

Global Climate Change
Tuesday, November 16 2004 - 9:30 AM - SR 253

The Testimony of
The Honorable John McCain
Chairman, U.S. Senator (R-AZ)

- Much attention has been devoted to the recently released Arctic Climate Impact Assessment by the Arctic Council and the International Arctic Sciences Committee. This assessment adds to a substantial and growing body of evidence that clearly demonstrates that climate change is real and has far-reaching implications for society. I congratulate and thank those who have spent the past four years working on this effort.

- The preface of the report states that it is essential that decisionmakers have the latest and best information available regarding ongoing climatic changes in the Arctic. I strongly agree with that statement. It is in this spirit we meet today to continue the series of climate change hearings held by this Committee. I hope they will continue after my chairmanship is over. • The Administration's recently released report entitled, *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005*, which was described by Dr. James Mahoney, Director of the U.S. Climate Change Science Program, as "the best possible scientific information" on climate change, states that "Comparisons of index trends in observations and model simulations shows that North American temperature changes from 1950 to 1999 were unlikely to be due only to natural climate variations. Observed trends over this period are consistent with simulations that include anthropogenic forcing from increasing atmospheric greenhouse gases and sulfate aerosols."

- This report is consistent with the National Academy of Sciences' (NAS) 2001 report that states, "Greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise...."

- And now, the Arctic Climate Impact Assessment clearly demonstrates how the Arctic region is acting as the "canary in the coal mine." This assessment is consistent with these and other earlier scientific reports which project that the Arctic would experience the dramatic effects of climate change before other parts of the world. • Let me also note that one of the more interesting aspects of the Assessment is how it has integrated the best scientific knowledge with the traditional knowledge of the indigenous people of the Arctic. It demonstrates a tremendous amount of respect for those who have lived off the land for many generations and, therefore, understand the environment in ways that the rest of us do not. I think this approach can and should be used as a model for future assessments. • According to the report, the term Arctic comes from the ancient Greek word for "country of the Great Bear." It has been said that we will have to rename Glacier National Park since all the glaciers are melting. Will we have to do the same for the Arctic, if the Polar bear becomes extinct as the assessment has projected by the end of the century? • Today's first panel will discuss the Assessment in more detail. The policy

recommendations stemming from this assessment will not be available until next week. • We will also have a second panel today which will discuss some of the governments efforts to understand more about the environment of the other polar region, Antarctica.

- The polar regions play a key role in our understanding of the Earth's climate, environments, and ecosystems, and are critical links in the global climate system. Last month, I introduced a Resolution to celebrate the anniversaries of the International Polar Years and the International Geophysical Year, which passed the Senate. The next International Polar Year to occur in 2007 - 2008 is envisioned to be a coordinated campaign of observations, research, and analysis at the North and South Poles. These activities will provide valuable information regarding the impact of polar environmental changes on the conditions of environment changes across the globe.

- I welcome our witnesses here today and look forward to their testimony.

The Testimony of

Dr. Robert Corell

Chairman, Arctic Climate Impact Assessment, and Senior Fellow, American Meteorological Society

Mr. Chairman, Members of the Committee, thank you for the opportunity to participate in today's Full Committee hearing on the release of the Arctic Climate Impact Assessment's report entitled, "Impacts of a Warming Arctic". I am Dr. Robert W. Corell, Chair of the Arctic Climate Impact Assessment (ACIA) and I am honored to testify before you today on behalf of an international team of 300 scientists, other experts, and elders and other insightful indigenous residents of the Arctic region who have prepared this comprehensive analysis of the impacts and consequences of climate variability and changes across the Arctic region, including the impacts induced by increases in UV radiation arising from depletion of stratospheric ozone in the region. The scientific analysis and assessment conducted in the ACIA is documented in two reports, both published by Cambridge University Press. • A Scientific Report: A series of assessment reviews and analyses has lead to a more integrated understanding of climate variability and change for the Arctic region (across sectors, sub-regions, indigenous and local interests). This scientific document is fully referenced, and is composed of detailed scientific and technical information describing current understanding of climate change, climate variability and increased UV radiation and their consequences over the entire Arctic region. This 1200 plus page report has been completed and is in final production for release in the weeks ahead. This report provides the scientific foundations for the Overview Document. • An Overview Report: This 140 page document, which is titled "Impacts of a Warming Arctic", is a comprehensive plain language summary of the scientific aspects of the assessment and is designed to synthesizes the key findings of the assessment and place those insights in a policy-makers framework. It states our collective consensus of understanding and knowledge concerning the consequences of climate change over the entire Arctic region. This report was released last week in Reykjavik, Iceland at the ACIA Scientific Symposium (Nov. 9-12) and provides the foundations for our discussions here today. The ACIA is a comprehensively researched, fully referenced,

and independently reviewed evaluation of arctic climate change and its impacts for the region and for the world. It is the first such assessment ever conducted for the Arctic. As we reported to you and your committee in March of this year, the Arctic Council called for this assessment in 2000, and charged two of its working groups, the Arctic Monitoring and Assessment Programme (AMAP) and the Conservation of Arctic Flora and Fauna (CAFF), to conduct this assessment in cooperation with the International Arctic Science Committee (IASC). The Scientific Report: The scientific report is organized around eighteen chapters that address a broad range of issues concerning climate and UV changes across the circumpolar Arctic. These chapters are: 1. Introduction 2. Arctic Climate – Past and Present 3. The Changing Arctic: Indigenous Perspectives 4. Future Climate Change: Modeling and Scenarios for the Arctic Region 5. Ozone and Ultraviolet Radiation 6. Cryospheric and Hydrologic Variability 7. Arctic Tundra and Polar Desert Ecosystems 8. Freshwater Ecosystems and Fisheries 9. Marine Systems 10. Principles of Conserving the Arctic's Biodiversity 11. Management and Conservation of Wildlife in a Changing Arctic Environment 12. Hunting, Herding, Fishing and Gathering: Indigenous Peoples and Renewable Resource Use in the Arctic 13. Fisheries and Aquaculture 14. Chapter 14: Forests, Land Management and Agriculture 15. Human Health 16. Infrastructure: Buildings, Support Systems, and Industrial Facilities 17. Climate Change in the Context of Multiple Stressors and Resilience 18. Summary and Synthesis

The Overview Report: The Overview Report, entitled, "Impacts of a Warming Arctic", provides the foundations for our discussions today and concludes that: "The Arctic is now experiencing some of the most rapid and severe climate change on Earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social, and economic changes, many of which have already begun. Changes in arctic climate will also affect the rest of the world through increased global warming and rising sea levels". These climate changes are being experienced particularly intensely in the Arctic. Arctic average temperature has risen at almost twice the rate as the rest of the world in the past few decades. Widespread melting of glaciers and sea ice and rising permafrost temperatures present additional evidence of strong arctic warming. These changes in the Arctic provide an early indication of the environmental and societal significance of global warming. An acceleration of these climatic trends is projected to occur during this century, due to ongoing increases in concentrations of greenhouse gases in the earth's atmosphere. While greenhouse gas emissions do not primarily originate in the Arctic, they are projected to bring wide-ranging changes and impacts to the Arctic. These arctic changes will, in turn, impact the planet as a whole. For this reason, people outside the Arctic have a great stake in what is happening there. For example, climatic processes unique to the Arctic have significant effects on global and regional climate. The Arctic also provides important natural resources to the rest of the world (such as oil, gas, and fish) that will be affected by climate change. And melting of arctic glaciers is one of the factors contributing to sea-level rise around the globe. Climate change is also projected to result in major impacts inside the Arctic, some of which are already underway. Whether a particular impact is perceived as negative or positive often depends on one's interests. For example, the reduction in sea ice is very likely to have devastating consequences for polar bears, ice-dependent seals, and local people for whom these animals are a primary food source. On the other hand, reduced sea ice is likely to increase marine access to the region's

resources, expanding opportunities for shipping and possibly for offshore oil extraction (although operations could be hampered initially by increasing movement of ice in some areas). Further complicating the issue, possible increases in environmental damage that often accompanies shipping and resource extraction could harm the marine habitat and negatively affect the health and traditional lifestyles of indigenous people. Another example is that increased areas of tree growth in the Arctic could serve to take up carbon dioxide and supply more wood products and related employment, providing local and global economic benefits. On the other hand, increased tree growth is likely to add to regional warming and encroach on the habitat for many birds, reindeer/caribou, and other locally beneficial species, thereby adversely affecting local residents. Potential complications include projected increases in forest disturbances such as fires and insect outbreaks that could reduce expected benefits. Climate change is taking place within the context of many other ongoing changes in the Arctic, including the observed increase in chemical contaminants entering the Arctic from other regions, overfishing, land use changes that result in habitat destruction and fragmentation, rapid growth in the human population, and cultural, governance, and economic changes. Impacts on the environment and society result not from climate change alone, but from the interplay of all of these changes. One of the additional stresses in the Arctic that is addressed in this assessment results from increasing levels of ultraviolet radiation reaching the earth's surface due to stratospheric ozone depletion. As with many of the other stresses mentioned, there are important interactions between climate change and ozone depletion. The effects of climate change on the upper atmosphere make continued ozone depletion over the Arctic likely to persist for at least a few more decades. Thus, ultraviolet radiation levels in the Arctic are likely to remain elevated, and this will be most pronounced in the spring, when ecosystems are most sensitive to harmful ultraviolet radiation. The combination of climate change, excess ultraviolet radiation, and other stresses presents a range of potential problems for human health and well-being as well as risks to other arctic species and ecosystems. To communicate the results contained in the 1200 page Scientific Report of this assessment, the more non-technical and plain language Overview Report we are discussing today, integrates the scientific aspects of the assessment through ten Key Findings. A more detailed listing of these ten Key Findings is contained in Attachment I at the end of this testimony, the essence of which is contained in this list of ten Key Findings: 1. Arctic climate is now warming rapidly and much larger changes are projected, 2. Arctic warming and its consequences have worldwide implications Arctic vegetation zones are very likely to shift, causing wide-ranging impacts, 3. Animal species' diversity, ranges, and distribution will change Many coastal communities and facilities face increasing exposure to storms, 4. Reduced sea ice is very likely to increase marine transport and access to resources, 5. Thawing ground will disrupt transportation, buildings, and other infrastructure, 6. Indigenous communities are facing major economic and cultural impacts, 7. Elevated ultraviolet radiation levels will affect people, plants, and animals, 8. Multiple influences interact to cause impacts to people and ecosystems, 9. Elevated ultraviolet radiation levels will affect people, plants, and animals, and 10. Multiple influences interact to cause impacts to people and ecosystems. We appreciate the opportunity to meet with the Committee and to outline some aspects of these ten Key Findings contained "Impacts of a Warming Arctic". This Overview Report details the major findings of the assessment. For example, the reductions in sea ice depicted on the

next page is based on the analyses conducted in this assessment which show that September sea-ice extent, already declining markedly, is projected to decline even more rapidly in the future. The three images show the average of the projections from five climate models for three future time periods. As the century progresses, sea ice moves further and further from the coasts of arctic land masses, retreating to the central Arctic Ocean. Some models project the nearly complete loss of summer sea ice in this century.

Further, sea level rise has the potential for significant impacts on societies and ecosystems around the world. Climate change causes sea level to rise by affecting both the density and the amount of water in the oceans. The primary factors contributing to this rise are thermal expansion due to ocean warming and melting of land-based ice that increases the total amount of water in the ocean. Global average sea level is projected by IPCC to rise 10 to 90 centimeters during this century, with the rate of rise accelerating as the century progresses. However, recent studies suggest the potential of up to 1 meter (~3 feet) by the end of the century. This would have profound impacts for Florida as depicted in this graphic. Over the longer term, much larger increases in sea level are projected. Sea-level rise is expected to vary around the globe, with the largest increases projected to occur in the Arctic, in part due to the projected increase in freshwater input to the Arctic Ocean and the resulting decrease in salinity and thus density. Sea-level rise is projected to have serious implications for coastal communities and industries, islands, river deltas, harbors, and the large fraction of humanity living in coastal areas worldwide. Sea-level rise will increase the salinity of bays and estuaries. It will increase coastal erosion, especially where coastal lands are soft rather than rocky.

This summary graphic to the right projects some the major changes in both the landscape and the Arctic oceanic basin. As Larisa Avdeyeva of Lovozero, Russia has indicated “Nowadays snows melt earlier in the springtime. Lakes, rivers, and bogs freeze much later in the autumn. Reindeer herding becomes more difficult as the ice is weak and may give way... All sorts of unusual events have taken place. Nowadays the winters are much warmer than they used to be. Occasionally during winter time it rains. We never expected this; we could not be ready for this. It is very strange... The cycle of the yearly calendar has been disturbed greatly and this affects the reindeer herding negatively for sure.” These changes observed by this elder in Russia are also consistent with and documented by the scientific analyses of this assessment and are projected to continue in the coming decades. I’d like to conclude by noting that the impacts of climate change in the Arctic addressed in this assessment are largely caused from outside the region, and will reverberate back to the global community in a variety of ways. The scientific findings reported here can inform decisions about actions to reduce the risks of climate change. As the pace and extent of climate change and its impacts increase, it will become more and more important for people everywhere to become aware of the changes taking place in the Arctic, and to consider them in evaluating what actions should be taken to respond. The IPCC concluded in 2001 that “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities”. The findings of this assessment are consistent with this perspective. Based on both our analyses and those of the IPCC, carbon dioxide concentrations in the atmosphere will remain elevated above historic levels for centuries, even if emissions were to cease immediately. Some

continued warming is thus inevitable. However, the speed and amount of warming can be reduced if future emissions are limited sufficiently to stabilize the concentrations of greenhouse gases. The more than 30 scenarios developed by the IPCC assume a variety of different societal developments, resulting in various plausible levels of future emissions. Of these scenarios, the ACIA used a moderate IPCC scenario, B2, for all of its model simulations of future climate change in the Arctic, adding in some cases the A2 scenario to explore additional aspects of climate change across the circumpolar Arctic. None of these scenarios assume implementation of explicit policies to reduce greenhouse gas emissions. Thus, atmospheric concentrations do not level off in these scenarios, but rather continue to rise, resulting in significant increases in temperature and sea level and widespread changes in precipitation. The costs and difficulties of adapting to such increases are very likely to increase significantly over time. If, on the other hand, society chooses to reduce emissions substantially, the induced changes in climate would be smaller and would happen more slowly. This would not eliminate all impacts, especially some of the irreversible impacts affecting particular species. However, it would allow ecosystems and human societies as a whole to adapt more readily, reducing overall impacts and costs. The impacts addressed in this assessment assume continued growth in greenhouse gas emissions. Although it will be very difficult to limit near-term consequences resulting from past emissions, many longer-term impacts could be reduced significantly by reducing global emissions over the course of this century. This assessment did not analyze strategies for achieving such reductions, which are the subject of efforts by other bodies.

Attachment I Key Findings of the Arctic Climate Impact Assessment : 1. Arctic climate is now warming rapidly and much larger changes are projected. • Annual average arctic temperature has increased at almost twice the rate as that of the rest of the world over the past few decades, with some variations across the region. • Additional evidence of arctic warming comes from widespread melting of glaciers and sea ice, and a shortening of the snow season. • Increasing global concentrations of carbon dioxide and other greenhouse gases due to human activities, primarily fossil fuel burning, are projected to contribute to additional arctic warming of about 4-7°C over the next 100 years. • Increasing precipitation, shorter and warmer winters, and substantial decreases in snow cover and ice cover are among the projected changes that are very likely to persist for centuries. • Unexpected and even larger shifts and fluctuations in climate are also possible. 2. Arctic warming and its consequences have worldwide implications. • Melting of highly reflective arctic snow and ice reveals darker land and ocean surfaces, increasing absorption of the sun's heat and further warming the planet. • Increases in glacial melt and river runoff add more freshwater to the ocean, raising global sea level and possibly slowing the ocean circulation that brings heat from the tropics to the poles, affecting global and regional climate. • Warming is very likely to alter the release and uptake of greenhouse gases from soils, vegetation, and coastal oceans. • Impacts of arctic climate change will have implications for biodiversity around the world because migratory species depend on breeding and feeding grounds in the Arctic. 3. Arctic vegetation zones are very likely to shift, causing wide-ranging impacts. • Treeline is expected to move northward and to higher elevations, with forests replacing a significant fraction of existing tundra, and tundra vegetation moving into polar deserts. • More-productive

vegetation is likely to increase carbon uptake, although reduced reflectivity of the land surface is likely to outweigh this, causing further warming. • Disturbances such as insect outbreaks and forest fires are very likely to increase in frequency, severity, and duration, facilitating invasions by non-native species. • Where suitable soils are present, agriculture will have the potential to expand northward due to a longer and warmer growing season.

4. Animal species' diversity, ranges, and distribution will change. • Reductions in sea ice will drastically shrink marine habitat for polar bears, ice-inhabiting seals, and some seabirds, pushing some species toward extinction. • Caribou/reindeer and other land animals are likely to be increasingly stressed as climate change alters their access to food sources, breeding grounds, and historic migration routes. • Species ranges are projected to shift northward on both land and sea, bringing new species into the Arctic while severely limiting some species currently present. • As new species move in, animal diseases that can be transmitted to humans, such as West Nile virus, are likely to pose increasing health risks. • Some arctic marine fisheries, which are of global importance as well as providing major contributions to the region's economy, are likely to become more productive. Northern freshwater fisheries that are mainstays of local diets are likely to suffer.

5. Many coastal communities and facilities face increasing exposure to storms. • Severe coastal erosion will be a growing problem as rising sea level and a reduction in sea ice allow higher waves and storm surges to reach the shore. • Along some arctic coastlines, thawing permafrost weakens coastal lands, adding to their vulnerability. • The risk of flooding in coastal wetlands is projected to increase, with impacts on society and natural ecosystems. • In some cases, communities and industrial facilities in coastal zones are already threatened or being forced to relocate, while others face increasing risks and costs.

6. Reduced sea ice is very likely to increase marine transport and access to resources. • The continuing reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources. • Seasonal opening of the Northern Sea Route is likely to make trans-arctic shipping during summer feasible within several decades. Increasing ice movement in some channels of the Northwest Passage could initially make shipping more difficult. • Reduced sea ice is likely to allow increased offshore extraction of oil and gas, although increasing ice movement could hinder some operations. • Sovereignty, security, and safety issues, as well as social, cultural, and environmental concerns are likely to arise as marine access increases.

7. Thawing ground will disrupt transportation, buildings, and other infrastructure. • Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen sufficiently to permit travel. • As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized, requiring substantial rebuilding, maintenance, and investment. • Future development will require new design elements to account for ongoing warming that will add to construction and maintenance costs. • Permafrost degradation will also impact natural ecosystems through collapsing of the ground surface, draining of lakes, wetland development, and toppling of trees in susceptible areas.

8. Indigenous communities are facing major economic and cultural impacts. • Many Indigenous Peoples depend on hunting polar bear, walrus, seals, and caribou, herding reindeer, fishing, and gathering, not only for food and to support the local economy, but also as the basis for cultural and social identity. • Changes in species' ranges and

availability, access to these species, a perceived reduction in weather predictability, and travel safety in changing ice and weather conditions present serious challenges to human health and food security, and possibly even the survival of some cultures. · Indigenous knowledge and observations provide an important source of information about climate change. This knowledge, consistent with complementary information from scientific research, indicates that substantial changes have already occurred. 9. Elevated ultraviolet radiation levels will affect people, plants, and animals. · The stratospheric ozone layer over the Arctic is not expected to improve significantly for at least a few decades, largely due to the effect of greenhouse gases on stratospheric temperatures. Ultraviolet radiation (UV) in the Arctic is thus projected to remain elevated in the coming decades. · As a result, the current generation of arctic young people is likely to receive a lifetime dose of UV that is about 30% higher than any prior generation. Increased UV is known to cause skin cancer, cataracts, and immune system disorders in humans. · Elevated UV can disrupt photosynthesis in plants and have detrimental effects on the early life stages of fish and amphibians. · Risks to some arctic ecosystems are likely as the largest increases in UV occur in spring, when sensitive species are most vulnerable, and warming-related declines in snow and ice cover increase exposure for living things normally protected by such cover. 10. Multiple influences interact to cause impacts to people and ecosystems. · Changes in climate are occurring in the context of many other stresses including chemical pollution, overfishing, land use changes, habitat fragmentation, human population increases, and cultural and economic changes. · These multiple stresses can combine to amplify impacts on human and ecosystem health and well-being. In many cases, the total impact is greater than the sum of its parts, such as the combined impacts of contaminants, excess ultraviolet radiation, and climatic warming. · Unique circumstances in arctic sub-regions determine which are the most important stresses and how they interact.

The Testimony of

Dr. Mark Serrez

Research Scientist, National Snow and Ice Data Center, University of Colorado

The dominant feature of the Arctic Ocean is its floating sea ice cover. This thin, variable layer strongly controls the heat balance of the planet, and changes in size with the seasons and year by year. On average, the ice covers about 14 million square kilometers in winter and about half this area in summer. The ice typically ranges from 1-5 m in thickness, depending on the region, season and year. Records for the past several decades document significant shrinking of the ice cover, with extreme retreat in the past three years. There is some evidence of attendant thinning of the sea ice. The observed decline in Arctic sea ice is fundamentally in accord with climate model projections of continued ice losses through the 21st century. MAJOR POINTS 1) Over the past 30 years, the annual average extent of Arctic sea has decreased by about 8%. Losses for this period are much larger in late summer to early autumn (15- 20%). The most accurate assessments of Arctic sea ice extent are for late 1978 onwards. These are based on NASA satellite data (so-called “passive microwave” imagery). Other forms of satellite data (back to the early 1970s), ship reports and aircraft reconnaissance can extend the record back to the beginning of the 20th century. It appears the decline in sea ice began around 1960, with the late summer and early autumn losses again standing out. The last three years (2002, 2003, and

2004) have seen extreme sea ice reductions. 2) There is evidence that the sea ice cover has also become thinner. There are no reliable methods to monitor sea ice thickness from satellites. The best information comes from upward-looking sonar carried by submarines operating under the ice. Comparisons between sonar records collected during 1958-1976 with more recent data (1993-1997) indicate that between the two periods, mean ice thickness at the end of summer decreased by over a meter for much of the central Arctic Ocean. Subsequent analyses, based on both observations and state-of-the-art sea ice models, give further evidence for thinning from the late 1980s through 1997, but with some recent recovery. 3) The observed changes in Arctic sea ice extent and thickness are best explained from a combination of climate warming and changes in the circulation of the sea ice. Changes in temperature over the Arctic Ocean have been assessed using data from Russian manned ice camps (1950-1991), arrays of drifting buoys (1979 onwards) and satellite remote sensing (1981 onwards). While each analysis yields somewhat different results due to differences in data type and record length, they convincingly point to spring/summer warming and a longer summer melt season. Starting around 1970, the so-called North Atlantic (or Arctic) Oscillation (NAO), a large-scale pattern of variability in the atmospheric circulation, began to shift towards its "positive mode." While this is known to have contributed to recent Arctic warming, the primary impact on the sea ice is through changes in the surface winds, which alter the circulation of the ice cover. There is ample evidence that through various mechanisms, these altered wind patterns have helped to reduce the extent and thickness of the ice. The NAO has regressed to a more neutral state in the past five years, yet the ice cover has continued to decline, as seen in the extreme losses of 2002, 2003 and 2004. 4) The sea ice reductions are in fundamental agreement with model projections. Global climate models used in the Arctic Climate Impact Assessment and other investigations point to continued sea ice losses through the 21st century in response to greenhouse gas warming. There are disparities between different models in the projected rates and spatial patterns of change. Ice loss is nevertheless a universal feature of the projections. 5) Attribution of the observed Arctic sea ice decline to greenhouse gas warming is complicated by variability in the atmospheric circulation. Building on Point #3, the decline in Arctic sea ice extent has been "boosted" by changes in the atmospheric circulation associated with the NAO. The NAO has and will always contribute to "natural" variability of the Arctic climate system, which complicates detection of a greenhouse signal. However, while the past five years have seen this atmospheric pattern return to a more normal state, the sea ice cover is still declining. There is also growing evidence that through various mechanisms, the effects of greenhouse warming may favor the positive mode of the North Atlantic Oscillation that fosters sea ice losses.

SUMMARY STATEMENT The most reasonable assessment is that the Arctic sea ice cover is beginning to respond to the effects of greenhouse gas warming. This assessment is based on: (a) observational evidence, (b) increasing confidence in projections from state-of-the-art global climate models, (c) ice core records indicating that carbon dioxide levels in the atmosphere are now the highest of the past 400,000 years, (d) other "proxy" records (such as from tree ring analyses) indicating that recent climate warming is moving outside of the bounds of natural variability over the past 1000 years. The particularly strong natural variability in the Arctic climate system lends some uncertainty to this assessment. Another source of uncertainty is the extent to which

greenhouse gas loading and stratospheric ozone losses in the Arctic alter major patterns of atmospheric variability such as the North Atlantic Oscillation.

Respectfully Submitted,

Mark C. Serreze, PhD National Snow and Ice Data Center University of Colorado,
Boulder

The Testimony of

Dr. Igor Krupnik

Research Anthropologist, Arctic Studies Center, Department of Anthropology

Thank you for this opportunity to comment on the impact of Arctic climate change on the lives and culture of northern peoples.

As an anthropologist with the Smithsonian Institution's Arctic Studies Center and with some 30 years of fieldwork in Arctic communities, I would like to provide a few details on the human and cultural aspects of Arctic climate change. I have been involved in the Arctic Climate Impact Assessment (ACIA) process since its first workshop in February 200 and served as a contributing author on its chapter discussing the human aspects of Arctic climate change. Normally, we keep hear about the 'warming of the Arctic' in the language of temperature curves, shrinking sea ice, atmospheric fluxes, and ocean circulation. It is the task of scholars to collect such data and to provide information to the public about the impacts and consequences of rapid climate change. The current ACIA report illustrates perfectly this crucial societal mission of polar science.

But as the changes in the Arctic are unfolding, they also have a growing impact upon the daily life of people who live there. In towns and villages across the North, people take notice and speak up about what they see happening in their 'back-yard.' They are usually far more articulate than scientists in presenting their observations. They talk passionately and with first-hand knowledge; they are great public speakers on the issues of Arctic climate change. In fact, I wish there was a person from a northern community to do this job today.

Recently, scientists have begun to pay more attention to the observations, records, and knowledge of Arctic residents. Several projects have been launched to document these observations, to record it in reports and papers, electronic databases, and CD-Roms. The ACIA study made a critical breakthrough in opening this local knowledge to the polar science community and to the general public. Its forthcoming full report will, for the first time, feature a 60-page chapter titled "The Changing Arctic: Indigenous Perspectives." This chapter reviews the impacts observed in many arctic communities, due to climate change and increased variability in ice, weather, and temperature regimes. It also discusses people's perspectives on future impacts of climate change, such as the effects on their way of life, land and water use, diet, and social and cultural activities.

In all northern communities, knowledge about the environment is regarded as a critical pillar of local culture and identity, as a prized value, and the very foundation of the way of life. Individual scholars, research institutions, and agencies are now actively promoting programs in the documentation of 'local environmental knowledge.' Overall, northern communities are responding to the partnership with scientists with great enthusiasm. But, as the ACIA report illustrates, much more could and should be done.

Arctic residents are very astute observers. They go on the sea ice or to the bush every day, year after year. An impressive amount of data is routinely collected and processed, year after year, in hundreds of Native villages and camps. No wonder Native people are so proud of their knowledge, which is praised highly by many natural and social scientists alike. This knowledge has to be matched to the various records produced by scientists, to become a part of the overall discussion on the impacts of Arctic climate change.

Arctic people are also highly inquisitive monitors. They rarely speak in terms of such common climate indicators as temperature, precipitation, or atmospheric pressure; but they operate with many more signals of change than scientists do. As a result, when local people talk about "unusual things" they can cite change to almost every component of the environment: from sea ice and weather to currents and winds, marine mammals and fishes, plants and berries. This integral view should become the bedrock of any assessment of future climate change.

Arctic residents are not—and have never been—immune to the many agents of change. Through ages of adaptation, they have developed a comprehensive knowledge of their environment, navigation and orientation, weather forecasting, and animal behavior. These days however, such expert knowledge is not bestowed automatically upon everyone who was born or lives in the North. People have to keep going onto the sea ice or to the bush, in order to rely upon familiar observation practices and to use dozens of local terms for various types of ice, snow, winds, weather conditions, plants and animals. Those conditions can hardly be met in many northern communities of today, where kids are normally at school until the age of 16. Today, they hunt with their fathers on weekends or during school vacations. When they become adults, many move to towns and become weekend or part-time hunters, at best.

There are many other agents of change that arrived with technological modernization. As the Global Positioning System, aerial imagery, and radio weather forecasts are now the elements of daily life, the generational knowledge on safety rules, navigation, and weather prediction becomes endangered. High-speed snowmobiles and motorboats have replaced dog-teams and skin boats; but the names and terms for every feature of local environment are fading away.

As valuable local expertise becomes endangered, due to modernization, rapid environmental change brings other concerns. Normally, we hear about 'human costs' of rapid Arctic climate change in terms of the damaged roads and buildings, thawing permafrost, increased storms, and beach erosion. The most publicized case includes some

Native towns in Alaska, like Shishmaref or Kivalina, that soon could be washed away by storm waves. Those towns will have to be relocated, at a price of many hundred million dollars. However, there are other 'human costs' associated with the current climate change that are revealed in the ACIA report, particularly in the many case-studies attached to its full version.

Much like polar scientists, northern residents face the same basic challenge, namely, whether the changes on their watch are unique and, thus, worrisome, or the scope of change is within the range of personal experience and community memory. Unlike scientists, however, local residents are extremely frustrated by their limitations to grasp the scope of change. As the weather 'goes wild' and the Arctic becomes a 'friend acting strangely,' invaluable old knowledge no longer works and may soon become irrelevant. This feeling of loss and uncertainty is now a common theme in many northern communities affected by climate change. Local reports illustrate a growing uneasiness among elders in forecasting the weather, enforcing traditional safety rules, and teaching younger people. Stories are told of expert hunters being confused and lost on ice or in rough waters; of young hunters who stopped listening to the elders, because the old wisdom does not 'fit' anymore.

Of course, people are experimental and industrious in exploring new strategies and they try new approaches eagerly. Eventually, new economic opportunities will emerge and other resources will thrive, because of the changed conditions. Better transportation conditions, particularly in the summer time, may be the first and the most obvious benefit of the warming Arctic. But the readjustment will come with a price and with certain losses. As we recognize that, we may become more attentive to what people discuss today in northern towns and villages about the weather going 'wild,' and the Earth being 'faster' now. I believe that such a perspective on the human cost of arctic adaptations should be added to every story of change told by temperature curves and climate computer models.

With this in mind, I want to cite four basic conclusions that come from the data presented in the ACIA report.

First, environmental knowledge of Arctic residents and their observations of current climate change provide highly useful and reliable data to scholars, policy-makers, and general public. Further documentation of knowledge and observations of Arctic residents would be of great value, so that scientists and respective agencies can make more use of it. This is critically important to future efforts in global environment research, including the forthcoming International Polar Year 2007-2008, and other major interdisciplinary programs.

Second, rapid climate change is endangering traditional ecological knowledge of arctic residents with respect to the local environment and subsistence practices. The weakening of this knowledge will be a great loss to local communities and to future scientific inquiries regarding global environmental change. Programs to counter this trend include

local education, publication activities, and community-based initiatives in the preservation of cultural heritage.

Third, many northern communities are going through a stressful transition, as a result of rapid environmental change, but also due to many economic factors and other agents. Activities that address this challenge include local job training, education, health and social services as well as communal programs that deal with social stress, safety regulations, youth problems, and community management.

Fourth, established subsistence activities, local safety, and food practices are basic aspects of daily life to be the most affected by Arctic climate change. Re-adjustment may be long and it will take a toll on arctic communities that have limited resources. This re-adjustment will likely result in proposals for various co-management arrangements, innovative land- and game-use practices, and increased collaboration with local institutions that represent arctic residents.

Thank you for this opportunity to comment on the impact of Arctic climate change on northern peoples.

Igor Krupnik, Ph.D. Ethnologist, Arctic Studies Center National Museum of Natural History, Smithsonian Institution 10th and Constitution Ave, NW, Washington, DC 20013-7012 202-633-1901, krupnik.igor@nmnh.si.edu

The Testimony of

Dr. Ghassem R. Asrar

Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration

Mr. Chairman and Members of the committee, I appreciate the opportunity to appear here today to discuss NASA's research on the climate change impacts in Antarctica. The ice-covered polar regions of the Earth represent a critical element of the Earth system. Not only are they believed to be especially sensitive to changes in climate, but they are expected to amplify these changes, because the melting of ice, which is highly reflective, tends to be self-compounding as it causes the surface to darken and absorb more solar energy. Additionally, the removal of sea ice from the high-latitude oceans allows more heat and water vapor to enter the atmosphere, which in turn enhances warming. Despite their importance and sensitivity, comprehensive study of polar regions has been greatly limited – until recently - by their difficulty of access, and the challenges associated with observing them on appropriate scales.

The Earth's great ice sheets, Greenland and Antarctica, store 77% of the Earth's fresh water. The sea ice that blankets much of the Arctic Ocean and surrounds Antarctica in the austral winter has a tremendous effect on ocean circulation by influencing the density of the near surface water as sea ice forms and melts, and also by modulating the exchange of energy and moisture between the ocean and the atmosphere. Though they are far-

removed from where most people live, the polar regions exhibit a profound influence on the Earth as a whole and impact the lives of everyone on the planet.

For decades, NASA has been a leader in studying these remote, harsh, and dangerous regions of the Earth by providing a unique capability to observe them from the air and from space. NASA utilizes this unique perspective to remotely examine high-latitude processes on large scales, and with frequent visits that are not achievable from the surface. These efforts directly complement those of the National Science Foundation and other agencies that employ surface-based observations on land, by ship, or by other means. Such a complementary structure among organizations allows a comprehensive view of polar processes at the full range of scales and detail necessary to understand their physical mechanisms and their relationship to the planet and its inhabitants.

NASA has invested substantially in studying the role of the ice-covered regions of the Earth, how they influence and respond to global climate change, and the growth and shrinkage of glaciers and ice sheets and their contributions to sea level. Toward that end, we have developed dozens of airborne and spaceborne sensors and funded hundreds of scientists over the last 30 years. These investments have paid off tremendously by revolutionizing our understanding of polar processes and their significance. An important part of our scientific portfolio consists of multi-decadal observations of ice extent, ice melt, snow cover, polar temperatures, stratospheric ozone, etc., through remote-sensing observations that were pioneered by NASA, and in many cases subsequently carried out operationally by our sister agencies. At the same time we continue to innovate, developing new and exciting ways to examine some of the most critical, yet poorly understood processes in the polar regions. These capabilities include precise gravity observations, detailed topographic measurements of the ice surfaces, ice sheet and sea ice velocity measurements, deformation mechanics of sea ice, vertical structure of the polar atmospheres, etc. This approach allows us to obtain crucial new insights into polar phenomena, but with a multi-decadal context.

As with Greenland, one of the most significant implications of future warming in Antarctica is the likely contribution of the Antarctic ice sheet to sea level rise. Many have thought that the response time of ice sheets to changes in climate is hundreds or thousands of years, but observations over the last few years have shown that ice sheets can respond much more quickly. A recent NASA study has shown that to be the case in the Antarctic Peninsula, which has warmed by about 4 degrees Fahrenheit in the second half of the 20th century. As a result, the Larsen B ice shelf, located adjacent to the eastern side of the peninsula, disintegrated dramatically in 2002. This ice, hundreds of feet thick and believed to have been in the region for more than 10,000 years, disappeared in about one month's time.

In and of itself, this ice shelf disintegration is of no consequence to sea level, since it was floating to begin with. What is of consequence, however, is what happened in the months that followed. All observed glaciers that were once buttressed by the ice shelf accelerated – some by as much as 8-fold - flushing their ice into the nearby Weddell Sea. At the same time, nearby glaciers that continue to be buttressed by what remains of the Larsen ice

shelf have shown no acceleration. Data from NASA's Ice Cloud and Land Elevation Satellite (ICESat) indicate that the accelerating glaciers thinned by nearly 125 feet in six month's time. This rapid loss is not likely to be sustained, as the ice adjusts to its new boundary conditions, and some of these glaciers have already slowed slightly. It is of considerable significance in the near term, however, and the study makes clear that ice sheets can respond very quickly to changes in climate. This continues to be reinforced by observations elsewhere in Antarctica that show similar acceleration and thinning of glaciers and ice streams, as their floating ice shelves begin to diminish.

In the case of the West Antarctic ice sheet, which contains the equivalent of about 20 feet of sea level, the rapid response to climate warrants particular attention because the ice sheet rests on a soft sediment base, which is inherently unstable. In the geological past (roughly 12,000 years ago and again 9,500 years ago), sea levels have risen by rates as high as three feet per decade. The ICESat mission has been specifically designed to examine changes in these ice sheets, and these data, when combined with data from other satellite and aircraft sensors, in situ measurements, and models, are providing remarkable insights to the current state of the ice sheets, and their likely behavior in the future.

A key to understanding the significance of this and other Antarctic ice phenomena lies in being able to predict if and how the Antarctic continent will change in the future. We have developed models that couple our satellite data with our best understanding of atmospheric processes to tackle this complex problem. Ground and satellite observations show that while the Antarctic Peninsula has warmed more rapidly than most places on Earth, most of the continent has cooled. Recent modeling activities at NASA's Goddard Institute for Space Studies (GISS) indicate that this cooling phenomenon is likely caused by the strong state of what is called the Southern Annular Mode (or SAM). The SAM is a coherent pattern of winds and pressure changes that describe much of the variability of the mid to high latitudes in the southern hemisphere. When the pressure differences between the mid-latitudes and the pole are high and winds are strong, we refer to this as a positive (or high) SAM and when it is small we refer to it as negative (or low).

The SAM in the last several decades has been strongly positive. The most recent NASA study on the subject indicates that greenhouse warming and low ozone levels over Antarctica have contributed to this condition by lowering temperatures in the stratosphere. Greenhouse warming lowers these temperatures by increasing the efficiency with which the stratosphere emits its energy. Reductions in ozone, which is a greenhouse gas, have cooled the stratosphere directly by reducing its ability to trap heat. These low stratospheric temperatures set up a condition that strengthens the westerly winds that tend to circle Antarctica and create a barrier to the movement of warmer air from the low latitudes toward the main parts of Antarctica. The result is a cooler continent.

According to this model, as these ozone levels increase (following the agreements under the Montreal Protocol that were established to reduce the emissions of CFCs that destroy ozone), their cooling effects will diminish, which will inhibit further strengthening of these westerly winds. Consequently the model predicts that the westerly winds will no longer offset the radiative effects of increased carbon dioxide. As a result, the Antarctic

continent will likely reverse this cooling trend and experience accelerated warming in the next several decades. In view of the importance of the high-latitude regions in global climate and the rapid responses of ice sheets to changes in climate, such changes would have important implications for global climate and sea level.

The key to understanding our environment and making informed policy decisions is accurate and reliable information. Through our space-based perspective, our ability to incorporate our observations into reliable models, and our domestic and international partnerships, NASA is providing the necessary tools for examining these changes, understanding the mechanisms that control them, and predicting their future behavior.

REFERENCES:

SCAMBOS, T., C. HULBE, AND M. FAHNESTOCK, 2003, CLIMATE INDUCED ICE SHELF DISINTEGRATION, IN THE ANTARCTIC PENINSULA, IN ANTARCTIC PENINSULA CLIMATE VARIABILITY: HISTORICAL AND PALEOENVIRONMENTAL PERSPECTIVES, ANTARCTIC RESEARCH SERIES, VOL. 79., PP. 79-92.

MEIER, M., 1990, ROLE OF LAND ICE IN PRESENT AND FUTURE SEA LEVEL CHANGE, IN SEA LEVEL CHANGE, NATIONAL RESEARCH COUNCIL, PP. 171, 184.

KOERNER, R.M., 1989, ICE CORE EVIDENCE FOR EXTENSIVE MELTING OF THE GREENLAND ICE SHEET IN THE LAST INTERGLACIAL. SCIENCE, 244, 964-968

CUFFEY KM, MARSHALL SJ, 2000, SUBSTANTIAL CONTRIBUTION TO SEA-LEVEL RISE DURING THE LAST INTERGLACIAL FROM THE GREENLAND ICE SHEET, NATURE 404 (6778): 591-594 APR 6 2000

THE ANTARCTIC "SPECULATION" COMES FROM: ALLEY, R.B., AND R.A. BINDSCHADLER, 2001, THE WEST ANTARCTIC ICE SHEET AND SEA LEVEL CHANGE, THE WEST ANTARCTIC ICE SHEET: BEHAVIOR AND ENVIRONMENT, ANTARCTIC RESEARCH SERIES, VOL. 77, PP. 1-11

WARNER, R.C., AND W.F. BUDD, 1998, MODELLING THE LONG-TERM RESPONSE OF THE ANTARCTIC ICE SHEET TO GLOBAL WARMING, JOURNAL OF GLACIOLOGY, VOL 27, PP.161-168.

The Testimony of

Dr. Scott Borg

Section Head, Antarctic Science Section, Office of Polar Programs, National Science Foundation

Thank you, Senator McCain, and members of the Committee, for this opportunity to speak about climate change research supported by the National Science Foundation in Antarctica. While my testimony is focused on the Antarctic I should note that NSF also has a vigorous Arctic research program in climate change called SEARCH – Study of Environmental Arctic Change.

I am Dr. Scott Borg, by training a geologist and currently the Head of the Antarctic Sciences Section at the National Science Foundation. The Foundation has been designated as the lead federal agency to represent US national interests in Antarctica. My group at NSF is responsible for selecting, based on the Agency's merit review system, the research projects that are performed in the United States Antarctic Program (USAP).

While NSF supports the bulk of US Antarctic research there are also important partnerships in climate change research with other agencies such as NASA, NOAA, and the USGS. Facilitating research partnerships between university based researchers and scientists from other federal agencies is particularly important because of the need to achieve an interdisciplinary understanding of Antarctica as an integral part of a global system.

Because Antarctica is at the bottom of the world and mostly uninhabited, we easily overlook how big it is. The continent is larger than the United States and Mexico combined. Two huge ice sheets cover almost all of it, and they average more than a mile thick. These ice sheets contain 90 percent of the world's ice, enough to raise sea level by over 60 meters if they were to melt. The other 10 percent is in the glaciers of Greenland and in mountainous parts of the world.

Antarctica is by far the world's largest region of cold, and its cold and ice have consequences for the world's climate. In geological deep time, before about 35 million years ago, Antarctica was not glaciated. Global average temperatures were 3-4 degrees C warmer than today, atmospheric carbon dioxide was higher by a factor of two compared to today and there were no polar ice sheets. Geologists call these conditions a greenhouse world. Beginning about 35 million years ago, the world began to cool, the circum-Antarctic current became fully developed and ice sheets formed on Antarctica. Geologists describe this as a transition to an icehouse world that we live in today. Over the last 400 thousand years, the world has oscillated between glacial conditions such as the last ice age, and slightly warmer interglacial conditions such as the present day. In central Greenland temperature changed about 25 degrees C between glacial and interglacial times and in central East Antarctica, temperatures varied 8 degrees C.

Greenhouse gasses trap solar energy and are an important factor in warming the Earth. Research results on the Vostok ice core demonstrate the strong coupling of greenhouse gas concentration with temperature through glacial-interglacial cycles over the last 420,000 years.^{iv} Measurements of atmospheric carbon-dioxide concentration at the South Pole show that the present concentration of carbon dioxide is higher than at any time during the last 420,000 years and that it continues to increase. This is a clear indication of how humans are affecting our environment.

A large fraction of Antarctic research supported by the Foundation is aimed at observing present conditions to understand interactions between the atmosphere, ice, and ecosystems; recovering and interpreting records of climate and ice sheet changes in the past to understand how the Antarctic system works; and gathering basic information about the ice sheets, the underlying continent, and surrounding oceans to develop a good understanding of how ice sheets affect and respond to changes in Earth's climate. The ultimate goal, of course, is to develop robust numerical models that can help us understand how the Antarctic will respond in the future.

Antarctica has three roles in climate. As I just suggested, it influences the rest of the world's climate. For example, in addition to just being big and cold, in the austral summer it reflects most of the Sun's heat back into space simply because the white ice is a good reflector. The area of Antarctic sea ice approximately doubles during the winter and shrinks back in summer. So, long-term changes in the extent of Antarctic sea ice would affect the heat budget of the planet. Some studies indicate reductions in sea ice regionally in the past few decades but there are not yet enough data to support a full understanding of any large-scale changes that may be occurring.

Secondly, Antarctica responds to global climate change. Scientists have long predicted that Earth's polar regions would respond earlier and more acutely than the lower latitudes. In the Arctic Climate Impact Assessment report you have heard a lot about the other end of the world, the Arctic, where sea ice is decreasing, permafrost is warming and melting, and native peoples are experiencing significant changes in their environment. In Antarctica, the most northern part of the continent, called the Antarctic Peninsula, average winter temperatures have warmed-up 6 degrees Celsius in the last 51 years.viii (Note that this is an average mid-winter temperature and not the average annual temperature discussed in the NASA testimony.) As Dr. William R. Fraser, an NSF-funded biologist, told this committee in May 2004, the species makeup of penguin populations along the Antarctic Peninsula is shifting as a result of the warming and the receding sea ice. Other changes are equally dramatic. Two years ago, the Larsen Ice Shelf broke up rapidly and dramatically, an unprecedented event in recorded history. The leading explanation for the cause of this break up is melt pond formation associated with regional warming. Changes indicative of warming are also evident in the Dry Valleys region near McMurdo Station. The water volume of ice-covered lakes has been generally increasing over the last three decades and there is some evidence that this trend has existed over the last century. Related research underway is examining the effects this may have on the cold desert ecosystem in the region.

While the observations mentioned above indicate warming, much of the rest of the Antarctic seems to be cooling slightly. Unfortunately, the low density of stations throughout the continent and the short time since measurements began (e.g. no continuous records prior to 1957) limits the conclusions that can be drawn about overall temperature trends. Nevertheless, just this year scientists using satellite data showed that a portion of the West Antarctic Ice Sheet is thinning and losing ice to the sea. Beginning now, and running for the next two months, National Science Foundation supported scientists, in a collaborative effort with the British Antarctic Survey, will be in the

Amundsen Sea Embayment part of this ice sheet collecting data to help us understand this change and what the future may hold. If the West Antarctic Ice Sheet were to disintegrate it would eventually raise sea level about 5 meters globally.

Finally, Antarctica records previous global change for study and understanding. The ice sheets, for example, are the world's unsurpassed history books of past climate that scientists have been able to read in considerable detail to see changes over the last 420,000 years. For example, records of atmospheric gasses from the Vostok ice core, which were produced as part of an international partnership between France, Russia, and the US, show that the concentration of carbon dioxide has not been higher than about 290 parts-per-million during this entire time.^{iv} This is important when we consider that the carbon-dioxide concentration measured at the US Amundsen-Scott South Pole Station has increased steadily from about 310 ppm during the International Geophysical Year (IGY) in 1957 to about 365 ppm today.^v This, in turn, is an important consideration given the significant effect of atmospheric carbon-dioxide concentration in climate models. To better understand these kinds of relationships, the US Antarctic Program is preparing to drill a deep ice core in West Antarctica within a few years, so that detailed records of the past 100 thousand years in Antarctica can be compared to similar records from Greenland.

Antarctic science is improving our knowledge of climate history, adding to our ability to quantify factors that affect climate, reducing uncertainty in projections, and improving understanding of the sensitivity of ecosystems to change.

Antarctic science is still at a relatively early stage of development. Antarctica was proven to be a continent only 164 years ago, and most research has taken place only since the IGY. Nevertheless, Antarctica has already served as an important sentinel of impacts on our environment. For example, twenty years ago the harmful impacts of Chlorofluorocarbons (CFC's) on our atmosphere were realized as a result of studies of the Antarctic ozone hole. American stratospheric chemists working on the ground at McMurdo Station, Antarctica, in the winters of 1986 and 1987, collected information key to determining the cause of the ozone hole. In response, the world's nations agreed to stop putting into the atmosphere the damaging CFCs that caused the ozone hole. We are still monitoring stratospheric ozone in Antarctica; the ozone hole is still there every austral spring, but now predictions indicate that it will be healed in 50 years or so. The incremental decline in stratospheric ozone over the rest of the planet has been turned around because of that work 18 years ago, by a few committed scientists in an Antarctic winter.

In another example, several years ago the Cape Roberts Project in Antarctica, done jointly by several nations including the United States, retrieved ocean-bottom sediments from beneath sea ice. Analysis showed that orbital forcing—changes in the shape of Earth's path around the Sun and of the tilt of Earth's axis relative to the orbit—were important factors driving the growth and retreat of the ice sheets during the period 20 to 24 million years ago when Earth was warmer than present, just as they have been important factors over the last 400,000 years. In a final example, the International

TransAntarctic Scientific Expedition has recently found signals from the El Nino Southern Oscillation in Antarctic snow samples, demonstrating the interconnections of polar and tropical components of Earth's climate system.

NSF, as the manager of the USAP, has been and remains particularly attentive to proposals for research that will help to understand Antarctica's role in the changing global climate system.

Thank you very much for the opportunity to discuss the relevance of Antarctic science to global change. Thank you also for your support of activities at NSF and for sponsoring Senate Resolution 466 supporting the International Polar Year. I would be happy to answer questions.