the scope of the problem. The potential for climate change to open the Northern Sea Route along Russia's northern coast and the historic Northwest Passage in the Canadian North hold the potential for major increases in maritime traffic through the Bering Sea. The Commission is aware of proposals by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA–NOS) for a program of improvements and upgrades in the maritime transport system and supports this program with a special emphasis on Alaska ports and transportation facilities.

Climate change will also affect fisheries. While the Commission hopes to address basic research questions in the region through the SEARCH and Bering Sea Programs which we have already recommended, a vast array of applied fishery research needs continue to be unmet. The Commission recommends that Federal Agencies work aggressively to address such problems which may result from climate change in the Arctic region.

Climate change will play an important role in the development of petroleum resources in the Arctic. Some effects such as earlier snowmelt and later onset of winter will hinder exploration and construction. Others such as an improved sea transportation season will help. In the somewhat longer run, the Commission is aware that climate change on the North Slope will change the requirements for restoration of abandoned sites and that climate change may be as important an influence on Arctic flora and fauna as petroleum exploitation activities. Since much of the research in this area is conducted by the petroleum producers, the academic research community needs to become familiar with their activities and vice versa. Federal Agencies need to make themselves aware of all of these results and to take climate change into account in their regulatory and environmental impact assessment processes.

At present there is little use of marine transportation for the shipment of petroleum in the Arctic but changes in the sea ice cover of the Arctic Ocean can be expected to increase interest in this inexpensive and efficient means of transportation. The Commission has a long history of interest in research into the problems of oil in ice covered seas. Many important questions remain to be addressed. Clearly, it would be better for all concerned if research into these questions were conducted before a serious spill in Arctic waters occurs rather than after the fact and in the face of the legal difficulties which might arise. The Commission notes the proposal for the Center for Advancing Marine Spill Response from NOAA–NOS. Such a center operating in concert with other activities established as a result of the spill in Prince William Sound could address these problems directly and effectively. The Commission supports and recommends to you the formation of this center.

The Arctic Research Commission in cooperation with the Navy/National Ice Center, the Oceanographer of the Navy and the Office of Naval Research recently sponsored a two day workshop on the roles and missions of the Navy in an Arctic Ocean in which climate change had caused serious regressions in ice cover including becoming ice-free in the summer. This workshop, based on the estimates of the future for the Arctic marine environment in a warming climate, concluded, among other things, that a an expanded program of Arctic Measurement, Modeling and Prediction (AMMP) would become essential for evaluation of Navy operations in the Arctic Ocean. The workshop participants concluded that the Arctic Ocean contains three significant features which require an AMMP program: the Arctic is very poorly known or understood, our observing network in the Arctic is virtually non-existent, and climate change will probably have greater effects in the Arctic than in any other potential operating area for the Navy. The Navy's response to these conclusions will require some time to formulate and become part of their planning. In the mean time, the Commission hopes that opportunities to improve these capabilities will receive your support, particularly through increased research by the High Latitude Research Program at the Office of Naval Research which, for your information, has declined by 87 percent over the last decade.

RESEARCH FACILITY REQUIREMENTS

The University of Alaska Institute for Marine Science and the Woods Hole Oceanographic Institution are engaged in design studies for new research vessels capable of operating in high latitudes and in the ice margin zone. While not icebreakers, these ships will be able to study this biologically active region without fear of accident due to an encounter with sea ice. These ships are being designed to be the most advanced fisheries research vessels in the academic fleet. The marginal ice zone is one of the most productive regions in the world and facilities to work in that environment are crucial for our understanding of climate change and its effects on fisheries. The Commission supports the efforts of these two outstanding institutions to design and build new, marginal ice zone ships.

From 1993 to 1999 the U.S. Navy carried civilian scientists on dedicated science cruises aboard U.S. nuclear fast attack submarines. This program, known as SCICEX (for Science Ice Exercises) brought a new dimension to Arctic oceanography. SCICEX gave researchers the opportunity to visit the Arctic in any season, to travel in straight lines for many miles at relatively high speeds, to stop and survey novel oceanographic features such as eddies and fronts and to gather extensive geophysical survey data of a quality and quantity not previously available in the Arctic. SCICEX data illuminated the changes noted above in the position of the Atlantic water front. SCICEX observations of the thickness of sea ice, when compared with earlier submarine observations, demonstrated the surprising reduction in ice pack thickness. In 2000 the L. MENDEL RIVERS, the last operational submarine of the Arctic capable SSN 637 Class conducted a brief "opportunity cruise" during its trip from the Atlantic to the Pacific Northwest where it was decommissioned and will soon be scrapped. This ended the era of annual, dedicated science cruises in the Arctic, cruises which conservatively doubled our data on environmental conditions in the region.

The Arctic Research Commission was the primary agent for the civilian research community in enabling the SCICEX Program in the early nineties. We are now searching for new opportunities to gather data on climate change in the Arctic Ocean. While the end of the SSN 637 Class has brought about a very severe reduction in the number of Arctic-capable submarines, there are two members of the Los Angeles or SSN 688 Class which have equivalent design features necessary for safe Arctic operations. The Commission remains in contact with the Navy submarine force to find ways to continue the SCICEX program.

In a similar vein, the Commission has conducted discussions with experts in the design of Autonomous Underwater Vehicles (AUVs). While these lack human presence and, as a result, lack the ability to exploit the unexpected, they are excellent vehicles for the systematic survey of water mass distributions, water properties, ice distributions and geophysical studies of bathymetry, gravity, magnetics and sediment structure. Unfortunately, AUVs capable of taking over where the SCICEX submarine cruises ended are not currently available and a substantial design and development effort is called for which the Commission supports and recommends to you as well.

For the long future, the Navy is considering the construction of a new dedicated research submarine known as NR–2 to replace the current NR–1. Unlike NR–1 which has limited depth, range, speed and endurance, it is expected that NR–2 will have improved capabilities in these areas. The research community has indicated the overwhelming importance of Arctic capability in the design of NR–2. When the opportunity arises for the Appropriations Committee to consider support for NR–2 we will be glad to expand on the importance of this ship for the study of the Arctic Ocean and its role in global change.

In conclusion, Mr. Chairman, let me make it clear that global change is already active in the Arctic and that its effects are expected to be greatest in the far North. Nine out of ten people on this Earth live on continents bordering the Arctic yet it remains the most poorly understood region of the world. The U.S. Arctic Research Commission through its Report on Goals and Objectives for Arctic Research has recommended a comprehensive schedule of research aimed at understanding and accommodating these changes. Thank you again for this opportunity to appear before you.

Chairman STEVENS. Well, thank you all very much. I'm glad that you take the time to come make this record. I just sit here and wish that my colleagues were here to hear you because it's extremely important, the presentations that you all have made.

Are there limiting factors now in our climate modeling? I'm thinking about the generation of computers we're dealing with or the sensitivity of the sensors we're dealing with. Do we have the technological basis to precede now to another phase of basic monitoring? Comments?

Mr. NEWTON. Additional data is always valuable and——

Chairman STEVENS. I'm talking about the technology base to provide it. Dr. Martinson.

Dr. MARTINSON. I do think we have the technology to start to improve our data base. And as far as the modeling goes, you are right. We have been limited for a long time by computer power, all sorts of issues about where we acquire our computers, et cetera. Those, I believe, have been resolved now. And this is particularly important for representing the Arctic region in global climate models because one of the things that the Arctic demands is very, very high spacial resolution in the models. We need finer resolution in the vertical and very small resolution from one grid cell to the next. And to put it in context, what dictates the resolution of a model is typically a certain dynamic characteristics of the basin we're studying. And these things all have great technical words, the Rosby radius of deformation (ph). And when you look at these characteristic scales, they dictate how small a grid cell has to be in order to resolve the physics that we need to resolve. And because of the stratification and the nature of the Arctic Ocean, this radius is so small that it demands that we have as many grid scales across the Arctic to resolve it properly as we need to have across the Pacific Ocean to resolve it. So as far as the models are concerned, we have to have as much power put into the Arctic as the entire Pacific Ocean. And every time you add a new grid cell or a higher resolution, you tremendously add a lot of computing time to the models and that limits our ability to make multiple runs or long, long runs. And we have to make long simulations in order to evaluate these long-term climate changes.

Chairman STEVENS. Did you have something to say, Dr. MacDonald?

Dr. MACDONALD. I would just add, in terms of tools, one of the key ways in which we can test these models in terms of their general predictions of Earth climate systems and in terms of their ability to get variability right is by comparing their results to paleoclimatic records. You can run a simulation when they had less $CO_2$; you can run a simulation for a climate 125,000 years ago when there was a lot of $CO_2$ and there's probably a little bit—less sea ice than today. Our problem or our need in supplying the data that they require—we're good with summer temperatures; we still have spacial sparsity in our network of sites. We are pretty poor with winter temperatures and we're still trying to develop techniques in which we can reconstruct winter conditions or reconstruct precipitation. The models are getting better at precipitation. We need to catch up with them there. And, finally, one key area—it's not an area I work in but—is getting proxies for where the sea ice was in the past, how it's changed in terms of past climate. We have a hard time understanding where sea ice was 6,000 years ago, 125,000 years ago. And that's a proxy record that really needs to be developed.

Chairman STEVENS. Dr. Brass.

Dr. BRASS. Mr. Chairman, the Commission actually visited the National Center for Atmospheric Research in Bolder last summer. And the climate modelers at NCAR are concerned about the limitations on their purchasing of supercomputers and supercomputer power. The United States is no longer the leader in producing super-duper high-speed, very high-speed computers and "Buy America" requirements restrict NCAR in what they can purchase. And they were quite concerned about that. I don't know if it's changed since.

Chairman STEVENS. Pardon me. It's Dr. Brass. I'm sorry. Thank you. What about our computer here, Mr. Newton? Is it sufficient for your needs?

Mr. NEWTON. It is being 100 percent utilized now, as I understand it. And it certainly is an outstanding—I can't speak to the sufficiency of the needs but I have not heard people say that it is inadequate.

Chairman STEVENS. Dr. Martinson, is there a limitation because of the "Buy America" concept on your research?

Dr. MARTINSON. Well, indirectly. I myself am not running these models on those machines but the community as a whole has felt crushed by the, you know, our restrictions. They have to run on the now slower machines and that issue has, apparently, been resolved. And I understand it's one for policymakers and we, of course, defer to your good judgment on that. But, yes, it does. We need very, very powerful computers to do these simulations.

And if you don't mind, I'd like to add one other comment to your earlier question about technological—are we there technologically to get the observations we need? Well, I can think of two instances where we are working on it but we're not there. One is, yes, we can see the sea ice extent. That's pretty easy to pick up. But we can't get the thickness. And everything we know about the thickness has come, or a huge fraction of what we know about the thickness, has come from this submarine, this SCICEX Program, which has been invaluable to our community. It's such a shame to see that go away. And some upward-looking sonar devices that have been put around here and there throughout the Arctic, we need to have some way to come up with an ability to remotely sense the thickness. It's a tough challenge. The other thing we need to get is an ability to remotely sense the salinity, the surface salinity, of the ocean waters which are essentially crucial to this conveyor belt and the insulating layer and everything else and salt is the fundamental property of interest in the high-latitude oceans. Temperature is the fundamental property in the low latitudes. But we can't get salt from these satellites very well right now.

Chairman STEVENS. And I don't want to prolong this but that slide you had which was entitled "A Great Ocean Conveyor Belt," can you call that back up? That's it. Let me congratulate you on your charts that you presented to us. Our prominent oceanographer here at the University showed me once that there was a northern pattern of—water from Prince William Sound that goes up through the chain and goes up into the Arctic. Is there a similar sink in the Pacific above the Bering Straits that has any impact on the rest of the world?

Dr. MARTINSON. Gee, I hate to answer to the Senator from Alaska no on that. But to the best of our knowledge the answer is no and that has been—a long-term fundamental oceanographic question is why on earth does all this deep water start in the North Atlantic? What's so special about the North Atlantic as opposed to the Pacific? And there have been studies that have suggested, during glacial periods, maybe we did have deep intermediate waters formed where you ask in the Alaskan regions and stuff radiating out of the Pacific. But it has to do with the primary atmospheric circulation patterns and what we think is the Pacific Ocean receives an excess of fresh water so it's just too fresh. And because of the Rocky Mountains. The atmospheric circulation pattern is steered so that we have a lot of evaporative cooling or evaporation out of the Atlantic which makes it a lot saltier. So this water's evaporated out of the Atlantic, deposited into the Pacific. And, as I mentioned before, it's the salinity which really sets the ability of this water to sink and form the deep waters and, right now, the Pacific's just not up to the task.

Chairman STEVENS. What I'm looking for is to see whether there's any moderating currents here that might offset, in our region—Dr. Royer (ph) was the one that did this—gave us a presentation once in Washington. I wonder are there any moderating factors at all that we know of in Eastern Russian and Northern Alaska that might offset some of the trend we're talking about?

Dr. MARTINSON. Well, I'm not actually not an expert on the local currents here. Dr. Royer actually is so if he says there is I would defer to that.

Chairman STEVENS. No, he told me there are but I don't know whether they're sufficient enough to moderate what you're predicting—what the models show us as far as our region is concerned. Dr. Brass.

Dr. BRASS. Senator, there is a connection and that is the water from the Pacific that comes up through the Bering Sea goes through the Bering Straits and tends to run toward the east along the north side of the Canadian Archipelago and to filter down through there into the Labrador Sea. The Labrador Sea is an important site for making deep water as well. I don't think anybody yet knows what effects changes in the Pacific are going to have on that because, unfortunately, there have been very few measurements that flow through the Archipelago. As part of the International Arctic Science Committee's activities, called ASOF which is the Arctic/Subarctic Ocean Flux Program, the Canadians are beginning to spin up a measurement program up there in the Canadian Arctic to see how that saltier Pacific water filters its way down to the Labrador Sea and what effect it may have there. It has an interesting signature because it's much higher in nutrients than the Atlantic water.

Chairman STEVENS. Do you know if there is a current across the top? We've got an open Northwest Passage now, an open passage across the top of Russia, I understood, the current flow from Russia over to the Bering Sea. Do we know which side—what's the flow of the current across the top of our continent?

Mr. NEWTON. It tends to move from the west to the east.

Chairman STEVENS. West to the east.

Mr. NEWTON. From Alaska, the Alaska coastline, along the Canadian Archipelago but it has changed significantly. One of the things that I am not capable of explaining the North Atlantic oscillation and the Arctic oscillation, if you will, which have changed the pattern flows of sea ice and currents in the Arctic Ocean by its movement in the central Arctic Basin. A traditional low pressure area that exists in that area has moved dramatically in the last few years. These are all the reasons that additional data collection is just so vital in the area that is so poorly understood.

If I may, Senator, to give you an example of how the paucity of information on the Arctic and the Arctic Ocean, which is really the driving force behind this global climate change as we view it. In the SCICEX Program in its 6 years of existence, 211 days under sea ice about 57,000 miles, 92,000 kilometers under sea ice collecting data on the ocean itself and ice thickness, we've essentially doubled the store of Arctic information available to science. I mean, that's all we did. We just doubled it and we did it for 6 years. When you compare that to the information and knowledge that exists about the temperate oceans where the access is easy and the costs of logistics are so much lower, you get an idea of how absolutely vital it is that we point resources in the direction of the Arctic in order to study it better.

Chairman STEVENS. We get too subjective. I know you gentlemen deal with the Arctic as a global situation. We deal with the Arctic as our Arctic.

Mr. NEWTON. A State situation.

Chairman STEVENS. But I remember so well coming on the Manhattan—I don't know if you all know that in 1969 a group of us came around on an ice-breaker tanker, trying to get through the Northwest Passage. Finally, it beat its way through but it was very difficult and, as it went back, it was hit by an iceberg and it broke through its double hull. We never use tankers to take the oil from the northern part of Alaska eastward because of that trip. But the impression I had of grinding, that grinding, breaking of that ice, day after day and, now, to know that it's open. It's been open now for 3 years. We need to know more about that. Where's that water coming from? How long is it predicted to occur? Is that going to sell? We've had applications, I understand, for cruise ships to come across through the Northwest Passage next year. And should we work with Canada to permit that? Currently, they're barred. I don't know. There's lots of questions out there for us from a policy point of view. Again, just provincial for us in Alaska, but I do think they're important to us to try to find out what can we learn about this and is it going to continue. I assume, from what your projections are, you don't project any reversal of the current warming trend in the Arctic, right? So we should anticipate that the Northwest Passage and the passage across to Russia—I think they call that the Eastward Passage.

Mr. NEWTON. Northern Sea Route.

Chairman STEVENS. Northern Sea Route? That will remain open also. It has tremendous military impact, tremendous.

Mr. NEWTON. Significant and certainly the political aspects, Senator, of dealing with foreign countries who claim that those particular passages are their national space as opposed to our interpretations of their being an archipelago and, therefore, ships are eligible for the right of innocent passage. There are tremendous concerns as the ice decreases on what we can do and how we can do it.

Chairman STEVENS. Again, I'm indebted to all of you for coming and I apologize for the absence of my colleagues. We will reconvene here at 2 o'clock for the—it is 2 o'clock, isn't it?

UNIDENTIFIED. two o'clock, right.

Chairman STEVENS. two o'clock for the afternoon panel. And I call your attention to the fact that we do have very distinguished witnesses: Dr. Margaret Leinen of the U.S. Global Climate Research Program, Mr. Dan Goldin, the Administrator of NASA, Dr. Rita Colwell, the Director of the National Science Foundation, Scott Gudes, the Acting Director of NOAA, and Dr. Charles Groat, the Director of the U.S. Geological Survey.

Thank you very much, gentlemen.

UNIDENTIFIED. Thank you, sir.

Chairman STEVENS. I want to thank you for your willingness to come and meet here and to contribute to our knowledge concerning climate change and its relationship to the Arctic Region.

This afternoon our panel is primarily of people who are involved in the Federal side of this operation. And I apologize to Margaret Leinen. I've been mispronouncing your name. Another senior moment, if you'll forgive me. We'll start with Margaret. She's involved with the U.S. Global Climate Research Program. Thank you very much.

## NATIONAL SCIENCE FOUNDATION

### STATEMENT OF DR. MARGARET LEINEN, CHAIR, SUBCOMMITTEE ON GLOBAL CHANGE, ASSISTANT DIRECTOR FOR GEOSCIENCES

Dr. LEINEN. Thank you, Senator Stevens. I am the Assistant Director for Geosciences at the National Science Foundation but I'm here in my capacity as Chair of the Subcommittee on Global Change Research which oversees the U.S. Global Change Research Program.

I'd like to thank you for the opportunity to appear before the committee here in Alaska and to discuss this program. The U.S. Global Change Research Program or USGCRP was established by Congress through the Global Change Research Act of 1990 to coordinate all of the national research effort on global change.

Understanding global change is probably the most extensive and most challenging scientific endeavor ever undertaken. And I realize that's a provocative statement but, when you think about the global scope, the complexity of the problems and the systems and the impact that this can have on all of our institutions, it's easy to see what a challenge it is.

USGCRP has assembled ten agencies involved in all aspects of global change. We are the program that coordinates all of the agency work that's done by Federal agencies in global change. All of the agencies that are appearing with me today are part of the U.S. Global Change Research Program and many of the scientists that you've heard from today have been funded by that program.

During the last decade the USGCRP agencies have had significant accomplishments, some of which you've seen and some of which are in the written testimony. Since we're meeting here in Fairbanks, many of us have highlighted those discoveries with relevance to Alaska and the Arctic. However significant these accomplishments have been, I must tell you that our work has really only begun. And you've seen that highlighted by the scientists who have talked about the uncertainties and the lengths between processes and impact that we need to develop. We have observed much of it on climate change here and around the world and have identified key factors that contribute to climate change. But for far too many aspects we're still uncertain of how the processes are related to the impacts. It's essential that we continue this research in order to establish a firm understanding of the important climate processes and the impacts that they will have on this Nation and on the world.

In bringing the agencies together, the USGCRP provides added value to the work of individual agencies. Let me explain. The first way that the program adds value is by insuring that studies can be put in the proper context of scale. Changes in Alaska take place in a tapestry of changes that are taking place around the world. There are often complex links between processes taking place in different parts of the world and understanding the links requires international collaboration as well as U.S. science. USGCRP supports this international collaboration and has developed a number of large scale international programs that have led to significant discoveries.

One important example comes from paleoclimate. Next slide. In order to understand whether the changes that we see in one region, like Alaska and that you saw described by Dr. MacDonald this morning, are unusual or whether they're just part of the fabric of natural climate variability, we look to the geologic record. Scientists in a program called PAGES made paleoclimatic reconstructions from geologic records extending back before instruments were available to create a temperature record for the entire Earth for the last 1,000 years. And you saw part of that in Dr. MacDonald's talk. The upper panel here shows the instrumental record from thermometers over the last—since 1860. The lower records shows that paleo-record developed for the last 1,000 years and it allows us to see how unusual the changes from the most recent century—on the far right hand side of the lower diagram—are in comparison with the entire last 1,000 years of temperature records. Assembling the data from many regions into one coherent picture requires the input of hundreds of scientists working collaboratively on records from all over the world. Their work demonstrated that the global average temperature increased by amount 1 degree fahrenheit during the last 100 years. While this is a small number, you can see from the diagram that it is a temperature change that is unprecedented over the last 1,000 years.

While processes are often global, the principal impacts of climate and global change are regional. Alaska's northern location and dependence on natural resources make it particularly vulnerable to climate change, as Dr. Martinson pointed out. Over the past few decades many changes have occurred in Alaska. Average temperatures are up by about 4 degrees fahrenheit since the 1950's. The growing season is 14 days longer than during the 1950's. The permafrost is as much as 7 degrees fahrenheit warmer than during the last century.

Conversely, many of the trends in Alaska could have far-reaching impacts on the globe as a whole. For example, warming permafrost could release large quantities of carbon, either as carbon dioxide or as methane, a more potent greenhouse gas. Local and regional changes in land use and land cover here and elsewhere and other human activities can also contribute to the global climate. Examples are changes in the reflectivity of Earth's surface due to land-cover change. Another is changes in carbon dioxide uptake as a result of changing land use.

Thus, in the U.S. Global Change Research Program we consider both down-scaling—that is looking at the global changes and how they impact an individual region—as well as up-scaling, looking at what's happening in regions and the impact that it will have globally.

A second way that USGCRP provides value is by insuring interdisciplinary approaches to problems. Few agencies have staff or mandates that cut across the entire scope of global change problems. USGCRP has assisted them in enlisting a superb cadre of scientists in academic and research institutions, as well as in Federal Government, with the competence to address these global change problems.

An example of why this is important comes from the carbon cycle. Next slide. While we put $CO_2$ into the atmosphere, the emissions—at the top of this slide—from energy production, deforestation and other activities, plants take it out of the atmosphere by photosynthesis. Another U.S. Global Change Research program, the Global Change and Terrestrial Ecosystem Program, determined that several factors affect the amount of carbon taken up by plants on land, including the regrowth of forests, fire suppression and other management practices such as reduced tillage. Also the beneficial effects of increased $CO_2$ in the atmosphere on plant growth and the deposition of nitrogen on landscapes from some forms of pollution. The comparisons between the emissions of $CO_2$, measured by atmospheric scientists—the top number—as well as the uptake of $CO_2$, the flux to land—the bottom number—which comes from terrestrial biologists, and the uptake of $CO_2$ by the ocean, measured by oceanographers, all show that the uncertainties in the uptake numbers are very large compared to what we know is in the atmosphere. There's growing evidence that there's a missing sink for carbon and all evidence points to it being in the Northern Hemisphere and being closely related to the biological cycling of carbon on land. Understanding this sink will require a broad range of disciplines and it's of tremendous policy significance for the management of carbon in the atmosphere. And so identifying, characterizing and predicting the fate of this Northern Hemisphere carbon sink will be an important part of the research of USGCRP in the next few years.

Another interdisciplinary example comes from water-cycle studies. Next slide. The National Academy of Sciences has stated that, quote, “Water is at the heart of both the causes and the effects of climate change.” It is essential to establish the rates and possible changes in precipitation—shown here, the trends for the last 100 years in precipitation, with green dots showing increasing precipitation, brown dots showing decreasing precipitation. Better time-series measurements are needed for water runoff, river flow and, most importantly, the quantities of water involved in various human uses. Studies of the water cycle and its relationship to climate change, globally and regionally, will be an important part of our work in the next decade. This is not just an issue of physical flows of water and energy, water and clouds and precipitation. There’s also a strong biological component because plants transfer large amounts of water from the land to the atmosphere, so much so that they determine the climate in many regions such as the tropical rain forests. So understanding changes in precipitation and water availability will require very large interdisciplinary research effort and will rely on several techniques that are represented by the agencies that are with me today. For example, NASA’s satellites, the National Science Foundation’s long-term ecological research stations and so forth. Third, the USGCRP provides an effective mechanism for participating agencies to engage in planning coordinated future activities. These planning efforts involve input from the scientific community to identify important and achievable objectives and interagency working groups make sure that the individual efforts of agencies, when integrated, will meet the agreed scientific objectives.

USGCRP is nearly finished drafting a new long-term strategy for the next decade. It is involved in close collaboration between many scientists, both in academic institutions and in the agencies. The over-arching goal for the second decade of the program will be to improve our capacity to project global change, to diagnose vulnerability and evaluate opportunities for enhancing the resilience of Earth’s systems and our human systems and, finally, to provide useful knowledge for decision-making by governments, communities and the private sector. The program must address issues from basic natural science to socio-economic impacts. Only through the entire scope of these areas can we span these difficult issues.

In Alaska—next slide—you’ve seen trends in polar bear activity, animal migration, growing seasons, et cetera, that may be related to 20th century climate change. Such studies reveal the vulnerability of ecosystems to global change. My written testimony cites work done under the auspices of USGCRP in publishing a national assessment which was published this last fall called “Climate Change Impacts on the United States” and your office has copies of this. It outlines the potential impact of climate change on the Nation as a whole, on several important socio-economic sectors like agriculture and, also, on specific regions. In December 1999 we published an assessment of the potential consequences of climate variability and change for Alaska and many of the agencies here were involved in sponsoring and making sure this assessment took place. The national assessment identified several key issues of concern in Alaska, thawing of permafrost, sea ice melting—which you've heard about today—increased risk of fire and insect damage to forest, the sensitivity of fisheries and marine ecosystem, and the increased stress on subsistence livelihoods. USGCRP will continue to provide the scientific foundation for such assessments and will continue to coordinate undertaking such assessments.

PREPARED STATEMENT

I hope that these comments show you the way that USGCRP serves to coordinate the activities, the broad and successful programs of research that are undertaken by the agencies through ensuring appropriate scale, through ensuring interdisciplinary approaches, through planning and through ensuring that we can assess the impacts of climate change. The sustained bipartisan support of Congress and of the Administration have made this possible. It's also resulted in investments which have developed a new generation of tools that promise more rapid progress in the years ahead. We will all benefit from the unprecedented amounts of high-quality data about the Earth that will be developed by the program and the more accurate and realistic models to project the changes ahead. Most importantly we expect to learn much more about the potential impacts of climate change and the way that we can manage them.

Thank you for your time.

[The statement follows:]

PREPARED STATEMENT OF DR. MARGARET LEINEN

INTRODUCTION

Mr. Chairman and members of the Committee, thank you for this opportunity to discuss with you the U.S. Global Change Research Program (USGCRP) and its potential to help us understand global change in polar regions. The USGCRP is the U.S. interagency program charged by Congress to coordinate the national research effort on global change. You will hear next from the agency heads of the National Science Foundation (NSF), the National Aeronautics and Space Agency (NASA), the National Oceanographic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS), three of the ten agencies that have research activities included under the rubric of the USGCRP. The USGCRP began as a Presidential Initiative in 1989 and was formally established by the Global Change Research Act of 1990. Every Administration and Congress has strongly backed the program since its inception. I know the Members of this Committee are strong supporters of this research program, which is one of our nations's most important scientific efforts. I want to thank you for your support on behalf of the scientific community. We look forward to working with the Congress to carry on this bipartisan tradition of support for sound science on global change.

I am submitting this testimony to outline some of the significant accomplishments of USGCRP-supported research and to cite a few key results of the U.S. National Assessment, particularly those related to Alaska. My statement also includes a description of key aspects of the Administration's fiscal year 2002 budget proposal for global change research, the current structure and research activities of the USGCRP, and new developments in planning the future of the USGCRP.

GLOBAL CHANGE AND THE CONTEXT FOR ALASKA

Global change is an extremely complex and challenging scientific topic. Our research of the past decade has shown us that Earth's climate system includes intricate links between the atmosphere, the ocean, the biosphere and our human activity. Furthermore, it is clear that large scale phenomena in one region, like the El Niño-Southern Oscillation in the tropical Pacific, reverberate through this climate system to create impacts in regions far from their origin, like Alaska. To understand which of the many changes that we are now seeing here in Alaska are related to global phenomena, which are related to natural climate variability, and which are due to human activity, requires that study of polar regions be done in a global context. Likewise, many climate-related trends in Alaska may result in complex feedbacks that have far reaching effects on the global climate. Thus, it is necessary for us to consider both "downscale" processes, i.e., the global-scale effects on regions, and "upscale" processes, i.e., regional-scale effects on the global scale. The USGCRP is a powerful means of ensuring that we can do both. Explaining how the Earth system functions, how it is changing, and how it is likely to change under human interventions in the future requires a coordinated research effort that cuts across many different scientific disciplines.

During this hearing you will hear testimony from four agencies related to their climate change studies. Much of that work has been done as a part of the USGCRP. In other cases the work has been interpreted in the context of global-scale studies. The USGCRP is the "glue" that allows us to coordinate across agencies to integrate across disciplines and enhance understanding of the implications of individual studies of climate change.

I would like to highlight some program accomplishments that exemplify links between global changes and changes in Alaska. Scientists working under the auspices of the USGCRP have:

—Observed and understood the growth in atmospheric concentrations of chlorofluorocarbons (CFC) that deplete the stratospheric ozone layer, and increased our understanding of how this layer in the stratosphere protects living organisms from exposure to higher levels of ultraviolet (UV) radiation. Ongoing research and observations have shown that CFC emission controls implemented under the Montreal Protocol treaty on depletion have begun to decrease the concentration of several man-made of these ozone-depleting gases in the atmosphere. Controls on the emission of CFC's are especially important for high-latitude regions like Alaska because they help prevent the destruction of the ozone layer and exposing people to potentially harmful levels of UV radiation.

—Determined from paleoclimatic reconstructions of pre-instrumental temperatures that the 1990s appear to have been the warmest decade (and 1998 the warmest year) in the past 1,000 years, and confirmed that the observed 20th Century warming far exceeds the natural variability of the past 1,000 years. Scientists concluded that the observed increase in global average surface temperature during the past century is consistent with a significant contribution from human-induced forcing. You will hear several examples of trends in Alaska that are consistent with warming: thinning sea-ice, permafrost thawing, etc. But it will only be through studying these trends in the context of the global climate that we can understand whether they are caused by human activity. Scientists understand that there may be far-reaching consequences of warming in high northern latitudes. The permafrost regions include large areas where methane, an important greenhouse gas, is trapped by freezing. Substantial thawing of the permafrost could release large quantities of this methane, further aggravating greenhouse effects. Thus, it is also necessary for us to "upscale" impacts from the polar region to their global effect.

—Documented during the past decade that regional air pollution can be transported over long distances and affect atmospheric composition on a global scale. Plumes of polluted air from industrializing areas of Asia reach Alaska, mineral dust from the Sahara Desert and smoke and ash from Mexican forest fires have also been shown to reach the U.S. The particles in these plumes, called aerosols, can have important health effects. But they also have an important role in the climate system and can result in changes in cloud cover and affect atmospheric temperatures.

—Detected and attributed to 20th Century climate change, alterations in ecosystems such as shifting of animal ranges and migration patterns, increases in the length of the growing-season, earlier plant flowering seasons, changes in tree growth and reproduction, and die-off of tropical corals. In Alaska you have seen trends in polar bear activity, animal migration, and plant growing seasons that may also be directly related to 20th Century climate change. Such studies reveal the unique and serious vulnerability of ecosystems to global change.

—Successfully predicted the onset of the 1997–1998 El Niño and the subsequent La Niña, as well as some of the resulting climate anomalies around the world. Improvements in the accuracy and lead times of predictions of seasonal climate fluctuations are providing important information to support decisions for resource planning and disaster mitigation. While the major impacts of these systems is on tropical and mid-latitude regions, other climate components, such as the Pacific Decadal Oscillation in the Northern Pacific Ocean, may permit extended climate outlooks for other regions as well. These global scale oscillations are central to understanding variability of climate and natural resources in Alaska—whether winters are cold or warm and whether salmon are abundant here or in the Pacific Northwest.

—Identified decreases in the extent and thickness of Arctic sea-ice during the past several decades, and demonstrated that the extent of such decreases may exceed what would be expected from natural variability alone. These changes are important for high-latitude marine life and those who draw sustenance from these natural resources.

—Concluded that land use change (including recovery of forest cleared for agriculture in the 20th Century) and land management (such as fire suppression), and reduced tillage, along with $CO_2$ fertilization, nitrogen deposition, and climate change, all appear to play important roles in the North America terrestrial carbon sink.

These examples of the way that climate change in Alaska is related to the planet as a whole hold true for virtually every large region of the globe and demand strong interactions between regional studies and global studies. Thus, although global in scope, the USGCRP nonetheless relates many of its activities and accomplishments in terms of specific regional issues.

Let me note one additional accomplishment. In response to the requirements of the Global Change Research Act, the USGCRP helped to produce the first national assessment, Climate Change Impacts on the United States, recently submitted to Congress. The purpose of the assessment was to synthesize, evaluate, and report on what is known about the potential consequences of climate variability and change for the nation. It includes a detailed examination of the possible impacts of change on various geographic regions and socio-economic sectors.

The overall USGCRP assessment process consisted of three elements: (1) the overview cited above, (2) sectoral evaluations for agriculture, water, human health, coastal areas, and forests, and (3) a number of regional reports. Most of the USGCRP participating agencies have sponsored specific sectoral or regional activities. The Alaska report, Preparing for a Changing Climate (1999), was one of the first regional reports published. It was sponsored by DOI/USGS, NSF, NOAA, and by the non-governmental the International Arctic Science Committee, and outlined a number of critical issues facing the state. A few of the key issues include: permafrost thawing and sea-ice melting, increased risk of fire and insect damage to forests, sensitivity of fisheries and marine ecosystems, and increased stresses on subsistence livelihoods. I will return to them later in the testimony.

In later testimony you will hear about changes in the fisheries in Alaska, especially the critical salmon fishery. You will hear about these changes in the context of the complex relationship between fish catches and climate changes. During the past decade we have begun to understand that tropical and mid-latitude climate events, such as El Niño, influence and modify the climate systems of the North, such as the Pacific Decadal Oscillation, and that these northern systems directly affect the temperature, precipitation and runoff in Alaska. Some believe they exert a strong control on fishery success. Improvements in the accuracy and lead times of predictions of seasonal climate fluctuations are providing important information to support decisions for resource planning and disaster mitigation in many parts of the U.S. They also allow us to develop a deeper understanding of the way that Alaska's fishery resource is affected by far-reaching global changes.

Over the next several years, in addition to supporting research that will continue to improve our understanding of the Earth's environment and how it is changing, we expect the USGCRP will continue to promote efforts to advance our knowledge about the implications of such change for society. We intend to do this through research that focuses on the interactions of multiple stresses with resource patterns and demands created by populations in particular places. In addition, the program will continue to support activities that assess the potential consequences of global change and conduct periodic assessments as called for under the Global Change Research Act. By developing the capability to tie the new knowledge gained through research to the needs of people in communities, we are striving to assist the country to adapt to change and avoid detrimental outcomes.

## CLIMATE CHANGE VULNERABILITIES AND POTENTIAL IMPACTS IN ALASKA

Alaska's northern location and dependence on natural resources make it particularly vulnerable to climate change. The region could experience some benefits from climate change, including more favorable conditions for ocean shipping and offshore drilling operations (from reduced sea-ice) and new commercial timber development (from expansion of some forests). However, such potential benefits must be considered in the context of 100–200 years of potential ecological upheaval during the transition to a fundamentally different environment.

Over the past few decades, many changes have been observed in Alaska:

—Average temperatures have increased statewide by about 4 degrees F since the 1950s. The largest warming, of about 7 degrees F, has occurred in the interior regions in winter, and summers in the interior are becoming much warmer and drier

—The growing season has lengthened by more than 14 days since the 1950s

—Precipitation increased by 30 percent over much of the state between 1968 and 1990

—Continuous permafrost has warmed as much as 7 degrees F during the last century, and all permafrost measurement sites in Alaska warmed between the mid-1980s and 1996

These changes have already produced impacts. In contrast to other regions of the U.S., most of the most severe environmental stresses in Alaska at present appear to be climate related. Global climate models project continued rapid Arctic warming. Climate models used in the U.S. National Assessment project that average annual temperatures in Alaska could increase 5–18 degrees F by 2100. Because there are many uncertainties in model estimates, we cannot make a firm prediction at regional scales, although temperature increases in this range are judged a possibility.

The National Assessment addressed and documented several key issues of concern in Alaska. I have summarized some of their results but in the interest of brevity, have omitted detailed citations.

*Permafrost Thawing*.—Extensive thawing of discontinuous permafrost has already been accompanied by increased erosion, landslides, sinking of the ground surface, disruption of forested areas and major impacts on human infrastructure. Present costs of thaw-related damage to infrastructure have been estimated at about $35 million per year. Continued warming is expected to result in the thawing of the top 30 feet of discontinuous permafrost during the next 100 years, which would result in much greater impacts than those currently being experienced. For example, replacing the supports for the Trans-Alaska pipeline is estimated to cost approximately $2 million per mile. Large-scale thawing of ground ice can result in the transformation of landscape through mudslides, subsidence of up to 16 feet, formation of flat-bottom valleys, and formation of melt ponds that can grow for decades to centuries.

*Sea-ice Melting*.—Evidence indicates that the extent and thickness of Arctic sea-ice has been decreasing since the 1960s, and climate models project that losses will continue. Some models project that year-round ice will disappear completely by 2100. Recent modeling calculations indicate that recent sea-ice trends are consistent with the effects of present greenhouse warming and are highly unlikely to be the result of natural climate variability. Retreat of sea-ice increases coastal erosion and the risk of inundation, and also causes large-scale changes in marine ecosystems, thus threatening the population of marine mammals and polar bears. Aerial photography has revealed erosion of up to 1,500 feet over the past few decades along some stretches of the Alaskan coast, threatening villages in some locations.

*Increased Risk of Fire and Insect Damage to Forests*.—The recently observed warming has increased forest productivity in coastal areas, but reduced it in some interior areas where forests are more moisture-limited. Warming has been accompanied by large increases in forest disturbances, including blowdown, insects, and fire. Since 1992 a sustained outbreak of spruce bark beetles has caused more than 2.3 million acres of tree mortality on the Kenai Peninsula, the largest loss from a single outbreak documented in the history of North America. There are no clear trends in forest fire frequency at this time. The overall area of Alaska, Yukon and Northwest Territories of Canada have show almost a doubling in the average annual burn area since 1960. Additional research is needed.

*Sensitivity of Fisheries and Marine Ecosystems*.—The Gulf of Alaska and the Bering Sea support the Nation's largest commercial fishery, employing about 20,000 people and accounting for revenues of about $1.5 billion in 1995. There is increasing evidence that yearly and decadal climate variability, likely having its origin in the tropics and mid-latitudes, is a factor in the fluctuating productivity of these marine ecosystems, along with ocean circulation and human harvesting practices. Further research is needed to explain the relative effects of the multiple stresses on fisheries. Rapid and extreme shifts in the organization of these ecosystems occurred in 1924 and 1946. There is some evidence for another shift in the mid-1990s, with large declines in the Bristol Bay Sockeye salmon run accompanied by huge runs of Pink salmon. Projected climate change could have a large effect on these ecosystems.

*Increased Stress on Subsistence Livelihoods*.—Subsistence practices are probably more important in Alaska than any other state. The subsistence harvest by rural residents is about 43 million pounds of food annually, or about 375 pounds per person. The significance of such practices in Alaska goes beyond the provision of food. Subsistence activities are also associated with harvests making important contributions to health, culture, and identity. Climate changes in Alaska are already causing serious harm to subsistence livelihoods. Many local populations of marine mammals, fish, and seabirds have been reduced or displaced. Reduced snow cover, shorter river ice seasons, and permafrost thawing all obstruct travel and the harvest of wild food. Continued warming is likely to lead to further ecosystem changes.

While continued increases in $CO_2$ concentrations and temperatures are likely to bring significant climate change to Alaska, there are many remaining uncertainties about the actual rate and magnitude of change that will occur, the regional effects of temperature change on the hydrological cycle, and, perhaps most importantly, about the adaptive capacity of species and the most likely effects on ecosystems and human communities. The USGCRP is working with its international research partners in the other countries with lands in the Arctic region to conduct a major assessment of Arctic changes over the next several years that should help reduce these uncertainties. The monitoring and analysis of changes in Alaska will continue to be an important priority for the USGCRP in the years ahead.

THE BUDGET FOR FISCAL YEAR 2002

The overall fiscal year 2002 USGCRP Budget Request is approximately $1.64 billion about 4 percent less than last year's enacted level. About $804 million of this total is devoted to scientific research, which is basically level with last year's budget. Within the total request, surface-based climate observations at NOAA are increased by $13 million (about 100 percent), continuing the vital upgrade of these capabilities that was begun last year. The space-based observation component of the budget is reduced by about $89 million (about 10 percent), to a total of $819 million. This decrease is mainly a consequence of decreases in NASA development costs as the first generation Earth Observing System (EOS) satellites (e.g., Terra, Aqua and Aura) are completed and launched.

Some important highlights of the budget proposal include:

—*Improved Climate Observations.*—The fiscal year 2002 budget provides $26 million (an increase of $13 million) to enhance NOAA surface-based observations. Measurements of atmospheric trace gases, aerosols, ocean temperatures, and ocean currents will also be expanded, and implementation of the Climate Reference Network to provide, for the first time, simultaneous, automated, and well-located measurements of changing temperatures, precipitation and soil moisture across the U.S., will be continued.

—*Carbon Cycle Science.*—The fiscal year 2002 budget request continues strong support for carbon cycle science, providing $225 million (an increase of $9 million or 4 percent) to study how carbon cycles between the atmosphere, the oceans, and land, and the role of farms, forests, and other natural or managed lands in capturing carbon. Key agencies include NOAA, USDA, DOE, NASA, NSF, DOI/USGS, and the Smithsonian Institution.

—*Research on Human Dimensions of Global Change.*—The fiscal year 2002 budget provides $107 million to study the impacts of global change, including stratospheric ozone depletion and climate variability and change, on communities and human health, an increase of $7 million, or 7 percent. Key agencies include NIH, EPA, NSF, DOE, and NOAA.

ORGANIZATION OF THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

The agencies that participate in the USGCRP include the USDA, DOC/NOAA, DOD, DOE, HHS/NIEHS, DOI/USGS, EPA, NASA, NSF, and the Smithsonian Institution. Each year these agencies join to refine research priorities for the program. In 1998, the National Research Council (NRC) released its report, Global Environmental Change: Research Pathways for the Next Decade (NRC, 1998), often referred to as the "Pathways" report. This report, like many others about the USGCRP issued by the NRC, was commissioned by the program and continues to strongly influence the definition of the nearterm research challenges for the program.

For fiscal year 2002, the USGCRP is currently addressing a series of closely linked program elements that are directly responsive to the scientific challenges described in the cited NRC report:

*Understanding the Earth's Climate System.*—The focus is on documenting past and current causes and rates of change and improving our understanding of the climate system as a whole, and thus improving our ability to predict climate change and variability. In fiscal year 2002 $487 million is proposed for USGCRP climate research efforts. Climate is a naturally varying and dynamic system with important implications for the social and economic well being of our societies. Understanding and predicting climate changes across multiple time scales (ranging from seasonal to interannual, to decadal and longer) offers valuable information for decision making in those sectors sensitive to rainfall and temperature fluctuations, including agriculture, water management, energy, transportation, and human health. Improving our understanding, of climate change, and determining how much of the observed changes in the climate are attributable to human activities, and how much to natural variability, requires that we improve our understanding of both natural variability and human effects. Such improvement depends on a balance of observations, studies of underlying Earth system processes (such as the El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the Arctic Oscillation), and predictive modeling.

*Composition of the Atmosphere*.—The focus is on improving our understanding of the impacts of natural and human processes on the chemical composition of the atmosphere at global and regional scales, and determining the effect of such changes on air quality and human health. In fiscal year 2002 $310 million is proposed for this research area. Changes in the global atmosphere can have important implications for life on Earth, including such factors as the exposure to biologically damaging ultraviolet (UV) radiation, the abundance of greenhouse gases and aerosols (which in turn affect climate), and regional air pollution. Human activity that can affect atmospheric composition includes the use of chlorofluorocarbons and other halogenated hydrocarbons, fossil fuel combustion and the associated release of air pollutants, and changes in agricultural and forestry practices that affect the concentration of gases such as nitrous oxide and methane, as well as that of smoke. As a result, this research is a central component of our effort to understand global change.

*Carbon Cycle Science*.—The focus is on improving our understanding of how carbon moves through the Earth's atmosphere, land, and water, the sources and sinks of carbon on continental and regional scales, and how such sinks may change or be enhanced. This area continues as a very high priority for the USGCRP, with $225 million proposed in fiscal year 2002 for the comprehensive examination of the carbon cycle as an integrated system, with an initial emphasis on North America. Comparison of North America to other regions will also be important for understanding the relative importance of this region in the global context. Data from atmospheric and oceanographic sampling field campaigns over the continent and adjacent ocean basins will be combined with atmospheric transport models to develop more robust estimates of the continental and subcontinental-scale magnitude and location of the North American terrestrial carbon sink. Local-scale experiments conducted in various regions will continue to improve our understanding of the mechanisms involved in the operation of carbon sinks on land, the quantities of carbon assimilated by ecosystems, and how quantities might change or be enhanced in the future.

*The Global Water Cycle*.—The focus is on improving our understanding of how water moves through the land, atmosphere, and ocean, and how global change may increase or decrease regional water availability. For fiscal year 2002 $312 million is proposed. The cycling of water through the land, atmosphere, and ocean is intimately tied to the Earth's climate through processes including latent heat exchange and the radiative effects of water in its vapor, liquid, and solid phases. The global water cycle is emerging as a top research priority in part because changes appear to be occurring already. Long-distance atmospheric transport of water, along with evaporation and precipitation, are the principal inputs in hydrologic process and water resource models. The primary goal of this research is a greater understanding of the seasonal, annual, and interannual variations of water and energy cycles at continental-to-global scales, and thus a greater understanding of the interactions among the terrestrial, atmospheric, and oceanic hydrosphere in the Earth's climate system.

*Biology and Biogeochemistry of Ecosystems*.—The focus is on improving understanding of the relationship between a changing biosphere and a changing climate and the impacts of global change on managed and natural ecosystems. The budget includes $198 million in fiscal year 2002 for ecosystem research. The biosphere consists of diverse ecosystems that vary widely in complexity and productivity, in the extent to which they are managed, and in their economic value to society. Ecosystems directly provide food, timber, fish, forage, and fiber, as well as other services such as water cycling, climate regulation, recreational opportunities, and wildlife habitats. Management of ecosystems and natural resources will be an important aspect of society's response to global change. Better scientific understanding of the effects of multiple stresses and the processes that regulate ecosystems, will improve our capability to predict ecosystem changes and evaluate the potential consequences of management strategies for sustainability.

*Human Dimensions of Global Change*.—The focus is on explaining how humans affect the Earth system and are affected by it, and on investigating the potential response strategies for global change. The budget includes $107 million in fiscal year 2002 for the study of the human dimensions of global change. Scientific uncertainties about the role of human socio-economic and institutional factors in global change are as significant as uncertainties about the physical, chemical, and biological aspects of the Earth system. Improving our scientific understanding of how humans cause changes in the Earth system, and how society and human health and well-being, in turn, are affected by the interactions between natural and social processes, is an important priority for the USGCRP.

A much more detailed description of accomplishments and plans in each of these research areas will be included in the fiscal year 2002 edition of Our Changing Planet, the USGCRP annual report, which we plan to deliver to Congress in the near future.

NEW DIRECTIONS FOR THE USGCRP

The USGCRP is drafting a new long-term research strategy that will increase the program's focus on understanding the resilience of natural and managed ecosystems as well as the vulnerability of these systems and human society to global change. The planning process has been informed by a series of NRC reports, including "Pathways", Our Common Journey, A Transition Toward Sustainability, (NRC, 2000), Grand Challenges in Environmental Sciences (NRC, 2000), and a number of other focused NRC reports, scientific assessments and internal analyses.

A particular need identified in many of these documents is to improve understanding of the potential consequences of global change, especially at regional scales such as those experienced in Alaska. We know that regional impacts will vary significantly, but do not yet have the ability to project regional variations accurately. In addition, local and regional changes in land use/land cover and in other human activities can also combine to affect global climate. Examples are changes in planetary albedo due to land cover change and changes in carbon dioxide uptake as a result of changing land use. The importance of regional research efforts is most recently highlighted in the January 2001 NRC report, The Science of Regional and Global Change: Putting Knowledge to Work. It states that a high-level focus is needed to ensure that "regionally focused environmental research and assessments are developed to complement global-scale research and transform its advances into usable information for decision making at all spatial scales". Thus ecosystem research, land-use/land-cover change research, and regionally focused environmental research are critical elements of our long-range planning.

Another critical need is to improve understanding of the cycling of carbon, nitrogen and water through the Earth's atmosphere, vegetation, soils, oceans and hydrological systems. The interactions of climate change with the Earth's water cycle and carbon cycle are particularly important. The Pathways report identified improved understanding of the changing global biogeochemical cycles of carbon and nitrogen as a research imperative. It noted that better understanding of carbon sources and sinks was needed to "understand the fractional impacts of any industrial or agricultural input to that natural system". The Pathways report also stated that ". . . water is at the heart of both the causes and the effects of climate change. It is essential to establish the rates and possible changes in precipitation, evapotranspiration, and cloud water content (both liquid and ice). Additionally, better time series measurements are needed for water runoff, river flow, and most importantly, the quantities of water involved in various human uses."

The complex relationships between atmospheric composition and human activity continue to remain high priorities for our future research, as does study of climate variability and change—whether anthropogenic or natural.

Improving our understanding of biogeochemical cycling and regional-scale impacts requires more sophisticated multi-scale observing systems, more powerful computing systems and more capable models, and the design and implementation of regional-scale process studies and large scale ecosystem manipulation experiments. All of these points are strongly emphasized in the Pathways report, which found that modeling and climate prediction were key crosscutting themes, and that improving the USGCRP observations program is essential. The NRC has emphasized the need for improved high-end climate modeling and long-term climate observations in three focused reports sponsored by the USGCRP, Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities (1998), Adequacy of Climate Observing Systems (1999), and Improving the effectiveness of U.S.

*Climate Modeling (2001).*

The technical needs identified in these reports include:

—Procurement of new supercomputers to be dedicated to climate modeling and development of improved climate models;

—Upgrade of existing ground-based measurement networks for temperature, precipitation, vegetation, soil moisture, snow depth and snow cover, and river flow, and installation of new more advanced measurement stations;

—Upgrade of atmospheric chemistry measurements, including improving the quality of existing stations, adding new stations to measure change in chemistry and fluxes of carbon dioxide between the atmosphere and terrestrial ecosystems.

—Procurement of new satellite systems and maintenance of selected existing systems (especially Landsat and some parts of NASA's Earth Observing System) over the long-term, and ensuring research quality measurements on the NPOESS satellite system that is now being developed by NASA, DOD, and NOAA; and

—Increasing the number and quality of measurements of sea-surface temperatures and currents.

We believe that the distributed interagency approach to global change research is one of the USGCRP's greatest strengths. It brings the entire research capability of the federal government to bear on this enormously complicated problem. In addition, it effectively leverages intellectual and financial resources from research efforts taking place in federal agencies and in the academic community supported by federal funding. It also brings a high level of scientific oversight and review. Our current program has proven very effective at coordinating among the USGCRP agencies, each of which has a distinct mission and budget. However, our new strategic plan emphasizes tightly integrated scientific research and explicitly links research on global change with the information needs of resource managers, communities, and the economy.

Our strategy for achieving this integration involves three elements: scientific guidance, interagency coordination, and program integration by the Subcommittee on Global Change Research (SGCR). The U.S. science community brings essential expertise to the USGCRP activities and we will develop a scientific steering mechanism for each of the elements of our program, as well as for the overall integrated program under the guidance of the SGCR. This mechanism will be used to develop detailed science plans for each of the elements.

Once science plans have been developed and reviewed by the community, interagency working groups of program officers must translate them into implementation plans that can guide budget priorities and the planning of specific research campaigns, joint announcements of research opportunity, and other mechanisms for integrated research. The interagency working groups will provide annual program level evaluation of progress toward the scientific goals; review will also be provided by the scientific steering groups.

The USGCRP planning process has identified a number of opportunities where the USGCRP is poised to make significant progress on these issues. I would like to highlight two areas in my testimony today—climate modeling and climate observations.

## CLIMATE MODELING

Modeling is among the most important components of the USGCRP. Climate change research and analysis are particularly dependent on modeling studies, which are an essential tool for synthesizing observations, theory, and experimental results to investigate how the climate system works and how it is affected by human activities. Model experiments provide the only means for predicting near-term oscillations in climate (such as the onset of El Niño or La Niña conditions) and projecting the longer-term response of the climate to increases in greenhouse gas concentrations. They are thus critical for resource and community management and planning, scientific assessment of climate change, and evaluation of the potential effects of policy choices.

Given the importance of these activities, the USGCRP commissioned the NRC to prepare two reports to provide guidance on how to further develop U.S. modeling efforts, Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities, and Improving the Effectiveness of U.S. Climate Modeling. These reports provide valuable guidance to improve U.S. climate modeling efforts.

The USGCRP sees its challenge as maintaining and strengthening research that will help to establish a common modeling framework, developing a strategy and implementation plan for enhancing high-end modeling, and developing criteria for determining when the high-end modeling effort has become primarily an operational activity and hence no longer solely the province of the research program.

A number of significant steps have already been taken towards meeting these challenges:

—The capability and capacity of computing facilities at several major U.S. modeling centers have been upgraded or are scheduled for upgrading. For example, facilities at DOE's Oak Ridge National Laboratory have recently been upgraded, and the National Center for Atmospheric Research (NCAR) is finalizing plans to upgrade the Climate System Laboratory (CSL) computer.

—Common modeling frameworks are being developed to improve the compatibility and portability of model codes, thus ensuring that software advances can be more easily shared among centers and laboratories. DOE and NASA have requested proposals to further develop these common frameworks.

—Investigation of the suitability of distributed memory, high-end computers for climate modeling are underway through the DOE Scientific Discovery to Advance Computing (SciDAC).

—NASA, NOAA, DOE, and NSF are increasing their coordination of modeling activities. A number of bilateral interagency activities have shown substantial progress, and current strategies to support their evolution to a unified modeling framework are underway. For example, the NSF and DOE Avant Garde Software Project is developing a software engineering framework for the Community Climate System Model. In addition, NCAR, NASA, and DOE are committed to a jointly held software repository to support collaboration and possible of modeling activities. This is targeted at building a model to support applications from data assimilation to climate assessment, and those provide a controlled experimental environment to bring together information obtained across the complete range of time-scales from weather to multi-decadal.

Additional near-term steps are underway to support the objective of adding new capacity for high-end modeling in a fashion that permits building on the many strengths of the current U.S. modeling program.

Steps include:

—Formation of a task force to develop specific recommendations on an approach and schedule for developing high-end modeling capacity. The recommendations of the task force will be reviewed and acted upon by the SGCR and will be included in the USGCRP Strategic Plan.

—Development of a multi-agency implementation plan that identifies current agency efforts and needed functional augmentations to assure that a focused systematic modeling capability is developed to meet the stated goals. This requires integration with observing systems activities.

—Development of a multi-agency response that addresses the human resources and performance challenges outlined in the above mentioned reports.

## LONG-TERM CLIMATE OBSERVATIONS

The NRC report, Adequacy of Climate Observing Systems (1999), which warned of degradation of U.S. capabilities, has had a significant effect on the USGCRP. Briefly, over the past several years, many in the national and international climate science community have pointed out serious and growing problems in our existing observation system, and, in particular, a need for additional attention to preserving and enhancing surface based observational capabilities.

The fiscal year 2002 budget augments NOAA's budget by $13 million to enhance the long-term surface-based observations that are needed for climate change research. This includes funding for the U.S. Climate Reference Network which will establish an in situ network to meet long-term climate observing requirements. Automated stations in selected sites will make very accurate measurements of precipitation, temperature, and soil moisture. There is also fiscal year 2002 funding for upgrade and expansion of the long-term measurements of atmospheric trace gases and aerosols at the Alaska, Hawaii, Samoa, and Antarctica observatories, and also for enhanced observations of the oceans. Finally, we have included support for improving the availability and distribution of these climate data and forecasts to the scientific community and general public.

These new resources will be managed within the context of the USGCRP, and they will help us build on the progress of the last year, which has seen a series of important enhancements to our nation's observational programs, both inside and outside the traditional USGCRP. We are improving our ocean observing capabilities by deploying additional buoys in the Atlantic and northern Pacific oceans and modernizing the cooperative observer network that supplies temperature and precipitation data that are useful for both climate and weather research. Most significantly, we have seen the successful deployment of a number of new NASA satellites, including LANDSAT-7, QuikSCAT, ACRIMSAT, and EOS Terra, and look forward to EOS Aqua and Aura in the future. It is no exaggeration to say that we have begun a new era in Earth observations. These new satellites will provide unprecedented amounts of high quality data on land cover, clouds, vegetation, surface winds, solar irradiance, ocean temperatures, and other variables to USGCRP-supported researchers and other users. These data are critical to understanding how the Earth system is changing, and I am confident that we will be able to look back in ten years and see that their availability led to major scientific advances. The successful development and deployment of these missions is a credit to NASA and its international and interagency partners.

An important aspect of getting the most out of these improvements in technology over the long term will be the development of a closer relationship between the research and operational communities in both space-based and surface-based observing programs and scientific research programs. We are making progress in this area as well, with deeper involvement by the USGCRP research community in the design and development of the next generation of operational systems, such as the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

CONCLUSION

This description shows that the USGCRP is continuing a broad and successful program of research on global change that is improving our understanding of how the Earth system is changing, and of the human role in such change. It also demonstrates the clear need to develop new capabilities to understand the regional contributions to global change, to develop finer scale regional projections of change, and to link researchers and potential users more closely in assessment of impacts and adaptation options, so that the nation can prepare for change before it occurs. As we look ahead to the next year, and the next decade, we can expect to develop a much fuller understanding of the processes of change. The sustained bipartisan support for global change research has not only enabled steady scientific progress, but has also resulted in the development of a new generation of tools that offer the promise of more rapid progress in the years ahead. We will benefit from unprecedented amounts of data about the Earth, and these data will be of higher quality than ever before. We will develop more complex and accurate models that permit more realistic simulation of the Earth system. Most importantly, we can expect to learn much more about the potential consequences of change for ecosystems and for human society.

Thank you, Mr. Chairman, for your attention today. I would be happy now to answer your questions.

Chairman STEVENS. Thank you very much, Ms. Leinen. Our next witness is the Administrator of NASA. I apologize to him publicly. I introduced him as the Administrator of NOAA at noon, but Scott's got a replacement there already. I do thank you very much, Dr. Goldin, for coming and being part of this process and I would like to have your testimony now. Thank you.

## NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

### STATEMENT OF DANIEL S. GOLDIN, ADMINISTRATOR

Dr. GOLDIN. Thank you, Mr. Chairman. Thank you for inviting me to testify along with my colleagues on this very crucial subject of climate change.

The trip I made to your beautiful State last summer was a real eye-opener for me. This is such a diverse land and most of us who live in the lower 48 States have little understanding of the true challenges faced by your constituents. After talking with the people here and seeing first-hand the environmental conditions they face where they live and work, it became clear to me that Alaska is being under-served by America's space program. And I'm here to tell you that NASA can and will do better and, in fact, tomorrow we'll be going to a workshop in Anchorage to bring together the scientific leadership of Alaska with our NASA people to see how we could better utilize our space resources.

What the agency brings to this scientific discussion is the ability to put the climate changes we see in the larger planetary context. Our view of Earth from space allows us to study our planet as a dynamic system of land, oceans, atmosphere, ice and life. This view from space allows us to see that the Earth's climate is regulated by a giant thermostat where the continual cycling of water and carbon interact to maintain global temperatures. The polar regions play a significant role in this thermostatic regulating mechanism. That is why Earth, alone among its neighbors in our solar system, supports such abundant and diverse life. This view allows us to see climate changes, adjustments, the setting of this global thermostat with a magnitude and consequences we are just beginning to understand. I might point out Venus had a runaway greenhouse effect because it didn't have the cleansing of the carbon dioxide out of the air by the precipitation of rain that scrubs carbon out. Our thermostat does that for us here on Earth. So Venus is now 700 degrees. Mars doesn't have the tectonic activity which recycles the carbon from the carbonates that fall on the rocks and go into the oceans and come back up the volcanoes and, as a result, Mars is cold and dry with a very thin atmosphere. By studying relative planetology, we better understand our own and are very fortunate to have this thermostat I talked about.

It is fitting we hold this hearing in Alaska because its immense area has a great variety of physical characteristics. Nearly one-third of the State lies within the Arctic Circle. The southern coast and the panhandle, at sea level, are fully temperate regions but in the adjourning Canadian areas lies the world's greatest expanse of glacial ice outside Greenland and Antarctica. Changes in Alaska in the polar regions are the best early indicators of global climate change. Alaskans are already seeing some dramatic changes in the environment and the members of the morning panel and the distinguished members on this panel will be talking about those issues. While it is unclear at present how much is due to human influences, it is clear that both human and natural factors are at work and the impacts are real. Damage to structures and infra-structure due to just permafrost thaw today is costing Alaska $35 million. Other changes are apparent as well. For example, we have been developing models of sea ice processes that control and are influenced by climate changes. This has been greatly facilitated by all-weather instruments such as passive microwave sensors and, more recently, active microwave sensors such as scatterometers and synthetic aperture radar. These instruments are providing important new insights to sea ice processes. Recent accomplishments in this area have included detection of a decrease in seasonal and perennial sea ice cover dynamics, initial estimates of ice thickness and separation of thin ice development. We are also using advanced lasers to measure changes in glaciers and ice caps and ice sheets for a comprehensive analysis of changes in the Arctic land ice. These new observational capabilities enable studies of the sensitive marginal ice zones in ways that were not previously possible.

I'd like to show you a brief video capturing examples of some of these global and regional scale changes and how NASA enables the world to observe them.

Let's begin far from the marble halls of our Nation's capital, Washington D.C. Out of space we see the Earth in a whole new light, a shining sphere of water, air and land. Let's for moment suspend time and speak about NASA's vision.

Have you ever wondered why the Earth alone among its neighboring planets harbors highly-diversified life forms? The answer is that on planet Earth the water and carbon cycles work together to form a giant thermostat that operates to keep global temperatures in a livable range. A combination of natural and human-induced factors is at work to adjust this global thermostat but even slight adjustments can have sizeable impacts.

Now, what does all this mean to Alaska and the rest of North America? Here we see differences in the ice pack around the Pole. Shifting like an ethereal breath, ice flows like ease of bell-weathers of climate change. By keeping a close eye on their condition, we maintain an early-warning system of our planet's health.

Research into climate change is one of NASA's most important charges. Ours is the task of providing policy-makers with information to make sound decisions.

Here in Alaska you know that change can be both subtle and profound. The churning blue surrounding the North Pole in these images highlights a gap in atmospheric ozone. NASA experts on the international research mission called SOLVE determined that a particular type of cloud is responsible for disintegration of ozone. Where these clouds form ozone levels drop. This is a process of change in the North that we at NASA are working to understand better.

But what of life? The physical sciences of purely intellectual exercises cannot relate to our lives. We're looking here at the heartbeat of the planet's life cycle, the pulse of carbon as it gets absorbed and released by all living things over the world as the seasons endlessly turn. Here we see plumes of light bursting from rivers and jets of plankton powering the processes of global oxygen production and sustainable fisheries. These moving tapestries of life are akin to a baseline medical checkup for life on Earth.

This work requires powerful engines. For an agency that knows something about engines, it's important to say that we're also on the cutting edge of another time. These are the engines of the information age. Currently NASA is working on a computational leap so profound that it vastly surpasses current capacities.

Here's a glimpse of the future. This is a picture of the Earth's climate at work as seen by the virtual brain of a present-day supercomputer. The wispy white trails indicate water vapor. Soil moisture appears as mottled greens and browns. Models like these are the leading edge of the revolution in Earth Science.

We once built and flew entirely independent satellites and asked ourselves afterwards whether their data could be combined somehow to answer Earth System questions. Today we are flying a fleet of four complimentary Earth-observing satellites. We are developing new ways to field constellations of complex, semi-autonomous instruments capable of studying the Earth as a system, exploring how its various parts interact to produce weather. Future missions like global precipitation measurements call for coordinated fleets of highly-reliable advanced satellites designed to deliver near real-time information to climate experts and water-resource managers. But the future urges us to monitor other events, too, including ozone layer changes, Earth's overall energy budget, trends in ocean forcing (ph) and trends in ocean waters to see how our giant thermostat is being adjusted.

From space the State of Alaska shines as the Nation's North Star. Your history, your people and your insatiable thirst for adventure inspire all of us at NASA to reach beyond the limits of imagination.

Today we push back the boundaries of what we know so that we may see beyond the frontiers of tomorrow.

Dr. GOLDIN. I hope this video has succeeded in conveying the scope and magnitude of the challenge of global change research. As you could see, NASA and its sibling agencies are rising to that challenge. Key pieces of the climate research endeavor are being conducted right here at the University of Alaska in Fairbanks. These include the polar dimensions of the global water cycle where much of the world's fresh water exists as ice. This great University also hosts the Alaska SAR Facility that collects vast amounts of data on how land surface change influences the climate system.

I want to make three points to you this afternoon and leave you with one key message about how we need to move forward.

The first point is that climate change research is a marathon, not a sprint. We have learned enough to know that human civilization is having an impact on the climate system, but it is difficult to accurately and quantitatively distinguish this from natural variability. It will take decades to completely understand the climate system. In the meantime, the Federal science agencies must provide timely, useful information to decision-makers who cannot wait for final answers to take action. We at NASA are committed to providing the best scientific understanding in the fastest possible time to support these decision-makers in government and industry.

Which brings me to the second key point: We need to understand all the ways that human activities affect the global environment and document the full range of forcing factors and responses in the climate system. The science programs that underlie policy discussions need to be comprehensive. We need to be sure that, as a society, we do not get locked into one single-point solution and have no place to go if it doesn't work out politically or economically.

Third and finally, we need to make the investments in research that will answer the key science questions and prepare us for the future. We need to continue on the path the Administration has endorsed for scientific observation of the Earth and continue the technological innovation that will expand coverage of the polar regions. We are taking the first step in deploying the Earth-observing system. This is now in full swing. For example, ICEsat, which will be launched this winter, will provide the first-time comprehensive and repeated coverage of the Arctic Regions, enabling the detection of changes in elevation of ice masses in order to assess their contributions to sea level changes. The EOS terra and aqua satellites will provide unprecedented detailed information on the spacial extent of snow cover, surface temperature and cloud properties over the Arctic Region. The measurements of sea surface winds heighten dynamics by adjacent and Quick-sat satellites will enable our understanding of ocean circulation and energy exchanges within the Arctic and Equatorial Regions of the globe.

I thank the President for his decision to fund the development of the next phase of EOS in the fiscal 2002 budget. This will assure continuity of the key measurements and enable new ones required to further enhance our understanding of the Arctic Regions and their critical role in the global climate system.

We are also developing the next generation of radar altimeters that will provide all-weather observation to the Arctic Regions. This advanced technology will enable estimates of the height of sea ice above the water level, free board height, from which ice thickness can be deduced.

In addition, we are also developing techniques, initially using aircraft and, then, hopefully later spacecraft, to determine the surface salinity of the water which is key to understanding the thermal conductivity and heat capacity of the ocean and getting at the energy balance talked about this morning.

This is the one message I'd like to leave you with today. We have an opportunity to take another giant step towards the goal of understanding the role of the Arctic Regions in the global climate system. In preparing for this hearing it became abundantly clear to me that we don't place a high enough priority on the Arctic research in the Federal establishment. Those of us who oversee, fund and manage climate research agencies have the opportunity to give our Nation and its children and grandchildren a great gift. That gift is the capability to understand and predict changes and the consequences of change in this cosmic thermostat that enables planet Earth to sustain life.

PREPARED STATEMENT

Mr. Chairman, this morning I have talked with Dr. Rita Colwell, Director of the National Science Foundation and Chairperson of the Interagency Research Policy Committee, along with Mr. Scott Gudes of NOAA and Dr. Chip Groat, the head of the USGS. We all agreed to work together through the IARC under Dr. Colwell's leadership, as a vehicle to bring together the relevant Federal agency heads to establish how we could focus our collective effort on the Arctic Region in response to your challenge of making faster progress in this slowly changing region of our Nation. We intend to work focused and hard and we thank you for inviting us to this important hearing.

[The statement follows:]

PREPARED STATEMENT OF DANIEL S. GOLDIN

Mr. Chairman: Good afternoon. I am pleased to be here today with my colleagues from NASA's sister agencies to testify on the very crucial subject of climate change.

The climate change issue has been getting a lot of press attention lately, along with considerable dialog among scientists and economic experts. Discussions center around a few key questions: To what extent climate change is due to natural variability and/or human-induced factors, what are the magnitude of future changes, and what if anything we can or should do about them. Decision-makers in both government and industry are watching this exchange and trying to glean from it some reliable information on which to base the multi-billion dollar policy and investment decisions they face. They have to make those decisions while we are in the midst of a multi-decade climate research endeavor. It is the job of the Federal science agencies to provide them the best available input, at each point in time, in a clear, understandable form, with clarity on the robustness and uncertainties in our state of knowledge.

It is fitting that we hold this hearing here in Alaska. It is the general understanding of the science community that changes in Alaska and the polar regions are the best early indicators of global climate change. If substantial change occurs in the climate system, it is expected to show up first and largest in the polar regions. This is due to the prevalence of ice and permafrost in the polar regions, coupled with the close proximity of average temperatures to the freezing point during significant portions of the year. Small changes in temperature bring large expanses closer to water's phase change from solid to liquid over longer periods of time. And this can have major effects on plant, animal, and human life in this broad expanse.

Today, I would like to review with you the science behind climate change, some of the evidence of change both globally and here in Alaska, what we know and don't know about climate change, and how we are going about finding out.

SCIENCE AND SIGNS OF CLIMATE CHANGE

The Earth has a wonderful natural capacity to regulate surface temperatures to make life comfortable for humans and other life forms. The Earth's climate system, alone among other planets, constitutes a thermostat of cosmic proportion.

We know now that the operation of this thermostatic mechanism is based on external forces such as the solar energy we receive from the sun and a set of complex interactions that take place among the atmosphere, oceans, continents and life on Earth. For example, the two physico-chemical cycles: the carbon cycle through the Earth's atmosphere, ocean and the lithosphere on the one hand; and the water cycle between the atmosphere, rivers and land, and the oceans on the other play a major role in operation of Earth's climate thermostat. Together, they serve to capture just the right amount of incoming solar energy as heat in the atmosphere. The process by which gases such as water vapor and carbon dioxide help to keep energy from escaping into space is called the "greenhouse effect," and it's a good thing; the Earth would be too cold in its absence to support human life.

Both the carbon and water cycles are responsible for removing carbon dioxide from the atmosphere. Carbon dioxide dissolved in rain water slowly, but relentlessly, attacks rocks through the process of "weathering." The resulting carbonates find their way through rivers to the oceans and the ocean floor, where they slowly accumulate and constitute enormous limestone deposits. Except for the activity of the Earth's interior and the constant recycling of the Earth's crust, carbon would have long disappeared from the atmosphere and oceans, thus making the Earth forever sterile for life as we know it. As far as we know, this is what happened on Mars. In contrast to Mars, Earth has active plate tectonics that constantly recycle its crust; no piece of the ocean floor is older than 200 million years. The result of this recycling causes constant outgassing of carbon dioxide into the atmosphere, thus replenishing the carbon supply for life to thrive on. On geological time scales, what keeps carbon dioxide from building up too much is the evaporation and precipitation of water through the atmosphere, which is driven by incoming sunlight. Had the water cycle failed to control the on-going accumulation of carbon dioxide through precipitation, the Earth's atmosphere would have suffered a runaway greenhouse effect and made conditions unlivable at the surface of the planet. Such, apparently, was the fate of Venus. On either side of Earth, Mars and Venus represent planetary systems unregulated by carbon and water cycles. Earth, as Goldilocks might have said, "is just right." It has its own thermostat, comprised of these two cycles, to keep temperature and precipitation in balance.

Over hundreds of thousands of years, the natural variability in this system has produced what appear to us as extremes, such as ice ages, where low temperatures persist for long periods. The past ten thousand years has been marked by a very stable climate regime. However, the last 150 years have witnessed some important changes. The industrialization of human society and the clearing of land for agriculture have resulted in carbon dioxide levels 30 percent higher than in pre-industrial times, with even larger increases in other concentrations of methane, aerosols (dust particles such as soot), and wholly new chemicals such as chloroflorocarbons. Today, carbon dioxide levels are higher than any time in the past few hundred thousand years. The past 150 years have also seen an increase in global average surface temperature of more than 1F (.75C), after being stable for the previous thousand years. This has been accompanied by a rise in sea level of about 1.5mm/year over the past hundred years, due in part to thermal expansion of the oceans.

These changes are reported in global averages, but in fact they are not evenly distributed over the globe. As I mentioned earlier, the more dramatic changes are occurring at the poles. NASA-sponsored researchers have determined that over the past few decades, Arctic sea ice has decreased 4 feet (about 40 percent) in thickness and summer sea ice extent is declining about 3 percent per decade. Our aircraft altimetry flights over Greenland have shown that the ice sheet is thinning on the coasts and thickening in the interior. Here in Alaska, surface temperatures have increased 4 to 7F (2 to 4C) since the 1950's, and precipitation increased 30 percent between 1968 and 1990. These changes are having real impacts on Alaskans, as documented in a recent report on the regional impacts of climate change—Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change (2001), by the U.S. National Synthesis Team facilitated by the U.S. Global Change Research Program, undertaken to fulfill the assessment requirement of the Global Change Research Act of 1990. These range from a two week lengthening in the growing season to a sustained infestation of spruce bark beetles which caused widespread tree deaths over 2.3 million acres on the Kenai Peninsula. Permafrost thaw-related damage to structures and infrastructure is estimated to be $35 million per year at present.

The key questions are: Are these changes due to natural variability in the Earth system, or to human-caused changes in the composition of the atmosphere, or both? And if so, what can or should we do about it? It is the business of the Federal science agencies to answer the first question, and to provide decision-makers with tools to think about the second.

## WHAT WE KNOW AND NEED TO KNOW ABOUT CLIMATE CHANGE

The causes of climate change have been a subject of scientific speculation for a long time. Benjamin Franklin proposed that volcanic eruptions could affect atmospheric temperatures, a prediction borne out by the global impact of the eruption of Mt. Pinatubo. In the late 19th century, the Swedish physicist Svante Arrhenius proposed that carbon dioxide ($CO_2$) emissions could enhance the Earth's natural greenhouse effect, leading to global warming. In the 1970's, cooler than average temperatures briefly were a cause for concern. But by the late 1980's, the century-long trend in warming had resumed, and the very hot summer of 1988 turned national attention to the prospects of global warming due to increasing concentrations of greenhouse gases in the atmosphere. The story is not a simple one, however. A recent National Academy of Sciences report, Reconciling Observations of Global Temperature Change (NRC, 2000), notes that surface temperatures are rising, but lower to mid-troposphere temperatures have risen much less. A team of NASA-sponsored researchers has worked over the past few years to assemble a consistent satellite data record of global atmospheric temperatures, providing the motivation for this NRC study.

One might ask why NASA is in the climate science business. After all, we are most closely associated in the public mind with exploration beyond the bounds of Earth. The answer is simple. Climate change is a global phenomena involving all major components of the Earth system—its land, oceans, atmosphere, ice, and life. And if we want to understand global-scale phenomena, we have to have a global view of Earth—the view that the vantage point of space provides. It is this global view and the resulting ability to study the Earth as a dynamic system that NASA provides. We provide the larger context in which, for example, the National Oceanic and Atmospheric Administration (NOAA) can study ocean impacts on weather and climate. This is an active area of collaborative research between the two agencies. NASA technology produced the Landsat program which enables the U.S. Geological Survey (USGS) and NASA to examine land cover change and its impacts on the atmosphere. NASA is the world's premier innovator of advanced remote sensing instruments and related research for the study of the Earth from space, and we are the key source of improvements in our partners' operational systems. The U.S. Global Change Research Program serves to coordinate climate research among the participating Federal agencies.

NASA is tackling questions that are at the frontiers of our understanding, that have substantial societal relevance, and that cannot be addressed without the contribution of the global view from space. We seek to understand:

—Variability in the Earth system, and to identify trends in the midst of this variability;

—Forces acting on the Earth system due to both natural and human-induced factors, and the proportional impact on near and long-term climate; for example, increasing aerosol (particle) concentrations in the atmosphere and how they ei-

ther reflect or scatter incoming solar radiation, or formulate or dissipate rainfall and snow;
—Responses of the Earth system to change, such as changes in ocean circulation patterns, and how some of these responses feed back to become forcings themselves;
—Consequences of change in the Earth system in such areas as regional weather, ecosystems productivity, and fresh water availability; and
—Prediction of change to forecast which trends will continue into the future, which is where the real payoff is, e.g., reliable forecasts of climate one season in advance for agriculture, commercial fishing, and transoceanic shipping.

An example is our work on the global water cycle. NASA seeks to understand how global precipitation, evaporation, and the cycling of water are changing. We want to know for two major reasons. First, the water content of the atmosphere is a key indicator of climate change. If the atmosphere is warming, we would expect increases in the atmosphere's water content. Second, and more important for society, these patterns of precipitation and evaporation are what determines fresh water availability worldwide. If these patterns change, specific regions could gain or lose fresh water resources, with significant implications for agriculture, hydroelectric power generation, human health and recreation.

This Earth-as-a-system approach to the climate change problem has already proven extremely productive. For example, we now have a quantitative picture of the Earth's energy budget—that is, how much of the Sun's energy reaching the Earth is reflected, scattered in the atmosphere, absorbed in the atmosphere, reflected off the Earth's surface, or absorbed by the Earth's surface and re-emitted as heat. Accounting for all this incoming energy, which is an external force acting on the climate system, allows researchers to determine which key changes can result in adjustments to Earth's thermostat. Most of these measurements can only be made from above the Earth's atmosphere, though it is crucial to combine these with ground-based and in situ data to get the complete picture. We have also developed a long-term data set on cloud cover and cloud type, knowing that the water vapor comprising clouds is an important "greenhouse gas" itself. Using the TOPEX/Poseidon spacecraft, we have developed a detailed picture of global ocean circulation, and can now measure sea-level change globally from space.

One important outcome of this approach is the identification and estimation of the forcing factors that drive climate change. "Forcing" is measured in units of Watts per square meter ($W/m^2$), analogous to measuring the pressure applied to a surface area. In this case, the 'pressure' is the energy (in Watts) introduced or retained (via the greenhouse effect) in the atmosphere that eventually is manifested as heat, and the 'surface area' is the atmosphere itself, treated as a two-dimensional blanket over the Earth. The attached graph displays a summary of these forcing factors and their strengths. Carbon dioxide, methane, ozone, black carbon (soot) and solar energy are shown to have a positive forcing, that is a net warming, effect on climate, while other aerosols (dust particles), cloud changes, and land cover alterations tend to show a negative forcing effect, i.e., a net cooling effect. The overall net effect is a positive forcing of 1.6 $W/m^2$ in total over the past 150 years, which we believe translates into about a 1.2C increase in temperature. It is this increase that many scientists connect with the observed worldwide retreat of alpine glaciers, lengthening of the growing season and decline in sea ice in some high northern latitude regions, and modest increases in sea level. Because of the long response time of the oceans to such forcing, the effect of additional greenhouse gases on atmospheric temperatures is not immediate. We have only experienced about 0.75C increase in global average temperatures thus far; a further increase of about 0.5C is yet to come from greenhouse gases already in the atmosphere today. One key feature to note on this figure is the presence of the thin bars in each column, representing the uncertainty in the forcing influence of each factor. In some cases, particularly the clouds and aerosols, the uncertainty is as great as the estimates themselves!

A principal goal of climate research is to monitor variability and trends in the climate system, to quantify the forcing factors acting on climate, and to incorporate this information into computer models representing climate system interactions to attempt to assess the responses of the Earth system to changes in these forcing factors. Such models are run against known past and current conditions to test the validity of the climate system relationships contained within it, and then employed to establish climate predictions for the future. However, even past occurrences of climate change are difficult to model even though the inputs and outcomes are known. Success in "predicting" present conditions from real, past data, enables some tentative predictions of changes 10 to a 100 years in the future. The outcome of the model depends significantly on what assumptions about future greenhouse gas emissions one adopts as input. In the climate change assessment community, these assumptions are called emission scenarios.

The choices of what to put into a model are thus an essential part of the climate research challenge. They directly effect the consideration of the consequences of climate change and predictions outlined for the future. These latter two steps are, for government and private sector decision-makers, the all-important assessment processes that provide the basis on which they will be asked to make choices.

CLIMATE ASSESSMENTS AND ALTERNATE SCENARIOS FOR ACTION

Two assessments of climate change and potential impacts have been published in recent months. The first is Climate Change 2001: The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The 3rd assessment predicts climate-related changes under a "business as usual scenario", i.e., without constraints on human-induced greenhouse gas emissions:

—Global average surface temperature rise of 1.5 to 5.8C (2.5 to 10F) by 2100;
—Global mean sea level rise of 0.09 to 0.88 meters (4 to 35 inches) by 2100;
—Global average water vapor and precipitation increases, with unknown impacts on storm frequency/intensity.
—Continued widespread retreat of alpine glaciers, with ice sheet mass losses in Greenland and increases in Antarctica.

The second is Climate Change Impacts on the United States, referred to earlier, which uses two emissions scenarios in the mid-range of the IPCC set of scenarios to estimate impacts of climate change on eight specific regions of the country and six cross-cutting activities (e.g., forestry).

These assessments predict substantial changes both globally and in the U.S., with substantial consequences for diverse populations around the world. Of importance to Alaska, for example, the Climate Change Impacts report predicts the complete disappearance of summer time Arctic sea ice by 2100.

What are we to make of these things? As a science Agency, we can only speak to the scientific issues.

I'd like to make two observations in this regard. First, over the past ten years, the worldwide scientific consensus has been building toward a view that climate is changing, and that human activities are partly responsible. This is based on two broad sets of evidence. One is the observation of increasing emissions and atmospheric concentrations of $CO_2$ and other greenhouse gases, and the results emerging from climate models that assimilate these data. The second is observations of current phenomena that may be the results of warming that has already occurred in this century, such as the increase in surface temperature, retreat of glaciers worldwide and the lengthening of the growing season in northern latitudes. There are some important skeptical voices, however; some scientists point out the limitations in climate models, such as how the role of clouds in moderating Earth climate should be represented. NASA's Earth Science Enterprise funds scientifically meritorious research on all sides of this question, including two scientists who have done the most work in attempting to construct a globally consistent atmospheric temperature record from satellite data.

The second observation is that, while $CO_2$ emissions continue to increase, the average growth rate of $CO_2$ concentrations of the atmosphere has been nearly flat for the past two decades. This is due to the sequestration (storage) of carbon in the oceans and in forest regrowth, as well as a "decarbonization" of energy sources (e.g., increasing use of natural gas rather than coal). The IPCC emissions scenarios may be underestimating the potential for reduction of $CO_2$ growth rates from these factors.

This opens the door to new possibilities for consideration by decision-makers in government and industry. One alternative scenario for action on the climate change issue has recently been proposed by Dr. James Hansen, Director of NASA's Goddard Institute of Space Studies. Dr Hansen co-authored a paper with four other scientists on climate change in the 21century, published in Proceedings of the National Academy of Sciences. In that paper, Dr. Hansen defines an "alternative scenario" for the forcing agents that cause climate change, based on his fresh look at the Figure (Attachment I) describing the forcing factors acting on climate. In considering this figure, he notes that the combined impact to date of methane ($CH_4$), ozone ($O_3$), and black carbon aerosols (soot) are about the same as that of $CO_2$. In contrast to the IPCC's "business as usual" scenario, in which temperatures will rise from 1.5 to 5.8C over the next 100 years in response to an increased forcing of 3 $W/m^2$ over the next 50 years, Dr. Hansen believes the alternative scenario can manage this increased forcing down to 1 $W/m^2$ or 0.75C (plus the 0.5C already in the pipeline). And this could occur with a constant, or slightly smaller, growth rate over the next

20 years (consistent with the past 20 years) in $CO_2$ concentrations. By controlling other greenhouse gas emissions in the near term, we might essentially buy time for new technologies to enable a more economically natural reduction of human-induced $CO_2$ emissions in mid-century.

Dr. Hansen makes two additional observations of relevance to decision-makers. First, he posits that emissions of these three substances are easier (and thus less costly to the economy) to control than $CO_2$. Second, he predicts that reduction of emissions of these three will have important human health benefits as well. Ozone and soot, two of the forcing factors cited by Dr. Hansen, are major contributors to respiratory infections and respiratory-related deaths worldwide. He quotes a recent study showing that air pollution in France, Austria and Switzerland alone cause 40,000 deaths and half a million asthma attacks annually. Dr. Hansen offers an alternative that addresses the other greenhouse gases; we need others in the science community to propose their ideas as well and provide decision-makers with some choices.

HOW WE ARE MOVING TO ANSWER THE ESSENTIAL QUESTIONS

It is important to keep in mind that the U.S. is doing more to understand the science of climate change than any other nation. In fact, the U.S. invests more in this area than the rest of the world combined, about $1.7 billion per year compared to approximately $1 billion internationally. (These numbers are based on fiscal year 1999 data, the last year for which international data is available. The fiscal year 2002 President's request is $1.6 billion, reflecting the passing of the peak funding year for the Earth Observing System. The U.S. numbers are totals are for the U.S. Global Change Research Program). The international numbers are derived from the 2000 report of the International Group of Funding Agencies for IPCC). These numbers do not include any nation's meteorological satellites even thought they are essential data sources. The U.S. is the world leader in this arena as well. NASA's Earth Science Enterprise comprises about $1.2 billion of the U.S. $1.7 billion investment; we are the largest provider of research as well as the principal supplier of Earth system observations. This is in addition to what our partner agencies are investing, who use some of these same data.

All of this research is openly solicited and peer-reviewed, and most is conducted by researchers at U.S. universities. And, we have already learned a great deal. Working with NOAA, we have uncovered the mechanics behind the El Niño/La Niña phenomena, and are well on our way toward a true predictive capability. We now have a much better idea of how much rainfall occurs over the global tropics, which is the key factor in the exchange of heat energy between the tropics and the higher latitudes. We have a 20-year or more record of global land cover change and of incoming solar radiation to help us understand natural variability and long-term trends. And, we have made the first measurements of Greenland ice sheet thinning and thickening with an advanced laser system.

*Research In and For Alaska*.—Much of the research and many of the observing capabilities NASA develops are directly beneficial to Alaska. We recently produced from Landsat data a land cover data set that can be used as a baseline against which to compare future changes. The Terra satellite allowed us to measure snow cover extent over all of North America this past winter. Last year, we funded the measurement of land surface topography around key Alaskan airports and other key infrastructures to help improve aviation safety and inform future civil engineering decisions. Early next year, we will launch ICEsat, the first space-based laser altimeter, which will measure the topography of the world's ice sheets. We have funded research in glacier volume, sea ice extent and thickness, and earthquake and volcano vulnerabilites. And, of course, we have invested $100M in the Alaska Synthetic Aperture Radar (SAR) Facility since 1993. The Alaska SAR Facility is the world's premier capability for acquiring and processing synthetic aperture radar data, performing these services for satellites from around the world. Together with our sister agencies, we are exploring a new cooperative research program called SEARCH that is specifically focused on the Arctic region to gain a long-term perspective on Arctic change and the impacts of change on regions such as Alaska. Finally, as we meet here, another meeting is taking place in Anchorage tomorrow. NASA's Earth Science Enterprise is sponsoring a joint NASA/Alaska regional workshop with state, local, and tribal officials to explore the application of remote sensing to practical problems faced by Alaskans.

*Climate Research Tools*.—The two principal tools of climate research are observations of the climate system to characterize its variability, trends and responses, and models to help assess the consequences and predictability of future changes. These are closely related; observations are employed to establish the initial conditions to constrain model runs, and to capture properly the climate system relationships in the models. The need for better observations is established in part by the uncertainty bars seen in the figure depicting forcing factors (Attachment I). It is also apparent in thinking about the responses of the climate system to change. What is really happening to the polar ice caps, sea ice, sea level, ecosystems, and weather as a result of climate changes over decades and longer? The need for better models is apparent from the sheer complexity of the climate system compared to our current understanding, from the diversity of results from competing modeling efforts, and from the high stakes involved in the policy and investment decisions faced by governments and industries both here and abroad. I will address both observations and models below.

*Observations*.—As I indicated earlier, we have made enormous progress in our early attempts to characterize the Earth system with such pioneering satellites as TOPEX/Poseidon. Currently, we are in the midst of deploying the Earth Observing System (EOS), the world's first satellite observing system designed to monitor the major components of the Earth system and probe the key interactions among land, oceans, atmosphere, ice, and life to identify their variability and trends. For example, the Terra satellite launched in 1999, provides our first integrated look at land, atmosphere and oceans, and directly addresses the impact of clouds in the climate system. The Aqua satellite, to be launched later this year, carries instruments to make the best direct global measurements of atmospheric temperature and humidity. These instruments are also prototypes of the next generation weather sensors that will improve the accuracy of 3 to 5 day forecasts to better than 90 percent and enable extension of the range of weather forecasting to 7 days. The Aura satellite, planned for launch in 2003, will attempt the first measurements of ozone in the lower atmosphere from space and will enable study of the chemical processes that control atmospheric composition. The ICEsat instrument, to be launched at the end of this year, will yield for the first time precise, global measurements of ice sheet topography to help us understand changes in the mass balance of ice sheets. Other EOS measurements will continue ocean surface height and ocean surface winds measurements to probe the connection between weather and climate, and improve the Nation's ability to forecast hurricane landfall and occurrences of El Niño. Complementing EOS, a series of small exploratory satellites will attempt the first 3–D measurements of clouds and aerosols in the atmosphere, with the specific purpose of reducing the uncertainties of their impact on climate change.

The Administration has funded the next generation of EOS sensors in its fiscal year 2002 budget request. This includes continued development of a "bridge mission" that will transition climate-quality measurements to the operational weather satellite system to ensure the long-term data record that climate science requires. This is an essential point. We need decades of data to fully distinguish climate trends from natural variability, and natural from human-induced influences on climate. The solar cycle, for example, is eleven years long, and we only have two cycles' worth of data thus far to help us understand the impact of solar variability on Earth's climate variations. The President's fiscal year 2002 budget request also funds a Global Precipitation Measurement (GPM) mission. Precipitation is the heat engine of atmospheric circulation, governing the transfer of energy from the tropics to the higher latitudes. GPM will help us to understand how are global precipitation, evaporation, and the cycling of water changing. We want to know this for two reasons. First, the water content of the atmosphere is a key indicator of global climate change. If the atmosphere is warming, we would expect increases in the atmosphere's water content. Second, and more important for society, these patterns of precipitation and evaporation are what determines fresh water availability worldwide. If these patterns change, specific regions could gain or lose fresh water resources. GPM will help us observe and understand patterns of rainfall over continents that will in turn feed models of water storage and river flow. We need reliable forecasting capabilities that will help us manage these water resources effectively. GPM will also provide precipitation data to weather forecasting models, dramatically improving hurricane track prediction and forecasts of landfall. I thank the President for his support of an aggressive climate observation and research program in the fiscal year 2002 budget request.

NASA has already begun to envision where Earth observations should go toward the end of this decade and beyond. For example, today's geostationary weather satellites do not permit observation over the polar regions, yet climate and weather are strongly influenced by ocean and atmospheric changes occurring over the poles. Polar weather is strongly influenced by frequent sharp temperature contrasts between sea ice, open ocean and land and the effects of local topography. Available data sets needed for input into numerical weather models typically lack the time and space resolution needed to provide good forecasts. This is especially true for predicting mesoscale features such as "polar lows," which present severe hazards to shipping and the fishing industry. While improved surface-based observation networks are needed, the remote nature of the polar regions points to the need for increasing reliance on satellite data. One possible future course of evolution for Earth observation (as resources become available in the future) might be sentinel satellites beyond geostationary orbit to give us the polar coverage we need to spot those early warning signs. Sentinel satellites at L1 and L2 (the neutral gravity points on either side of the Earth on the Earth-Sun line), for example, would provide those polar views, as well as continuous, full-disk, day and nighttime observations of the Earth to observe diurnal change and global temperatures. If global average temperatures rise, it would show up clearly in global nighttime lows. Other priority observations that could be made, as resources become available, are measurements of the responses of the Earth system to change, and the factors such as aerosols that influence those responses. Observing capabilities to follow up on others beginning in the EOS-era, such as ice sheet topography and atmospheric chemical constituents, are highly desirable as well. However, the observations funded by the President's fiscal year 2002 request provides a robust capability for climate research that will get us well on our way.

While I've focused on space-based observations, it is important to recognize the essential role of surface, balloon, and aircraft-based observations. These make many measurements not possible from space today, as well as provide a means to calibrate and validate satellite data. The ability of scientists to study climate depends as much on data from ocean buoys and air and water sampling networks as it does on satellite data. I'm sure my colleagues from our sister agencies who operate these observing systems will make this point better than I can.

While much work remains to be done in establishing the required observations, we are on the right path. We know what observations are required and what kinds of missions and networks can provide them. We have a plan for observing missions for the next decade and an expanding web of domestic and international partnerships to produce an integrated observing system.

*Models*.—What requires greater national attention is state of climate modeling in the U.S. Climate predictions, such as those used by the IPCC and the U.S. National Assessment, are based on computer models that represent the physics of the climate system in mathematical equations. These models are initialized by real-world observations, and those initial conditions are then allowed to evolve along pathways that reflect our best attempts to simulate the forces acting on the climate system and its own innate variability.

In the opinion of the National Research Council (NRC) and some quarters of the climate modeling community in the U.S., the U.S. leads the world in focused modeling of selected Earth system components, but has fallen behind Europe and Japan in global Earth system modeling. This is viewed as a strategic shortcoming, since international discussions on climate change are thus being fed by models from other countries, and because, given the growing economic value of climate prediction data, some other countries are not sharing data freely and openly, as has been the practice in the past. The fact that two foreign models and no American ones were used as the basis for the Regional Assessment of Climate Change on the U.S. resulted in criticism of that assessment process and its report in both Congress and the NRC.

Two reasons are cited as to why the U.S. has fallen behind. One is that U.S. modeling efforts are fragmented, with no overall guiding strategy. While the existence of competing modeling centers is seen as a strength, the fact that they have different standards and procedures means that collaboration is difficult. The NRC [Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities, 1998], while recommending the development of a National Climate Model for use as a reference standard, believes this can be accomplished through better coordination. However, the NRC states that agencies engaged in climate research are not now performing this function, and need to establish a coordinated national strategy, including a common modeling and data infrastructure (software, model code, etc).

The second is that U.S. researchers do not have access to the computers they consider best suited to run climate models, which are made in Japan. Both European and Japanese climate modeling centers are using these Japanese-built machines. Much is made of this point, perhaps too much. There are four legs supporting the modeling stool—observations, computational capability, software, and the modelers themselves. An argument can be made that all four face current limitations, and future investments in model improvement must be balanced across them to achieve the most improvement for the dollar. As important as computing power is the software engineering that enables efficient use of that power. A Teraflop machine exists currently, but running today's complex climate models without a wholly new, compatible software set reduces that machine's efficiency to about 12 percent of its theoretical maximum. Climate models require not just a computer but a computational hosting medium, comprising both powerful computing engines and a set of algorithms that direct that computing power to portions of the climate modeling problem that need it. The NRC has done a service by penetrating to the next layer in the area of computational limitations, acknowledging that the Japanese-built "vector parallel processor" machines are best for situations where a single model uses all or a large fraction of the computing resource, while the U.S. "massively parallel processor" approach is better suited to run many smaller jobs in parallel, such as comparisons of runs with minor variations introduced, or reprocessing of data sets.

Both issues need to be addressed in a U.S. modeling strategy. While the modeling issues seem as complex as the climate system itself, the bottom line is fairly straightforward. Today, the best we do routinely is about 5 gigaflops of sustained performance. This enables modeling at resolutions of about 2 by 2.5, or about 220 km in resolution on the surface of the Earth. Experimentally, we are approaching 30 gigaflops, which will enable about 1 by 1, or about 100km. In five years' time, we may get to 3 teraflops for one quarter of a degree or less, or 10 to 20 km in resolution. But these will only enable simulation of time frames of hours to seasons. They will be great for regional weather, but not for global climate. The decadal and longer time scales needed for climate modeling require two to four orders of magnitude improvement beyond what is foreseen in the next five years!

Clearly, we will not get there by brute force extraction of better performance from present silicon-based technology and associated software tools. And yet that is where the vast bulk of government and industry investment is being made. To make real progress on climate modeling, we are going to have to step out beyond the current computing paradigm into a whole new one. Increasing the speed of today's supercomputers alone will not achieve the two to four orders of magnitude improvement required. That is because it is not a matter of increasing speed in the same direction, but of identifying shorter pathways to move from data to information to knowledge. A good analogy to illustrate what I mean is how the brain instantaneously integrates an enormous amount of data from our senses and rapidly forms mental pictures and reasons to conclusions. Consider that hundreds of billions are being invested around the world each year in infrastructure, property development, and coastal zone management that make implicit assumptions about climate stability. Investments in climate modeling are well worth it to shape and thus protect those much larger investments. We intend to partner with the computing and information industry to address our needs while at the same time taking advantage of the strong commercial marketplace pull for advanced computing. This is vastly preferable to the traditional government research approach of investing large sums in single purpose systems that have limited utility on the outside and quickly become obsolete. We intend to sponsor a workshop with research and industry leaders to start defining this new approach.

Of course, we can't just stand by and wait for the next revolution in computing technology. We need to be exploiting the data we currently have in the best modeling and computing systems we have to serve governments and businesses that need to make decisions today. NASA and NOAA are taking such a step together in establishing a Joint Center for Satellite Data Assimilation. In addition, NASA is working with USGCRP partner agencies on a strategy for high-end modeling. We need to continue to exercise our available computing technology, getting more out of it by focusing on the software engineering that enables supercomputers to run climate models efficiently.

SUMMARY

I hope I have helped you navigate your way through this complex topic of climate change. Let me summarize what I believe are the key points.

—The first is that climate change research is a marathon, not a sprint. We have learned enough to know that human civilization is having an impact on the climate system, but it is difficult to completely distinguish this from natural variability. It will take decades to completely understand the climate system. In the meantime, the Federal science agencies must provide timely, useful information to decision-makers who cannot wait for the final answers to take action. We are committed to providing the best scientific understanding in the fastest possible time to support these decision-makers in government and industry.

—Which brings me to the second key point—we need to understand all the ways that human activities affect the global environment, and document the full range of forcing factors and responses in the climate system. The science programs that underlie policy discussions need to be comprehensive. We need to be sure that as a society we do not get locked into one single-point solution, and have no place to go if it doesn't work out politically or economically.

—Third and finally, we need to make the investments in research that will answer the key science questions and prepare us for the future. We need to continue on the path the Administration has endorsed for scientific observation of the Earth, and continue the technological innovation that will expand coverage of the polar regions. But in contrast to the observing situation, we need a whole new approach to climate modeling. The path we are on now will result in only incremental improvement; it will not get us where we need to go in truly understanding the responses of the Earth system to climate forcing, nor will it result in the reliable decadal and centennial climate prediction capability we need. Hundreds of billions of dollars are being invested in property and infrastructure and coastal zone management that make implicit assumptions about climate. We intend to form a government/industry partnership in advanced computing and modeling to validate or adjust those assumptions to protect that much larger investment. I suspect that the secondary applications of such an advanced modeling capability will themselves make such an endeavor well worth the effort.

NASA is committed to doing its part, in partnership with our sister agencies, to produce timely, reliable scientific information for Federal, State, Local, Tribal and industrial decision-makers. The climate change problem is tough, but a well-thought out and funded strategy for research can help our Nation act in the best interests of our citizens, their children, and the generations to come.

Thank you for the opportunity to testify before you today.

Chairman STEVENS. Thank you very much. That's good news, Mr. Goldin. I appreciate it very much. Our next witness is Dr. Rita Colwell, Director of the National Science Foundation.

## NATIONAL SCIENCE FOUNDATION

### STATEMENT OF DR. RITA COLWELL, DIRECTOR

Dr. COLWELL. Good afternoon and thank you, Chairman Stevens, for the opportunity to testify. I applaud the Committee's initiative in drawing attention to the critical issue of climate change in the Arctic and, due to the marvels of science and engineering and technology, my staff at NSF watched this morning's session and they are watching it this afternoon. So, to the folks back on the East Coast, Hi. I may add also that transmission of the proceedings today is courtesy of collaboration between NSF and NASA, yet another example of cooperation between our two agencies.

I'd like to say that this is an excellent opportunity to outline some findings from the National Science Foundation's investment in understanding a very complex picture of environmental change in the Arctic. And it's a very appropriate location to address the issues right here at the University of Alaska Fairbanks and in partnership with the International Arctic Research Center with Dr. Akasofu and his team here at the University.

I'd like to set the stage for my testimony with a short video. I think it indicates very well the wide spectrum of the NSF support for investigating the Arctic environment from just about every vantage point, so we'll just have the video, very briefly.

ARCTIC CONSERVATION EROSION OF BARROW, ALASKA

(Caleb Pungowiyi talking; sounds of the ocean) I'm noticing these mud slides, like pretty bad. But, now, it's the permafrost that's coming down and the ground being disturbed and more of the permafrost being exposed to the heat and the sun and the wind, you know. Now, there's more rain and sun is shining all the time and warmer summers. I don't know the impact. It doesn't look good for the community, anyway. I think we'll have to evacuate the community and move somewhere else. [Sounds of various machines] These types of changes—I don't know. We're usually pretty good at adapting to shorter changes but, something like this, who knows what could go on.

(Unknown speaker) I believe that the Arctic is a very, very important ecosystem to the health of the rest of the planet.

Dr. COLWELL. The last words that you heard—I hope you could hear them—on the video are critical. They were that Arctic peoples have long adapted to change but they find the recent variations in the environment very disturbing. And so comprehending the course and the causes of this change is a key goal for the NSF's activities in the Arctic but it's one that we still are quite far from achieving.

We now have an extraordinary number of examples of environmental change. In the oceans we see thinning sea ice, unusual blooms of algae, die-offs of seabirds, plummeting fish populations. And on the land, the permafrost is melting in some areas and the caribou migration patterns are changing in relation to their food supply. And so we work with the Alaskan and the Arctic Natives as they contribute their own observations on the transformations that they themselves see in their way of life. And the value of a very broad historical knowledge of the Alaskan indigenous peoples was beautifully highlighted this morning by Caleb when he discussed the efforts and the observations that are being made. For example, fishermen in 1993 observed a couple of new species of salmon. There are only eight such fish in their catches and that's something that a scientific sampling might not have picked up. So it's very important to work closely with the indigenous peoples in the Arctic Region.

The evidence for climate change in the Arctic is mounting and it's serious but the picture is not yet comprehensive. We don't know whether this change is part of a cycle or is following a long-term, possibly irreversible trend. We need abundant and accurate observations over time to improve the computer models that help predict the environmental change. However, we know very little about the Arctic compared to the rest of the globe. Access is limited, especially in the winter months; and the National Science Foundation, as the major supporter of basic research in the region, is committed to gathering oceanic, terrestrial, atmospheric, and cultural information that will help us refine our models and interpret those changes appropriately.

NSF also plays a vital Federal coordinating role for Arctic research and, as NSF Director, I chair the International Arctic Research Policy Committee, IARPC.

So we turn now to some specific work that the NSF is supporting on Arctic climate change in three very vital areas: sea ice; ocean ecology; and terrestrial impacts. And several of these efforts are part of the U.S. Global Change Research Program.

Now, let's begin with what seems to be a moonscape but it's actually sea ice off Barrow, Alaska, and it was photographed very recently by a robotic aerosonde. These are small pilotless planes. They're lightweight. They can travel long distances. For example, they weigh 29 pounds and they can traverse 1,500 miles. And they carry a variety of instruments to monitor sea ice and refine climate models. And if you look very closely at the right side of the image, you can see the yellow arrow. It points to another aresonde flying below. We know that the Arctic climate is tremendously sensitive to changes in sea ice and that changes in the region's climate can altar global climate. And we also know that the sea ice cover has been shrinking about 3 percent every 10 years since the early 1970's. We heard about this this morning.

Sea ice was also a very important focus of the recent SHEBA Project, the Surface Heat Budget of the Arctic Ocean, SHEBA. We heard about it this morning. The ice station SHEBA consisted of the ice-breaker frozen in the ice and left to drift for a year. SHEBA has been the largest single project that NSF has undertaken in the Arctic. The Office of Naval Research and NASA were also partners in the project. SHEBA results are already improving simulations of Arctic climate and the regions effects on global climate.

We have also established an environmental observatory at the North Pole. This is a 5-year effort to take the pulse of the Arctic Ocean and to determine its effect on climate. Automated instruments transmit the data by satellite. And this year we also carried out a hydrographic survey from the North Pole toward Alaska.

Our Scientific Ice Expeditions, SCICEX, took yet another approach. In cooperation with the Office of Naval Research and the Navy, we used submarines to explore the Arctic Ocean ice from below, as well as chart the sea floor of the Arctic Ocean. This was the only way, really, to determine sea ice thickness remotely. And these cruisers, along with the U.S. Navy submarine data, show that the ice in the central Arctic Ocean has thinned an average of about 43 percent over the past 20 years. These submarines are no longer available, unfortunately, since most of the sub-class has been retired. However, we are moving to a new way of exploring under the sea ice with autonomous underwater vehicles and you can see it here in the artist's rendition.

Native hunters, fishermen and scientists have all noted many signs of change in the ocean ecology of the Arctic. In 1997, unusually calm, clear weather preceded the first-known Bering Sea bloom of *coccolithophorid* algae, seen here in the NASA images as a milky-green cloud in the water. We don't know how it's going to affect the rest of the marine food chain and it's something we do need to find out.

Another remarkable change is the almost exponential increase in the bio-mass of jellyfish in the eastern Bering Sea and this began in 1989. It's quite possible that this signals extreme stress in an ecosystem. A seabird called the short-tailed shearwater died off enmasse, big numbers, during the warm year of 1997. Almost 200,000 shearwaters perished, apparently through starvation.

Finally, the spectacled eider, a beautiful bird. This threatened diving duck congregates in spectacular flocks south of Saint Lawrence Island and research is helping to assess whether a decline in food is related to the precipitous drop in the population of this duck.

A major NSF effort, the Global Ocean Ecosystem Dynamics Program, is focusing on change in marine environments and the U.S. GLOBEC has targeted the Georges Bank in the Atlantic, the California Current System, the West Antarctic Peninsula and the coastal Gulf of Alaska. NSF puts about $13, almost $14 million into this study and NOAA $3 million for GLOBEC in fiscal year 2001.

Research in the Gulf of Alaska, as you can see here, is just beginning. The program explores how climate change affects marine populations, including those of marine commercial fish. The main target fish for the Alaska phase is the pink salmon which, as you well know, had a dock value of about $34 million in year 2000. And we're also looking at the zooplankton that it feeds on.

Let me turn to some patterns of change we see on land. Permafrost covers the entire Arctic, including Alaska north of Fairbanks. If warming continues, the permafrost thaw zone could release huge amounts of carbon dioxide or methane which are greenhouse gasses. At the NSF's long-term ecological research station at Toolik Lake, Alaska, over a quarter century of observations have shown that the water has warmed by about 2 degrees centigrade and the alkalinity, the Ph, has increased. Measurements over longer timescales are absolutely critical to tracking climate change.

At the same time, migration patterns of caribou have shifted due to changes in their tundra food source. This affects villages that subsist on reindeer herding. Reindeer are joining up with their wild brethren, the caribou, and they're disappearing into the wild.

We believe we're beginning to uncover the drivers of climate change in the Arctic. Researchers have identified a major pattern of climate fluctuation called the Arctic Oscillation. It's a large-scale pattern similar to the southern cousin, the El Niño Southern Oscillation, and some scientists hypothesize that the Arctic Oscillation, along with anthropogenic effects, control Arctic climate.

Can the pieces of the Arctic climate puzzle—the sea ice observations, the shifts in ocean ecology, changes we're observing on land—be linked to the Arctic Oscillation? Is the Oscillation cyclic or is it following a long-term trend? So nine government agencies, including NSF, through our Office of Polar Programs at NSF, are involved in a coordinated program that's large-scale research called SEARCH, the Study of Environmental Arctic Change. I will insert into the record the program. To comprehend the fragments of environmental change that we're tracing, that we're monitoring in Alaska, we must ultimately understand the dynamics of climate across the entire region.

PREPARED STATEMENT

In his book about the Yup'ic people, called "Always Getting Ready," James Barker, the Alaskan photographer, describes how the elders commonly caution the young that "one must be wise in knowing what to prepare for and equally wise in being prepared for the unknowable." And I think this perspective serves us equally well in our quest to understand the mysteries of Arctic climate.

Thank you, Mr. Chairman.

[The statement follows:]

PREPARED STATEMENT OF DR. RITA COLWELL

Good afternoon, everyone, and thank you, Senator Stevens, for giving me the opportunity to testify today. I applaud the committee's initiative in drawing attention to the critical issue of climate change in the Arctic. I am very pleased to have this opportunity to outline some of the findings from the National Science Foundation's investments in understanding the complex picture of environmental change in the Arctic.

I would like to set the stage for my testimony with a very short video that suggests the wide spectrum of NSF's support for investigating the Arctic environment from every vantagepoint, from work with peoples of the region to major research platforms. Let's see the video.

The last words in the video are important: Arctic peoples have long adapted to change. But they find recent variations in the environment new and disturbing. Comprehending the course and causes of this change is a key goal of NSF's activities in the Arctic—but one that we are still far from achieving. Absolutely critical to reaching this goal is our joint work with the other Federal agencies involved with climate change and the Arctic.

We are enumerating an extraordinary number of examples of environmental change. In the oceans, researchers have found thinning sea ice, unusual blooms of oceanic algae, die-offs of seabirds and plummeting fish populations. On land we find permafrost melting in some areas, and changes in caribou migration patterns related to food supply. We work with Alaskan and Arctic Natives as they contribute their own observations on the transformations that they see changing their way of life.

The evidence for climate change in the Arctic is mounting and serious, but our picture is not yet comprehensive. We do not yet know for certain whether this change is part of a cycle, or is following a long-term, possibly irreversible trend. Understanding the causes, however, is critical to making good policy decisions.

We need copious and accurate observations over time to improve computer models that help us to predict environmental change, but—compared to much of the globe—the Arctic is data-poor. It is difficult to reach much of the region, especially in the winter, and there are very few research stations. The National Science Foundation is committed to gathering the information—oceanic, terrestrial, aquatic, atmospheric, cultural—that will help us refine our models, and help us interpret these changes.

NSF has a unique role in that effort. We are the major supporter of basic research in the region. We also support the entire spectrum of science and engineering. We include the social sciences, which are so critical to incorporating native knowledge into the climate change picture, and to tracing the threat of contaminants to the health of the Arctic peoples. This broad support lets us take a comprehensive approach, which is the key to understanding the complexities of climate change.

In addition, NSF plays a vital Federal coordinating role for Arctic research. As NSF director I chair the International Arctic Research Policy Committee. I'll describe one of that group's new efforts later.

Finally, along with NOAA, we are supporting the Arctic Climate Impact Assessment, whose secretariat is based at the International Arctic Research Center, here at the University of Alaska-Fairbanks. This collective effort by the Arctic council nations will assess climate change in the region and its expected impact on the environment, economy, resources, and public health. NOAA will discuss ACIA in greater detail today.

Let me turn now to some specific work NSF is supporting on Arctic climate change. I will sketch some examples of NSF-backed research in three vital areas: sea ice, ocean ecology, and terrestrial impacts. Several of these efforts are part of the U.S. Global Change Research Program. [aerosonde image of sea ice near Barrow]

We begin with what seems to be a moonscape, but is actually the sea ice off Barrow, Alaska, photographed recently by a robotic aerosonde. These small, pilotless planes, or drones, are being developed to monitor sea ice and to refine climate models. If you look closely at the right side of the image, you can see a yellow arrow. It points to another aerosonde flying below.

We know that the Arctic climate is tremendously sensitive to changes in sea ice, and that changes in the region's climate could alter global climate. We also know that sea ice cover has been shrinking about 3 percent each decade since the early 1970s, when constant satellite monitoring began.

The aerosondes can help us to learn more. These relatively inexpensive devices—$40,000 each—can fly in hazardous conditions and over an extremely wide range. Such capabilities are assets for obtaining measurements where the use of human pilots would be costly and dangerous.

*[Artist's conception: aerosonde transmitting data from Alaska by satellite]*

The aerosonde data travel by satellite to the scientists' home computers.

*[SHEBA: aerial or ice-level view]*

Sea ice was also an important focus of the recent SHEBA project—short for Surface Heat Budget of the Arctic Ocean. Ice Station SHEBA consisted of an icebreaker frozen in to the ice and left to drift for one year. SHEBA has been the largest single project NSF has undertaken in the Arctic.

Data from SHEBA revealed some serious flaws in current climate models. They do not depict surface reflectivity, or the role of clouds in Arctic climate, with accuracy. Nor do the models properly represent the way heat is exchanged between the ocean, atmosphere, and ice. SHEBA's results are already improving simulations of Arctic climate and the region's effects on global climate.

*[North Pole Environmental Observatory]*

We have also established an environmental observatory at the North Pole, a five-year effort to take the pulse of the Arctic Ocean and its effect on global climate. This year we carried out a hydrographic survey from the North Pole toward Alaska. Meanwhile, at the station, automated instruments transmit climate data by satellite from the ice surface and from instruments anchored to the sea floor.

*[SCICEX: sub emerging through ice]*

Our Scientific Ice Expeditions—or SCICEX—took another approach. In cooperation with the Office of Naval Research and the Navy, we used Naval submarines as a unique research platform to explore the Arctic Ocean ice from below, as well as to chart the seafloor. These cruises, along with U.S. Navy submarine data, show that ice in the central Arctic Ocean has thinned an average of 43 percent over the past 20 years.

*[artist's rendering: new autonomous under-ice vehicles]*

Such Naval submarines are no longer available for scientific use. Most of this sub class, capable of surfacing through ice, has been retired. However, we are moving to a new way of exploring under the sea ice. The under-ice equivalent of the aerosondes are autonomous underwater vehicles, shown here in an artist's rendering. They are designed to make long duration (11-day) forays under ice-covered oceans, and can transmit their position and data while underway. We are supporting efforts to gather data this way in difficult and inaccessible environments.

*[coccolith blooms from space]*

Native hunters, fishermen, and scientists all have noted many signs of change in the ocean ecology of the Arctic. As we saw in the video, during the winter of 2000–2001, ice was almost absent in the Bering Sea. Striking environmental change is being documented there; I have time to describe only a sampling of the changes being studied with NSF support.

In 1997, unusually calm, clear weather preceded the first-known Bering Sea bloom of coccolithophorid algae, seen here as a milky-green cloud in the water. The carbonate plates of this phytoplankton are reflective and show up well in satellite imagery. This organism is a new component of the food web in this part of the ocean. We do not know how it will affect the rest of the marine food chain.

*[jellyfish]*

Another remarkable change is the almost exponential increase in the biomass of jellyfish in the eastern Bering Sea, beginning in 1989. Few fish, birds or mammals eat jellyfish. In other oceans, a rise in jellyfish populations has signaled extreme stress in an ecosystem.

*[shearwater die-off; map and closeup picture]*

A seabird called the short-tailed shearwater died off en-masse during the warm year of 1997. Almost 200,000 shearwaters perished, apparently through starvation. That is about 10 percent of the population. The die-off may be related to major changes in a food source: shifts in the mix of species of crustaceans in the Bering Sea.

*[spectacled eider]*

We've already seen another seabird in the video, the spectacled eider. This threatened diving duck congregates in spectacular flocks south of Saint Lawrence Island in March and April to feed on clams in the bottom sediments. Benthic studies show that bivalve populations are declining in biomass and shifting in species mix. NSF-funded work is helping to assess whether a decline in this food is related to the precipitous drop of this duck's population in both Russia and Alaska.

*[Steller sea lion]*

The population of the Steller sea lion, ranging from Northern California to the Gulf of Alaska, the Aleutians, and Japan, has also dropped dramatically in the Bering Sea, down to 10–20 percent of peak levels. For example, NSF and NOAA data show severe declines in pups and adults around the Pribilof Islands since the 1980s. Forage fish have declined and killer whales increased near the Pribilofs; both trends may have affected sea lion populations.

*[Little Diomede]*

NSF is now supporting the establishment of an environmental observatory on Little Diomede Island in the center of the Bering Strait. North Pacific water rich in nutrients and organic material flows through this narrow strait into the Arctic Ocean. The observatory will collect chemical, biological and physical data on this water. Local teachers at the village school are participating in the study, and collaborating with a teacher in the U.S. mainland.

*[GLOBEC: 4 sites targeted by U.S.]*

A major NSF effort to understand change in marine environments is the Global Ocean Ecosystem Dynamics program. U.S. GLOBEC has targeted the Georges Bank in the Atlantic, the California Current System, the West Antarctic Peninsula, and the coastal Gulf of Alaska. NSF provides $13.5 million and NOAA $3 million for GLOBEC in fiscal year 2001.

*[GLOBEC: U.S. West Coast]*

Research in the Gulf of Alaska, shown here, is just beginning. The program explores how climate change affects marine populations, including those of commercial fish. The main target fish for the Alaska phase is the pink salmon (with a "dock value" of $34 million in 2000), and the zooplankton it eats. The overall salmon population picture is very complex, but this study will shed new light on this economically important fish.

*[Fishing vessel Sea Eagle]*

In the Gulf of Alaska, researchers will collaborate with the fishing industry, including using the commercial fishing vessel Sea Eagle to sample fish populations.

*[Northern Hemisphere map: Distribution of permafrost]*

Let me turn now to sketch a few patterns of change we see on land. Permafrost covers the entire Arctic, including Alaska north of Fairbanks.

If warming continues, the permafrost thaw zone could release vast quantities of carbon dioxide or methane, which are greenhouse gasses. Further warming of the Arctic could therefore lead to increased greenhouse gasses—accelerating climate warming.

*[Toolik Lake panoramic view and two graphs: temperature and alkalinity]*

At the NSF's Long-term Ecological Research Station at Toolik Lake, Alaska, over a quarter-century of observations have shown that the lake has warmed by 2 degrees centigrade and that the alkalinity of the water has increased. The change in the water chemistry may be due to thawing permafrost. Measurements over longer time-scales are absolutely crucial to tracking climate change.

*[reindeer pictures]*

Physical changes alter food supplies and change the habits of wildlife, many species of which are economically important to Alaskans. Some villages subsist through reindeer-herding. Migration patterns of both the Porcupine Caribou Herd and the Western Arctic Herd have shifted due to changes in lichen, which is their tundra foodsource.

Caribou herds have made unprecedented and massive incursions onto reindeer ranges on Alaska's Seward Peninsula. NSF and other agencies have supported documentation of Native knowledge and of their observations of environmental changes such as these. As the reindeer join up with their wild brethren, the caribou, and disappear into the wild, the herders lose their livelihood. One study is tracing the ecological, economic, and social effects of this change.

Another urgent concern of Arctic natives is the flow of contaminants from elsewhere that find their way to the Arctic, transported by the atmosphere, oceans, and rivers. Shifting climate patterns could affect the transport of these contaminants. In one study, elders helped scientists design research on whitefish and contaminants in freshwater lakes.

*[Arctic Oscillation]*

We believe we are beginning to uncover the drivers of climate change in the Arctic. Researchers have identified a major pattern of climate fluctuation, called the Arctic Oscillation. It is a large-scale pattern similar to its southern cousin, the El Niño-Southern Oscillation. Some scientists hypothesize that the AO plus anthropogenic effects control Arctic climate.

*[SEARCH]*

Can the pieces of the Arctic climate puzzle—sea ice observations, shifts in ocean ecology, changes on the land—be linked to the Arctic Oscillation? Is the Oscillation merely cyclic or is it following a long-term trend? Answering these questions will require not only more research but also greater integration of Arctic science.

Nine government agencies, including NSF—through our Office of Polar Programs—are exploring a coordinated, large-scale effort to study environmental change in the Arctic. I'm pleased to be the lead Federal official in working with the Administration on these plans for SEARCH, the Study of Environmental Arctic Change. To comprehend the fragments of climate and environmental change we trace in Alaska, we must ultimately understand the dynamics of climate change across the entire region, which in turn have global connections.

NSF supports research in the Arctic at the smallest and largest scales, and across the disciplines, and results are flowing in. But the most powerful answers will require integrating all the data from our numerous sources into a single coherent picture. Today, our new technologies—such as the Internet—and our new perspectives on collaborating across disciplines and institutional boundaries, set the stage for understanding the complexities of climate change.

In his book about the Yup'ik people, called "Always Getting Ready," James Barker, the Alaskan photographer, describes how the elders commonly caution the young that "one must be wise in knowing what to prepare for and equally wise in being prepared for the unknowable." This perspective serves us equally well in our quest to understand the mysteries of Arctic climate. Thank you.

[CLERK'S NOTE.—The following report "The Interagency Program for the Study of Environmental Arctic Change (SEARCH), prepared by the Interagency Working Group for the Study of Environmental Arctic Change, June 29, 2001, can be found in the subcommittee files.]

Chairman STEVENS. Thank you very much, Dr. Colwell, and thank you very much for coming. Our next witness is Scott Gudes, Acting Director of the National Oceanic and Atmospheric Administration. He's accompanied by Thomas R. Karl, the Director of NOAA's National Climatic Data Center. Scott.

## DEPARTMENT OF COMMERCE

### NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

**STATEMENT OF SCOTT B. GUDES, DEPUTY UNDER SECRETARY FOR OCEANS AND ATMOSPHERE**

Mr. GUDES. Thank you. I also have Dr. Calder who's the head of our Arctic Research Program.

Chairman STEVENS. Pardon me. Thank you. Nice to have you here, Doctor.

Mr. GUDES. Chairman Stevens, let me thank you on behalf of Secretary Evans, the men and women at NOAA, for your interest in climate, for your interest in the oceans and the atmosphere and all of our programs. I would note that for most of the agencies up here, you're not only the Chairman of the Appropriations Committee, you're also on our Authorization Committee and I don't know if all the people here in Fairbanks and Alaska understand the significance of that. We certainly do know your leadership over the years and what an impact you've made in all of our programs.

Let me say, first, that climate research and climate observations and forecasts are an important area for NOAA. They have been since the inception of the agency back in 1970. In fact, you may remember that Dr. Bob White, the first Administrator of NOAA, was a big advocate of NOAA moving forward into climate. And he points out that, when the Stratton Commission was created, it was a theory that the Pacific controlled a lot of the climate in the continental United States; That El Niño had a major impact on rains, and he pushed forward (indiscernible) effort that NSF worked on and NOAA worked on. And, now, in 1997, when we came forward with a prediction of heavy rains in California with an El Niño event people saw that in fact that came to fruition, that we can forecast climate.

Climate is seasonal for NOAA. We come forward with a forecast every few months from the Weather Service and our research components, and we talk about drought probability in an area or higher than normal temperatures. It is also this longer-term type issue that we're talking about today. And I should note that, of our seven strategic goals at NOAA, two of them relate to climate, seasonal to interannual and the decadal to centennial change. In fact, we spend about, in total, about $240 million a year on climate programs and all those sort of categories.

Okay, next slide. Here, I'd just like to note that climate is important to all of our programs here in Alaska, that Alaska is important to NOAA programs. And we have some 460 plus employees that work around the State. We have, of course, the regional head of—our Alaska Fisheries is in Juneau where I'll be going tomorrow. We have the Tsunami Warning Center in Palmer. We have research and Weather Service employees in Barrow, all over the State and, in fact, we have 50 contract employees here in the Fairbanks area that operate and control all of our polar satellites. Climate affects all these activities around the State. It's important to everyone. It's important to our Weather Service employees who are out in those rural communities like St. Paul and Kotzebue and Nome and Yukatat and they're there—when you were talking about coastal erosion yesterday, they're there; they're taking part; they're members of those communities. But it relates to probably all the sort of services and operations that we perform. It obviously, as Dr. Colwell just mentioned, it relates to fisheries and marine mammals. It relates to coastal management and our efforts to prepare communities for coastal storms. It relates to weather and, I think Orson Smith mentioned this morning, river forecasting. That's one of the Weather Service's missions. In fact, our River Forecast Center is in Anchorage, for Alaska. It relates to public safety and that goes to the core of the mission of NOAA. So climate is a major issue and it's a major issue for us here in Alaska.

Next slide. I think most of this was covered this morning. I think it's important to note that you really can't focus on the climate here in Alaska without understanding the total global climate system that's been referred to by a few people here. But I think there's two points on this chart I'd just like to make that weren't covered. One is, on the lower left, those are measurements of $CO_2$ and other gasses in the atmosphere. That's done at our Barrow Observatory. You visited our South Pole Observatory back in January 1998. We have four that are these continuous measurements. Mauna Loa goes all the way back to 1959. And so we have these sort of records that enable the world to know from a ground-based source just how much $CO_2$ or methane or other gasses are in the atmosphere. The other measurement, where it says "Warming of World Oceans," that should say 3,000 meters, about 10,000 feet. Dr. Syd Levitus (ph) of our National Ocean Center and Tom Delworth (ph) of our Geophysical Fluid Dynamics Lab have come up with research that shows that the world oceans—again, this is a global measurement—down to about 10,000 feet have warmed by a bout a tenth of a degree fahrenheit since 1955. And they believe—again, as Mr. Goldin pointed out, it's always an issue of how much is natural variation—but they believe this is, again, anthropogenic, human forcing factors. A tenth of a degree fahrenheit may not sound like that much but, given that the world's oceans, or this sink, that they're the energy that drives the world climate system, I'm told that that is enough energy to fix the United States energy crisis. In fact, it provides the United States—so much heat and energy for the United States and California for 15,000 years. And, as Tom Karl pointed out, enough heat that's stored in the oceans to melt the whole Polar Ice Cap. It's a lot of energy and it will affect the atmosphere in future years or it could affect the atmosphere in future years.

Next slide, please. Now, again, a few of these things were covered by others but I'll just point out a few here. That was the Northwest Passage you talked about. That's in 1998 which is the warmest year on record globally and it just shows just how open the Northwest Passage was that you talked about before, with oil tankers.

Let me mention the precipitation anomalies. That actually shows one of the issues about climate, that we certainly have a lot of research still to do because I think you've heard me and others say that Alaska's becoming warmer and wetter. But what that chart actually shows is that Alaska became wetter quite some time ago. And, actually, in the recent warming—yeah, right at the end there, it's going up but that the major change in precipitation took place in Alaska quite some time ago.

And, then, finally, let me just point out an Arctic sea ice. A few of us have talked about that, about the Arctic sea ice is thinning, it's receding. I'd just like to point out that that's one of the points about what I think we do as an operational agency. We in the Navy with Coast Guard participation run the Joint Ice Center in Suitland and that data base comes from the Joint Ice Center, which are continuous measurements. It's that sort of issue about climate.

Okay, next slide. Again, most of these things were covered but on the left we have a simulation that shows what's happened with Alaska's temperatures since 1945. And it demonstrates a few things, that there's a lot of variability, that it's not linear, it's not equal, and that, within Alaska, different regions are affected differently in a given year. And, obviously, as you get to the—red being warmer—as you get to the 1990's—and, of course, 1998 I think you'll see that Alaska was much warmer. But, again, there's variability and you have to look for those long-term signatures, that long-term monitoring, to be able to look and see what's really changing.

Okay, next slide. Now, I think there were a few people this morning who talked about it. One of the key things, I think, about climate and really understanding climate is that to really be able to do it right—it's not all that glamorous. It's about observing systems and, in fact, we talk in NOAA about climates reference networks and cooperative observing systems and about the Cooperative Observer Network. Well, right now, in the United States, we have about 11,000 people, 11,000 sites, where people take observations every day for us. You see that sometimes on your local TV networks and people talk about how much rain there was in a location or what the temperature is. That's about how we are able in this country really to get much better climate information. It's about those long-term measurements. And it's something we really need to look at automating and rationalizing as we move forward in the future. And we've done some of that at NOAA. Now, let me just point out here that, in understanding climate change in Alaska, you get a feel for what percentage Alaska is of the land area of the United States. It's about 14 percent. If you look on the left there, that's the Cooperative Observer Network, the Automated Surface Observations, those sort of sites I was talking about within the State of Alaska. You can see how sparse the observational network is. On the right, we're taking the land area of Alaska and saying, "Okay, let's take a look inside the Lower 48. Look how many more observing stations there are." What that means is we have a lot better understanding, a lot more continuous data, in the lower 48 in temperature and precipitation, soil moisture content, of the kind of things we need to take a look at in terms of understanding of what's going on in climate. So in looking toward the future, the kind of issues that we at NOAA would talk about are this sort of long-term observing systems. Again, a climate reference network, I think one of our premier sites is about—I think they cost about $50,000. We just put one in or are putting one into Barrow. But these are the type of systems that one needs to do long-term. On the right is weather buoys. Mr. Chairman, you came forward last year and gave us money to put in seven additional weather buoys off the coast of Alaska. Obviously, this is important to fishermen but it's important to everyone to know what's going on with the waves, what's going on with the temperature, what's going on with the surface pressure. And we have seven additional buoys in this year's budget. So we're following your lead in the 2002 budget.

And, then, finally, I have an animation up on the right. We've talked a lot about the oceans and about salinity this morning. The Argo system under the National Ocean Partnership Program where we give the money to NOPP with the Navy. But the Argo Program is, if you will, a radiozon, a weather balloon, that's for the oceans. And these buoys go down to 2,000 meters, they drift. They come up every 10 days and they give us salinity and temperature. They come to the surface and they transmit those to satellites. We're up in this year's budget to about 275—a procurement of 275 of these buoys per year. We're moving toward a worldwide system of 3,000 Argo floats and we believe, spaced properly, this could give us the sort of knowledge and information that we have, for example, in the atmosphere with weather balloons and radiosondes which are launched twice a day. So it's about those long-term observing measurements; it's about those ground-based measurements in conjunction with satellite measurements that we think really unlock the secrets globally about what's going on.

Okay, next slide. Just real quickly, we have in our 2002 budget a climate initiative. This follows up to the initiative last year. Arctic Ocean fluxes were talked about this morning. We have about half a million dollars for that. That's looking at the fresh water incursion that we were talking about before. Let me just mention—we were talking about supercomputing. Our premier modeling center is the Geophysical Fluid Dynamics Laboratory in Princeton University. And that $3 million is to provide the type of supercomputing capacity we believe that we need to run those climate models that were talked about to get the mesh smaller, to get them run longer. There was one of the presentations this morning that used the GFDL model input is one of those ensembles. And it is a question of having the best people and giving them the tools to do the job, getting that data I talked about and getting the data assimilated into the models. We're working with NASA on a joint data assimilation center right now, not just in climate but in weather as well. It's a really key issue. We do not use enough of the data we get from satellites now.

Last slide. And, then, finally, as you know, we're an operational satellite agency. We run geostationary satellites; that's on the upper left. Those are the ones that most people in the United States see on television every night. But as you can see as you go toward the Poles, because the Earth curves, it really doesn't cover Alaska very well. Those two satellites do not. And so it's actually our polar satellites that provide the best coverage for Alaska. They provide the atmospheric soundings which are put into our models. They provide the imaging; they provide the search and rescue services, SARSAC, where we get that information to the Coast Guard. That's saved over 12,000 lives in the last 20 years.

And the replacement satellite for that—it's called NPOESS, National Polar Orbiting Environment Satellite System. And if you will, let me just make a few points. DOD and NOAA have run two separate systems for 40 years. NPOESS is converging those systems into one satellite system. It'll provide all those things I mentioned for both the civil community as well as for military commanders. It also includes altimetry. We talked about sea surface height; we talked about sea surface temperature. It includes altimetry and it includes scatterometry, sea surface winds. And we're working on an aerosol sensor to take a look at particles in the atmosphere, dust particles, soot, which affect climate. We're very enthusiastic about that at NOAA and Commerce. We believe the Department of Defense is but it is a new requirement that's coming forward for the system.

Just one final thing about NPOESS. It's critically important; it's one of our major systems and our budget has an $83 million increase. For NOAA, this is quite large but, in order to get that system delivered by late 2008, we have to—we really have to keep it on schedule. It becomes a weather system and a climate system and for Alaska it is the environmental satellite—operational environmental satellite system.

PREPARED STATEMENT

Mr. Chairman, that's a few of the things we're doing at NOAA. We're major participants in USGCRP. We're participants in SEARCH. We're honored to be here and we work very closely with all the agencies up here today and, once again, we very much appreciate your support.

[The statement follows:]

PREPARED STATEMENT OF SCOTT B. GUDES

Thank you, Chairman Stevens, for inviting me to testify about the research that the National Oceanic and Atmospheric Administration (NOAA) is doing on climate change, and how climate change is affecting the Arctic region. It is a pleasure for me to visit Alaska once again, and to share with you our interests in the dramatic environmental changes occurring in the Arctic, especially in Alaska—the U.S. Arctic. NOAA has a long history of awareness of the issue of climate change and its impacts on society. Since the mid-1970s, NOAA has sought to understand the mechanisms that control the Earth's climate. Our initial focus was on the equatorial Pacific Ocean and after several decades of observation and research, we know enough about the El Niño-Southern Oscillation phenomena to be able to predict it and to anticipate impacts in the U.S. and Latin America. Our more recent efforts have contributed to discovery of other climate cycles and modes of variability. Most recently, we have become aware of the Arctic Oscillation and its Atlantic component, the North Atlantic Oscillation. The Arctic Oscillation may well be the second most important mode of climate variability, after El Niño, in shaping our country's weather and climate.as related to the way in which nature manifests its major climate variations and change.

Over the last few years, NOAA has increased its involvement in Arctic science and the sponsorship of activities designed to improve our awareness of the Arctic environment and how it is changing. I will describe these activities, identify the key gaps in our knowledge and capabilities, and indicate a possible future direction for NOAA's activities to reduce uncertainties about climate change in general, and in the Arctic.

When I refer to the Arctic, I include the entire Bering Sea and Aleutian Island region, as well as the Arctic Ocean and its surrounding seas, and, of course, all the land traditionally included in the Arctic, as well as the atmosphere overlying these areas.

OBSERVED ARCTIC CHANGES AND THEIR RELATIONSHIP TO NOAA'S MISSION AND EXPERTISE

Other presentations at this hearing have described the dramatic changes that have occurred in the Arctic over the past few decades. A great many of these changes have occurred in the atmosphere, the ocean, and cryosphere, including sea ice. Detecting and anticipating these physical changes fall squarely within NOAA's mission to observe and predict the evolving state of the oceanic and atmospheric environment. NOAA now believes the Arctic Oscillation, described to you yesterday, is nearly as important as the El Niño phenomenon in controlling temperatures in the eastern U.S. Other factors, such as the Pacific Decadal Oscillation and the recently described Atlantic Multidecadal Oscillation also may be significant modes for influencing our nation's weather and climate.a one of several major oscillations in the atmosphere and like the El Niño phenomenon and the Pacific-Decadal Oscillation is an important factor influencing high latitude and northern hemisphere temperatures. These oscillations are preferred modes of atmospheric circulation. Evidence suggests that changes in these modes of atmospheric and oceanic circulation are the principalone of the ways through which changes in global climate are manifested. NOAA is responsible for weather and climate observations and forecasts for the U.S., and for contributing to understanding climate variability and change on global and regional scales. The linkages between the Arctic Oscillation and other modes of variability in the atmosphere and oceans are the subjects of current NOAA research.

The observed changes in sea ice relate strongly to several NOAA missions. Sea ice cover in the Arctic is a key variable in controlling the radiative balance of the Earth. Sea ice reflects much of the incident radiation during the Arctic summer and restricts loss of heat from the ocean in the Arctic winter. Better representing sea ice extent, concentration, and thickness in climate models is an emerging research priority for NOAA. Increased absence of ice is likely to increase opportunities for marine transportation and this may increase demands on NOAA's nautical charting program and the National Ice Center. If this occurs, then Arctic coastlines are likely to become more at risk from maritime accidents. If so, NOAA's hazardous materials response activities may be called upon. Absence of shore fast ice is one cause for the increased coastal erosion that has occurred in several of Alaska's coastal communities. NOAA's ongoing efforts in storm surge prediction and mitigation could contribute to this issue in the Arctic. Changes in sea ice also affects the habitat and subsistence use of many marine mammals in the Bering Sea and Arctic. NOAA has trust responsibility for several of these species

We believe that ocean regime shifts observed in the Bering Sea should also be included among the critical changes in the Arctic over the past few decades and we have strong suspicions that these play a critical role in stock abundances of the commercial and forage fish in the Bering Sea.

The point of this discussion is to make it clear that NOAA's activities are central to the need for timely and high quality science and services related to Arctic change. NOAA's current activities are responsive to this need, but we hope to do even better in the future.

## NOAA ACTIVITIES IN THE ARCTIC

In the broadest sense, NOAA spends about $30 million per year for on-going Arctic activities, many of which are part of, but this is supplemented by a broader programs that, which also provide observations, data, analyses, and forecasts. These programs are spread among all five of our line offices and include a mix of research and operational activities. Listed below are the highlights of these that are relevant to the topic of this hearing.

—Atmospheric Trace Constituents (Barrow Observatory): Continuous and discrete measurements of atmospheric trace constituents (for example, greenhouse gases) that are important to understanding global change.

—Marine Fisheries Assessment: Assessment by the National Marine Fisheries Service (NMFS) of U.S. living marine resources in Arctic waters.

—Marine Fisheries Research: NOAA's Pacific Marine Environmental Laboratory (PMEL) and Alaska Fisheries Science Center (AFSC) conduct the Fisheries Oceanography Coordinated Investigations (FOCI) program in the Bering Sea and North Pacific. FOCI is concerned with understanding and predicting the impacts of inter-annual variability and decade-scale climate change on commercially valuable fish species.

—Marine Mammal Assessment: Long-term research by NMFS's National Marine Mammal Laboratory on the population biology and ecology of Arctic marine mammals. NMFS also participates in the Marine Mammal Health and Stranding Response Program, which oversees the Arctic Marine Mammal Tissue Archival Program (AMMTAP) in collaboration with Department of Interior (FWS, BRD, and MMS) and the National Institute of Standards and Technology (NIST). The AMMTAP collects, analyzes, and archives tissues for contaminants and health indices to provide a database on contaminants and health in marine mammal populations in the Arctic.

—Coastal Hazards: Activities directed towards developing a better understanding of the effects of tsunami propagation and run-up.

—Ocean Assessment: A wide range of programs and activities directed toward NOAA's environmental stewardship responsibilities, including environmental monitoring and assessment, technology transfer, and education and outreach. Ocean assessment includes the National Status and Trends Program, the Coastal Ocean Program, and other pertinent activities of the recently formed National Centers for Coastal Ocean Science (NCCOS), National Ocean Service.

—Stratospheric Ozone: A program that is developing an understanding of the dynamics and chemistry of the potential for Arctic ozone depletion, as part of activities directed to understanding the global depletion of stratospheric ozone.

—Data Management and Access: The process of collecting, quality control, data access, and long-term preservation of all data collected is one of NOAA's mandate's. We operated three National Data Centers and over ten World Data Centers which archive atmospheric and climatic data, ocean-related data, and geophysical data. We also archive all of the biological data we collect

—Remote Sensing: A substantial program (jointly with NSF and DOE) for developing, testing, and using ground-based remote sensors for Arctic meteorological research. The emphasis is on prototypes for future operational systems that can operate in the Arctic with minimal attention. The scientific issues include boundary layer turbulence and structure, cloud macro- and micro-physical properties, and cloud-radiative coupling relevant to Arctic climate.

—Aircraft/Vessels: Platform support from the Office of Marine and Aviation Operations (OMAO) to conduct the research and observations associated with NOAA's Arctic research program.

—Climate and Global Change: Studies that are assessing changes in the arctic and others areas affecting the arctic, including causative factors of climate change and the environmental response to these changes and variations. NOAA's Arctic Research Office chairs the Interagency Working Group on the Study of Environmental Arctic Change (SEARCH).

—Arctic Ice: The National Ice Center, jointly operated by NOAA, the U.S. Navy, and the U.S. Coast Guard, provides analyses and forecasts of ice conditions in all seas of the polar regions, the Great Lakes, and Chesapeake Bay. Since 1974, the NIC has produced weekly ice charts depicting Arctic and Antarctic sea ice conditions, as well as tracked large Antarctic icebergs. In October of 2000, NIC released a compilation of its ice charts from 1972 to 1994. Scientific study of NIC's sea ice charts will prove a valuable resource in determining how global climate change has affected the sea ice cover over this 22-year timeframe. The NIC is striving to add to this data set, and plans to release the data for 1995–20001 by the end of this year. The National Snow and Ice Data Center (NSIDC), affiliated with NOAA's National Geophysical Data Center (NGDC), archives many new and rescued ice data sets.

—Arctic Weather: Research primarily addressing two forecast problems: detection of the Arctic front and the effect of the Arctic front on local weather.

—Boreal Forest Fires and the Arctic: Modeling, research, and observations to understand the influence of Northern Hemisphere boreal forest fires on atmospheric chemistry in the Arctic, especially focusing on the production of surface-level ozone and other pollutants and the atmospheric and climate effects of the input of soot.

—Arctic Research Initiative: Program supporting research, monitoring, and assessment projects to study natural variability and anthropogenic influences on Western Arctic/Bering Sea ecosystems. These activities are a U.S. contribution to the Arctic Council's Arctic Monitoring and Assessment Program. Projects supported by this program are expected to lead to better understanding of Arctic contaminants and their pathways, the effects of climate change including increased ultraviolet radiation, and the combined effects of stresses from climate change and various contaminants.

—Surface Weather and Climate Observing Networks: The National Weather Service operates two operational observing networks in Alaska, accounting for over 100 stations. Recently the National Environmental Satellite Data and Information Service (NESDIS) initiated the development of a Climate Reference Network which will add to the existing weather networks.

—Space-based observations of Change: In the arctic regions, including Alaska, much of our information is derived from satellite measurements. For example, changes in sea-ice and snow cover extent have been carried out for over three decades using NOAA's operational polar orbiting satellites. NOAA's polar orbiting satellites have been crucial in providing global coverage of ocean surface temperatures since the early 1980's. Perhaps of most importance has been the contribution of NOAA's polar orbiting and geostationary satellites to provide climate data related to the tracks and intensity of tropical and extra-tropical cyclones. Other elements monitored by NOAA satellites include clouds, winds, and water vapor. NOAA/NESDIS has operated two operational polar orbiting satellites over the past four decades, as well as two geostationary satellites, thereby providing necessary spatial and temporal coverage of the Earth.

—Alaska Sea Grant and the West Coast and Polar Regions Undersea Research Center: These NOAA institutional programs conduct a diverse set of research programs in Alaska that include research on the Arctic Ocean and Bering Sea. Among these are environmental affects on commercial and protected resources, and sub-sea research on high-latitude productivity, nutrient exchange, and benthic community structure.

In 1999, NOAA organized the Arctic Research Office and received funding for the Arctic Research Initiative into our requested budget. With these steps, NOAA declared its awareness of the importance of the Arctic and particularly the Alaskan Arctic in several science issues relevant to NOAA's missions. In particular, NOAA's Arctic science interests include weather and climate, marine ecosystem productivity, and long-range transport of contaminants. Activities in all of these areas were supported with Arctic Research funds. It is important to note that NOAA's Arctic Research program is implemented in close cooperation with the Cooperative Institute for Arctic Research (CIFAR) at the University of Alaska. This cooperation has been fruitful in several ways, but most importantly in ensuring that research priorities are set based on the intersection of NOAA's mission priorities and the knowledge of scientists with first hand experience in the Arctic. In fiscal year 2000, NOAA, NSF, and CIFAR had the opportunity to collaborate with a new organization, the International Arctic Research Center (IARC), also at the University of Alaska. This NOAA/CIFAR/IARC collaboration provided a unique opportunity for organizing a very significant research effort focused on the Arctic. The combined resources of the IARC and of NOAA's Arctic Research program were brought to bear on research themes closely related to the topic of this hearing. Specifically, several projects each were supported under the following themes: Detection of Arctic Change; Arctic Paleoclimates; Interactions/Feedbacks and Modeling of Arctic climate; Changes in the Arctic Atmosphere; and Impacts to Arctic Biota and Ecosystems. Overall, thirty-nine individual research projects and a few supportive workshops and data management activities were funded for two years. NOAA acknowledges the willingness of the National Science Foundation to support the second year of many of these activities through its cooperative agreement with the IARC.

As an outgrowth of discussions among NOAA, the IARC, and the National Science Foundation in fiscal year 2000, we agreed that the IARC could be the site for the Secretariat of a new international activity, the Arctic Climate Impact Assessment, or ACIA. The ACIA is being conducted by scientists from all eight Arctic countries as an activity of the Arctic Council. During the recent period of leadership of the Arctic Council by the United States, the U.S. offered to lead this assessment. NOAA is the minor co-sponsor of the ACIA, while the National Science Foundation is providing the major support to the ACIA through the IARC. The Secretariat for the ACIA is located at the University of Alaska and is headed by Dr. Gunter Weller, who is also Director of NOAA's Cooperative Institute for Arctic Research. The ACIA will result in 2004 in a summary of knowledge regarding past climate variability and change over the entire Arctic, projections of Arctic climate variability in the future, and an evaluation of the impacts of climate variability and change on the biological environment, human uses of the environment, and social structures. The Arctic Council will use this summary of knowledge to prepare a policy report discussing actions that governments should consider in response to anticipated changes in Arctic climate. More information on ACIA can be found on its website at http://www.acia.uaf.edu.

While the main product of the ACIA will not be available until 2004, its first outcome is a key report on Arctic climate modeling. The following quote from the report's summary is quite revealing:

"The Arctic is recognized as the area of the world where climate change is likely to be largest, and is also an area where natural variability has always been large. Current climate models predict a greater warming for the Arctic than for the rest of the globe. The impacts of this warming, including the melting of sea ice and changes to terrestrial systems, are likely to be significant. The projections of future changes are complicated by possible interactions involving stratospheric temperature, stratospheric ozone, and changes in other parts of the Arctic system. For this reason, current estimates of future changes to the Arctic vary significantly. The model results disagree as to both the magnitude of changes and the regional aspects of these changes."

The report goes on to state that models indicate a warming of the Arctic of 2 to 6 degrees Celsius by 2070, but with considerable uncertainty. These uncertainties stem from our assumptions about the future, from the models themselves, and from inherent limitations in our ability to predict climate. We know that the Arctic undergoes considerable climate variation on decadal and longer time scales (e.g., the warming of the 1930's and cooling over the next few decades) and this must be considered in addition to any anthropogenic change.

In the current fiscal year, NOAA continued to emphasize Arctic environmental change and initiated an additional ten projects that will provide new information on Arctic Ocean circulation, atmospheric advection of heat and moisture, and the role of sea ice and snow cover in influencing the state of the Arctic Oscillation. These projects are planned to continue through fiscal year 2002. The NOAA/CIFAR collaboration was again utilized to implement these projects. Another benefit of this collaboration that deserves mention is the ability to provide support to the most capable scientists who are interested in research in the Arctic. Over the years, support has been provided to scientists from NOAA, from other federal agencies, from several of our institutional academic partners, and from other academic and research organizations. Many projects have involved foreign collaborators as well.

NOAA was given an unexpected opportunity this year to evaluate how changes in the higher latitudes impact marine ecosystem productivity. NOAA was asked by the Congress to evaluate the possible role of climate and ocean regime shifts on populations of Steller Sea Lions. Once again, NOAA turned to its collaboration with CIFAR to define and implement a research program. Twelve projects were selected for funding utilizing the standard peer review practices that characterize all of the NOAA/CIFAR activities. Six of these projects have the goal of evaluating existing data to determine if there is any evidence that climate variability or ocean regime shifts could be wholly or partly responsible for the dramatic decline in the population of Steller Sea Lions in the Aleutian Islands and western Gulf of Alaska. This decline occurred over the past 30 years, a period in which at least one major ocean regime shift has been recorded and the Arctic Oscillation shifted to its high index state. The project reports will be available in about 2 years. NOAA is also supporting the collection of new data in key regions in the Aleutian Islands and near Kodiak that will allow future evaluation of the role of ocean conditions in the population dynamics not only of Steller Sea Lions, but also the mammals, birds, and fish that inhabit these regions.

REMAINING KNOWLEDGE, INFORMATION AND DATA GAPS

*Recent climate assessments*

Over the past several months two state-of-knowledge assessments have been completed addressing climate change and climate impacts both globally and nationally. On a global basis, the Intergovernmental Panel on Climate Change (IPCC) has assessed the science of climate change and the potential impacts of such changes. On a national basis the full report of the National Assessment of Climate Change Impacts has just been released. It focuses on the impacts of climate change within the borders of the United States. These reports outline our present state of knowledge about how the climate has changed in the past, whether it is presently changing, what may be causing these changes, what is likely in the future given various scenarios of changes in atmospheric composition, and the potential economic and ecological impacts of these changes. All of these reports also find that significant climate change and impacts are emerging in Arctic areas, and particularly in Alaska. Moreover, all projections suggest that these areas will continue to see larger changes in climate than the rest of the planet.

The United States National Assessment outlines a national research strategy that would help us reduce the uncertainties about climate change impacts, and the IPCC report also identifies key uncertainties. One of NOAA's concerns relates to potential surprises that are possible due to incomplete understanding of the climate system. Some examples of these have been proposed with some rationale for their occurrence such as: a complete shutdown of the North Atlantic Circulation which transports heat to the high latitudes, large releases of methane, a potent greenhouse gas, into the atmosphere as the climate warms (currently frozen in the arctic tundra), major changes in circulation and precipitation due to an ice-free arctic, significant changes in the strength of El Niño due to warming of the Pacific Ocean, and others. A better understanding of the science will minimize the risk of such unanticipated climate change.

Since the assessments have already been the subject of several Congressional hearings, and are the focus of an ongoing National Academy of Sciences analysis I will not elaborate on their findings. Instead, I will emphasize how NOAA is helping to reduce remaining uncertainties about climate change and climate change impacts.

*Reducing uncertainties about climate change*

It is important to realize that the climate change issue is being addressed within NOAA using the well-proven scientific method of beginning with reliable good old fashion observations, then we work to developing theories about the nature and behavior of the observations, and lastly we testing our theories by making predictions about the relationships among the observations. Traditionally, in laboratory experiments it is relatively easy to control for all relevant factors except the one being testing. This helps scientists evaluate theories, but in nature our ability to control relevant factors is severely constrained. Instead, theories are tested by comparison with the existing we rely on an extensive collection of past observations or proxy data from tree rings or ice cores, for example. to test our theories We cannot wait decades into the future to test our understanding. This requires a comprehensive collection of reliable historical data. Moreover, it becomes critical to know which variables need to be monitored and with what frequency, spatial extent, and accuracy. Fortunately, our work over the past Century, and the assessments of the last decade, have provided considerably insight as to what needs to be monitored. They have also provided insights as to how best test and develop our theories about the operation of the climate system and its impact on society and the environment. As an operational agency, NOAA's ongoing programs, as described above, will serve to advance our state of knowledge about climate and reduce uncertainties about climate change and its impact. They will fill important information gaps required for informed decisions by governments, industry, and the public. NOAA's role in addressing climate variability and change, and reducing uncertainties contributes to the interagency U.S. Global Change Research Program.

I would be remiss however, if I did not emphasize some of the greatest challenges NOAA faces related to increasing our understanding of climate change and its impacts are in the Arctic including Alaska. These challenges include cover various areas ranging from deployment of observing systems under harsh conditions, improving global climate modeling by adding regional (including the Arctic) and interdecadal skilling,to and providing access to the vast array of data and information collected by NOAA.

*Key measurements for understanding climate change*

One of the most important lessons we have learned from the last decade is that a single comprehensive observing system for global change is not the right approach. The attempt to satisfy too many requirements can result in an observing system that is neither optimally useful nor sustainable. A special need in the ongoing development and implementation of observing systems during the next decade will be the development and implementation of hierarchical observing strategies, methods, and tools that integrate local, regional, and global scale data. NOAA intends to formulate an observing strategy for the Arctic.

TEMPERATURE AND PRECIPITATION

Our longest instrumental surface weather records are derived from two basic NOAA weather networks, the Cooperative Weather Observing Network (COOP) and the First-Order Automated Surface Observing System (ASOS). Data from these networks have been painstakingly analyzed by numerous scientists to tease out a long-term record of climate variation and change. There are numerous difficulties in using these data for the purpose of documenting climate variations and changes, as apparent by the relatively large uncertainty band related to observed global temperature changes during the past Century, e.g., 0.4 to 0.8°C/100 years and mid-to-high latitude changes in precipitation, e.g., a 5–10 percent increase in precipitation.

The uncertainty can be much greater for poorly monitored high latitude regions such as Alaska, where the warming is estimated to be several times larger. Large uncertainties arise because of the additional cost of monitoring in remote and harsh environments. As a result, Alaska has the lowest density of surface temperature and precipitation observations of all states. The lack of an optimized observing network for monitoring decadal climate variations and change and the low density of stations leads to substantial uncertainties. For example, in Alaska, all the ASOS sites are located at major airports near urban areas, and in the Arctic, the urban warming influence can confound our interpretation of the changes we see. The ASOS network, together with the volunteer COOP network, helps define the climate across the state from a total of just over 100 stations, in contrast to areas in the lower 48 states where we have over 1,000 stations for similar sized areas.

Up until this past year these two networks have been the basis for virtually all our information about changes in temperature and precipitation. NOAA has recently been provided funds to begin operation of a surface observing network for temperature and precipitation that meets the climate change monitoring requirements developed by the U.S. National Research Council and the World Meteorological Organization. A Climate Reference Network is now being developed, and one of the first Climate Reference Stations is now being installed near Barrow, Alaska, the location of NOAA's benchmark observatory for measuring changes in atmospheric constituents. Completion of this network will ensure that NOAA's ability to precisely measure temperature and precipitation change, including changes in extremes. Changes in precipitation extremes are expected to be quite pronounced in Alaska and other high latitude regions as temperatures increase, but these changes can be especially difficult to monitor.

In addition to observations in Alaska, climate-quality data is needed for temperature and precipitation over the Arctic Ocean as well. NOAA's Arctic observing strategy will include this requirement.

ATMOSPHERIC CONSTITUENTS

Quantifying the trends, sources and uptakes of long-lived greenhouse gases is fundamental to our understanding of current and future climate. The measurements taken at our Barrow site, one of our four benchmark greenhouse gas monitoring sites, provides one of the most important sets of measurements to monitor changes in greenhouse gas concentrations. We have recently received much needed funding to begin improving our greenhouse gas monitoring capability at these sites. There are numerous questions about the trends and radiative effects of these gases that NOAA will be addressing over the next few years. For example, how is atmospheric carbon dioxide taken up by the oceans and land, why has the rate of increase of the potent greenhouse gas methane changed, what is the relationship between the ozone hole recovery and increases of greenhouse gases? On this latter point multiple data sets reveal that there has been a cooling trend in the lower stratosphere over the past two decades. Model simulations point out unequivocally that the global-mean lower-stratospheric cooling is due to decreases in stratospheric ozone, increases in gases like carbon dioxide, and increases in stratospheric water vapor. It now appears possible that this cooling may delay the recovery of the ozone hole.

There are several important additional steps that we are building into our long range plans. This includes enhancing our monitoring capability for carbon dioxide, methane, and nitrous oxide and other trace atmospheric constituents that are radiatively active. This will require additional investments in our benchmark stations and the planning and implementation necessary to begin measurements from space. Maintenance and dissemination of gas standards must also be enhanced as we also collect data from around the world from dozens of international sites.

It is very important to begin a long time-series of measurements of carbon dioxide from tall towers to determine the uptake of carbon dioxide by forests and soils. Four new towers are planned (for various forest-cover regions), adding to the existing two. This expansion will provide an initial estimate of uptake by North America. We would like to institute three new chemical monitoring sites in the Pacific to give information about the contents of the chemical mix of the Asian plume as it is transported eastward. This will provide greater detail than is possible with only one existing site, in Hawaii.

One of our key uncertainties related to understanding climate change relates to our incomplete knowledge about changes in radiatively active anthropogenic aerosols. This is a complex issue because aerosols like those produced by burning high sulfur fossil fuels produce micron size particles that reflect solar energy back to space and cool the planet, but they also interact with the formation of clouds, affecting their lifetimes and radiative properties in ways we do not fully understand. To make matters more complex there are other aerosols produced by humans that tend to radiate back to earth more radiation than they reflect back to space (soot or carbonaceous aerosols), contributing to a warmer planet. Unfortunately, long-time series of these measurements are difficult because they vary greatly in space, unlike greenhouse gas measurement. NOAA has convened an interagency workshop to evaluate ways we could begin a long-time series of these measurements. We are exploring the feasibility of including some of these instruments aboard our future satellite missions.

### CRYOSPHERIC INDICATORS, E.G., SNOW COVER AND SEA-ICE EXTENT AND THICKNESS, PERMAFROST, LAKE- AND RIVER-ICE

NOAA's polar orbiting satellite data and surface-based observations have been used to show that major changes in the cryosphere are now underway, and even larger changes are projected to occur this Century in the high latitudes including Alaska. The lake and river ice season (now estimated to be 12 days less compared to the 19th Century), permafrost, sea ice, and snow cover extent are all estimated to be decreasing. Further, the surface reflectivity of these regions is a major climate feedback. NOAA's research has shown that the melting of ice in high latitudes has likely contributed to about 50 percent of the warming during spring in the mid- and high-latitudes. Reliable time series of cryospheric variables are necessary to test the predictive skill of our models. Massive losses of snow cover and sea ice are likely-irreversibly large, so it is very important that we accurately measure and model this change. This takes on added importance since the impacts of these changes are already apparent in the Arctic, and likely to become more significant.

NOAA's researchers, the Snow and Ice Data Center and NOAA's Operational Satellite Processing Center are working to ensure that a seamless record of changes in the arctic can be preserved as there are multiple demands and uses of these data.

### OCEAN TEMPERATURE, SALINITY, AND CIRCULATION

To project the pace of changes in sea-ice, sea-level, and other aspects of climate it is critical to couple the fast-response of the atmosphere with the sluggish response of the oceans. The measurement of ocean temperature, salinity, and circulation are now a primary goal of NOAA's participation in the National Ocean Partnership Program (NOPP). To advance this goal, NOAA in partnership with other nations, is deploying an array of oceanographic profiling floats, called Argo, that provide information about ocean temperature, salinity, and circulation from the ocean surface and subsurface waters.

NOAA is working to accelerate the deployment of the profiling floats, as we now have evidence to suggest that the ocean's heat content has increased substantially since over the last half of the Twentieth Century. This increase in ocean heat content is consistent with several of climate model simulations of Twentieth Century Climate when these models are forced with increases in greenhouse gases, estimates of changes in anthropogenic sulfate aerosols and changes in other climate characteristics, like volcanic aerosols. It will be very important to understand how much heat the oceans are taking on as changes in greenhouse gas concentrations increase. NOAA is working to define an ocean observing strategy for the Arctic that will complete the global strategy. New technologies will be needed for observations in ice-covered areas and international cooperation will be essential for access to critical areas of the Arctic under national jurisdiction.

## CLOUDS AND WATER VAPOR

One of the most important aspects of uncertainty continues to arise because of inadequate information about clouds and water vapor. This includes cloud amount, type, height, the phase state (ice or water), and the amount of water vapor in the atmosphere. Water vapor is the most prevalent greenhouse gas and there are important feedbacks between rising temperatures related to increases in carbon dioxide and increases in atmospheric water vapor. Unfortunately, the Global Upper Air Network just established by the Global Climate Observing System of the World Meteorological Organization is failing due to lack of support. At the present time only about half of the global network is reporting data, even after the WMO had identified a set of key stations across the world as key indicators and markers of climate change. NOAA is exploring ways in which we can help to correct this situation since we are very much dependent on a global network of climate-quality upper air measurements of water vapor. We are also working to provide high-altitude balloon-borne measurements of water vapor in the stratosphere at our baseline observing network sites at Barrow, Hawaii, American Samoa, and the South Pole.

Cloud-related characteristics from satellite measurements are critical for global coverage, and these must complement surface measurements to ensure adequate calibration. NOAA is now working to develop automated cloud information that extend our current monitoring capability above 12,000 feet.

## SEA LEVEL

As ocean temperatures warm and glacial ice melts, global average sea level is increasing. Sea level rise during the 20th Century is estimated to be between 0.1 and 0.2m, and is projected to increase between 0.1 to 0.9m by the end of the 21st Century. Generally, increases in sea level are expected to be higher in high latitudes. NOAA maintains a global network of tide gauges which have provided the data to calculate global sea-level rise, but there are many local and regional variations. High quality tide-gauges are a high priority within NOAA to ensure adequate reference points to gauge sea level changes.

NASA, in cooperation of our French partners, has been flying a satellite altimeter as part of their Topex/Poseidon mission which provides high precision global sea level data when calibrated with tide-gauges. The instrument has proven to be very reliable and is ready to transition from a research experiment to regular operations. NOAA is working with NASA and international partners to begin an orderly transition from research to operations to ensure global coverage of changes in sea-level.

## PALEOCLIMATIC DATA

One of the most important developments in the recent few years has been the ability of researchers to assemble paleoclimatic data from tree rings, corals, historical records, bore holes, and ice cores to develop a 1,000 year record of northern hemisphere temperatures. These data show that temperature increases during the 20th Century have been larger in the Northern Hemisphere than any time during the past 1,000 years. Much work remains however. Important regional information is sparse, there are large uncertainties between some of the data sets. For example, temperatures inferred from the conduction of heat from the atmospheric surface layer to deeper layers within the earth's crust show larger increases of temperature compared to temperatures inferred from the other proxy data. Understanding these differences will improve our confidence regarding the causes of recent temperature increases and the sensitivity of climate to changes in atmospheric composition and other factors. Lastly, data from the southern hemisphere has not yet been compiled, and some of the records from which our scientists derive important information are disappearing. Critical glaciers in tropical climates are melting away as temperatures increase. It is now recognized that changes in the tropics are the key drivers of climate change elsewhere on the planet, including the arctic NOAA is working with other agencies, like NSF, to accelerate our efforts to collect valuable paleoclimatic data.

WEATHER AND CLIMATE EXTREME EVENTS

At the present time, NOAA is working to adequately monitor changes in weather and climate extremes. Billion dollar weather and climate disasters are affecting the U.S. at increasing rates, and many of these are related to excessive precipitation events and major storms. But at the present time, we have conflicting analyses related to whether there have been substantial increases in the intensity of many important extreme weather and climate events. For example, some analyses reveal a major increase in the intensity of severe North Pacific storms, but other analyses do not confirm such increases. Meanwhile, we have strong evidence to indicate that heavy and extreme precipitation events are increasing in many areas, but as I have indicated measurements in the high arctic, including Alaska, are confounded by an inadequate number of observing sites, imperfect measurement systems, and measurement biases. We know that changes in extreme weather and climate events are often the determining factor related to the economic and ecological impacts of climate change. For these reasons, NOAA is placing a high priority on adequate investments to help ensure our observing systems provide the information necessary to systematically monitor changes in climate extremes and weather events.

*Improved modeling capabilities*

Testing our theories about climate change and projecting future climate cannot proceed without climate models. Today, NOAA Research is continuing to use climate models to simulate past climate, especially the climate of the last Century and the past 1,000 years, where we have sufficient observations to test our ideas about the behavior of climate. NOAA is working to add Arctic processes to its existing global climate models. One of the major issues we are addressing relates to the amount of computer power necessary to provide the climate model simulations necessary to meet the demands for multiple simulations based on various scenarios of future emissions of anthropogenic atmospheric constituents, and the multiple simulations required to bound the uncertainty of climate due to its chaotic nature, and the need to achieve greater regional and temporal resolution. More computer hardware is only part of the answer. NOAA closely coordinates its modeling activities with other agencies, and is stepping up its efforts to train scientists throughout the climate community to assist us on this national problem, through NOAA's Climate and Global Change Program. In addition, we believe that it is also important to ensure that an adequate supply of computer students engage in this challenging problem of optimally configuring computer models for state-of-the-science computation, storage, and data access. NOAA is providing scholarships to those scientists interested in working in these fields.

Lastly, a very recent National Research Council report outlined a strategy to improve our modeling capabilities in this nation. NOAA believes such a strategy would go a long way to reducing uncertainties about regional climate change in the Arctic.

*Improved information about future climate*

There are two areas that NOAA will be emphasizing in the immediate future to help business, industry, state and local governments, and individuals minimize the risk of climate change and maximize its potential benefits. This relates to the use of Climate Normals for planning and design, and improved access to data and information.

CLIMATE NORMALS

Climate normals have been used by millions of users over the past few decades to assist with design and planning for a wide-variety of applications. Traditionally, the Official U.S. Climate Normals are calculated by the NOAA every ten years, and by international agreement they reflect the climate over the past 30 years. Important research questions remain as to the appropriate historical period to use for planning over the lifetime of new structures. For example, how many years of the climate record should be used to project the kind of climate conditions a new structure is likely to encounter? Over the past few years, as the climate has been significantly changing many users are finding that the traditional climate normals are not capable of bounding the conditions they are experiencing. This is leading to design failures. As a result, NOAA has taken initial steps to provide users with information more suited to a changing climate. We have developed models and software which begin to integrate historical climate data with various user-defined and model scenarios of future climate. Recently the National Homebuilders Association worked with scientists at NOAA's National Climatic Data Center to develop a new Air Freezing Index, which based on the Association's figures has saved over $300 million annually in building costs, and over 300,000 MW of energy each year since using the index to re-engineer building codes. Last year, the National Climatic Data Center developed a prototype of the Next-Generation Normals which was used in the National Assessment of Climate Change. Over the next few years NOAA will be issuing updated Climate Normals, and we are committed to making this information more useful to our users in a changing climate.

DATA AND INFORMATION ACCESS

NOAA has responsibility for providing long-term stewardship and access to all the nation's atmospheric and oceanic data. This is an enormous responsibility, which is heightened by what many of our constituents have recently emphasized. The number one priority for them over the next several years is more effective access to more than 1 petabyte of data that NOAA has in its archives. This amount of data is equivalent to the data stored on over 100,000 modern personal computers. NOAA also has millions of pages of historical data not yet computer accessible. Many of the records hold the key to documenting past climate variability and change. Our users have also told us that the environmental data we store has now taken on such economic applicability that they consider our environmental data as important as economic data to effectively manage and operate their businesses.

NOAA is committed to making the data readily available. Over the next five years, NOAA's data volume is expected to increase five times. The challenge for us is not only to be able to preserve the data, but to provide effective access to these data. NOAA is committed to addressing this challenge and we will be working very closely with regional and local interests to ensure that our services are as effective as possible.

FUTURE NOAA ACTIVITIES IN THE ARCTIC

NOAA expects to continue all of the operational activities described earlier and improve and enhance the quality and utility of our services whenever possible. As one example, the Alaska Region of the Weather Service in cooperation with the IARC is beginning to define activities that will become the Alaska component of NOAA's climate services program.

For the long term, NOAA intends to continue to focus its Arctic Research Initiative on the three major areas of weather and climate, marine ecosystem productivity, and long-range transport of contaminants. Using existing resources, NOAA can continue a viable program in these areas by focusing on one at a time for two year funding periods. Specifically during 2003, NOAA will use these existing resources for synthesis and reporting of the outcome of the several projects funded in fiscal year 2000 through fiscal year 2002 under the Arctic Research Program, the joint CIFAR/IARC activity and the special funding for climate impacts on Steller Sea Lions. In addition, the first drafts of chapters in the Arctic Climate Impact Assessment should be available for review in 2003. We expect this synthesis activity to provide significant new insight and knowledge that will provide guidance for future Arctic research.

In particular, this synthesis effort will provide a background for NOAA's future emphasis on the Study of Environmental Arctic Change or SEARCH. This is a new effort being planned by nine federal agencies under the auspices of the Interagency Arctic Research Policy Committee with the active involvement of a science steering committee. The SEARCH program will consider all portions of the Arctic environment (atmosphere, ocean, land, ice, biosphere) and seek to understand the longer-term changes that have occurred and to anticipate the changes that may occur over the next several decades. It will attempt to link these Arctic changes to the global climate system and to consider the social and economic implications of Arctic change not only to Arctic resources and residents, but also to the more populated mid-latitude regions. The SEARCH program is based on the knowledge that, while the Arctic may seem distant to most people, it is connected to the rest of the world and that processes in the Arctic have far reaching and significant impacts.

Because the Arctic may be affected most strongly by climate change under the global warming scenarios of the IPCC, we must build the high quality data base needed to describe how the environment of the Arctic evolves over the next several decades. NOAA intends that its role in SEARCH focus on such sustained observations of the sea ice, atmosphere, and ocean, including its biota. As mentioned earlier, special strategies and technologies are needed for climate observations in the Arctic. NOAA intends to develop these as its participation in the SEARCH program evolves. Because we suspect that changes in the Arctic atmosphere will affect lower latitudes, we need to increase our effort to relate Arctic change to changes throughout the northern hemisphere. It is possible that changes in the Arctic can even influence the global ocean circulation and the distribution of heat and moisture from the tropics to the poles, and NOAA has to be concerned over this as well.

I have already discussed the current imperfect nature of climate modeling, yet the use of models is essential in evaluating our possible future. NOAA will work with its interagency partners to improve the reliability of climate models, and to develop regionally focused models that will allow us to see more clearly what might happen in the Arctic and elsewhere. While models allow us to think ahead, a well founded observational program is essential for observing climate change as it happens and so increase our ability to adapt to near-term changes and evaluate the performance and requirements of models of the more distant future. NOAA's focus on sustained observations, simultaneous analysis of the resulting data, and development of data-based climate services is a logical evolution of NOAA's historic missions and provides a solid core for other SEARCH and climate and global change objectives.

NOAA is particularly pleased to be working closely with the other agencies to build a complete picture of the Arctic environment. It will take a few years of planning and budgeting for NOAA to be able to do all that it should under SEARCH and other programs, but the process is well underway. In two years, NOAA will have important new information on Arctic Ocean circulation, atmospheric transport of heat and moisture, the role of sea ice and snow cover on the state of the Arctic Oscillation and other important modes of climate variability, and an analysis of the role of ocean variability in productivity of marine mammals and other species. Appended to this testimony are brief descriptions of each project funded in fiscal year 2001 under the Arctic Research Program, and the special funding for Steller Sea Lions and climate variability.

In conclusion, Mr. Chairman, let me state that NOAA is committed to providing the required observations, data analysis, data access and archiving, and modeling capability to minimize unacceptable risks related to an uncertain future climate. We have outlined a significant number of items that challenge our existing understanding and we will be placing special emphasis on them in the future. The risk of failure could prove enormously costly. We look forward to continuing to work with you on these issues, as they are of one of the great challenges of the 21st Century for this nation, as well as the residents of Alaska.

Chairman STEVENS. Thank you very much. Again, I'm going to put all of your full statements in the records. I do thank the fact that some of you have summarized portions of them. Our next witness is Dr. Charles Groat, the Director of the U.S. Geological Survey.

## DEPARTMENT OF THE INTERIOR

### U.S. GEOLOGICAL SURVEY

**STATEMENT OF CHARLES C. GROAT, DIRECTOR**

Dr. GROAT. Thank you, Senator Stevens. Being in this position at the close of a day after many people have testified I could do as a colleague of mine once did, she said "You've heard everything that needs to be said but you haven't heard it from me." And go through it again. I am going to take liberty that the position does accord of emphasizing a few key points that others have made today and that I would care to make on behalf of the USGS and the Department of the Interior because I think they're points that relate the science to the management of the resources that people in Alaska and the people across the country care about. To do that, I'll refer again to the report that Dr. Leinen referred to and that is the assessment report that was done in Alaska as was done in other parts of the country. The USGS was pleased to be a major sponsor of workshops that led to that report. Another statement that Dr. Leinen made is that as part of the Global Climate Change Research Program's goals is that as a scientific community, we have to be able to link the research we do to the information needs of resource managers. These workshops were intended to bring the State of the science and what we know about global change together with resource managers saying, "How can this information be useful to you?" And one of the things we learned from these workshops across the country was that there needs to be a degree of specificity that is meaningful to managers so that it can influence and affect their day to day decisions is important to them and that it needs to be communicated in a way that they can make use of it.

So a very important goal of the research program in general is the ability to project regional variations accurately. And as many of the scientists have affirmed here today, we aren't quite there yet but we are getting closer. I think many of the very impressive graphics that you saw represent real progress from where we were 5 years ago because our models are better, our understanding of the processes are better but we still have a ways to go to make our information specific enough to be useful for people on the ground who have to make decisions about the things they either regulate, manage or, in the private sector, do for profitable purposes. And as a part of the Department of the Interior, the USGS is particularly aware of the importance of that for Alaska because of the important role that the Department of the Interior plays in managing Alaska resources. The Bureau of Land Management, the Fish and Wildlife Service, National Park Service and Minerals Management Service all have major responsibilities to apply knowledge of the type we've talked about today to their management responsibilities in Alaska and they take that very seriously. But no more seriously than does the Alaska Fish and Game, the other State agencies in this State and in other States who have similar and in some cases closer responsibility to manage resources important to their States and region. So I don't think any of us in the scientific community want to play down one bit the importance of bringing our science to bear on regional problems by making our science relevant in scale and scope to those problems.

As does NOAA, we have a significant—the USGS does—number of people, 225 scientists and support staff, here in Alaska that are working as part of the Global Change Research Program and also as part of understanding the resources that are so important to this State, both living and non-living.

We're involved, as are the other agencies represented at this table, in the Global Climate Change Research Program and we bring to it a perspective, particularly in our geological side, that I think we can't fail to emphasize—we should not fail to emphasize. That is the time perspective of change. We've talked about decadal changes; we've talked about centuries; we even talked about thousands of years. But if we look into deep geological time, we remember that there were tens-of-thousands-of-year cycles that brought major ice sheets to the country, to the continent, to the globe, and that perspective has to be there as well. So as we look at cycles of different scopes and scales, we have to recognize that the natural world has as much to teach us about these changes as does the anthropogenic world about influencing those changes.

We're also involved in a significant way in the carbon cycle research, the water cycle work, and the impacts of change on ecosystems.

But I want to stress this afternoon, as we wrap up the testimony in this hearing, the point that has been made by several of the speakers today. That has to do with the importance of observations and monitoring. It's clear that if we are going to have better models that make scientific information and data meaningful to regional resource managers, we have to have the computing power that you questioned about and that others have mentioned, to make this effective. Our models will only be as good, in a sense, as the power we have to create them. They'll also only be as good as the data that we put into them. We have to have the observational data to make these models relate to the landscape. And to do that we have to have data gathered for long periods of time. We've been at it for 120 years and those long-term records are of extreme importance in putting together observational information about the landscape and its processes over these long periods of time. We have to have on the ground observations as back up and as substantiation for all of those data that the wonderful technology that's been described here today bring to us from space and from remotely-sensing technology of different kinds. The technology is truly amazing. We don't lack for technology. It's developing faster than we can utilize it. But we have to have the will and the resources to apply that technology, not only to Alaska but to the landscape and the seascape and the atmosphere if we're going to have the observations of the density and intensity that we need to drive these models and make them useful at the regional scale.

I'd like to provide a few examples of that. We've heard much about permafrost and the severe impacts melting it can have on the landscape, on carbon dioxide and on methane and the atmosphere. Clear. How do we know about permafrost changes? We know about it in part because of 21 deep bore holes that the USGS maintains in the National Petroleum Reserve in which we have observed permafrost temperature changes over the years.

We also know how this applies to what I think is one of the overwhelming lessons we have to learn from climate change in Alaska, the impact this change has on the infrastructure. This has been mentioned by many speakers. And in this State, where permafrost is such a serious element in the landscape, that change can be costly to the Native populations and to their subsistence economy.

It can also be critical to some of the great desires this State has to expand its economy. As we look to developing oil and gas resources on the North Slope, as we look to moving that gas south to the 48, we have to be worried about pipeline construction and, about production facilities construction. The state of the permafrost, the state of the landscape and processes such as landslides, as Dr. Colwell's slide showed, are extremely important for us as we design that infrastructure. A painful example of how important that is was brought about by the construction of the Trans-Alaska Pipeline. That pipeline would have cost about a billion dollars should it have been buried. But the work we did and the work other agencies did in understanding permafrost conditions resulted in a $7 billion bill simply because it had to be elevated. Short-term, high cost. Long-term, who knows how many billions of dollars it would have cost to repair a pipeline that wasn't properly designed based on the understanding of permafrost and other environmental conditions. So from an infrastructure point of view critical to the economy of this State, we cannot place too little emphasis on the importance of the monitoring of Permafrost.

We've talked about forests a little bit. Permafrost isn't a suitable host for forests but, as we see the thawing of the permafrost, commercial forests may expand three to four times. That's important to the economy of Alaska. So there are some up sides to the commercial interests that are realized as permafrost melts and as the climate changes: perhaps an expansion of the forest industry. The downside, of course, is that some of the diseases and insect pests increase as well.

Another monitoring subject of importance is glaciers. Now, we've talked about sea ice extensively and, clearly, perhaps the most critical ice element in the economy and the ecology of Alaska, but we have a lot of mountain glaciers in Alaska. In fact, there are tens of thousands of mountain glaciers in Alaska and, with exception of only a few that are close to the coast, since the Little Ice Age in the mid-1800's, they've all been receding over the past century and a half. And that information, like the canary in the mine, is further evidence that, on the landscape as well as on the sea, warming is having a significant effect. And we, along with several other agencies, 25 Nations, 50 institutions, are about to turn out an atlas that will demonstrate globally the shrinkage of glaciers and how this is an important indicator of climate change. Again, a monitoring effort, a measurement effort, that is very important.

The same thing can be said for land cover change. As we look at land cover and vegetation and its importance, we have to be able to monitor that from space, with ground truthing. Landscape processes that are important and that affect the infrastructure are extremely important.

So putting the emphasis where others have put it as well, information to make our science relevant, and monitoring to give us the long-term perspective and to feed models are extremely important.

And let me close with something even more fundamental that is relevant to Alaska, fundamental data needs which are not being met in Alaska right now and they're not being met by the USGS, to a large degree. And that is topographic mapping. It's hard to understand the landscape if we don't have maps at suitable scales, such as orthophoto quads and standard topographic maps at a scale of 1 to 4,000. Alaska is only partially covered whereas the lower 48 is totally covered. What we do have up here is mostly 40 years old. So there's a tremendous need, if we're concerned about change, documenting it, and relating it to the landscape, and if we're concerned about the infrastructure, to have maps that accurately portray the landscape.

As fundamental as topographic maps are geologic maps. If we're going to understand the landscape and change elements, we have to understand the rocks and soils that underpin it. Geologic mapping of critical areas underlain by permafrost and underlain by resources critical to the State of Alaska,—its minerals and its energy resources, have not been adequately mapped. They need further attention as further buttressing of our understanding of the landscape and the elements in it.

Water resources have been mentioned. Clearly quantity of water is extremely important. We have over 7,000 stream gauges across the country. Only 120 of those are in Alaska. And there are major river systems in Alaska that are ungauged. We need to understand the hydrologic relations as run-off changes, and as channel characteristics change. We can do much of this from space with the technology that NOAA and NASA bring us, but on-the-ground observations and measurements are essential to verifying and to documenting those changes. Water quality will change with time as processes change. We have to be able to monitor the changes in the composition of those streams.

The same is true of habitat change. The ecological systems that are critical to salmon and seal and waterfowl and the fisheries have to be monitored, using remote sensing data, using the kind of data that Scott Gudes described for the oceans. But we need on-the-ground as well as in-the-water sensors to understand these habitat changes.

In conclusion I would just emphasize clearly the importance of science in understanding global change in Alaska, the importance that scientist must place on making that science relevant to regional managers, which means the scale of our models, the scale of our observational data, must be usable, whether they're Federal landscape managers or whether they're State landscape managers or whether they're private sector trying to improve the economy of the State.

PREPARED STATEMENT

We've recently established an Alaska Science Center to bring our disciplines—our biologists, geologists, hydrologists and map people-together to do a more integrated job of portraying the landscape and living resources. And I think that this integrated effort that has been part and parcel of what my colleagues here at the table have described, is going to be what brings climate change understanding and the usefulness of it to managers really together to do what the program needs to do. And I think we're all committed to that, Mr. Chairman, and we welcome the opportunity to do.

[The statement follows:]

PREPARED STATEMENT OF CHARLES C. GROAT

INTRODUCTION

Mr. Chairman and Members of the Committee, thank you for this opportunity to present testimony on behalf of the U.S. Geological Survey (USGS) regarding scientific research being conducted on climate change in the Arctic region and how climate change is impacting that region, with special emphasis on Alaska.

Within the Arctic region, Alaska hosts some of the most important hydrologic, biologic, mineral and energy resources of the Nation and is subject to a wide variety of natural hazards, particularly earthquakes, volcanic eruptions, and landslides. Rich in pristine wilderness and natural resources, Alaska has some of the largest tracts of federally owned land in the country. Some of the "crown jewels" of the National Park Service and the National Wildlife Refuge System occur in Alaska. The Department of the Interior (DOI) is responsible for the management of more than

218 million acres of Alaska, an area larger than the entire State of Texas. More than 50 percent of the lands that Interior manages are in Alaska. More than 40 percent of the Nation's freshwater supply and more coastline than the rest of the States combined are found in Alaska. More than 3,100 miles of designated rivers in the Wild and Scenic River System are in Alaska. Of the national total, nearly 70 percent of designated Wilderness areas—more than 57 million acres, roughly the size of Oregon—are in Alaska. Areas classified as wetlands total 170 million acres, more than all other States combined.

As the principal science agency of the DOI, the USGS provides understanding of past and contemporary Alaskan environments and is positioning the region to better anticipate and prepare for what may happen in the future. The stewardship mission of the Department must be informed by an integrated scientific understanding of how climate changes may interact with other natural and human-induced environmental stresses. To advance that critical understanding, the USGS sponsored an assessment of the potential consequences of climate variability and change to Alaska with the University of Alaska, Fairbanks (UAF). The 1997 workshop, which received funding from DOI, was one of a series of regional workshops that the U.S. Global Change Research Program (USGCRP) sponsored as part of its national assessment of the potential consequences of climate change. The workshops brought together researchers, governmental agencies, industry, non-governmental agencies, and the public to assess the potential impacts of climate change on Alaska. The attached assessment report, "Preparing For A Changing Climate," addresses the following four questions:

—What are the current environmental stresses and issues that will form a backdrop for potential additional impacts of climate change?
—How might climate variability and change exacerbate or ameliorate existing problems?
—What are the priority research and information needs that can better inform decision making and the policy process?
—What coping options exist that can build resilience to current environmental stresses, and also possibly lessen the impacts of climate change?

This report is available online at http://www.besis.uaf.edu/regional-report/regional-report.html

IMPACTS OF CLIMATE CHANGE ON ALASKA

Current climate studies indicate that high-latitude regions of North America, especially Alaska and northwestern Canada, are presently experiencing some of the most dramatic warming in the world. Alaska has experienced the greatest warming of any State in the Nation over the past 50 years; this trend is consistent with model predictions that show increased temperatures at higher latitudes. USGS pioneered scientific studies of climate that showed some of the earliest evidence for warming in Alaska.

Alaska, like many other areas of the world, experienced a shift to warmer temperatures in the late 1970s. The following are some of the major climate-related trends in Alaska that scientists have observed:

—Air temperatures in Alaska have increased an average of 4° F since the 1950s, 7° F in the interior in winter, with much of the warming sparked by a large-scale arctic atmosphere and ocean regime shift in 1977.
—The 30-year air temperature record shows that increases are greatest in winter and spring and in the interior of Alaska and north of the Brooks Range.
—Recent reports suggest that summer sea ice has decreased about 3 percent per decade since the 1970s, multi-year sea ice has decreased by 14 percent since 1978, while sea ice has thinned at a rate of 4 inches per year from 1993–1997. These decreases in sea ice have affected subsistence hunting patterns and increased the danger of hunting on the ice.
—Boreholes reveal that permafrost temperatures in northern Alaska have increased 2–4° C (3.5–7° F) above temperatures 50–110 years ago; permafrost has thawed in some places to a point where it is discontinuous, resulting in increased road maintenance costs and ruining traditional ice cellars of some northern villages.
—Precipitation has increased about 30 percent for most of Alaska west of the 141 degrees West Longitude between 1968 and 1990; exceptions are the southeastern part of the State and summer precipitation in the interior, particularly around Fairbanks.
—Warmer conditions have allowed insects to thrive when cooler summers and colder winters would have normally destroyed or limited their extent; the spruce bark beetle has destroyed over 3 million acres of forest.

—The growing season in Alaska has lengthened by 13 days since 1950.

The 1997 UAF/DOI-sponsored Alaska workshop that was part of the "Preparing for a Changing Climate" assessment attracted people from within as well as outside of the State to discuss current and potential issues associated with the State's forests, tundra, coastal systems, permafrost, marine resources, wildlife, subsistence economy, and human systems (such as transportation, energy, and land use), under changing climate scenarios. With further warming in Alaska, a variety of consequences are possible. The location, volume, and species mix of fish catches could change, causing stress as the industry deals with relocation of harvesters and processors. While the permafrost is melting, the maintenance cost for pipelines could increase, but construction costs could be lower in areas where it has melted. The loss of sea ice could reduce costs for offshore oil and gas exploration and production and improve shipping, but coastal erosion could increase due to higher relative sea levels and increased storm intensity with concomitant impacts on coastal communities.

A longer growing season could improve agriculture and forestry yields, but warmer temperatures, increased summer drying, and disease-stressed trees could increase flammable vegetation, thus increasing the potential for forest fires.

Engineering must account for impacts of future thaw on existing infrastructure (highways, railroads, military and commercial airfields, buildings and the oil pipeline). For example, planning for future energy resources extraction and construction of the proposed natural gas pipeline will need to take into account the changing properties of soils that are experiencing permafrost thawing.

Fisheries may be at risk from climate change. For instance, sockeye salmon in this region support a long-established fishery, generating millions of dollars annually and providing thousands of jobs. They also play a critical role in Alaska's sensitive coastal ecosystems. Adult sockeye salmon returning to Bristol Bay's tributaries provide food for killer whales, grizzly bears, eagles, and other predators. Eggs deposited in the streams and rivers feed many other species of fish throughout the system. Even in death after spawning, tons of decaying salmon flesh contributes marine-derived nutrients used by both plants and animals along Alaska's rivers. Ongoing USGS studies are measuring historical patterns of sockeye growth in marine and freshwater environments and identifying linkages between growth rates and climatic conditions. These USGS studies, which will generate preliminary results in 2003, will provide a thorough analysis of the effects of climate change on sockeye salmon production in Bristol Bay during the freshwater and early marine life stages that are most likely to be sensitive to fluctuations in climate.

Preliminary research suggests climate change may be implicated in the annual greening of vegetation earlier in the year. Studies by USGS scientists indicate that during the 1990s the period of time when the active layer of permafrost begins to warm to when it refreezes again has increased by more than 30 days at several sites on the Alaskan North Slope. Studies of past geologic periods by USGS geologists show that forest replaces tundra during warm climatic intervals.

New studies by USGS researchers are showing that the coastal rain forest of the Tongass National Forest in southeastern Alaska has a complex and dynamic history. This forest, which did not exist in Alaska during the last ice age, is still expanding. Some of Alaska's National Parks may see a shift in the type of vegetation that dominates their landscapes as this forest continues to migrate northward. Policy and land management decisions by the National Park Service and the U.S. Forest Service depend on understanding the dynamic nature of this ecosystem.

USGS monitoring revealed that glaciers receded in the last decade of the 20th century at the highest rates of the 30-year monitoring record; recently de-glaciated terrains are rebounding, sometimes rising centimeters per year through both glacial rebound and tectonic forces; and ranges of plants and animals are changing and expanding northward. One of the major attractions for many of Alaska's National Parks (Denali, Wrangell-St. Elias, Glacier Bay, and Kenai Fjords) is the stunning array of glaciers that have shaped, and continue to shape, the rugged Alaskan mountain landscape. USGS researchers have used satellite imagery to make precise maps of these glaciers and to monitor their changes over time.

NATURAL RESOURCES AT RISK AND RESEARCH PRIORITIES FOR USGS

USGS is studying the effects of climate on Alaska's resources. These efforts are in close alignment with the USGCRP. The USGS acquires, manages, and makes available a treasure of remotely sensed data used by Alaskan, Federal, and State land management agencies for mapping, monitoring, and modeling vegetation, hydrology, and geologic processes; monitoring fires, volcanoes, and floods; and characterizing the landscape in support of the scientific and management communities. An example of the application of these data and tools is the Interagency Consortium

Program, which is designed to produce a consistent, comprehensive, and flexible land cover database for the State (the Multi-Resolution Land Characterization 2000 Program). The membership of this Federal consortium includes DOI bureaus (National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service, and USGS), Department of Agriculture (U.S. Forest Service), NOAA, NASA, and the U.S. Environmental Protection Agency. The consortium's objective is to provide repetitive coverage of satellite data that can be used to document and explain changes in land use and land cover. The Program is new to Alaska, and state-of-the-art land cover mapping and data analysis methodologies are being developed through research at the USGS Alaska Science Center.

The USGS is the developer and manager of the Internet-based Alaska Geographic Data Committee's (AGDC) Geospatial Data Clearinghouse. The AGDC's Clearinghouse serves as the Alaska Gateway to the data holdings of its members, over 40 Federal and State agencies, borough and municipal governments, Tribal Organizations, universities, and private companies within Alaska. The AGDC Gateway provides public access to everything from legal land status to detailed historical mining reports, USGS topographic maps, virtual visits to national parks, archives of remotely sensed data, and real-time stream-gage information. While its primary focus is on information that has a geographic context, the AGDC Clearinghouse also links to a broader range of environmental data through its Arctic Environmental Data Directory, which provides connections to the entire circumpolar Arctic international scientific community. Alaska agencies, native organizations, and the private sector are involved in analyzing and responding to critical issues that include hazard prevention, land conveyance, resource exploration and development, legal access and public safety, public use and resource assessment, and community and economic development.

Other ongoing USGS studies related to climate change in the Arctic include monitoring the Yukon River to document a 5-year baseline of water, sediment, and chemical loading delivered to the Bering Sea. Data will provide a baseline to compare changes that may occur in the Yukon over the next 20 to 50 years. This effort will focus on measuring the carbon and nitrogen in the river that are fundamental to the health of the ecosystem. USGS will also measure contaminants in air, water, sediment, and fish tissue that may affect people and wildlife.

USGS is measuring and modeling carbon cycling and nutrient storage as they relate to climate, permafrost, and fire. Partnerships with other scientific agencies allow USGS to contribute and interact with scientific experts of all disciplines on issues of carbon and nutrient cycling. USGS scientists play a key role in providing field-based data on soil, peat, wetlands, and water and gas chemistry. USGS also develops and applies mathematical modeling of the effects of climate on vegetation, soils, water, fire, and ecosystems. USGS monitors the permafrost temperatures in 21 deep boreholes in the National Petroleum Reserve, Alaska. Analysis of temperature profiles in the deep boreholes provided some of the first evidence that the Alaskan Arctic warmed 2–4° C (3.5–7° F) during the 20th century. Analysis of all the boreholes is being conducted under the Global Terrestrial Network—Permafrost in collaboration with other agencies and other countries.

USGS is providing information and research findings to resource managers, policymakers, and the public to support sound management of biological resources and ecosystems in Alaska. This includes studies of the role of Arctic and subarctic environments in maintaining wild stocks of nationally important marine and anadromous fish species and nationally important migratory bird populations; the ecology of marine mammals and their role and effect as top-end consumers in Arctic and subarctic marine environments; the role of Arctic and sub-arctic environments in maintaining the ecology of terrestrial mammals, and the role of top herbivores and carnivores in the dynamics of Arctic and subarctic terrestrial systems.

USGS is providing records of past climates and vegetation groups that existed in Alaska, which are key to understanding the likely consequences of future climate changes in high-latitude ecosystems. Current USGS work on the fossil record and climate history of Alaska suggests that future periods of cooler, drier climate would result in shrinkage of forest boundaries, lowering of the altitude-limited tree line, and expansion of tundra vegetation into lower elevations. A future change to warmer, moister climates would result in expansion of Alaska's forests into areas now occupied by tundra. Measuring and modeling climate-land interactions will provide a basis for resource planning for Alaska lands.

Plant fossils, such as leaves, wood, cones, pollen, and seeds, provide important evidence of how Alaska's vegetation has responded to climate changes over time periods of centuries to millions of years. USGS studies of the Alaskan fossil record of plants include data from many natural exposures and sediment cores. These data provide the basis for reconstructing the record of past vegetation changes over millions of years of Earth history. The fossil record shows that dramatic changes in high-latitude vegetation have occurred many times in the past, primarily in response to global climate changes.

USGS monitoring of volcanoes is providing information on the processes that trigger eruptions, generate volcanic ash clouds and result in volcanic emissions. The latter can impact climate (for example, the sulfur-rich 1991 eruption of Pinatubo volcano in the Phillipines caused temporary global cooling.) Studies of eruption dynamics, down-slope transport of lava and volcanic debris, and the history of past eruptions contribute to an understanding that goes beyond the question of "when" to also address the question of "what to expect" when a sleeping volcano wakes up. The issue of volcanic ash and aviation safety is another aspect of USGS volcano monitoring. The world's busiest air traffic corridors pass over hundreds of volcanoes capable of sudden, explosive eruptions. Airborne ash can diminish visibility, damage flight control systems, and cause jet engines to fail. The Alaska Volcano Observatory, a cooperative effort of USGS, UAF, and Alaska Division of Geologic and Geophysical Surveys, plays a major role in the effort to reduce the risk posed to aircraft by volcanic eruptions.

The USGS has provided critical information for Alaska's development decisions, through our scientific studies of permafrost, gas and oil resources, mineral resources, fish and wildlife populations and their habitats, and the impacts of petroleum exploration, development, pollution, and climate change on terrestrial and marine mammals, migratory birds, anadromous fishes, and marine invertebrates. USGS leadership in technical review and advice during the planning and permitting of the Trans-Alaska pipeline is an example. This role included a significant contribution toward designing the pipeline to withstand disturbance associated with permafrost.

In the past, Bristol Bay, Alaska, has produced more wild-caught sockeye salmon (*Oncorhynchus nerka*) than any other region in the world, with record runs exceeding 50 million fish annually. Recently, however, adult sockeye runs in Bristol Bay have declined 78 percent, even though counts of both juvenile fish leaving the rivers for the ocean and adults returning to the rivers to spawn have indicated strong sockeye salmon production in the freshwater tributaries to the Bay.

Recent developments have demonstrated that western Alaska salmon stocks are also in serious trouble. The returns of summer-run chum (*Oncorhynchus keta*) and chinook (*O. tshawytscha*) salmon over much of western Alaska during 2000 were the worst ever recorded. The weak returns of chinook (a 75 percent decrease) and chum (62 percent decrease) salmon into the Yukon and Kuskokwim Rivers have prompted regulatory actions by both the State and Federal fisheries managers that have resulted in the closure of subsistence harvests, and restrictions on commercial and sport fishing. The Yukon River pink salmon, which are not harvested, had a 90 percent decline in 2000. The USGS is conducting research addressing critical information gaps concerning the spawning ecology of Yukon River salmon. These studies will allow for long-term comparisons of salmon production in relation to significant shifts in the physical environments of the North Pacific leading to accelerated declines in species assemblages, including a marked decline in salmon runs returning to Alaska.

Polar bears live in the ice-covered portions of the Bering, Chukchi and Beaufort Seas adjacent to Alaska. Their dependence upon drifting ice makes polar bears an important indicator of global warming and its effects in the Arctic. Ongoing USGS research is investigating interactions between bears, their principal prey, ringed seals, and the changing sea ice that supports both of them.

USGS coordinates Arctic research with the Arctic Research Council and the Interagency Arctic Research Policy Committee (IARPC). Through this coordination, we ensure that USGS research complements, rather than duplicates, research of other agencies. IARPC, through an interagency working group, is coordinating a multiagency research program, "Study of Environmental Arctic Change" (SEARCH). Planning for SEARCH involves the Departments of the Interior, Agriculture, Defense, and Energy and the National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, and National Science Foundation.

Geologic maps are used by land, water, and natural resource managers at all levels of the government and by the private sector to achieve the most efficient use of Earth resources in a way that is sustainable and economically viable. Economic growth is driven largely by access to the Earth's resources. Geologic maps provide the spatial framework to locate these resources. Unlike topographic maps, which show the elevation of the Earth's surface, geologic maps display the array of soils, sediments, and rocks that are present at and below the Earth's surface. These maps are essential for a complete characterization of materials mobility in ecosystems.

Detailed geologic maps are useful for mineral and petroleum exploration, for hazard assessment, and/or for land and natural resource planning.

USGS is well positioned to contribute to meeting the challenges facing Alaska. USGS' long-term study of the biological, geological, hydrologic, and energy and mineral resource systems of Alaska have addressed not only the location and utility of the resources but also their origin, sensitivity to climate and disturbance, and the fate of these resources in the future.

Mr. Chairman, this concludes my testimony. Thank you for the invitation to present testimony on this important topic. I would be happy to respond to any questions Members of the Committee may have.

Chairman STEVENS. Thank you very much, Dr. Groat. I'm delighted to see you're here. I have decried the decline of your agency in Alaska and I hope that this issue will bring more of your people back here because I do think we need some monitoring on land that you are talking about.

I go back to the statement that Mr. Goldin made about getting together to try and see if we can get better coordination. Do you believe that coordination of the interagency efforts, the total effort, with regard to global climate change and its impact to the Arctic could be improved? Any of you disagree with that?

And Mr. Goldin has suggested that, Dr. Colwell, your agency take the lead in that effort. Are you prepared to do that?

Dr. COLWELL. As Chairman of the IARPC and with the SEARCH project, I am certainly ready to proceed.

Chairman STEVENS. And is there any disagreement about the concept of trying to validate the current predictions of the models we heard described this morning? Do you think you have that capability today?

Dr. COLWELL. With the data gathering that we need, I believe the most important action to take is to determine the gaps and to begin to fill them in. And I think what we all heard is that something is happening and we better find out whether it's cyclical or long-term.

Chairman STEVENS. This afternoon I was asked about the threat to our villages. It's my judgment that this is a perception of increasing rather than a current calamity of any kind. Any of you disagree with that?

It's the kind of thing that we need better information in order to deal with the future rather than at the present time facing any real traumatic conditions that we have to correct, with the exception of a couple of villages that have some real problems with regard to inundation of their airports. That's the current state of climate as far as I'm concerned. Any of you have any opinions contrary? Is there more immediacy there than I currently feel?

Dr. COLWELL. Well, I think the most difficult predictions have been for the Pacific Islands and for countries like Bangladesh where genuine calamities could occur if the predictions prove to be correct. I don't believe that kind of calamity will happen very soon, but I'll leave to my colleagues to comment.

Mr. GOLDIN. I think it's important that all citizens of our country become more aware of this interaction between the ocean, the land, the atmosphere, ice and life. It's something that needs to be part of their lives. I pointed out two examples of Mars and Venus.

Chairman STEVENS. Yeah.

Mr. GOLDIN. Earth is a very unique system and it has this thermostat. It is incredible how wonderful this thermostat works. It takes small perturbations. I think we all need to be aware of it. We all need to focus on it and there ought to be more discussion on it so we don't take things for granted. There are a lot of effects that take time and, to go fix them, could take even more time and you could get more negative effects. And education and focus I think is the real key issue here, not panic.

Dr. COLWELL. Taking a medical perspective one might say that we're dealing with what might be termed a "chronic" effect and often this can be worse than a fulminating or a dramatic effect because you don't see it, it creeps up on you, and then you have to deal with it in a way that makes it much more difficult.

Chairman STEVENS. Don't misunderstand. Change is there and it's worrisome but I think that we have time to try and prepare if we can get additional information. Mr. Gudes.

Mr. GUDES. I was just going to say, Mr. Chairman, that we work with communities around the country, communities in Florida, for example, that are at threat from hurricanes all the time and we work with vaporometric models, we work with evacuation plans, we work with trying to help these communities prepare for severe weather, severe storms. And I think that that's a good thing to do in the Arctic as well, especially as ice recedes and, given the amount of winds and weather that could be coming in, it makes a lot of sense to do that.

Chairman STEVENS. Thank you. Did you have something to say, Dr. Leinen?

Dr. LEINEN. Yes. I'd add one perspective and that is that, as you heard from the scientists this morning, if we assume that things will continue to change at the same pace that they're changing now, yes, we have time to prepare and we can understand how to project into the future. But one of the things that the scientists, especially the geologists, have shown us, is that there have been times in the past when climate changed over a scale of decades and changed to different climate States. That is one of the areas that the scientific community is really focused on for the future, trying to understand whether the change will be linear or whether there are thresholds that would precipitously change climate. I think that's one of the aspects that really motivates the scientific community to say that this is—that looking at the impacts and looking at the processes is something that's very, very important for us to do. That possibility of abrupt change.

Chairman STEVENS. Yes.

Mr. GOLDIN. Mr. Chairman, I think the observational issues will be resolved, both on the ground, under the ocean and from space. But there's one issue that gives me a very great level of concern that I think we need to move at more aggressively to get at the problem that was just brought up. Is it a linear change or is it going to accelerate and have feedback effects? And that is, I do not believe we have the computational capability to do what we need to do. And by computational capability I don't just mean the speed of a transistor or the speed of a computer. It is the integration of the analytical models, the climate models, the computational engine and the software that powers it. If we take a look at where we are today, we are probably somewhere on the order of ten thousand to a million times too slow if we use conventional computational mechanisms. And there is very little research that's going on beyond extrapolating out what we can get out of silicone. But we are reaching the financial and, in certain respects, the physical limitations of what we can do with silicone and the models that go with it using hard deterministic computing. If we take a look at feature size, we will get a little bit more out of it but you begin to get to the physical limits of what you could do with feature size. But more than that, fabrication technology is going to cost more and more. In the 1970's we could build chip factories to build feature sizes on the order of microns for tens of millions of dollars. To get a factor of ten improvement to go to tenths of microns where we are today chip factories now cost billions of dollars. So if we keep saying we're going to extend through Moore's Law, which says every year and a half you get a doubling of speed, without facing up to some of these physical and financial constraints, we have problems.

Another issue that has yet to be faced. We're talking about speeds, not a trillion operations per second, but something on the order of a thousand trillion operations per second or, if you will, a petaflop may be higher than that. But when you take a look at computer speeds like that, you're now talking about the time it takes a signal to travel at the speed of light which is three-tenths of a micron, so communications within the computers are going to approach some physical limits. Yet the conventional money is going in, in a very large degree, into this type of computing and we're not addressing the broader revolutionary computing that we're going to need. This, by the way, is not just important for global change which we need, but this is also essential to the continued productivity of our economy and to everything we do in this Nation. So I contend that there is a hole, a vacuum, and not enough focus, and we need to bring together the industry; we need to bring together academia and the various government experts on this subject. If we go and have the government sponsor custom machines, it becomes obsolete very fast and, if we look overseas and we have envy about these vector machines that are being developed overseas and say we have to buy them, that won't solve the problem. I submit this is an issue that, if we want to accelerate the pace of our understanding that my colleague just talked about, we have to address this issue. I am very concerned about it and somehow we haven't broken out. And that's one of the words of caution I say in response in thinking about the question you just asked.

Chairman STEVENS. Do you agree, Dr. Colwell?

Dr. COLWELL. Yes. I feel very strongly that Mr. Goldin has highlighted a very, very important area in which we must continue to invest in this country. And that is information technology research, because it drives the capacity to answer these huge questions that are so very important. And what I would add is that it's the ability to bring the data bases that the different agencies are gathering into a compatible, mergeable, analyzable set of data that allows us to determine the accuracy, precision and the value of the models and their ability to predict. There's no question that information technology drives this research. It underpins all of this.

And I would take it even further. I would say that we need to invest in mathematics research because the kind of research that's done in fundamental mathematics leads to advances in the information technology. So, yes, I agree.

Chairman STEVENS. Who should do that, Dr. Colwell?

Dr. COLWELL. This is research that we have as an interagency effort, the Information Technology Research Program. The NSF is the lead agency. We have been working together and I think what Dan is saying more—faster and more of it.

Chairman STEVENS. Being still Chairman of the Committee for another week, I'm constrained to say, "Is the money in the budget to do that?"

Dr. COLWELL. Mr. Chairman, I would say that this is an area in which we really have to invest and I think it's one that you should look at very carefully. I would agree.

Chairman STEVENS. Dr. Groat.

Dr. GROAT. Just to bring what they've both said very accurately and appropriately back to Alaska and your question about imminent danger or a progressive change and Dr. Leinen's linear versus nonlinear, we're sitting right in the laboratory where we will see that happen if it's going to happen, in a way other than a linear fashion. And some of the critical thresholds that may be reached to make it be different from that are probably going to be in the Arctic so the kinds of observational data meshed with the kinds of computational capability that Dr. Goldin and Colwell have described all come together with an Alaska example to increase our understanding of processes that are occurring. This as well as the need for the observational data and the computing power to make that meaningful and useful here to the people who have to make the decisions about Alaska and its resources.

Chairman STEVENS. Should the Defense Department be part of this operation, Dr. Colwell?

Dr. COLWELL. The Office of Naval Research and the NSF collaborate very effectively and also DARPA, the Advanced Projects Agency, is part of the IT effort. We all work together and the answer is, yes, it should be part of the effort.

Chairman STEVENS. Well, I do hope that you'll call a meeting when we get back to Washington and see if we can't compare notes. I would ask each one of you to review your budget and to tell us before we get into the intensive review of it, if there is a sufficient amount of money for you to collaborate and work together to solve the basic problems, not only of dealing with the increased monitoring here in the Alaska area but also in terms of this computer problem that seems to be pervasive as far as the whole government is concerned. I've also heard that from Defense, I'm sure you realize, and we have some basic problems about the position of our Nation relative to other Nations of the world in terms of the speed with which we are apparently able to tackle that problem of the next generation of computer systems. But I'm sure that there's many others that want to work with you on this and I'll be glad to get together a group of Senators that will plan to meet with you to try and work on that.

But I think we should have your review of the budgets for your agencies to make certain that you can go forward with what I believe is necessary, which is a process now of increasing the observation and analysis of the statistics that are available with regard to the Arctic, with particular reference, obviously, to our State, but to the Arctic region in general and to try and get some process of periodic validation of the predictions that we've been given by the scientists based on the models that have been used so far. I don't think any of them are going to feel offended if we try to say we want to increase the validity of those by periodically validating the predictions that are contained in the models.

But I do appreciate your coming and I appreciate those of you from the panel this morning.

Scott, do you have another comment?

Mr. GUDES. Yeah. I just wanted to clarify one thing in my statement. I've been trying to find a place to say that. I can't believe I did this on NASA TV but, when I was talking about NPOESS, I didn't mention—I should have—that NASA's a major participant in NPOESS and that one of the reasons why we're very positive about being able to get that satellite and be able to keep continuity is because NASA's come forward and they're a full participant in what's called NPOESS Preparatory Program in actually flying those instruments. So it actually is a great example of interagency cooperation, Department of Defense, NASA, Department of Commerce, NOAA. And I apologize for not mentioning that earlier in my statement.

Chairman STEVENS. Thank you very much. Again, I'm grateful to all of you for coming. Many of you have come long distances and had to change your schedules in order to accommodate the timing of this hearing. I do want to thank KUAC Radio and—all of us were provided the equipment, both audio and video equipment, for the hearing here today—and the University of Alaska for allowing us to occupy your space and for your support. And I thank all of you that have participated in the preparation of these visuals so that they can be more understandable to those who might review this record, be it on the video or on what we will print. We will print all of the information that you've provided to us in statement form. I don't think we'll reprint the bulletins you've already put out but I would like to make sure we have copies of those bulletins as you referred to so I can show them to my colleagues and their staffs when we return and show them the record that we will assimilate for today. I'm grateful to those who have participated in the staffing of this, also. You've had a considerable number of staffs accompany each one of you and I want to thank them and my own staff, Jon Kamarck and Cheh Kim for backing me up in terms of this hearing. But let me just make this statement. I had a lot of calls from some of my constituents saying, "What are you doing?" As a matter of fact you heard the question to me about, "Are you now endorsing the whole concept of global warming?" I've got to tell you that I told them I don't endorse or denounce the concept of global warming. I'm still in the process of trying to understand what's going on. But as I travel around my State, I find people such as Caleb who come to me and tell me what is happening and, in many instances, happening in a way that they feel was not predicted. And they think it is our duty in government to be aware of change and to predict what that change is going to mean to them in their daily lives and in their children's lives in the future as far as their own lifestyle. That's particularly true in the area of our villages. But even here, in terms of the process of planning ahead for our industrial base here, we've heard now, our forests—they're going to move further northward and westward and it's possible that they're—I assume from what I've heard—that their growing cycle may be faster. It may be accelerated in terms of their growth as this climate change takes place. That offers a positive side to this as far as we are concerned in terms of future utilization of some of the forest areas such as these up here right now. They're not that stable because of the permafrost that's under them and they don't have the kind of roots and don't grow to the height that trees do in southeastern Alaska. There's many changes that may come here that I think we ought to know more about, the capability to predict those changes and to understand what the changes will mean for future generations who live in this part of our country.

But it is a very serious matter as far as I'm concerned and I think more—I sort of got on to this a little bit with one of the bulletins one of you sent me. I don't know. That's what sparked this whole thing, the whole idea to get together and come up here and listen to Dr. Akasofu and his scientists who are working here and making these predictions and, then, try to understand what you all are doing in the areas that they are concerned with. But I'm very sincere to tell you that I think many of us want to understand this more. And it's not just a question of global warming. It is to us a concept to understanding the climate change that is taking place, not only now, but what might happen in the future and determining if there is an area where we who are charged with trying to set our legislative policies for the country should take action now in matters we have not in the past. So I thank you for your presence and for your interest and what you've contributed to our understanding of these issues today. And I thank all of you who have come to be part of the audience to listen. I'm further entranced by the subject as a result of listening to you all day so I hope we have more meetings. Dan?

Mr. GOLDIN. Mr. Chairman, I'd like to add another point. And it occurred to me as you were talking. In the lower 48 most Americans live in urban areas and cities and they are isolated from their environment. You know, people don't know that fall is coming because leaves fall off the trees; they know it's the start of the football season. And spring is the start of the baseball season. They don't see life coming into being and they're isolated in many circumstances from death because, when you're out in the wilderness, you see it in the animals. You see it in the life. Alaska has a huge change in climate compared to the lower 48. As I said, it's a harbinger of what might occur in the future. If I remember the numbers correct the average increase in global temperature is about a degree F and, in Alaska, you're experiencing 4 to 7 or 8 degrees F. The other issue in Alaska is—you could see it right away because Alaska's very close to the melting point of ice—and seeing the phase change is very, very apparent in permafrost, in the forests moving, in the sea ice melting.

And I just want to thank you again for focusing on this issue and, hopefully, Americans will get a sense about this. And, in the end, we're a democracy and it takes the knowledge of the people and making the people in the lower 48 sensitive to the changes taking place here I think is a very powerful message so that they can understand and, as a Nation, we could take proper action.

Chairman STEVENS. Whatever degree we don't understand many of these things now—we're still searching for answers—I think the one thing that comes through to me, as we discussed before, is that the Arctic is going to be more affected by this change in the near-term, and maybe even in the far-term, than any other part of our society. And, if that is so, then I think we ought to intensify the gathering of knowledge and validation of predictions in this area because, if we do, perhaps then we can understand even greater what's going to be coming as far as the part of our country that's south of us. Maybe that's wrong but I think we have to initiate some programs that intensify the search for statistics, for knowledge, in the region that we expect to have the most impact in the near future.

If you disagree, let me know, but that's my current feeling.

And I thank you all for coming. Appreciate you being here. Thank you very much for your assistance. And we'll check with you about the way we put your statements in the record, and the scientists the same way. Thank you very much.

[CLERK'S NOTE.—The following written testimony was submitted to the subcommittee for inclusion in the record.]

PREPARED STATEMENT OF DR. ELIZABETH C. WEATHERHEAD, UNIVERSITY OF COLORADO AT BOULDER

ULTRAVIOLET RADIATION IN THE ARCTIC

Ultraviolet (UV) radiation levels in the Arctic are generally considered by those who don't live in the Arctic to be quite low. The argument is simple: Very low sun angles, combined with traditionally high ozone levels mean that the UV in the Arctic should be low. In fact, we have measurements that support this view. Figure 1 shows noontime UV levels from four U.S. sites as measured by the Environmental Protection Agency's UV monitoring network. The data show strong seasonal cycles with UV in the Arctic never getting as high as UV in, for instance, Gaithersburg, MD. However, this understanding of low UV levels in the Arctic disagrees with the experiences of those who live in the Arctic. Figure 2 shows goggles which have been used for millennia by Arctic peoples to protect against snowblindness—a common Arctic eye problem that is due completely to ultraviolet radiation. The Arctic, in fact, is the only place on Earth where native inhabitants have had to develop ocular protection from ultraviolet radiation, again indicating that UV levels in the Arctic are not necessarily low. There are two important reasons for the disjoint between the idea that UV levels in the Arctic are low and the fact that UV effects in the Arctic are readily observable. First, daylight can be as long as 24 four hours in the Arctic, resulting in daily doses of UV to be much larger in the Arctic during times of the year when biologically production is high and humans are most likely to be outdoors. Figure 3 shows daytime integrated UV levels from the same four U.S. sites as measured by the EPA's UV monitoring network. Once the long days are taken into account, it is clear that the UV levels in the Arctic can easily be of the same order of magnitude as UV levels found elsewhere in this country. The second factor which needs to be taken into account when considering the effects of UV radiation in the Arctic is that while these measurements represent UV reaching a flat horizontal surface, this amount does not represent the exposure to our eyes, exposed skin, shrubs and most biological receptors. If instead we consider UV to, for instance, a vertical surface, the often snow-covered areas found in the Arctic magnify several times the amount of UV radiation our eyes or skin would receive. When we take into account these two factors: Long days and highly reflective snow surfaces increasing UV to many biological receptors, we come to understand why UV radiation has been a natural stressor to the ecosystems and people of the Arctic.

## OZONE IN THE ARCTIC

In the past few decades ozone levels have changed throughout much of the world. While many are familiar with the depletion that has taken place over Antarctica, fewer are aware that ozone depletion has been severe over the Arctic and sub-Arctic. In fact, ozone depletion in the Arctic is second only to the depletion observed in the Antarctic. These losses are supported by both scientific measurements and observations of those who live in the Arctic. Figures 4 and 5, from the National Aeronautics and Space Administration, show how ozone levels between 60 and 90 degrees N have changed over the past 30 years. We can see that there has been a considerable loss of ozone in the past decade, with large year-to-year variability. A number of scientific activities have been devoted to understanding ozone loss in the Arctic and the causes are understood to be fundamentally the same processes that deplete ozone in Antarctica and the rest of the world. However, because Arctic meteorology, especially the temperature and movements of air, is considerably different than in Antarctica, the ozone loss in the Arctic exhibits fundamentally different characteristics from the Antarctic ozone loss. To begin with, Arctic losses are less predictable from year to year than in the Antarctic. Ozone loss in the Arctic may also be strongly affected by anthropogenic climate change, which can cool temperatures in the vicinity of the ozone layer and increase ozone loss. State-of-the-art modeling efforts indicate further ozone depletion in the coming two decades for the Arctic; however these predictions are highly uncertain at this time.

## UV LEVELS IN THE ARCTIC

UV levels have been measured in the Arctic for only the past 10 to 15 years. These measurements have been extremely useful for showing how ozone, as well as a variety of other factors, including clouds, sea ice and snow cover, can affect ultraviolet radiation. The multiple factors that influence UV imply that the relationship between ozone and UV is not, in practice, a direct relationship. In addition, measurements show that considerable amounts of UV penetrate through water, ice and snow. Quality and extent of sea ice, clouds and surface reflectivity have a large impact. Changes that may result from anthropogenic climate change, including changes to sea ice, snow cover and clouds, will have a direct influence on UV levels received in the Arctic. Thus, already highly uncertain predictions for Arctic ozone are compounded by the uncertainty in what we expect due to changes in clouds, sea ice and snow cover, making predictions for future UV levels extremely uncertain.

Changes in ozone levels in the Arctic have resulted in higher UV levels on clear sky days. Not only have measurements confirmed the changes in UV levels in the Arctic, but reports from native peoples have been documented, at least for the Inuit in the Eastern Canadian Arctic. These people report that in the last 5 years or so, they have been experiencing sunburns, something that had previously been very rare. Older hunters who have spent long periods of time out on the sea ice in 24-hour sunshine rarely had their skin burn in previous years. From interviews and conversations, it is evident that the sunburns are mostly a new experience, or that the burns are now more severe than the Inuit had known previously. This native knowledge provides evidence of increased UV impacts in the Arctic under a depleting ozone layer and ties our relatively recent measurements of UV into an oral historical record that spans at least several generations.

## UV EFFECTS—OVERVIEW

UV is known to affect most biological systems. Studies confirm that UV can affect human skin, eyes and immune systems. UV has a direct effect on a variety of species including the eyes of virtually all animals, fish—particularly in the egg and larval stages—and both plant growth and quality. These effects, while identified for a number of species, have not been well studied. Many species have not been examined for the impacts of UV. Ecosystem effects can be much more complicated, and less intuitive, than what we can learn from studies of individual species in controlled laboratory settings. UV can also have secondary impacts, for instance by making species more sensitive to other stressors, particularly pollutants.

## UV EFFECTS—HUMANS

UV exposure has well known effects on humans, including sunburn, snowblindness and immune suppression. UV radiation is also related to long-term health problems such as cataracts, skin cancer and other skin-related diseases. These health issues can cost taxpayers billions of dollars each year through Medicare and other programs.

### UV EFFECTS—SPECIES

Research studies have shown that phytoplankton and other organisms, including those at the base of the food web, can be particularly susceptible to UV. Changes in the populations of these species could have wide impacts upward through marine ecosystems. Many fish species, including cod, herring, pollock, and salmonids, are also UV-sensitive, resulting in the death of many of the larvae before they are able to reach maturity. These losses impact not only the diversity of the marine ecosystem, but could also be very detrimental to the fishing industry, particularly in light of the crises that have occurred in salmon fisheries in recent years.

Terrestrial plants and animals are also directly affected by ultraviolet radiation. Leaf thickness, shoot growth and chemical compositions of plants are all affected by changes in UV radiation. Long-lived animals, including dogs, can develop cataracts under the same mechanisms as humans do.

### UV EFFECTS—ECOSYSTEMS

UV does not affect all species equally. However, the effects of UV on one species can have immediate effects on a number of other species. The complex interactions and feedbacks within any natural system make extrapolation of laboratory studies on individual species difficult. At times the results can be counter-intuitive. For instance, while UV kills off algae in a laboratory setting, UV causes the same algae to flourish in a natural setting, because it has an even more harmful effect on the larvae which eat the algae in a natural setting. The effects of increased UV across species affects terrestrial as well as aquatic systems. There is recent evidence that increases in UV radiation increases a plant's likelihood to produce lignins and a number of ill-tasting chemicals. This in turn makes the plants less likely to be digested or even eaten by the animals which feed on them. Therefore, while the direct effects of UV may be minimal on grazing animals, the indirect effects from changes in the quality, not quantity, of their food supply may be significant.

### UV EFFECTS—COMBINED EFFECTS

Environmental stressors, including pollutants, climate change and water availability can further tax a plant or animal's survival by combining nonlinearly with UV radiation. These combined effects can threaten organisms and ecosystems, and may be much more severe than the individual impacts. For instance, recent research has explored the role of UV radiation in enhancing the toxicity of certain chemical compounds. The combination of UV light and chemical molecules, particularly those associated with oil spills or petroleum contamination, can yield an effect known as photoenhanced toxicity. This effect has been shown to seriously injure or kill species that would typically be less harmed in the presence of the chemicals alone. Pollutants and other stressors are expected to remain significant, or as is the case for climate change, to increase in the Arctic in the coming years.

### SUMMARY

UV has long been a natural stress in the Arctic. Arctic ozone levels have decreased significantly in the last 10 years with large year-to-year variability that is difficult to predict. Future ozone and UV levels are highly uncertain and difficult to predict. Both human and ecosystem health effects can be costly, not only for the individual or species, but also in terms of economic costs to Medicare and to fisheries and other industries. Medicare, for instance, pays billions of dollars every year for cataract surgery, which is the number one therapeutic procedure performed on adults over age 65. The Alaskan Arctic is currently home to approximately half a million people. Much can still be learned about the effects of UV on these people and on the plants, mammals, and fish they harvest for food. Outstanding questions still remain, and the threat of increasing UV to the peoples and ecosystems of the Arctic is a significant concern.

A number of international organizations, including the International Arctic Science Committee (IASC), the Arctic Monitoring and Assessment Program (AMAP) and Conservation of Arctic Flora and Fauna (CAFF) have cited the uncertainties with respect to future UV levels and their effects as being a crucial area requiring immediate investigation. The U.S. agencies are poised to address these uncertainties in a coordinate manner through the Interagency Arctic Research Policy Committee's Study of Environmental Arctic Change (SEARCH).

## CONCLUSION OF HEARING

Chairman STEVENS. Thank all of you very much for your participation. The committee stands recessed.

[Whereupon, at 4 p.m., Tuesday, May 29, the hearing was concluded, and the committee was recessed, to reconvene subject to the call of the Chair.]

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