STUDY OF ENVIRONMENTAL ARCTIC CHANGE (SEARCH)

Report of the
Interagency Working Group
for SEARCH

Submitted To

The Interagency
Arctic Research Policy Committee

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Executive Summary

The Interagency Research Policy Committee (IARPC) is composed of senior officials from U.S. government agencies that have Arctic science activities. In March of 2000, the IARPC agreed to prepare a collaborative, multi-agency plan for Arctic science to complement and enhance the existing plans of the individual agencies. The U.S. Arctic Research Plan for 2000-2004 described four science topics of high priority that could serve as the basis for a multi-agency approach. One of these is Arctic Environmental Change, and it was proposed that this topic might elicit the widest interest among the agencies. After review of an emerging science plan for the Study of Environmental Arctic Change (SEARCH), prepared by a Science Steering Committee (SSC) composed of Arctic science experts, the IARPC concluded that SEARCH dealt with scientific issues of such importance and complexity that a multi-agency approach was appropriate. The IARPC chartered an Interagency Working Group to prepare a draft implementation plan for SEARCH for review by the IARPC.

The Study of Environmental Arctic Change (SEARCH) is focused on the suite of seemingly related atmospheric, oceanic, and terrestrial changes that has occurred in the Arctic over the past two decades. These changes are of such magnitude that the lives of Arctic residents are being altered. The impact of these changes may well go beyond the Arctic and may not only affect the U.S., but even have hemispheric or global impact. The SEARCH science plan outlines four testable hypotheses and describes a four-pronged science strategy. The combined efforts of several agencies at the Federal and state levels, academic scientists representing many disciplines, indigenous and other Arctic residents, and the private sector will be needed to fully understand the issues raised by SEARCH and to apply this understanding to the benefit of society.

The Interagency Working Group, recognizing the complexity of SEARCH and the necessity of working within existing agency planning processes, devised a three-tiered approach for implementation of SEARCH. The first tier takes advantage of various activities already planned for implementation in FY2001 by individual agencies that relate directly to the objectives of SEARCH, and proposes that many of these activities be implemented in coordinated fashion by two or more agencies. Ten separate science topics have been identified that could be undertaken in FY2001 in this way. Implementing these ten topics will provide a substantive beginning to a longer-term interagency program to support SEARCH.

The second tier identifies those new efforts that individual agencies have proposed for implementation in FY2002 that relate directly to SEARCH. The working group proposes that these new activities be implemented through a multi-agency approach that builds on and strengthens efforts begun in FY2001.

The third tier is a proposal from the working group that the agencies plan their FY2003 activities that support SEARCH in a collaborative mode from the outset. The agencies would devise a process to prepare both a budget and implementation strategy that can be presented to the Administration and the Congress as a single, tightly integrated plan for implementation of SEARCH.

The working group recognizes that the Science Steering Committee will have to be expanded to include experts from the physical, biological, and social sciences. Over the next several months, the SSC will continue to refine the SEARCH hypotheses and the SEARCH Science Plan to provide a solid foundation for agency planning efforts.

The working group recommends that the IARPC accept the approach described and assign to the working group the responsibility for designing a true, interagency plan for implementation of SEARCH.

Summary of SEARCH Science Plan

A complex suite of significant atmospheric, oceanic, and terrestrial changes has occurred in the Arctic in the last decades. It has become clear that these changes are affecting virtually every part of the Arctic environment and are now having both direct and indirect repercussions on human society. There is evidence that many of these changes are strongly connected with the Arctic Oscillation (AO), which is apparently a natural mode of atmospheric variation that is potentially active over a broad range of time scales including perhaps climatic time scales. There is evidence that the AO itself may be strengthened by the anthropogenic rise in greenhouse gases, thus suggesting a human cause for some of the recent changes in the Arctic. There are other potential modes of large-scale human influence on the Arctic too, such as long-range transport of contaminants, and high rates of biomass removal from the marine environment. Because of this interplay of natural and anthropogenic forcing factors, we do not know if the recent complex of changes is part of a pattern of natural variability or the beginning of a long-term shift. We also do not know what feedback processes on climate or ecosystems may be involved, or what the long-term impacts may be. Because the observed changes have made it harder for those who live in the north to predict what the future may bring, we have named the complex of recent changes Onami, Inuit for "tomorrow".

SEARCH has been conceived as a broad, interdisciplinary, multi-scale program with a core aim of understanding the complex of recent and ongoing intertwined changes (Onami). SEARCH includes four major types of activities:

- a long-term observational program to track the environmental changes;
- a modeling program to test ideas about the coupling between the different components of Onami, and to predict its future course;
- studies to test hypotheses about critical feedback processes; and
- an assessment component to understand the ultimate impact of the physical changes on the ecosystems and societies, and to distinguish between climate-related Onami changes and changes due to other factors such as resource utilization, pollution, economic development and population growth.

Activities undertaken as part of SEARCH will address a series of testable hypotheses. The first hypothesis is that:
Onami is related to or involves the Arctic Oscillation. A key objective of SEARCH will be to understand the interactions inherent in Onami in a rigorous quantitative way. Testing this hypothesis will tell us much about the interaction of the atmosphere, ocean, and land. It will allow us to tell how Onami is tied to the global atmosphere.

The second hypothesis is that:
Onami is a component of climate change. The AO is a fundamental mode of atmospheric variability and may be tied to climate change. Onami may be tied to climate change along with it or with the other large-scale patterns of atmospheric variability. The objective is to understand how Onami fits into the larger climate change picture.

The third hypothesis is related to the first two. It is that:
Yet unknown feedbacks amongst the ocean, land, and the atmosphere are critical to Onami. These feedbacks could determine whether the Onami, and the Arctic, play critical roles in climate change.

The final hypothesis is that:
Whether or not the recent Onami is tied to long-term climate change, the physical changes have effects on Arctic ecosystems and societies that are mixed with the effects of other human activity. The imperative growing from this idea is that we must distinguish between the changes (physical, ecosystem, and societal) associated with the large-scale, physical Onami phenomenon and the changes due to other causes, including human activities. Ultimately we hope to predict not only the course of Onami, but also its impact on society.

Chapter 1: Formation of the Interagency Working Group for the Study of Environmental Arctic Change (IWG-SEARCH), and its Terms of Reference

The Interagency Arctic Research Policy Committee (IARPC) was convened on March 8, 2000, under the Chairmanship of Rita Colwell, Director of the National Science Foundation. The IARPC had recently published its Biennial United States Arctic Research Plan (Arctic Research of the United States, Volume 13, 1999). The principal agenda item of the meeting was to consider a response to a letter from Neal Lane, the President's Science Advisor, that urged the IARPC to carry out the "arctic research plan within the resources available, and to make maximum use of Federal, international, and regional resources to achieve the objectives envisioned in the interagency arctic research plan". The IARPC agreed that the component of the US Arctic Research Plan that was most readily amenable to an interagency approach at the time was the one titled "Arctic Environmental Change". In large part, this decision was based on the existence of a Science Steering Committee (SSC) for the Study of Environmental Arctic Change (SEARCH) that the NSF had established in 1997. The SSC had prepared a draft Science Plan that could serve as a foundation for an interagency Implementation Plan (See text box for summary and Appendix 1 for annotated outline). The Chair of the SSC briefed the IARPC on the background and science goals for SEARCH. In response to the compelling nature of the briefing, and the recognition that the combined efforts of many agencies would be needed to achieve the goals of SEARCH, the IARPC agreed to establish an Interagency Working Group (IWG) to prepare an interagency approach to implementing the SEARCH Science Plan.

The Terms of Reference for the IWG, as modified by the IWG at its first meeting are:

A. The IWG-SEARCH is composed of representatives from each of the U.S. Federal agencies that comprise the U.S. Interagency Arctic Research Policy Committee. NOAA has agreed to serve as Chair of the IWG-SEARCH. The IWG-SEARCH will elect a Vice-Chair (Appendix 2). The principal responsibilities of the IWG-SEARCH are:

1. In concert with the SEARCH Science Steering Committee, prepare and publish a science plan for the Study of Environmental Arctic Change
2. Prepare and publish a coordinated interagency implementation plan for FY2001 that includes those activities that support the SEARCH science plan.
3. Prepare a coordinated interagency approach for FY2002 and beyond that supports the SEARCH science plan.
4. Ensure coordination between the plans developed by IWG-Search and the "Goals" established by the Arctic Research Commission.

B. The SEARCH Science Steering Committee will continue to be supported by the NSF Office of Polar Programs. Membership of SSC-SEARCH will be reviewed by IWG-SEARCH and additional members suggested, if necessary, to ensure that relevant scientific perspectives are included.

C. The IARPC has asked the IWG-SEARCH to report in June, 2000. At that time, the IWG-SEARCH will make available:

1. Summary of the draft SEARCH science plan
2. Proposed FY2001 Interagency Implementation Plan, based on President's FY2001 request
3. Outline of approach for FY2002 and beyond

Comments from the IARPC will determine the future work of the IWG-SEARCH.

D. Suggested milestones:

March 29 – First meeting of IWG-SEARCH - organization

Inter-sessional actions: prepare inventory of on-going agency programs and of plans and budgets for FY2001; review current draft of SEARCH science plan and evaluate SSC-SEARCH membership

April 18 – Second meeting of IWG-SEARCH – outline FY2001 implementation plan

Inter-sessional actions: prepare agency contributions to draft FY2001 implementation plan

May 10 – Joint meeting of IWG-SEARCH and SSC-SEARCH – outline updates to science plan; evaluate implementation approach

Inter-sessional actions: Submit updates to SEARCH Science Plan; review revised science plan; review draft FY2001 implementation plan; submit ideas on FY2002 approach
June 7 – Third meeting of IWG-SEARCH – revise implementation plan, outline FY2002 approach

The response of the IWG to the proposed Terms of Reference (items A-D above) was:

A. In discussing the draft Terms of Reference, the IWG accepted the draft with the changes described in Chapter 2.

B. The IWG agreed to accept the existing SEARCH SSC, but stated firmly that the SSC must be enlarged to fully represent the range of science topics included in SEARCH. NSF reiterated its intent to support the operation of the SSC.

C. The IWG agreed to the preparation of the three products, with appropriate redefinition of titles.

D. The IWG agreed to the schedule.

Chapter 2: Results and Proposed Products from the IWG-SEARCH and its Interactions with the SEARCH Science Steering Committee

The Interagency Working Group for the Study of Environmental Arctic Change (IWG-SEARCH) considered the instructions from the IARPC and agreed that their intent could be met by the following approach. For Fiscal Year 2001, the IWG agreed that the various agencies had many activities planned in the pending FY2001 President's request that directly supported the goals of SEARCH, and that would be enhanced if pursued on a bi- or multi-agency basis. It was agreed to develop a number of implementation plans organized around SEARCH-related projects or themes in which two or more agencies were interested. Taken together, these plans would constitute the FY2001 SEARCH Implementation Plan requested by the IARPC (Appendix 3).

The IWG was asked by the IARPC to consider development of a multi-agency budget initiative for FY2002. The IWG members agreed that such an effort would be desirable, but felt that it was too late to do so for FY2002. The IWG did agree to propose to the IARPC that they be tasked with developing a true, multi-agency initiative in support of SEARCH for FY2003. Even though a coordinated, multi-agency initiative for FY2002 cannot be developed, it is recognized that individual agencies are working on FY2002 initiatives that will support the SEARCH goals and hypotheses. The IWG will recommend to the IARPC that the IWG prepare a summary document that describes each agency's initiatives for FY2002 that support SEARCH. In this document, the IWG will identify how these agency-specific activities can be implemented in a coordinated fashion, building upon the specific plans for FY2001 implementation. This document will be prepared in time to be available when the President's FY2002 budget is released.

For FY2003, the IWG agreed that it would work to develop a coordinated interagency budget request, if direction to do so was given by the IARPC. Rather than using the SEARCH Science Plan itself as the foundation for such a coordinated request, the IWG agreed to prepare an internal document, perhaps called "Critical Science Needs for the Study of Environmental Arctic Change" that would describe the specific activities the agencies would plan to undertake in FY2003. This would be based on the SEARCH Science Plan, but would likely not cover every item in the Science Plan.

As a result of these decisions, the IWG-SEARCH, in conjunction with the SSC, envisions the following five products to be developed over the coming year:

1. FY2001 Implementation Plan
2. FY2002 Summary of Agency Budget Requests
3. FY2003 Coordinated Agency Budget Request (tentative)
4. Critical Science Needs for the Study of Environmental Arctic Change (background for FY2003 request prepared by agencies)
5. SEARCH Science Plan (underpinning science document prepared by SSC)

The FY2001 Implementation Plan is the document that will demonstrate that the agencies have the desire to work together to achieve the goals of SEARCH. Although the SEARCH Science Plan is still being developed, the focus of SEARCH is clear. It focuses on "understanding Onami and its implications for the physical environment, biology, and people". Onami is broadly defined to mean the suite of significant and potentially related changes that have been observed in the Arctic over the past two decades. Thus, SEARCH focuses on the longer-term dynamic aspects of the Arctic environment, rather than attempting to subsume all Arctic environmental research. Even with this clear focus, there is a diverse set of activities that are required to meet the goals of SEARCH, and not all of them can be undertaken in the immediate term.

FY2001 Interagency Science Activities

Within the expected resource base of the agencies in FY2001 and assuming reasonable decisions on re-allocation of those resources, the IWG has agreed to the following topics as areas of focus for FY2001 in support of SEARCH:

1. Arctic/Sub-Arctic Ocean Fluxes

2. Improved representation in models of Arctic ocean and climate processes using data assimilation and new satellite and ground-based sensors

3. Arctic climate and radiation networks coordination and maintenance

4. Application of New Capabilities and Technologies to Arctic Ocean Exploration and Discovery

5. Changes in Long Range Transport of Heat, Moisture, and Contaminants to the Arctic

6. Bering Sea Region Environmental Change

7. Assessment of the Effects of Environmental Change on Indigenous People and other Residents in Alaska (subsistence hunting, fishing, gathering; health; land-use and occupancy; cultural/spiritual well-being)

8. Response of Terrestrial Ecosystems to Climate Induced Changes in the Physical Terrestrial Environment, including hydrology and permafrost issues

9. Arctic Climate Impact Assessment (ACIA)

10. Changes in Arctic Glaciers and Ice Caps

Potential Coordination Mechanisms

Having agreed that the above topics represent fertile ground for interagency collaboration, the IWG considered how collaboration could be undertaken. It was agreed that the following represent feasible ways of having substantial, effective interagency collaboration in FY2001:

1. Issuance of Joint Call for Proposals
2. Program Manager Consultation on Decisions from Independent Calls for Proposals
3. Multi-agency Synthesis Meetings to Bring Together Results from Independent Activities
4. Multi-agency Planning Meetings to Define Mutual Science Objectives and Develop Collaborations for the Future
5. Interagency Agreements to Jointly Conduct Activities
6. Establishment of Joint Interagency Program Office
7. Annual meetings of Principal Investigators and Program Managers from participating agencies for joint projects.

Chapter 3: Conclusions and Recommendations

The IWG for SEARCH has concluded that the Science Plan for the Study of Environmental Arctic Change describes a complex and vital science problem, that it contains elements of interest to several of the Federal agencies, and that there is benefit to a multi-agency approach for implementing SEARCH. The IWG has developed a plan of action for FY2001-2003 that is being presented to the IARPC via this report. **The IWG makes the following recommendations to the IARPC and asks for a response by September 29, 2000:**

Recommendation 1: The IARPC should approve the proposed FY2001 SEARCH Implementation Plan composed of ten specific science activities, and empower the IWG-SEARCH to oversee its implementation and to report to the IARPC early in FY2002 on the degree of its success.

Recommendation 2: The IARPC should approve the preparation of a summary of agency requests for FY2002 that support SEARCH and charge the IWG with completing this action by January 2001.

Recommendation 3: The IARPC should agree to preparation of a coordinated interagency budget request for FY2003 to support SEARCH. The IARPC should empower the IWG to prepare this budget request and should provide guidance to the IWG for meshing this interagency request with the established agency budget processes.

Recommendation 4: The IARPC should agree to provide their representatives on the IWG with the necessary time and financial support to carry out these recommendations.

Appendix 1: Participants in IWG-SEARCH

Interagency Working Group Members

National Oceanic and Atmospheric Administration: John Calder (Chair)

National Aeronautics and Space Administration: Kim Partington (Vice-Chair)

U.S. Environmental Protection Agency: Suzanne Marcy

National Science Foundation: Michael Ledbetter

U.S. Department of Defense: Dennis Conlon, Don Perovich, Jackie Richter-Menge

U.S. Department of Energy: Merrill Heit

IARPC Liaison: Charles Myers (NSF)

Other Participants

Smithsonian Institution: William Fitzhugh

U.S. Department of Interior – Nolan Heath, Janet Hohn, Gordon Nelson

Arctic Research Commission: Garry Brass

Appendix 2: FY2001 Implementation Plans

A. Arctic/Sub-Arctic Ocean Fluxes
B. Improved Representation of Arctic Ocean and Climate Processes Through Integration of Models and Observations
C. Arctic Climate and Radiation Networks Coordination and Maintenance
D. Application of New Capabilities and Technologies to Arctic Ocean Exploration and Discovery
E. Changes in Long Range Transport of Heat, Moisture, and Contaminants to the Arctic
F. Response of Ecosystems of the Bering Sea Region to Environmental Change
G. Assessment of the Effects of Environmental Change on Indigenous People and other Residents in Alaska
H. Response of Terrestrial Ecosystems to Climate Induced Changes in the Physical Terrestrial Environment
I. Arctic Climate Impact Assessment
J. Changes in Arctic Glaciers and Ice Caps

TOPIC TITLE: Arctic/Sub-Arctic Ocean Fluxes
PARTICIPATING AGENCIES: National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), Department of Defense (DOD), National Aeronautics and Space Administration (NASA)

SCIENCE OVERVIEW:

The high latitude oceans form an important component of the total climate system, not least because the polar and sub-polar seas of both hemispheres are the formation regions for the deep water of the world's oceans. They thereby play a key role in the thermohaline circulation. The vertical overturning that regulates the thermohaline circulation is affected crucially by the buoyancy of the upper ocean layers. Atmospheric exchanges of heat and freshwater at the ocean surface have a direct influence on this, though other factors are also involved. These other factors include advection of relatively saline water from the south by the Atlantic Ocean circulation in the northern hemisphere, ice shelf processes in the southern hemisphere, and high latitude hydrological cycle. Particular high latitude processes involved in this context include sea ice formation and melt, iceberg discharge, and northern hemispheric riverine input.

For some time now, we have known or supposed that variability in the Arctic has some special role to play in the processes of global change. Polar amplification and feedback are recurrent themes in numerical climate modeling. However we have hitherto lacked many of the ocean time-series needed to demonstrate the basic features of long term hydrographic change within the Arctic Ocean. Gaining such information is essential to testing hypotheses 1 and 3 of the draft SEARCH Science Plan.

This situation improved dramatically during the 1990s. First, there was a major increase in the ship-based ocean-observing effort, contributed both by surface ships, and by the almost-annual submarine surveys of the US SCICEX Program (1993-99). These efforts provided vital data on ice thickness to complement available data on ice extent. Second, the release of a vast military archive of ocean data supplied the improved ocean "climatology" against which the new data-sets might be compared for evidence of change. Third, whether we use the newly-described Arctic Oscillation or the North Atlantic Oscillation as the more-appropriate index of Arctic climate, it seems clear that winter climatic forcing over the Arctic and its subjacent seas was at a century-long extreme state during the 1990s. This meant that when data and climatology were compared, the changes identified were spectacular and of a large-enough amplitude to be traceable through a gappy observing system and to stand out against a still-shaky climatology. Fourth, the development of a range of remote sensing techniques, including a now-mature capability to monitor the drift of the Arctic ice cover, means that we are in a much better position to investigate the relative roles of dynamics and thermodynamics in driving surface processes across the Arctic basin.

Three main changes in particular have characterized the period of the 1990s. The first was a more intense and more widespread influence of Atlantic water than previously observed, with a warming and spreading of the Atlantic-derived sublayer across the Eurasian Basin. Secondly, the increasingly anomalous southerly airflow over Nordic seas that accompanied this change is held responsible for a progressive warming and perhaps a strengthening of the two streams of Atlantic water that enter the Arctic Ocean, across the Barents Sea shelf and along the Arctic Slope west of Spitsbergen. The third new feature to emerge during the 1990s was the evidence to link this long-term variability of the Arctic Ocean with seas further south through evidence of an increased annual ice efflux through the western Fram Strait.

While these regional events seem unambiguous, we cannot yet answer the larger question of whether such changes in the ocean-atmosphere system of the Arctic have global change implications. We can identify a range of potential effects of course. These may be local, through the effect of a changing ocean-stratification and ice cover on surface heat flux or air-sea carbon dioxide flux, or remote, through the variable export of fresh waters and heat to the headwaters of the global thermohaline circulation for example. But we continue to lack knowledge of the mechanisms that are supposed to underpin these links to "global change", and while we may

have confidence that our observations have qualitatively captured the essence of recent Arctic variability, we are a long way short of being able to quantify these changes.

Thus, en route to answering the global change question, the priority issues would seem to be " how does the Arctic Ocean circulation work and what are the important inputs and outputs? In particular what do we have to do to improve our estimates of: the heat flux from lower latitudes to the Arctic Ocean, the freshwater flux from the Arctic to lower latitudes, and the feedback in the carbon dioxide cycle?"

FY2001 SCIENCE ACTIVITIES:

As a result of two planning meetings held in FY2000, a small set of priority research activities have been identified. In FY2001, the participating agencies will begin implementation of these activities, in full cooperation with similar efforts being conducted by other nations. Among the potential high priority activities are:

1. Trans-Arctic hydrography sections, building on the work conducted in the 1990's by icebreakers and submarines
2. Use of bottom- or ice-moored instruments, profiling floats, and autonomous vehicles to augment ship-based measurements of water mass properties
3. Establishing long time-series measurements to close the mass balance of heat, salt, and volume flux at the sites that link the Arctic and sub-Arctic oceans through use of moorings, acoustic measurements, or other relevant technology.
4. Use of satellite-based remote sensing to quantify ice extent, ice flux, surface ocean circulation features, and wind fields to complement in situ measurements of ocean fluxes. This will include the use of RADARSAT radar data to investigate late 1990s ice flux through the Fram Strait and scatterometer and passive microwave satellite data to investigate decadal-scale changes in patterns of ice dynamics across the Arctic basin.

COORDINATION MECHANISM(S) FOR FY2001:

The participating agencies participated in the planning meetings held in FY2000 and are engaged in consultation to provide a coordinated approach to this science effort. In particular, Program Managers intend to meet before final decisions on proposals received through individual agency announcements to coordinate funding actions and cost-share on proposals as appropriate. The agencies will support workshops, web sites and other means of promoting coordination among the scientific investigators in the the U.S. and other countries.

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NASA – Kim Partington 202-358-0746 kparting@hq.nasa.gov

TOPIC TITLE:	Improved Representation of Arctic Ocean and Climate Processes Through Integration of Models with Observations
PARTICIPATING AGENCIES:	National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Department of Defense (DOD), National Oceanic and Atmospheric Administration (NOAA)

SCIENCE OVERVIEW:

Models of the global climate system suggest that any persistent change is likely to be particularly evident at high northern latitudes. In recent years, indications of such change have been accumulating in phenomena as diverse as permafrost active-zone depths, sea ice thickness and extent, air temperatures, and the frequencies of Arctic cyclones. Our present level of understanding is such that we do not, in general, have a clear understanding of how these and many other observed changes interact, if at all. Until such a level of understanding is forthcoming it will be difficult to establish with certainty the extent to which these changes are a result of natural climate variability or are a result of anthropogenic activities. Achieving this level of understanding relates directly to SEARCH hypotheses 1 and 2.

We are now at the stage where we have an opportunity to develop techniques that allow us to explore these interactions, for the following reasons:

- We are now entering an era in which we have a greatly increased range of satellite sensors available (e.g. TERRA, AQUA, SEAWINDS, all satellites able to contribute to an improved knowledge of polar processes);
- Experiments such as SHEBA ("Surface Heat Balance of the Arctic Ocean"), and BOREAS ("Boreal Ecosystem-Atmosphere Study") have provided significantly improved understanding of processes of surface-atmosphere interaction;
- A higher-resolution ocean-ice model gives a vastly improved representation of ocean currents, including the connections to Atlantic and Pacific circulation;
- Availability of historical ice-draft data from formerly classified US and British submarine cruises;
- Access to historical Russian hydrographic data from the major freshwater sources to the ocean;
- A number of algorithm techniques have been developed over the last few years that have the potential to allow us to explore interactions between the various elements of Arctic climate more closely, particularly data assimilation.

GOALS:

In order to answer complex questions about the interactions of diverse elements of the climate system, we need strategies to be able to make sophisticated use of models and observations in the Arctic. At the same time, the design and implementation of these tools needs to be driven by the science questions. The aims of this activity are therefore as follows:

Ultimate objective

- To improve the ability of climate models to accurately simulate, predict, and assess the full scope of climate system interactions in the Arctic region and their connections to the global climate system;

Intermediate goals

- Development and implementation of statistical techniques using wide coverage data-sets to test hypotheses regarding the Arctic Oscillation and other significant climate system processes that operate in the Arctic region;
- Development of new models or improvement to existing models to address the physical basis for observed tele-connections in the Arctic climate system;
- Development and demonstration of techniques that allow synthesis of observations with models (specifically, but not exclusively, data assimilation), the aim being to provide new or

improved quality information on Arctic conditions, such as ice thickness distribution, that cannot be obtained using existing models or observations alone.

- Provision of requirements on (a) refinements to existing observation techniques, (b) the development of new observation techniques and technologies and (c) campaign strategies to enhance currently sparse data coverage (satellite, airborne and autonomous surface observations) for evaluating Arctic climate.

FY01 ACTIVITIES:

- Use of the RADARSAT Geophysical Processor System (RGPS) to process high resolution synthetic aperture radar data collected over the Arctic basin from 1996-2000. This system has been developed at NASA's Jet Propulsion Laboratory and is being operated at the Alaska SAR Facility. The RGPS combines a model of ice growth with Lagrangian observations of ice drift at high spatial resolution in order to provide information on the distribution and thickness of thin ice and hence provides information on heat and brine fluxes.
- "Role of the Polar Oceans in Contemporary Global Climate Change", an interdisciplinary study aimed at the use of a broad array of data types to investigate large-scale processes of energy exchange and momentum balance operating at the ocean-ice-atmosphere interface. In particular, objectives relate to the heat and moisture budget of the polar atmosphere and the influence of polar clouds.
- Assimilation of satellite measurements with the specific aim of improving estimates of heat and salt fluxes at polar latitudes;
- *Sub-set of new Oceanography research announcement successful proposers, starting 1/1/01* (3 year program, includes objectives related to polar ocean climate processes and pilot investigations of data assimilation techniques, NRA-00-OES-05);
- Initiation of SHEBA Ocean modeling phase to improve process, regional, column, and GCM representations of arctic in ocean-ice-atmosphere models;
- Developments to ocean-ice-atmosphere models, including inter-comparisons of different models, augmentations of sea-ice representation including the addition of snow cover and improved ice thickness distributions and use of models to investigate inter-annual variabilities and sensitivity to external forcings.

COORDINATION MECHANISMS FOR FY01:

- Workshop proposed for last quarter of FY01 to review state of knowledge related to intermediate goals and to consider any preliminary implications for ultimate objective. This will assist with plans for FY02 and beyond. For example, models at GFDL, NCAR, Hadley Centre, the Canadian Climate Centre, and the Max Planck Institute (and others) are used for global change studies. A workshop focusing on the similarities and differences of their results and plans might be useful.
- Continued NOAA-NASA collaboration on comparison of modeled and observed data
- Coordination of research announcements (starting with NASA research announcement, NRA-00-OES-05) for possible collaboration, joint funding, proposal reviews, etc.

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TOPIC TITLE: Arctic Climate and Radiation Networks Coordination and Maintenance
PARTICIPATING AGENCIES: National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Department of Energy (DOE), Department of Agriculture (USDA), Department of Interior (DOI), Smithsonian Institution (SI)

SCIENCE OVERVIEW:
Because of logistical difficulties, remote location, and sparse human habitation, long-term observation programs have historically been extremely limited in the Arctic. Yet to understand climate-scale change, long-term measurements are critical. Recent technological advances make it possible to enhance existing facilities and measurement programs. Several U.S. agencies have existing stations and networks in the Arctic to provide long-time series measurements of climate related variables. Among these networks are:

1. International Arctic Drifting Buoy Program (9 U.S. institutions and 9 other countries)
2. Barrow, Alaska Observatory (NOAA)
3. UVB and other radiation observations (NOAA, NSF, USDA, Smithsonian, DOI-NPS)
4. Atmospheric Radiation Measurement Program – North Slope (DOE)
5. Greenland climate network (NASA)
6. North Pole Station of automated buoys and oceanographic mooring (NSF, NOAA)

These monitoring networks are on-going operational or long-term research programs. In many cases, the measurement program in the US Arctic is coupled with similar activities in other countries, so that an international network is in place. The goals of the monitoring networks are to keep track of changes in the Arctic environment, and to provide a data base on which to initiate predictions of future changes. In some cases, the activities at these various Arctic sites already represent interagency activities, while in other cases, the lack of coordination is preventing existing infrastructure from being used to its full potential.

FY2001 SCIENCE ACTIVITIES:
The **International Arctic Buoy Program** (IABP) maintains a network of automatic meteorological and oceanographic data buoys in the Arctic Basin. These buoys monitor atmosphere, ocean, and ice in support of real-time operations research. The Arctic buoy program, active since 1979, now has 22 participating organizations representing 10 countries. U.S. contributions from NASA, ONR, NOAA, USCG and NSF are used for buoy procurements, logistics and data management. Overall program management is provided by the Navy/NOAA National Ice Center. IABP data management and program coordination is performed by the Polar Science Center at the University of Washington. At any one time, 10-15 U.S. owned buoys are operating in an overall Arctic network consisting of 30-40 buoys. Further information on the IABP can be obtained from IABP website at http://iabp.apl.washington.edu

The **Barrow Observatory,** established by NOAA in1972, conducts research based on the measurement of atmospheric constituents that are capable of forcing change in climate, and of those that may cause depletion of the global ozone layer. These measurements (numbering about 200) include the longest continuous records of atmospheric CO_2 and fluorocarbon trace gas concentrations, aerosol concentrations, surface and total ozone, and solar radiation in the Arctic. The site is an active participant in the WMO/WCRP Baseline Surface Radiation Network and works in close collaboration with the DOE ARM program. In addition to its own programs, the NOAA Barrow Observatory currently hosts 22 cooperative research projects from universities and other agencies covering topics such as trace gases, aerosols, magnetic fields, CO_2 fluxes, solar radiation, permafrost temperatures, atmospheric mercury and solar radiation. For more information, see the website at http://www.cmdl.noaa.gov/obop/brw/index.html

The measurement of **UV radiation** remains difficult, with no single sensing system adequate to satisfy all requirements. Hence, several agencies have UV programs in the Arctic. The NSF, USDA, DOI-NPS, and Smithsonian operate spectral filter devices at high-latitude sites, not all on

US territory. The DOE operates a radiation measurement program inland from Barrow. At Barrow itself, NOAA operates several instruments, with special emphasis on the need to derive column ozone information from the UV data that are collected. Elsewhere in the Alaskan Arctic, NOAA uses newly developed UV instrumentation to explore the spatial aspect of the high latitude UV problem. The UV measurement programs are usually integrated with measurement focusing on other aspects of the surface radiation budget, and at Barrow in particular they are coupled with monitoring programs addressing air quality.

The **Greenland climate network** was established in Spring, 1994 with the goal of monitoring climatological and glaciological parameters across the Greenland ice sheet. The network supports surface energy balance, climatology and snow accumulation rate studies. Changes in the mass balance of the ice sheet can be initiated through changes in surface energy balance and these observations play a key role in monitoring this process and in interpreting changes observed from remote sensing data. The observations are also of value to broader regional climate studies. More information is available at http://cires.colorado.edu/people/steffen.group/gc_net.html

The overarching goal of the **Atmospheric Radiation Measurement Program** (ARM) is to improve the performance of atmospheric general circulation models used for climate research and prediction. Field sites were designed to satisfy data requirements to model the instantaneous radiative flux through the atmosphere and to model the presence and life cycle of clouds in general circulation models of the atmosphere. The Arctic site was placed in the vicinity of Barrow, Alaska, to provide for logistical supportability and to take advantage of data being acquired by related programs such as NOAA Barrow Observatory. The Barrow facility is complemented by a limited set of instruments installed at the village of Atqasuk, about 100 kilometers south of Barrow, to document and take advantage of the differences between coastal and inland locations regarding cloud cover and net radiative fluxes. For more information see http://www.arm.gov/docs/sites/nsa/nsaaao.html

The **North Pole Station** established in 2000 by NSF, with the support of NOAA and JAMSTEC (Japan) and coordination by the Polar Science Center/University of Washington, is maintaining a 5-year remote North Pole drifting station for climate-related measurements. The second year deployment will take place in April 2001. Observations include times series of standard meteorological measurements, radiation, ice and snow thickness, upper ocean structure and regional currents. These observations will be compared to historical records from Russian North Pole stations. http://psc.apl.washington.edu/northpole/index.html

COORDINATION MECHANISM(S) FOR FY2001:
Workshop to review current status of climate and radiation monitoring in Alaska and the Arctic, and to provide recommendations for key elements of an interagency 5 year plan for initiation in FY2003. The plan would consider variables, sites, facilities, data archive, and data assimilation issues.

Workshop to plan the next 5 year implementation of the International Arctic Drifting Buoy Program.

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TOPIC TITLE: Application of New Capabilities and Technologies to Arctic Ocean Exploration and Discovery

PARTICIPATING AGENCIES: National Science Foundation (NSF), Department of Defense (DOD), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA)

SCIENCE OVERVIEW:

It is becoming increasingly apparent that the Arctic Ocean is the first region to see the more pronounced differences induced by global warming. The thickness of the Arctic ice pack has decreased dramatically over only the last few decades, and the extent of the pack is likewise in retreat. Nevertheless, the Arctic remains the least observed of the world's oceans, and new methodologies are essential to gain the information needed to understand this ice-covered, challenging environment. With the end of the U.S. Navy's SCICEX program, U.S. submarine assets are no longer available to the scientific community, and new vehicles (e.g., AUVs and ROVs) may fill that gap in capabilities. The launch of the new research icebreaker USS HEALY represents the most important new U.S. Arctic research capability in decades. The means must be created to observe the three-dimensional physical structure of the Arctic Ocean and its variability over both short (i.e., daily) and long (i.e., decadal and longer) time scales, which means that long term observatories must be developed. Complementary techniques must also be developed to study biological communities, and the interaction of humans with the changing environment.

GOALS:

The goals of this action area are to develop new technologies and to apply new capabilities to studies of the Arctic Ocean. Longer-lived (ca. 30 days), longer-range (ca. 1000s nmi), deeper-diving (ca. 4000 m) autonomous underwater vehicles (AUVs) are needed to continue exploration of the under-ice Arctic Ocean. Fixed or multi-deployable seafloor observatories are also needed to examine *in situ*, new polar scientific discoveries. Larger numbers of remotely operated vehicles (ROVs) are likewise essential. They must have better sensor capabilities, and be suited to a variety of tasks, from small-scale observations to large-scale payloads. Overall success will be dependent upon development of greater sensor capability – e.g., better and smaller electrical, acoustical and optical sensors. The outcomes of the exploration of the Arctic Ocean in the new millennium will be scientific discoveries, never before imagined, that will benefit society and our environmental stewardship of the planet Earth.

FY01 ACTIVITIES:

A. Autonomous Underwater Vehicle deployment in the Arctic Ocean.
A team of investigators led by Dr. Jim Bellingham of the Monterey Bay Aquarium Research Institute and MIT is building an under-ice, long-range AUV for deployment in FY01 to an Arctic site. The objective of the deployment will be to measure the inflow of Atlantic Ocean waters into the Arctic and its modification as it penetrates the Arctic Basin. The goal is to achieve an 11-day, 1400 km transect under the ice, in order to: 1) obtain new data on the modification of Atlantic waters in the Arctic; 2) demonstrate a powerful new survey capability for the entire Arctic Ocean; and 3) establish new standards for range, endurance and reliability for autonomous systems in polar research.

B. ACOUS
ACOUS (Arctic Climate Observations Using Underwater Sound) is an effort which employs precise measurement of the times of acoustic transmissions across long distances to infer the temperature structure of the intervening water column (frequently referred to as ocean acoustic tomography). As part of a joint effort initiated under the Gore-Chernomyrdin agreements, an acoustic source was manufactured in Russia and deployed in the waters north of Franz Josef Land in October, 1999. Since that time, a temporary hydrophone array north of Greenland has

recorded the source transmissions that have occurred every four days. This array will be retrieved and renewed in the FY2001 timeframe, providing an unprecedented time series of temperature structure in the Arctic over a two-year period.

C. High Spectral Resolution Lidar

An improved version of a High Spectral Resolution Lidar (laser radar) will be built, tested and deployed in either Prudhoe Bay or Barrow, Alaska, in FY2001. The instrumentation will provide a long term record of Arctic cloud and aerosol variables. The scientific goals include observations of a full annual cycle of cloud properties; providing a quantitative assessment of Arctic haze; and identification of pollution sources.

D. Aerosondes for Long-Term Measurements of the Atmosphere and Sea Ice Surface in the Beaufort/Chukchi Sector of the Arctic Ocean

This project will involve the development of an Arctic-capable aerosonde and instrument package, and collection of data in the Barrow, Alaska, vicinity. The aerosonde is an autonomous aircraft that builds on a design of a smaller platform that has flown in the Arctic. The improved aerosonde will be more robust and have increased navigational and scientific instrumentation than its predecessor. The improved aerosonde will be able to fly over land and sea ice in order to make measurements of surface and near-surface properties that play a role in the redistribution of heat in climate feedback systems.

E. Deployment of new buoy-mounted sensors

NSF and ONR are jointly supporting the Shelf Basin Interaction Study, which involves research into the shelf and near-shelf processes which produce the deep water of the Arctic Basin. One task of this work is to monitor the inflow to the Beaufort – Chukchi Seas from the Bering Strait. Two moorings are currently in place, but these moorings will likely be augmented in FY2001, and may include the additional participation of NOAA.

F. Development of enhanced airborne radar sounding techniques for glacial Ice

NASA is developing airborne radar sounding technology aimed at enhancing our ability to explore the internal and basal conditions of glacial ice masses and has applied this technology to the Greenland ice sheet. The techniques include developing an ability for high-resolution mapping volcanic layers within top 200 meters of ice that can be used to infer integrated, long-term accumulation rates and establishing the extent which basal conditions can be inferred from deep sounding radar.

COORDINATION MECHANISMS FOR FY01:

At the project level, coordination is effected through direct communications between agency program managers. In addition, a NOAA call for proposals in early FY2001 will take into account possible cooperation with NSF and ONR on the Shelf Basin Interaction Study.

DELIVERABLES:

1. Two-year record of trans-Arctic acoustic transmissions, and estimate of feasibility of pan-Arctic network.
2. Deployment of Arctic AUV in Arctic experiment.
3. Building a high-resolution lidar.
4. Building first prototype of Arctic aerosonde.
5. Deployment of enhanced moorings to monitor Bering Strait inflow into the Arctic.

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TOPIC TITLE: Changes in Long-Range Transport of Heat, Moisture, and Contaminants to the Arctic

PARTICIPATING AGENCIES: National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), U. S. Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), Department of Energy (DOE)

SCIENCE OVERVIEW:

The overall heat balance of the Earth is the result of processes that absorb the Sun's energy, that distribute it, and that radiate it back to space. Most energy is absorbed in the tropics, distributed pole-ward by ocean and atmospheric circulation, and radiated to space from the polar regions. Thus the energy budget in the Arctic is of critical importance for maintaining the overall global energy budget, and for controlling regional processes such as ice formation/melting, weather patterns, and precipitation rates. During the SHEBA experiment, conducted during an El Nino year, there were anomalous ice conditions related to anomalous atmospheric circulation. There was a net heat gain in the Arctic during that unusual year. Current Global Climate Models (GCMs) vary substantially in describing the basic Arctic climate, due in part to limited historical climate data, few weather stations, and great natural climate variability. Recent changes in temperature and the state of the Arctic Oscillation are not yet attributable to either natural variability or anthropogenic forcing. To test the SEARCH hypotheses, it is necessary to understand interannual variability in the transport of heat and moisture to the Arctic, and to improve models that describe regional impacts of anomalies in atmospheric circulation, in connection with the Arctic Oscillation. It is necessary to characterize the differential impacts of heat transported to the Arctic by the oceans or by the atmosphere. New polar orbiting satellites can help in this effort, but we need to learn how to properly interpret satellite data taken over surfaces such as sea ice.

NOAA, NSF and NASA are supporting retrospective studies of climate change in the Arctic. These large-scale changes are associated with a transfer of atmospheric mass from the high Arctic to mid-latitudes, with lower sea level pressure over the high Arctic and increasing zonal winds aloft. This shift is referred to as the Arctic Oscillation (AO). A major shift occurred in wintertime beginning 1989, and a more gradual shift is noticed in late spring and summer from the late 1960s. Changes in ice amounts and drift patterns are correlated with AO phenomenon.

Pollutants may be transported over long distances through the atmosphere and through the ocean. In particular, long-range atmospheric transport across the Pacific and Arctic from Pacific Rim countries, and south-to-north transport from the Americas, may be responsible for elevated pollutant levels found in many parts of the Arctic. The types of pollutants involved – many of which are implicated in issues such as global climate change, stratospheric ozone depletion, and global distribution of endocrine-disrupting chemicals – include photochemical, acidic, and other gaseous species; soil and anthropogenic aerosols; and toxics such as persistent organic compounds, heavy metals, and radionuclides. Marine species that migrate through out the Pacific basin and the Arctic can also be vectors for transport of pollutants from source areas to the Arctic. The risks from long-range transport are expected to increase as economic development increases.

FY2001 SCIENCE ACTIVITIES:

NOAA, NSF, and NASA are continuing a number of activities concerning long-range transport to the Arctic. NOAA has been monitoring gas and aerosol transport to the Barrow Baseline Station since 1972. NOAA, NSF and NASA have conducted research on Arctic haze and the effects of the haze on the radiation budget throughout the Arctic Basin. Archived data are being analyzed to better understand transport and climate changes that have occurred in the Arctic over the past 20 years. It has been established that March arctic haze concentrations (air pollution from Eurasia) have decreased by 50% between 1982 and 1997 at the Barrow baseline station. This

change is thought to be due to a reduction in source strength due to the economic downturn in Russia Backward trajectories from Barrow show that in the winter months combustion air pollutants from Siberian industrial regions dominate the air transported to Barrow.

The three agencies are collaborating on a relatively new program, namely, "Intercontinental Transport and Chemical Transformation (ITCT)." The program aims to develop a better understanding of the atmospheric and climatic implications of intercontinental transport and the intervening chemical transformation. The ITCT has recognized that transport to or from the Arctic is an issue that merits international scientific attention.

Additionally, the three agencies are collaborating on international experiments to study ozone in the high northern latitudes, including the recently completed 1999-2000 SAGE III Ozone Loss Validation Experiment (SOLVE) that examined springtime ozone loss in the Arctic

NOAA, EPA, and the DOE will continue a collaborative effort at Barrow to measure atmospheric mercury, especially reactive gaseous mercury. The air contains a readily measurable amount of gaseous mercury, derived from distant sources as well as from local incineration, etc. Most of this mercury is relatively inert, residing in the air in gaseous elemental form. Some of the mercury, however, exists in a chemically reactive form that deposits quickly to the surface and enters into ecosystem dynamics as a powerful interferent. This Reactive Gaseous Mercury (RGM) has been shown to exist in exceptionally high concentrations in Arctic air, probably because of UV-mediated in-air chemistry. The highest levels of RGM ever recorded in the atmosphere were recently measured at Barrow.

NOAA and NSF are supporting studies to monitor the fluxes of heat, water vapor, CO2, and ozone between the air and the ice/water/land surface of the North Slope, near Barrow. The data have demonstrated the consequences of land use change accompanying the exploitation of the North Slope oil and gas fields.

A conference titled “Trans-Pacific Transport of Atmospheric Contaminants” was sponsored by EPA, NOAA, and DOE in July 2000. This conference produced a set of recommendations for research to fill known gaps in knowledge on this subject. In FY2001, these agencies will begin to direct their related on-going science programs to fill these gaps.

Activities discussed here related to Arctic ozone depletion support the UNEP/WMO 2002 assessment on ozone depletion.

COORDINATION MECHANISMS FOR FY2001:

EPA, NOAA, DOE, and NSF will prepare a coordinated science strategy dealing with long-range transport of heat, moisture, and contaminants through the atmosphere to the Arctic.

An Interagency Agreement between NOAA and EPA will support continued measurement of mercury in the atmosphere at Barrow, Alaska.

NOAA, NASA, and NSF will prepare a coordinated approach for developing the U.S. contribution to the UNEP/WMO 2002 assessment on ozone depletion.

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TOPIC TITLE: Response of Ecosystems of the Bering Sea Region to Environmental Change

PARTICIPATING AGENCIES: U.S. Environmental Protection Agency (EPA); National Oceanic and Atmospheric Administration (NOAA); National Aeronautics and Space Administration (NASA); National Science Foundation (NSF); Department of the Interior (DOI)

SCIENCE OVERVIEW:

The Bering Sea ecosystem is among the most productive of high latitude seas. It is a rich, abundant, and ecologically diverse system that has attracted and supported aboriginal cultures across millennia. The ecosystems of the Bering Sea region are shaped by a kaleidoscope of oceanographic, geophysical, biochemical, economic, and cultural forces. Over the last two decades changes in Bering Sea resources have been profound. Steller sea lions declined 50 to 80 percent and are now listed as "endangered". Northern fur seals are listed as "depleted" under the Marine Mammal Protection Act. Bering Sea populations of common murres, thick-billed murres, and red and black-legged kittiwakes declined up to 90 percent. In 1999 the collapse of the salmon fishery in Bristol Bay led the State to declare the region an economic disaster.

Concurrent with biotic declines, there are significant changes in the oceanographic and atmospheric Arctic environment. Observations and historical analysis made by NOAA and NSF over the last six years show that the Bering Sea ecosystem experiences large inter-annual climate variability. Observations under the Southeast Bering Sea Carrying Capacity (SEBSCC) program and Inner Fronts program points to the influence of hemispheric processes on Bering Sea resources, explaining, many believe, the observed biotic declines. However, observed changes in biota have also been linked with a long history of natural resource exploitation spanning two centuries, but which has increased dramatically within the last few decades (NAS, 1996). There is rising evidence of increased loadings of pollutants being transported to and sequestered in Arctic oceanic, atmospheric, and terrestrial environments, and biota (AMAP, 1998). Alteration of the ocean floor from industrial fishing and change in terrestrial habitats caused by development activities has also occurred during the period of biotic declines, and cannot be excluded as factors in these declines. This suite of natural change and human influences are likely altering the biocomplexity of the Bering Sea in ways not yet understood. Quantifying the relative importance of natural and human-induced variations in explaining upper trophic level ecosystem change is a key management issue for the Bering Sea.

Concern about the Bering Sea has engendered large and intense research synthesis and planning efforts; it is a region of significant research investment. These efforts share a commitment by scientists from diverse disciplines and organizations to come together to define the most important research needs and share research results. The quality of past and current research is unquestioned. Yet our understanding of changes occurring in the Bering Sea and its biocomplexity remain elusive. This prompted the Arctic Research Commission to target an integrated assessment of the Bering Sea as one of its priorities for 2001. Ecosystems in the Bering Sea region provide an opportunity to test all four of the SEARCH hypotheses as they relate to biological change. Results will provide new insight on the causes of the biotic changes occurring in the Bering Sea and provide an estimate of what the future may hold for native people and commercial enterprises dependent on the Bering Sea's riches.

GOALS:

- Build an inter-disciplinary, integrated knowledge base for the Bering Sea
- Synthesize available information into conceptual models that identify potential linkages among natural and human induced stressors to achieve new insights and guide future research
- Perform integrated ecosystem-level assessments for the Bering Sea that link ecological, cultural, economic and health challenges to physical change in the environment, recognizing both natural phenomena and human activities that impact Bering Sea ecosystems and indigenous populations.

FY2001 SCIENCE ACTIVITIES:

- Complete a special journal issue of Deep Sea Research based on 5 years of climate research on the Bering Sea shelf ecosystem through coordinated NOAA/NSF field research programs. Results will be synthesized in a NOAA Coastal Ocean Program Decisions Analysis Series Report
- Continue NOAA studies, including Fisheries-Oceanography Coordinated Investigations (FOCI), habitat and effects of fishing research, marine living resource assessments, monitoring of commercial fish catch, and ecosystem-level assessments.
- Continue NSF support for studies of physical and biological processes that drive marine productivity
- Continue NSF support for a shelf-basin interactions initiative to define the physical forcing mechanisms that cause changes in the biogeochemistry and productivity of Arctic shelf/slope waters
- Initiate USGS study of Yukon River discharge to the Bering Sea, including evaluation of contaminant loadings

COORDINATION MECHANISMS FOR 2001:

In addition to science activities above, specific coordinating activities include agency cooperation to integrate available data and information into draft conceptual models that describe relationships among human activities, physical processes, and ecosystem change. These models will be based on: input by interested parties; traditional knowledge of Native Alaskans; and scientific research. Specific activities:

- Bering Sea Summit 2001 for all interested parties to establish goals
- Workshop with key scientists from multiple disciplines to build preliminary conceptual models.

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TOPIC TITLE:	Assessment of Effects of Environmental Change on Indigenous People and Other Residents in the Arctic
PARTICIPATING AGENCIES:	National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), Smithsonian Institution (SI)

SCIENCE OVERVIEW:
Where researchers have studied evidence of past and contemporary cultures, it is clear that survival in the Arctic has depended upon adaptability. Changes in the Arctic have been tied historically to both local and global processes. In addition to change driven by seasonal extremes and variability, human activity within the region has caused significant environmental, economic, social, and cultural change (e.g., colonization, marine mammal hunting, fur trade, gold rush, urbanization). Arctic residents today have the capacity to foster or discourage some of the most extensive and precipitous changes in the region (e.g., large-scale oil development, logging, alteration of fire regimes, redirection of freshwater flow to the Arctic Basin).

Change has also come from human activity outside the Arctic (e.g. animal domestication, high-seas fishing; transport of ozone, greenhouse gases, and nuclear waste to the region; the hunting of birds and mammals in southern portions of their migratory route). Because humans are a catalyst of change on global and regional as well as local scales, it is essential to incorporate the human dimensions in any study of the arctic system. The human capacity to adapt to change in the Arctic will be further tested, as the polar regions are expected to sustain the early and significant changes associated with contemporary global change. It is not just the Arctic that will be affected, however. Some physical changes that originate in the Arctic could propagate to lower latitudes, changing air and sea temperatures, and affecting economies. For example, major Atlantic and Pacific fisheries could depend on ocean conditions that are influenced by arctic processes affected, in turn, by changes in climate. Ten percent of U.S. oil supplies come from arctic petroleum developments that are designed to perform under current conditions. For these reasons and others, the Arctic is seen as an early warning system for emerging global changes that will ultimately affect other areas as well. The experience of arctic peoples is, thus, instructive for humans elsewhere in the world who are striving to accommodate exacerbated fluctuations and accelerating rates of change in their respective natural and social environments.

The Arctic is extremely vulnerable to climate change and its impacts. The special report on regional impacts of climate change by Working Group II of the Intergovernmental Panel on Climate Change (IPCC) noted that over the period of IPCC assessment, climate change will contribute to major physical, ecological, sociological, and economic changes already begun in the Arctic. A considerable interdisciplinary effort is needed to collect and analyze information on the implications of these environmental changes for human populations.

The environment dominates many aspects of daily life in the Arctic; environmental changes are likely to have immediate, important consequences to arctic peoples. Human activities themselves may be a cause of environmental changes in the Arctic. For example, archaeologists have found evidence of prey overkill by prehistoric hunters and fishers, followed in some instances by local population declines and site abandonments. More contemporary versions of this dynamic include boom-and-bust cycles of Russian and Canadian fur trades, gold-rush mining, and oil-field development. In addition to consuming resources, settlements may generate contamination on scales ranging from local to regional. Such problems may alter the trophic dynamics of the arctic system, affecting the abundance and safety of terrestrial and marine food resources upon which many arctic peoples depend.

The greatest potential for arctic environmental change, however, may originate from outside the Arctic. Long-range transportation of contaminants, the global build-up of greenhouse gases, and stratospheric ozone depletion all have the potential to alter environments. Arctic ecosystems are particularly sensitive to such alteration and may see relatively early and substantial changes. The

natural variability and vulnerability of arctic biophysical systems, combined with humans' close dependence on those systems, magnify the potential importance of global change for arctic residents. Accurate predictions of future impacts require the inclusion of a human component (socio-economic and health aspects) as critical elements in the arctic system.

GOALS:
To assess the effects of environmental change on indigenous people and other residents, a research program examining the dynamics of linkages between human populations and the biological and physical environment of the Arctic is required. That research program should incorporate an integrative, interdisciplinary approach including the following:

1. The biophysical basis for future human impacts on the functioning of the Arctic system;
2. Recent and past patterns of habitat use (including land, water, and ice) and resource use (including subsistence, land tenure, domestication, farming, fishing, and resource extraction) where human consequences of global change are expected;
3. Patterns of human response and adaptation to environmental change (including settlement decisions, shifts in resource use, migration, diversification, impacts of environmental change on human health, and economic transitions);
4. The basis for sustainability, viability, resilience, and vulnerability in future interactions between humans and their environment; and
5. Development and implementation of an educational framework that offers feedback and learning opportunities for local stakeholders, scientists, and decision-makers.

FY2001 SCIENCE ACTIVITIES:
Two workshops will be conducted that will bring together researchers representing the social and physical sciences to discuss opportunities for conducting research that will advance this research theme. One will emphasize the cultural and social aspects of change in the Arctic and the other will emphasize the human role in the biocomplexity of Arctic systems. A third workshop will bring Arctic residents together with sea ice scientists to discuss mutual understanding of the impact of different sea ice conditions on the subsistence and cultural practices of the indigenous population. A fourth workshop will explore the effects of early Holocene climate and environmental change on High Arctic Mesolithic settlement in the Laptev Sea region.

COORDINATION MECHANISMS FOR FY2001:
The participating agencies are engaged in consultation to provide a coordinated approach to this science effort. In particular, Program Managers intend to consult on proposals before funding decisions are made. The highest priority proposals to be considered under the interagency coordination activity will be those that:

- Integrate methods and principles from the natural and social sciences, especially in the context of integrated assessment of the Arctic system;
- Interpret scientific results on temporal and spatial scales that are relevant to policy decisions made at local to global levels;
- Incorporate traditional knowledge;
- Involve indigenous peoples in the design and implementation of research;
- Interact with and complement the activities of other arctic and USGCRP projects; and
- Coordinate interdisciplinary Russian-American studies of the Laptev Sea region.

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TOPIC TITLE:	Response of Terrestrial Systems to Changes in the Physical Environment
PARTICIPATING AGENCIES:	National Science Foundation (NSF), Department of Defense DOD), National Aeronautics and Space Administration (NASA), Smithsonian Institution (SI), Department of Interior (DOI)

SCIENCE OVERVIEW:

Dramatic changes have occurred in non-glaciated terrestrial systems in response to a predominately warmer physical environment during the past decade. Those changes are by no means monolithic but trends of environmental variables over most of the Arctic demonstrate a clear picture of cryospheric, hydrologic, and ecosystem response consistent with regional warming. Permafrost temperatures have warmed resulting in disappearance of some southern permafrost zones with northern permafrost zones thawing earlier, deeper, and remaining thawed later in the season. Hydrologic changes include decreased snow cover and depth, increased precipitation, and significant seasonally and spatially variable changes in runoff. The ecosystem response to changes in the physical environment resulted in changed tundra species composition, northern migration of tree line, increased abundance of shrubs, and a change within tundra regions from a sink to a source for carbon dioxide.

The changes in terrestrial environmental variables are by no means a simple direct response to regionally warming atmospheric temperature trends. Indeed, some areas of the Arctic are cooling and the terrestrial systems have responded accordingly. The predominant pan-Arctic trend, however, is one of a response consistent with environmental warming. If nothing else is clear about the changes in terrestrial systems it is the high degree of biocomplexity inherent in the myriad direct and indirect climate, hydrologic, soil, ecosystem feedback mechanisms. Increased understanding of the vulnerability of arctic terrestrial systems to projected continued warming is important to the management of renewable natural resources, decisions concerning changes in land use, maintenance of existing/future infrastructure, mitigation of environmental impacts, and the sustainability of arctic communities, particularly those depending on a subsistence lifestyle.

SEARCH APPROACH:

A central question arises from the recent trend of climate warming and terrestrial system change: Are the changes related and are they part of a natural cycle or anthropologically induced? There have been cycles of atmospheric temperature change for thousands of years and fluctuations in terrestrial systems on the same time scale. The degree of warming in high-latitudes observed in the past few decades occurred in the 1930/40s and repeatedly in the paleoclimate record of the past millennia. The difficulty in making connections is twofold: correlating the most recent warming trend to observed changes in terrestrial systems and tying either the warming or the terrestrial changes to anthropological causes. The data simply do not exist and the understanding of the feedback processes is too insufficient to produce reliable evidence of either relationship. Having admitted that the problem is unsolvable at present does not exclude the possibility that it can be solved with a coordinated approach using available techniques and in a reasonable time frame. SEARCH provides the framework for accomplishing that goal because it allows coordinated observations of changes within the system while taking a system-level view of the biocomplexity of the Arctic on a sufficiently long time-scale to begin to identify feedback processes acting in response to both natural and anthropogenic causes/effects.

While many research projects have been funded by Federal agencies that address aspects of terrestrial system response to climate change, the agency efforts have not been coordinated to maximize a system-level understanding of causes/effects. SEARCH will facilitate the needed coordination to produce a research outcome that builds on the earlier efforts and take advantage of those results to design an interagency research program that seeks a system-level understanding of the environmental processes. The research program will include:

- long-term data collection from environments shown to be sensitive to climate change on the decadal time-scale,
- limited manipulative experiments to induce changes in terrestrial processes in response to climate change, and
- modeling studies designed to integrate knowledge about processes and feedbacks in order to build a predictive capability.

FY2001 SCIENCE ACTIVITIES:

The participating agencies have identified research activities that will implement the terrestrial system change component of SEARCH. A list of the high-priority activities include:

1. Collection of historical and current hydrologic data for the rivers draining into the Arctic Ocean;
2. Ecological studies along an environmental transect from coastal plain tundra to tree line in northwest Alaska;
3. Continuation of long-term observations at Toolik Lake and Bonanza Creek Long-Term Ecological Observatories (LTERs) and the Barrow Environmental Observatory;
4. Carbon flux studies from key tundra biomes in Alaska;
5. Investigations to assess the impact of climate change on land management planning;
6. Chemical and biological process studies in snow-soil systems;
7. Development and application of ground penetrating radar systems to assess the state of the ground.
8. Satellite remote sensing/mapping of terrestrial environments;
9. Manipulative studies of the effects of warming and increased atmospheric carbon dioxide on tundra plant communities;
10. Collection of circum-Arctic permafrost temperature and thaw depth data;
11. Ecosystem/climate modeling studies.
12. Human migration, adaptation, and response to climate and environmental change in early Holocene Siberia and Alaska

COORDINATION MECHANISMS FOR FY2001:

Agency efforts will include support of workshops and web sites in FY 2000 and 2001:

(1) arctic hydrology in global change,
(2) arctic biocomplexity, and
(3) land-atmosphere-ice interactions.

The coordination meeting will identify an interagency approach to the SEARCH science effort in terrestrial system research as well as coordinate funding actions on research projects.

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TOPIC TITLE: Arctic Climate Impact Assessment
PARTICIPATING AGENCIES: National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA)

SCIENCE OVERVIEW:

Scientific research and indigenous knowledge are increasingly providing evidence of changes in the Arctic region that are regionally specific or unique and amplified compared to those observed in other regions. Indeed, the Onami defined in the SEARCH Science Plan has catalyzed the interest of the scientific community in performing a comprehensive assessment of climate change in the Arctic and of the impacts such change may have. Past assessments have not adequately addressed the complexity of the impacts of these recent changes or potential future changes to the Arctic people. A number of issues require focused attention through the assessment process. These issues include the effects on fisheries, herding, agriculture, human health, infrastructure and the variety of ecosystems in the Arctic. The impacts are likely to be complex and sub-regional in nature. The adaptation of the Arctic people, including the development of coping strategies will be greatly enhanced by this assessment process.

The goal of the Arctic Climate Impact Assessment (ACIA) is to:

- *Evaluate and synthesize knowledge on climate variability, climate change, and increased UV radiation and their consequences, and*
- *Provide useful and reliable information to the governments, organizations and peoples of the Arctic region in order to support policy-making processes.*

The assessment will include environmental, human health, and social and economic impacts and recommend further actions. This assessment will be conducted in the context of other developments and pressures on the Arctic environment, its economy, regional resources, and peoples.

The ACIA will be overseen by an Assessment Steering Committee (ASC), composed of experts and stakeholders from all of the Arctic countries. The ACIA will be strongly based on an analysis of existing and forthcoming information including peer-reviewed publications, indigenous knowledge, and other documented information and data.

An assessment of the consequences of climate change in the Arctic region will lead to the development of fundamental and useful information for the nations of the Arctic region, their economy, resources, and peoples. Examples include, inter alia:

- Providing clear scientific evidence on climate and UV variability and change within the Arctic at hemispheric and regional levels, indicating the nature of impacts on human health, the natural environment, and food and water resources;

- Identifying gaps in basic knowledge and fundamental data that need to be acquired in order to better understand climate variability and change at a range of scales;

- Providing a clear and structured basis for future research into climate change, UV and their impacts including interactive modeling;

- Identifying key strategies for future monitoring programs (parameters, measurement precision and frequency);

- Providing a foundation for adaptive and coping strategies to be developed;

- Providing benchmarks for future climate assessments;

- Offering guidance with respect to national and international policy on issues relevant to climate change and ozone depletion, including the combined impacts of both.

The nations south of the Arctic will feel the impacts of climate change, but perhaps to a lesser degree. These nations will also benefit from the assessment. Similarly, several non-Arctic nations conduct Arctic research and their scientists can contribute significantly to the assessment.

The assessment will be documented in the following volumes:

- **Scientific Document.** A series of assessment reviews and analyses that lead to an integrated understanding for the Arctic region (across sectors, sub-regions, indigenous and local interests) and for the circumpolar Arctic nations. The scientific document will be fully referenced, and will be 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. The content of the scientific document will be the responsibility of lead authors and writing teams. The volume will be subject to peer review guided by the ASC.

- **Synthesis Document (**max. 20 pages, excluding tables and figures). A comprehensive summary that synthesizes the main findings of the assessment and places in a policy-makers framework the state of our knowledge concerning the consequences of climate change over the entire Arctic region. The synthesis document will be concise, insightful, and could be titled, "An Arctic Climate Impact Assessment: A Summary View." This volume will be prepared by the ASC in concert with a scientific editor and lead authors in a simple, jargon-free language meant for policy-makers and the broader public, and will be subjected to peer review guided by the ASC.

- **Policy Document.** AMAP and CAFF will produce a final document and will relate the information from the synthesis and scientific documents to the policy needs of the Arctic Council and provide recommendations for follow-up measures. AMAP and CAFF will address the question of what strategies can be recommended to cope with current environmental stresses, and possibly lessen the impacts of these changes in the climate and ultraviolet radiation. These recommendations will include advice relevant to national and international policy as well as advice to inhabitants of the Arctic.

FY2001 SCIENCE ACTIVITIES:

During FY2001, experts from the U.S. and other countries with Arctic interests will begin to prepare the assessment documents. There will be a number of general workshops (e.g., modeling) and workshops focused on preparing specific chapters of the assessment report. A communications and outreach strategy will be implemented to ensure that indigenous people and other Arctic residents and stakeholders are involved in the ACIA. First drafts of some chapters will be available for review by the end of FY2001. It is anticipated that this international Arctic Climate Impact Assessment will help shape the future directions of national programs such as SEARCH.

COORDINATION MECHANISM(S) FOR FY2001:

Both NSF and NOAA are represented on the Assessment Steering Committee, and in this way are involved in the first order planning for the Assessment. Both agencies are working together to establish a Secretariat at the University of Alaska, Fairbanks, to support the ACIA. The involvement of both agencies is defined in a proposal from the University to the NSF and in an agreement between the University and NOAA. Specific funding requirements have been identified and agreed to by NSF and NOAA.

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TOPIC TITLE: Changes in Arctic Glaciers and Ice Caps
PARTICIPATING AGENCIES: National Aeronautics and Space Administration (NASA), National Science Foundation (NSF)

SCIENCE OVERVIEW:
The Arctic contains many bodies of terrestrial ice that range in size from the Greenland ice sheet, with a volume of about 2.6×10^6 km^3, down to systems of glaciers that each represent an integrated response to their own regional climate. Any persistent climate change in the high northern latitudes could, through glaciers and their relationship to sea level, have major global impacts. It is therefore important to establish the extent to which Arctic glaciers are contributing to global sea level rise and, just as importantly, to estimate their sensitivities to any additional climate-induced change. This implies not only measurement of their current mass and its change through time, but also a knowledge of the mechanics of these glaciers and ice caps and the extent to which they are sensitive to external forcing. In the long term, this implies that studies of glaciers and ice caps become integrated with models of climate.

The Program for Arctic Regional Climate Assessment (PARCA) has been active as a NASA program since 1995 and has involved collaboration with NSF at a logistical level. The aims of this program are to understand the roles of Arctic glaciers and ice caps in the climate system. To date this program has focussed on the Greenland ice sheet. Recent results indicate that the Greenland ice sheet has been close to a state of overall balance during the last few years.

Smaller Arctic ice caps and glaciers are thought to be contributing, at some imprecisely determined level, to the current sea level rise of about 2.4 mm/yr. NSF has been supporting surveys of north-west North American glaciers. This area is one of the largest glaciated regions in the world outside of the polar regions, but only five to six glaciers out of thousands have been regularly monitored and have long-term records. NASA has begun a pilot study within the Global Land Ice Measurements from Space (GLIMS) program to use high-resolution satellite imagery (especially Landsat and ASTER) to quantify the extent of key sub-Arctic glaciers and changes in their extent.

GOALS:
The aims of this activity are as follows:

Ultimate objectives
- to establish the current mass balance of the major bodies of Arctic terrestrial ice and their relative contributions to observed sea level rise;
- to establish the sensitivities and rates of response of Arctic ice masses to both observed and possible climate change scenarios.

Intermediate goals (FY01)
- To publish a comprehensive revision of the mass balance of the Greenland ice sheet and to publish a special issue of Journal of Geophysical Research on PARCA;
- To archive and publish new data-sets of the Greenland ice sheet from the 1993-1999 PARCA field program, including accumulation from ice cores, basal topography, outlet glacier velocity fields, etc.;
- Completed airborne mass balance and volume change measurements on up to seventy glaciers in Alaska and Canada (and a few in Washington state) by using newly developed instrumentation and techniques.

FY01 ACTIVITIES:

- Development of internal radar sounding techniques for monitoring glacial ice and analysis of existing radar sounding data as a means of improving knowledge of the interior and basal properties of the Greenland ice sheet ;
- Investigation of mass balance characteristics of Canadian Ice Caps, including analysis of data collected during 2000;
- Polar ice sheet mapping from long term scatterometer and radiometer observations, for investigation of surface melt trends;
- *Program for Arctic Regional Climate Assessment*, one year NASA studies to be selected starting 1/1/01. These will include analysis of FY99 field season data in Greenland, including ice core data
- Investigation of the mass balance of north-west North American glaciers
- Surface velocities of outlet glaciers in eastern Greenland by the use of high-resolution (34 m pixel size) declassified intelligence satellite photographs (DISP) from 1963 to 1968.
- Initial acquisition of ASTER 15m stereo images of Greenland outlet glaciers and Alaska / western Canada glaciers to use for future advance/recession and surface velocity assessment.

COORDINATION MECHANISMS FOR FY01:

- Combined NASA-NSF meeting for FY01 to review results from analysis of FY99-00 field season data and to combine reporting of NSF and NASA activities.

DELIVERABLES:

- Joint NASA-NSF meeting annual report and executive summary.
- Journal of Geophysical Research special issue on PARCA, expected to be published during 2001.

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