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ARCTIC RESEARCH

OF THE UNITED STATES

INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

About the Journal

The journal *Arctic Research of the United States* is for people and organizations interested in learning about U.S. Government-financed Arctic research activities. It is published semi-annually (spring and fall) by the National Science Foundation on behalf of the Interagency Arctic Research Policy Committee (IARPC) and the Arctic Research Commission (ARC). Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act (ARPA) of 1984 (PL 98-373) and established by Executive Order 12501 (January 28, 1985). Publication of the journal has been approved by the Office of Management and Budget.

Arctic Research contains

- Reports on current and planned U.S. Government-sponsored research in the Arctic;
- Reports of ARC and IARPC meetings; and
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector and other nations.

Arctic Research is aimed at national and international audiences of government officials, scientists, engineers, educators, private and public groups, and residents of the Arctic. The emphasis is on summary and survey articles covering U.S. Government-sponsored or -funded research rather than on technical reports, and the articles are intended to be comprehensible to a nontechnical audience. Although the articles go through the

normal editorial process, manuscripts are not refereed for scientific content or merit since the journal is not intended as a means of reporting scientific research. Articles are generally invited and are reviewed by agency staffs and others as appropriate.

As indicated in the U.S. Arctic Research Plan, research is defined differently by different agencies. It may include basic and applied research, monitoring efforts, and other information-gathering activities. The definition of Arctic according to the ARPA is "all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian chain." Areas outside of the boundary are discussed in the journal when considered relevant to the broader scope of Arctic research.

Issues of the journal will report on Arctic topics and activities. Included will be reports of conferences and workshops, university-based research and activities of state and local governments and public, private and resident organizations. Unsolicited nontechnical reports on research and related activities are welcome.

Address correspondence to Editor, *Arctic Research*, Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington VA 22203.

Cover *Sockeye, pink, and chum salmon.*

ARCTIC RESEARCH

OF THE UNITED STATES

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NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230



July 7, 1999

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

I am pleased to transmit through you to the Congress the enclosed Biennial Revision to the United States Arctic Research Plan for years 2000 to 2004. This Plan is required under Public Law 98-373, as amended by Public Law 101-609, the Arctic Research and Policy Act.

The Plan describes scientific and engineering research to support implementation of U.S. national policy objectives in the Arctic. It also includes research initiatives that relate to understanding and protecting the Arctic environment. It is submitted on behalf of the Interagency Arctic Research Policy Committee for which the National Science Foundation serves as chair agency.

It is a distinct honor for the member agencies to serve on the Interagency Committee and for the National Science Foundation to chair it.

Sincerely,

Rita Colwell
Director

Enclosure

United States Arctic Research Plan

Biennial Revision: 2000–2004

Introduction

The United States Arctic Research Plan published in this issue of *Arctic Research of the United States* was prepared by the Interagency Arctic Research Policy Committee (IARPC). The Plan is a consensus document that reflects the views of twelve IARPC agencies. It responds to recommendations of the U.S. Arctic Research Commission and to recommendations of scientists who provided advice to the IARPC agencies.

The Plan includes four special focus multiagency research programs agreed to by the Federal agencies and includes multiagency cross-cutting issues such as research support and logistics, facilities, international activities, and data and information. The Plan describes high-priority research needs of the agen-

cies but does not include every possible Arctic research idea that might be suggested. The Plan also responds to environmental and strategic objectives of U.S. Arctic policy.

The Plan is a living document. In accordance with the Arctic Research and Policy Act, it is revised every two years. Readers who have comments on the Plan, or suggestions for improvement, are invited to submit their comments to: Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230, or to the appropriate IARPC staff representative listed on the inside back cover of this issue of *Arctic Research of the United States*.

Lake Clark, Alaska.



United States Arctic Research Plan

Biennial Revision: 2000–2004

Executive Summary

Background

The United States has substantial economic, scientific, strategic, and environmental interests in the Arctic. As required by the Arctic Research and Policy Act of 1984 (Public Law 98-373),* a comprehensive Arctic Research Plan is prepared by the Interagency Arctic Research Policy Committee and submitted to the President, who transmits it to Congress. Section 109(a) of the Act requires a biennial revision to the Plan. This document, the sixth biennial revision to the Arctic Research Plan, updates the plan and elaborates on requirements of Section 109(a).

United States research in the Arctic and this biennial revision are governed by U.S. national policy on the Arctic, research goals and objectives agreed upon by the Interagency Committee, and guidance provided by the Arctic Research Commission.

It is in the national interest of the United States to support scientific and engineering research to implement its national policy objectives, including:

- Protecting the Arctic environment and conserving its living resources;
- Promoting environmentally sustainable natural resource management and economic development in the region;
- Strengthening institutions for cooperation among the eight Arctic nations;
- Involving the indigenous people of the Arctic in decisions that affect them;
- Enhancing scientific monitoring and research on local, regional, and environmental issues (including their assessment); and
- Meeting post-Cold-War national security and defense needs.

The Arctic Research and Policy Act requires cooperation among agencies of the U.S. Government having missions and programs relevant to the Arctic. It established the Interagency Arctic Research Policy Committee to “promote Federal interagency coordination of all Arctic research activities” [Section 108(a)(9)]. The Interagency Committee, chaired by the National Science Foundation

(NSF), continues to provide the mechanism for developing and coordinating U.S. Arctic research activities.

Revision to the Plan

This sixth revision to the United States Arctic Research Plan includes two major sections. The first of these presents the Special Focus Interagency Research Programs. For this biennial revision of the plan, agencies agreed that the following four programs are ready for immediate attention as inter-agency focused efforts:

- Arctic Environmental Change
- Arctic Monitoring and Assessment
- Assessment of Risks to Environments and People in the Arctic
- Arctic Marine Sciences.

The second major section is the Agency Programs, which represent the objectives of Federal agencies, focusing on the period covered by this revision (2000–2004). They are presented in seven major categories, and where common activities exist they are presented as collective programs:

- Arctic Ocean and Marginal Seas
- Atmosphere and Climate
- Land and Offshore Resources
- Land–Atmosphere–Water Interactions
- Engineering and Technology
- Social Sciences
- Health.

Since the passage of the Act, the Interagency Committee, the Arctic Research Commission, and the State of Alaska have addressed issues related to logistics support for Arctic research. This revision considers issues related to surface ships, submarines and ice platforms; land-based and atmospheric facilities and platforms; coordination; and data facilities.

Budgetary Consideration

Appendix C presents a summary of each agency’s funding for the 1998–2000 period. The total interagency Arctic budget estimate for FY 99 is \$221.5 million; for FY 00 it is \$220.3 million. For some agencies, budgets for Arctic research are projected to decrease. Program descriptions may be assumed to reflect the general direction of agency programs.

* Amended on November 16, 1990 (Public Law 101-609); see Appendix E.

1. Introduction

1.1 National Needs, Goals, and Objectives

United States research in the Arctic and this biennial revision are governed by U.S. national policy on the Arctic (announced by the U.S. Department of State, September 1994), the Declaration on Establishment of the Arctic Council (announced by the U.S. Department of State, September 1996), research goals and objectives agreed upon by the Interagency Committee, and guidance provided by the Arctic Research Commission.

1.1.1 National Needs and Problems

The national interest of the United States requires support of scientific and engineering research to implement its national policy objectives, including:

- Protecting the Arctic environment and conserving its biological resources;
- Assuring that natural resource management and economic development in the region are environmentally sustainable;
- Strengthening institutions for cooperation among the eight Arctic nations;
- Involving the Arctic's indigenous people in decisions that affect them;
- Enhancing scientific monitoring and research on, and assessment of, local, regional, and global environmental issues on Earth and in near-Earth space; and
- Meeting post-Cold-War national security and defense needs.

U.S. Arctic research uses the northern polar region as a natural laboratory to study processes that also occur at lower latitudes. Where appropriate this research should be coordinated with the efforts of state and local governments and the private sector. The research should be carried out in a manner that benefits from and contributes to international cooperation. Arctic research policy is subject to periodic review and revision. The role of the Arctic in meeting national needs and addressing key policy issues is further highlighted below.

1.1.2 Nonrenewable Resources

The U.S. imports approximately 50% of its hydrocarbon needs. Twenty-five percent of our domestic production comes via the Trans-Alaska Pipeline System from Prudhoe Bay in Arctic Alaska. The best estimates are that at least 20% of the Nation's future reserves lie on the northern Alaskan

coastal plain and adjacent continental shelf. Also, 12% of the Nation's gas reserves lie in the same region, and there are plans for a gas pipeline to transport this resource south. Gas hydrate reserves have been estimated to range from 10^{11} to 10^{14} cubic meters in Alaska and its offshore region. In addition to oil and gas, the Arctic has large coal and peat resources. The U.S. Arctic has been estimated to contain about as much coal as the remainder of the U.S. However, U.S. Arctic coal production will be limited until the energy needs of Alaska grow substantially or the Pacific Rim countries provide sufficient impetus for further coal development.

Minerals are also important Arctic resources. The Red Dog lead-zinc-silver mine, north of the Arctic Circle, is one of the largest zinc-producing mines in the world, producing 60% of the U.S. zinc output. The Arctic shelves also contain mineral deposits. At least one offshore tin mine has been brought into production in Russia. Dredging for sand and gravel on the Arctic Ocean shelves supports hydrocarbon development and other large coastal and offshore construction projects.

1.1.3 Renewable Resources

Arctic and Bering Sea waters support some of the most productive fisheries in the world. The Bering Sea supplies nearly 5% of the world's fishery products. An estimated 4 million metric tons of 43 commercial species are caught every year by fishermen from the United States, Russia, Japan, and other nations. Since the passage of the Magnuson Fishery Conservation and Management Act in 1976, American groundfish operations in Alaska have developed into an industry with an annual product value estimated at \$2.2 billion. Dutch Harbor-Unalaska, Alaska, is the leading U.S. port in the quantity of commercial fish landings. Alaska leads all states in both total volume and total value of fish landings.

Dramatic and unexplained fluctuations have occurred in the catch of groundfish and shellfish and the stocks of marine mammals. There is considerable concern that the walleye pollock population will "crash" as others have in the past. Managing for sustainable yields requires further research.

The impact on the coastal economy of Alaska and other northwestern U.S. states is magnified by

substantial capitalization in vessels, port facilities, and processing plants and related income to a broad sector of the economy. A sustainable, predictable fishery stock is fundamental to the viability of this sector of the U.S. economy. Research on Arctic marine ecosystems is essential for understanding and managing their resources.

1.1.4 Global Change

High latitudes may experience the earliest onset of global warming if a “greenhouse effect” occurs on Earth. Global climate models suggest that the amount of warming may be significantly greater in northern high-latitude regions than in lower latitudes, but the models do not agree on the amount of warming to be expected at high latitudes.

Furthermore, there is growing evidence that the polar regions play a key role in the physical processes responsible for global climate fluctuations and in some circumstances may be a prime agent of such fluctuations. For example, North Atlantic deep water formation may be affected by a delicate balancing in the amount of fresh water that is exported from the Arctic Basin and that flows from the East Greenland Current into the region of deep vertical convection in the North Atlantic. Heat flux through the variable ice cover of the Arctic Ocean may have a profound effect on the surface heat budget and the global climate.

Arctic biological processes can also affect global processes and result in positive feedback on CO₂ increase and warming. It remains unclear whether Arctic ecosystems are functioning as sources or sinks for excess CO₂. For example, a shift in vegetation from tundra to trees could have significant effects on regional climate.

High-latitude warming may disturb the equilibrium of Arctic ice masses and hence global sea levels. Such events are preserved in the geologic record, and polar regions are a natural repository of information about past climatic fluctuations.

The Arctic ozone layer has exhibited significant changes—concentrations are decreasing. These are expected to deepen over the next decade, as atmospheric chlorine and bromine reach high levels because of previous releases. Their causes and implications will continue to be a subject of research. Additional data may shed light on the causes and effects of both catastrophic and evolutionary global change. Arctic research provides a critical component of virtually every science element in the U.S. Global Change Research Program.

1.1.5 Social and Environmental Issues

Arctic populations live in close contact with their environment and are highly dependent on marine and terrestrial ecosystems. Contaminants pose a potential threat to the health of Arctic residents who rely on subsistence foods (fish, marine mammals, moose, and caribou). Heavy metals, organochlorines, soot, and other pollutants accumulate at high latitudes because of atmospheric and oceanic circulation patterns and subsequent concentration in food chains and organic soils. The effects of environmental change, including climate changes, can have enormous impacts on Arctic ecosystems, on the response of wildlife to ecosystem productivity, and on the human use of wildlife.

Other issues of importance to Arctic residents include social and economic changes such as those resulting from large-scale development and population influx. Many of these changes are positive, such as increased educational and employment opportunities, better medical care, and the use of modern technology. Other changes, such as social and cultural disruption, have been a cause for concern. Research addressing the phenomena of rapid social change, human–environment interactions, and the viability of small subsistence-dependent communities sheds light on the complex relationships between environment, economy, culture, and society.

Recent studies have found that concentrations of carbon dioxide and methane in Arctic haze layers are elevated with respect to background levels. Concentrations of these two gases are correlated, suggesting a common anthropogenic source (fossil fuel combustion) and subsequent transport into the Arctic. Soot carbon has been traced for thousands of kilometers across the Arctic, where it remains suspended in a dry, stable atmosphere. Ozone depletion in the polar vortex has enormous health implications to the people of the entire Northern Hemisphere.

High latitudes are also particularly susceptible to adverse conditions in the space environment, which can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses. These space environment effects, generally referred to as “space weather,” are often associated with transient phenomenon on the sun that may cause geomagnetic storms on Earth, with the occurrence of bright, dynamic auroral displays and the development of intense ionospheric currents. These induced currents can cause massive network failures in electric power distribution sys-

tems and permanent damage to multi-million-dollar equipment in power generation plants.

1.1.6 U.S. Goals and Objectives in Arctic Research

Arctic research is aimed at resolving scientific, sociological, and technological problems concerning the physical and biological components of the Arctic and the interactive processes that govern the behavior of these components. The objectives include addressing the needs for increased knowledge on such issues as using the Arctic as a natural laboratory, national defense, natural hazards, global climate and weather, energy and minerals, transportation, communications, renewable resources, contaminants, environmental protection, health, adaptation, and Native cultures.

More specific long-term goals have been developed by the Interagency Committee to further guide the revision of the Plan:

- Pursue integrated, interagency, and international research and risk assessment programs for the purpose of managing Arctic risks;
- Continue to develop and maintain U.S. scientific and operational capabilities to perform research in the Arctic;
- Promote the improvement of environmental protection and mitigation technology and the enhancement of ecologically compatible resource use technology;
- Develop an understanding of the role of the Arctic in predicting global environmental changes and perform research to reveal early

signals of global changes in the Arctic and determine their significance;

- Develop the scientific basis for responding to social changes and the health needs of Arctic people;
- Contribute to the understanding of the relationship between Arctic residents and use of wildlife and how this relationship might be affected by global climate change and transported contaminants;
- Engage Arctic residents, scientists, and engineers in planning and conducting the research and report results to these individuals and the public;
- Continue to document and understand the role of permafrost in environmental activities;
- Advance knowledge of the Arctic geologic framework and paleoenvironments;
- Contribute to the understanding of upper atmospheric and outer space phenomena, particularly their effects on space-borne and ground-based technological systems;
- Develop and maintain databases and data and information networks; and
- Develop and maintain a strong technological base to support national security needs in the Arctic.

In addition to these goals and objectives for Arctic research developed by the Interagency Committee, the Arctic Research Commission has provided further guidance for U.S. Arctic research. This revision of the Plan is consistent with these Commission recommendations.

1.2 Budgetary Considerations

The Act does not provide separate additional funding for Arctic research. Agencies are expected to request and justify funds for these activities as part of the budget process. Table 1 presents a summary of each agency's Arctic research funding for the 1998–2000 period. The total interagency Arctic budget estimate for FY 99 is \$221.5 million; for FY 00 it is \$220.3 million. Appendix C contains a detailed listing of existing Federal agency programs and budgets, divided by major subelements. The plan contains the detailed agency budgets through FY 00. For some agencies, budgets for Arctic research are projected to decrease. These decreases reflect the competitive budget environment. However, program descriptions may be assumed to reflect the general direction of agency programs.

Table 1. Arctic research budgets by individual Federal agencies (in millions of dollars).

<i>Agency</i>	<i>FY 98 Actual</i>	<i>FY 99 Budget</i>	<i>FY 00 Proposed</i>
DOD	15.3	20.7	7.8
DOI	42.0	48.3	43.0
NSF	49.0	67.0	67.5
NASA	33.7	33.9	41.8
NOAA	15.1	17.6	18.5
DOE	3.5	3.5	3.4
DHHS	16.1	16.5	17.6
SI	0.5	0.5	0.5
DOT*	6.6	7.6	14.6
EPA	0.5	1.1	0.8
DA	3.4	4.8	4.8
DOS	0.0	0.0	0.0
Total	185.7	221.5	220.3
* plus icebreaker support	23.5	23.5	23.5

1.3 Interagency Coordination

The Arctic Research and Policy Act (Appendix E) requires cooperation among agencies of the U.S. Government having missions and programs relevant to the Arctic. It established the Interagency Arctic Research Policy Committee to “promote Federal interagency coordination of all Arctic research activities” [Section 108(a)(9)]. The Interagency Committee, chaired by the National Science Foundation (NSF), continues to provide the mechanism for guiding and coordinating U.S. Arctic research activities. The biennial revisions of the U.S. Arctic Research Plan serve as guidance for planning by individual agencies and for coordinating and implementing mutually beneficial national and international research programs.

Since the last revision of the Plan, significant progress in implementing recommendations has been made and accomplishments continue to be identified. These include activities of the Interagency Committee and the Arctic Research Commission. Additional information can be found in the journal *Arctic Research of the United States* (Volume 12, Spring/Summer 1998), published by NSF on behalf of the IARPC.

The Act mandates coordination of U.S. Arctic research programs. Mechanisms for appropriate levels of coordination continue to evolve. Three levels of coordination and cooperation are needed for an effective national Arctic research program:

- Individual agency, and independent investigator, research programs;
- National coordination; and
- International collaboration.

Each element requires a mechanism for internal program development, review, and implementation, and each needs to be linked to the other two. The national effort is performed through the Interagency Committee. A staff oversight group of the Interagency Committee provides coordination, assisted by working groups representing specific agency programs. These are reported in the subsequent sections.

Many interagency agreements and planning and coordinating activities already exist. Coordination with global change programs is an integral part of Arctic program development and implementation. Improved communication at all levels through existing newsletters and journals is encouraged.

1.4 International Cooperation

On September 18, 1998, the United States assumed the chair of the Arctic Council, an eight-nation forum established in 1996 to bring together in a senior policy setting the environmental conservation elements of the Arctic Environmental Protection Strategy (AEPS) and broader issues of common concern related to sustainable development. In addition to the eight nations (Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the U.S.), the region’s indigenous communities are recognized as Permanent Participants of the Arctic Council. Canada chaired the Arctic Council until September 1998, at which time the United States assumed the chair until September 2000. The United States chairmanship of the Council will culminate in a Ministerial meeting to be held in Alaska in the fall of 2000.

The Arctic Council is entirely consistent with the objectives articulated in the U.S. Arctic Policy Statement of 1994 and offers an important vehicle for pursuing them. These policy objectives include:

- Protecting the Arctic environment and conserving its living resources;

- Promoting environmentally sustainable natural resource management and economic development in the region;
- Strengthening institutions for cooperation among the eight Arctic nations;
- Involving the indigenous people of the Arctic in decisions that affect them;
- Enhancing scientific monitoring and research on local, regional, and environmental issues; and
- Meeting post-Cold-War national security and defense needs.

The United States has been an Arctic nation, with important interests in the region, since the purchase of Alaska over a century ago. National security, economic development, human rights, and scientific research remain cornerstones of these interests. At the same time the pace of change in the region—particularly political and technological developments—continues to accelerate, creating interdependent challenges and opportunities for policy makers in Arctic regions.

U.S. Arctic policy reflects these elements of continuity and change. It emphasizes environmen-

tal protection, sustainable development, and the role of indigenous people, while recognizing U.S. national security requirements in a post-Cold-War world. It also is concerned with the need for scientific research—particularly in understanding the role of the Arctic in global environmental processes—and the importance of international cooperation in achieving Arctic objectives.

The U.S. works in consultation with the State of Alaska, Alaskan indigenous people, and Alaskan nongovernmental organizations (NGOs) on Arctic issues and policy making. Federal agencies continue to give careful consideration to local Alaskan needs, including the unique health, social, cultural, and environmental concerns of indigenous people, when developing Arctic plans and policies. Representatives of the State of Alaska, Alaskan indigenous people, and Alaskan NGOs will continue to be included as appropriate on U.S. delegations to Arctic-related international meetings. The U.S. achieved its goal of attaining on-par representation for its Aleut population in Alaska as a Permanent Participant on the Arctic Council and will continue to support involvement by other qualified Native organizations.

1.4.1 Arctic Environmental Protection Strategy

The U.S. expanded its international cooperation under the Arctic Environmental Protection Strategy (AEPS). Beginning in 1989 the eight Arctic countries began discussions on improving Arctic cooperation. In 1991, in Rovaniemi, Finland, they reached agreement on AEPS. In 1996, in Ottawa, Canada, the Arctic Council was created to address issues of sustainable development in the Arctic and to oversee and coordinate the programs established under AEPS. This nonbinding effort has primarily operated through four working groups to address environmental issues relevant to the circumpolar area:

- *Arctic Monitoring and Assessment Program (AMAP)*: Assesses the health and ecological risks associated with contamination from radioactive waste, heavy metals, persistent organics, and other contaminants. Recommends targeted monitoring to collect current data from areas of special concern.
- *Conservation of Arctic Flora and Fauna (CAFF)*: Studies the adequacy of habitat protection and ways to strengthen wildlife protection through an international network of protected areas and more effective conservation practices.

- *Protection of the Arctic Marine Environment (PAME)*: Creates international guidelines for offshore oil and gas development in the Arctic, organizes and promotes the drafting of a regional action plan for control of land-based sources of Arctic marine pollution, and collects information on Arctic shipping activities.
- *Emergency Preparedness and Response (EPPR)*: Provides a forum in which participants work to better prevent, prepare for, and respond to the threat of environmental emergencies in the Arctic. Activities include risk assessment and recommendation of response measures.

1.4.2 Sustainable Development and Environmental Protection

A basic premise of U.S. Arctic policy is that the work of the Arctic Council, particularly in the field of sustainable development, needs to build on the environmental protection considerations of AEPS, which has now been integrated into the Council. The Arctic Council Declaration describes sustainable development as “including economic and social development, improved health conditions, and cultural well-being.” Further, the concept of sustainability is reflected in its description of environmental protection, which refers to “the health of the Arctic ecosystems, maintenance of biodiversity in the Arctic region, and conservation and sustainable use of natural resources.” Terms of Reference for the Council’s sustainable development efforts have been negotiated and adopted by the eight Arctic governments with the participation of the region’s indigenous communities. In the Iqaluit Declaration signed in Canada on September 18, 1998, Ministers of the eight Arctic governments welcomed sustainable development proposals from Arctic states and Permanent Participants in the areas of Arctic children and youth, health, telemedicine, resource management (including fisheries), cultural and ecotourism, technology transfer to improve Arctic sanitation systems, and national sustainable development strategies. The Ministers directed that work be completed on these proposals and funding sought, so that projects could be initiated as quickly as possible before the next Ministerial meeting. The Ministers also established a Sustainable Development Working Group, comprising Senior Arctic Officials (one from each Arctic state) and Permanent Participants, or their designated representatives, whose task is to facilitate completion of work on the proposals listed above and propose possible priority areas in the further development of the sustainable development program.

1.4.3 Scientific Research

The United States continues to plan to further international scientific research through development of an increasingly integrated national Arctic research program. Particularly during the U.S. chairmanship of the Arctic Council, this integrated program will seek to support international cooperation in monitoring, assessment, and environmental research as well as in social science research related to sustainable development.

The Interagency Arctic Research Policy Committee, with advice from the U.S. Arctic Research Commission, coordinates Federal efforts to produce an integrated national program of research, monitoring, assessments, and priority setting that most effectively uses available resources. U.S. Arctic policy recognizes that cooperation among Arctic nations, including coordination of priorities, can make essential contributions to research in the region. To this end the results of the AMAP assessment on the state of the Arctic environment provide an important tool in influencing future research priorities.

1.4.4 Conservation

The United States works both nationally and internationally to improve efforts to conserve Arctic wildlife and protect habitat, with particular attention to polar bears, walruses, seals, caribou, migratory birds, and boreal forests.

Consistent with the Agreement on Conservation of Polar Bears, the U.S. is discussing ways to improve conservation of polar bear populations whose range extends to Russia and the United States. The U.S. also works to better implement existing measures, such as the 1916 Migratory Bird Treaty, to conserve populations of migratory species of birds that breed in the Arctic.

1.4.5 Cooperation with Russia and Other Nations

The United States engages the Russian Federa-

tion on Arctic environmental issues on a bilateral and multilateral basis. The U.S.–Russian Joint Commission on Economic and Technological Cooperation (formerly known as the Gore–Chernomyrdin Commission) remains the principal venue for a bilateral dialogue on environmental issues, including species conservation, antipoaching campaigns, and declassification of Arctic environmental information derived from national security data, under the Environmental Working Group. In addition to the broad-based cooperation within the Arctic Council, which, among other things, aids in establishing a more effective environmental regulatory infrastructure in Russia, other multilateral forums now exist to address specialized concerns. Through NATO, we engage the Russian military on defense-related environmental issues. On a trilateral basis, with Norway, we focus on the cleanup and consolidation of waste generated from military activities through the Arctic Military Environmental Cooperation (AMEC) process. Our support of the International Atomic Energy Agency's International Arctic Seas Assessment Program also has provided a conduit for monitoring and assessing radioactive contaminants in the seas adjacent to the Russian Arctic.

The former Soviet Union (FSU) had an extensive nuclear power program with numerous supporting waste management activities that currently involve ad hoc storage of low- and intermediate-level radioactive wastes by shallow land burial and in surface water impoundments, as well as storage of high-level wastes. The Mayak, Tomsk, and Krasnoyarsk sites all lie within a few kilometers of the edge of the West Siberian Plain and Basin. Past and continuing disposal of wastes at Mayak, Tomsk, and Krasnoyarsk to surface waters (for example, the Ob and Yenisey Rivers) and surface water impoundments, and by deep well injections at Tomsk and Krasnoyarsk, have the potential for contaminating the Arctic Ocean, the western Siberian oil and gas fields, and the regional water resources.

1.5 Revision to the Plan

This sixth revision to the United States Arctic Research Plan includes two major sections:

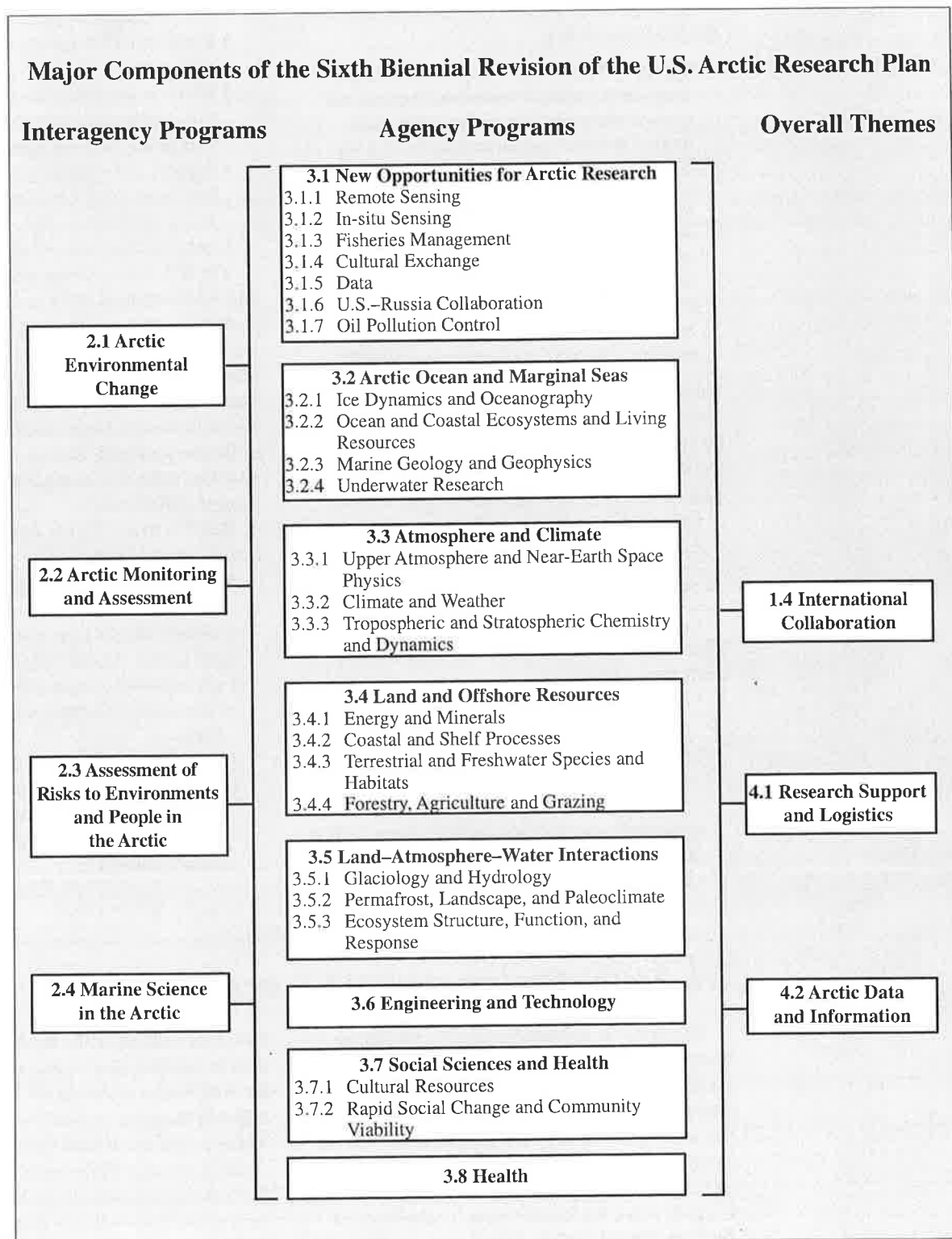
- Section 2. Special Focus Interagency Research Programs; and
- Section 3. Agency Programs.

The Agency Programs represent the objectives of Federal agencies, focusing on the period covered

by this revision (2000–2004). They are presented in seven major categories, and where common activities exist they are presented as collective activities. Individual agency mission accomplishments were discussed in the Spring/Summer 1998 issue of *Arctic Research of the United States* and will be updated in 2000. The complementarity of the

interagency and agency programs is shown in the figure on the next page. Several overall themes transcend essentially all integrated and research mission components.

Section 4 presents current activities related to field operational support necessary for implementation of the proposed interagency programs and research mission activities.



2. *Special Focus*

Interagency Research Programs

In 1990 the Interagency Committee agreed on the following policy:

The IARPC agrees that a more comprehensive approach to funding of research and baseline programs is required to ensure a long-term, viable research and development presence in the Arctic. This presence will ensure support of the national needs, which include renewable and nonrenewable resource development, environmental protection, and partnerships with the private sector and residents of the Arctic. It will complement other national and international scientific programs, such as Global Change. To this end the IARPC agencies agree to develop, starting in 1992, an integrated interagency program sufficient for meeting national needs.

Subsequently the IARPC agencies examined Arctic research from an interagency perspective. For this biennial revision of the plan, agencies agreed that the following four programs are ready for immediate attention as multiagency focused efforts:

- Arctic Environmental Change
- Arctic Monitoring and Assessment
- Assessment of Risks to Environments and People in the Arctic
- Arctic Marine Sciences.

These coordinated, multiagency programs are being designed to:

- Focus research activities in concert with national policy;
- Build on individual agency efforts in reconnaissance, monitoring, process studies, and modeling;
- Facilitate research and logistics coordination through regionally focused programs;
- Take maximum advantage of remote sensing

and new technologies;

- Strengthen interagency data and information management;
- Draw on the strengths of the academic, industrial, and government research communities in planning and implementing programs;
- Support and enhance programs to acquire long-term measurements of key parameters and environments; and
- Enhance international research collaboration.

The U.S. has a substantial economic, strategic, and environmental stake in the Arctic. Domestic energy reserves and the explosive growth in Bering Sea fisheries harvests are two examples of our dependence on Arctic resources. Sound management decisions for sustainable development of Arctic resources hinge on enhanced understanding of the environment, leading to better forecasts. In addition, there is a strong international commitment to collaborate.

Benefits to the Nation from Arctic research include improvements in:

- Knowledge of fishery resources and controlling dynamics;
- Models and data for assessing past climates and global change and their effects;
- International cooperation in a strategic region;
- Forecasts of weather, ice, and ocean conditions;
- Protection of the Arctic environment;
- Understanding the causes, effects, and limits of air and water pollution; and
- Protection and understanding of cultures and cultural resources.

2.1 Arctic Environmental Change

The Arctic is undergoing significant change. This change appears to involve the atmosphere, sea ice, and ocean. The change is important in its own right, if only as a clear example of the coupling among the air, ice, and ocean. Moreover, the Arctic including the Bering Sea is a significant component of the global climate system in several respects. First, the Arctic Ocean's stratification and ice cover provide a control on the surface heat

and mass budgets of the north polar region and thereby on the global heat sink. For example, if the distribution of Arctic sea ice were substantially different from the present, the altered surface fluxes would affect both the atmosphere and the ocean and would likely have significant consequences for regional and global climate. Second, the export of low-salinity waters, whether liquid or in the form of desalinated sea ice, has the potential

to influence the overturning cell of the global ocean through control of convection in the sub-polar gyres, which in turn feed the North Atlantic. For example, recent suggestions that North Atlantic and Eurasian climate variability may be predictable on decadal time scales rest in part on the variability of such upstream forcing in the Greenland Sea. Finally, the atmospheric circulation of the Northern Hemisphere has been changing as part of a pole-centered pattern, which links the conditions over the Arctic Ocean to changes in both the Icelandic and Aleutian Lows. The remarkable recent changes in the Arctic Ocean and the overlying atmosphere are therefore of wide interest in the context of global climate, as are the recent changes in the Bering Sea ecosystem and in the atmosphere/sea-ice systems that influence these changes in the Bering Sea ecosystem. The latter changes have significant economic, social, and cultural importance to the U.S.

In the last five or six years, change has become apparent in the hydrography of the Arctic Ocean. The results of several recent expeditions indicate that the influence of Atlantic water is becoming more widespread and intense than previously found. Data collected during the cruise of the USS *Pargo* in 1993, the cruise of the *Henry Larsen* also in 1993, the summer 1994 Arctic Ocean Section of the *Polar Sea* and the *Louis S. St Laurent*, and the cruise of the USS *Cavalla* in 1995 all indicate that the boundary between the eastern and western halocline types, which used to parallel the Lomonosov Ridge, now lies roughly parallel to the Alpha and Mendeleyev Ridges. In terms of longitudinal coverage, this means the area occupied by the eastern water types is nearly 20% greater than previously observed.

The greater intensity of the Atlantic influence is also manifest in warm cores observed over the Lomonosov and Mendeleyev Ridges in the *Pargo* and *Louis S. St Laurent* data, with temperatures over the Lomonosov Ridge greater than 1.5°C. Other scientists also observed an Atlantic layer temperature increase over the Mendeleyev Ridge. The historical data give no indication of such warm cores and show a temperature over the Lomonosov Ridge nearly 1°C lower. U.S.–Russian oceanographic climatological data indicate significantly lower average temperatures during the period 1950–1989 in the Lomonosov Ridge region.

The observed salinity and temperature differences represent a fundamental change. The start of the change may have been in the late 1980s. The cruise of the *Oden* in 1991 shows a slight warming

near the Pole, and other research identifies higher than usual temperatures in the Atlantic water inflow in 1990. The differences from climatology are too large and spatially consistent to be attributed to instrument error or normal seasonal and interannual variability.

There are some indications that the observed shift in frontal positions is associated with a decadal trend in the atmospheric pressure pattern. Pressure fields and ice drift data show the whole patterns of pressure and ice drift for 1993 were shifted counter-clockwise 40–60° from the 1979–1992 pattern, just as the upper ocean circulation pattern derived from the hydrographic data of the 1993 cruise of the USS *Pargo* is shifted relative to climatology. The yearly average pressure maps in the International Arctic Buoy Program (IABP) data reports indicate the shift in the atmospheric pressure pattern began in about 1988–1989. Before that time the Beaufort High was usually centered over 180° longitude. After 1988 the annual average Beaufort High was weaker and usually confined to western longitudes. This change is consistent with other findings that the annual mean atmospheric surface pressure is decreasing and has been below the 1970–1995 mean in every year since 1988. Therefore, the temporal shift in the atmosphere roughly corresponds to our estimate of when the ocean changes began. The atmosphere might drive the observed changes in ocean circulation by Ekman pumping, and the effect of these circulation changes may reach deeper with time.

These changes in the Arctic Ocean need to be studied in detail because they may represent a decadal-scale change. Some simulations of both wind-forced and thermohaline-forced regimes have suggested that decadal-scale variability may occur in the coupled air–ice–ocean system of the high northern latitudes. On the other hand the changes may represent the start of a longer-term shift. While it is difficult to distinguish between anthropogenic climate change and other natural variability, it is also true that climate models are nearly unanimous in predicting amplified polar response to greenhouse warming. The connection between lower atmospheric pressure in the Arctic and incursion of warm Atlantic water into the Makarov Basin may indicate an important link in how the climate system manifests polar amplification. In any case, examining the evolution of the changes over time will increase our understanding of the interplay of the Arctic with the rest of the globe.

Although climate changes in the Bering Sea are difficult to detect because of the large year-to-year variability that can mask longer-term trends, meteo-

rological conditions in the winter and spring–summer seasons seem to have changed from the 1980s to the later 1990s. The Bering Sea system underwent a major change in 1977, from a cold regime to a warm regime, primarily due to an intensification of the Aleutian Low over the North Pacific Ocean. In the 1990s the low shifted westward, and high pressure set up over Alaska, circulating cold Arctic air over the Bering Sea. Winters have become slightly colder with more ice, and summers warmer with clearer skies.



Tustumena Lake, Alaska.

Climate change at decadal time scales in the Bering Sea region, often referred to as regime shifts, appears to have a significant impact on the ecosystem through alterations of the nutrient–phytoplankton–zooplankton sequence (bottom-up effect), and there is ample reason to believe that significant effects also occur at higher trophic levels (top-down effect). Such changes in the ecosystem are of utmost importance to management concerns about sustaining productivity and protecting endangered species. Climate change on the decade scale originates primarily in the atmosphere and spans the North Pacific Ocean, northeastern Asia, and the western Arctic. It is unclear how much decadal variability is generated in the atmosphere and how much is forced through feedback with sea ice extent, snow cover, and sea surface temperature.

The primary forcing resulting from climate change is a change in surface wind stress, which in turn affects horizontal and vertical (upwelling) currents and mixing in the surface layer (mixed layer depth). In addition, lessening of winter northerly winds will reduce ice production and

extent. This in turn has a profound effect on ocean temperature over the southeast Bering Sea shelf. Air–sea heat and moisture fluxes are also altered, as can the locations of such features as fronts and the generation of eddies. One index of climate variability suggests that a shift occurred in 1990, while another indicates that the warm regime established in the 1970s persisted through the spring of 1998. Global warming occurs on longer time scales, and its effects will be superimposed on decadal and annual changes. Natural climate cycles can be influenced by anthropogenic factors, and anthropogenic variations are often masked by natural fluctuations. Knowledge of existing and emerging climate patterns is useful for predicting the impacts of climate change on the ecosystem. Determining how climatic changes are transferred via the ice–ocean system to the biota, however, is essential. An understanding of the mechanisms of the interaction will permit management choices based on knowledge rather than inference.

A number of ocean mechanisms are critical to the dynamics of the ecosystem, including transport via currents, distribution of temperature, and turbulence (mixed layer depth and temperature). Ocean currents are driven by wind, tides, and the heat and salt balance in the ocean. The source waters for the Bering Sea flow through the Aleutian passes from the North Pacific Ocean and strongly influence circulation. For the eastern shelf the Aleutian North Slope Current carries Alaskan Stream water primarily from Amchitka and Amukta Pass eastward along the north side of the Aleutian Islands, forming the Bering Slope Current in the southeastern corner of the basin.

Mean northward transport through the Bering Strait, driven by a sea level difference between the Bering Sea and the Arctic Ocean, provides the only connection and exchange of water between the Pacific and Atlantic Oceans in the Northern Hemisphere. A regional consequence of the transport is that the supply of nutrient-rich water to the northern shelf upwells, thereby stimulating primary production. During ice formation, cold saline water produced over the northern shelf flows northward. Globally this water plays a role both in maintaining the Arctic Ocean halocline and in ventilating the deep waters. Transport through the Bering Strait will decrease if the Arctic warms to a greater extent than the North Pacific. How this will impact the flux of nutrient-rich water onto the eastern shelf is not known, but there is some evidence from carbon isotope data that productivity of the Bering Sea has been declining since the mid-1960s.

At its maximum the seasonal sea ice extent fluctuates over 1000 km from north of the Bering Strait in summer to the Alaska Peninsula and southeastern Bering Sea shelf break in winter. The amount of production and advection of ice depends on storm tracks, with the greatest ice production occurring in years when the Aleutian Low is well developed and winds from the north are common. Large variations (hundreds of kilometers) occur in the maximal sea ice extent.

2.1.1 Summary Interpretation of Observations

To summarize the observations, the Arctic is in the midst of change extending from the top of the atmosphere to below 1000 m in the ocean. The strengthening of the polar vortex has resulted in lower surface pressure and a consequent weakening and distortion of the Beaufort Gyre. The added positive vorticity or weakening of the Beaufort Sea ice gyre has been apparent in the drifting buoy data, and it is associated with divergence of the ice pack as well. The increased divergence has been postulated to cause increased summer ice melt and the observed freshening of the Beaufort Sea mixed layer. The change in circulation may also account for the decreased ice cover on the Siberian shelves. The change in atmospheric circulation has also resulted in increased advection of heat and moisture into the Greenland Sea and Barents Sea regions. This in turn has resulted in the temperature increase of the Atlantic water inflow to the Arctic Ocean.

The eastern Bering Sea consists of an oceanic and a shelf regime. Within the broad shelf regime (more than 500 km), three distinct domains exist, which are characterized by contrasts in water column structure, currents, and biota. The balance between mixing (tidal and wind) and buoyancy flux (freshwater discharge, ice melt, solar radiation) generates the domains. In the coastal domain (bottom depths less than 50 m), tidal and wind mixing usually overlap, resulting in a weakly stratified or mixed water column. During summer, these waters are separated from deeper waters by a structural front located near the 50-m isobath. The dynamics of this feature result in prolonged primary production, which via zooplankton supports vast numbers of sea birds and other biota. Over the middle shelf domain (bottom depths between 50 and 100 m), the overlap between the top and bottom mixed layers is limited. During summer, moderate wind stirring results in a two-layered water column, where the lower layer temperatures often are less than 2°C throughout the summer (known

as the Cold Pool). These two-layer waters are separated from deeper water by a very broad (greater than 100 km) middle transition zone with complex dynamics. The outer shelf domain (bottom depths between 100 and 200 m) is oceanic in character, with mixed upper and lower layers separated by fine structure.

Ice melt plays a critical role in heat and salt fluxes, the generation of both baroclinic flow and water column structure, and the extent of cold bottom water (Cold Pool) located over the middle shelf, which has a dramatic influence on the distribution of higher-trophic-level biota.

Mixing associated with individual storms is another mechanism affecting biota through the nutrient-phytoplankton-zooplankton sequence. The timing and duration of storms can resupply nutrients and/or alter primary production and other biological processes due to changes in mixed-layer depth and increased turbulence.

2.1.2 Scientific Questions

The observations and modeling results leave three fundamental questions:

First, is the Arctic change part of a cycle or does it represent a climatic shift? Some scientists argue that the Arctic Ocean circulation can be divided into anticyclonic and cyclonic regimes that oscillate with a 7- to 10-year period. They argue that the present change is simply a large expression of the cyclonic phase. Anecdotal Russian information suggests a similar warming period during 1920–1940. However, examination of the last 40 years of Russian hydrographic data shows no deviations of the magnitude described for the 1990s. The trend since the 1960s suggests a longer-term shift. It seems entirely plausible that the present change may be the result of a combination of a long-term trend and normal oscillations. If this is so, we can expect to see the conditions of the 1990s reverse somewhat, but to recur and become more prevalent. Only time and long-term monitoring will reveal the answer to this question.

Second, what are the interconnections between the changes we see in the physical properties of the Arctic atmosphere, sea ice, and ocean and other changes both in and outside the Arctic region? Perhaps the most important aspect of this question is, what are the interconnections between the atmosphere, sea ice, and ocean that might constitute a positive feedback and reinforce the change? For example, could the changed circulation cause ice divergence and increased ice melt in summer, and might this result in more heat being stored in the

mixed layer for release the following winter? Might this in turn reinforce the changed atmospheric pressure pattern? Clearly another critical issue is the connection with lower latitudes. Can effects in the Arctic drive hemispheric changes in the atmosphere? Conversely do lower-latitude processes drive the Arctic changes? In this regard it is noteworthy that the Arctic Oscillation, which seems to be driving the changes in the basin, is based on analysis of the whole Northern Hemisphere pressure field down to 20°N. These major interconnection questions are composed of many detailed questions, such as:

- What are relative contributions of dynamic and thermodynamic factors in the variability of ice conditions and their present trends?
- How much of the upper ocean circulation is locally forced by way of the sea ice, and how much is forced by other means, such as inflow from the boundaries?
- How do changes in Arctic Ocean inflows and outflows relate to global climate? What is the role of inflow variability on change in the Arctic Ocean, and what is the effect of variability in Arctic Ocean buoyancy export on North Atlantic ventilation? How do changes of inflow into the Bering Sea affect the balance of salt in the Arctic Ocean?
- What is the relation of the changes to river runoff? How is runoff processed on the shelves, and what is the variability of the products? What influence does variability in shelf conditions have on ocean stratification and ice cover? Are the Arctic Ocean and its adjacent seas undergoing a change in their convective regime?
- Is the invasion of Atlantic water into the Canada Basin increasing, declining, or remaining the same? When might we expect the Atlantic layer warming to penetrate into the Canada Basin?
- What and where are the Arctic Ocean's "pressure points" or points of sensitivity to global changes?
- Is there an increase in the length of the melt season associated with the observed subsurface changes in the Arctic Ocean?
- How do Arctic ice and ocean variability drive atmospheric teleconnections with lower latitudes?
- Will reductions in sea ice permanently shift the climate of the sub-Arctic?

Third, what are the probable long- and short-term consequences in the Arctic region? This con-

cerns consequences outside the realm of atmospheric and oceanic interactions that might relate to climate change. They have to do with habitability and effects on the Arctic ecosystem. The concerns include such detailed questions as:

- What are the implications of the observed changes for ecosystems and for delivering and retaining contaminants? Will climate and circulation changes in the Arctic affect nutrients, productivity, and carbon sequestering in the Arctic?
- With a significant change in ice cover over the Arctic shelves, to what extent will the primary productivity processes change? How will the ecosystem change, including species changes that could greatly impact higher trophic levels (fish, benthos, mammals, and birds)?
- Will the thinning of sea ice affect the rate of exchange of carbon dioxide with the atmosphere?
- Will modification of sea ice extent and timing of the maximum extent significantly affect ecosystem dynamics in the marginal ice zone?

2.1.3 Future Study

A new program titled Study of Environmental Arctic Change (SEARCH) is under development. The changes in the Arctic warrant study by a multifaceted approach of measurements, data analysis, and modeling. The change obviously involves the ocean, ice, and atmosphere at high latitudes, and the atmosphere and ocean effects likely extend to lower latitudes. The effects of change should be noticeable on land as well. The wind, temperature, and snow accumulation on the Greenland Ice Cap may be affected, and evidence for such changes in the ice core record may give us a proxy time history of previous similar changes. There may be important effects on the marine ecosystem and human activity in the Arctic as well.

A number of Federal and Alaskan agencies and interested scientists have developed over the last several years a Bering Sea Ecosystem Research Plan. Among the key questions that this research plan would seek to answer are:

- What are the mechanisms and relevant time scales of climate-induced variability of the physical environment that most influence the biological changes of the ecosystem? For example, are physical environmental regime shifts the dominant factor driving major biological changes in the ecosystem?
- Can we separate anthropogenic effects from natural variability?
- What would be the effect of global climate

warming on the physical environment and how would the predicted change affect the present species mix and productivity of the Bering Sea?

- How does climate variability affect physical oceanographic processes (for example, current, fronts, eddies, stratification, etc.) and, in turn, how do these processes affect biological productivity, trophic structure, and yields of living marine resources?
- How does climate variability influence the seasonal production and extent of sea ice and what is the impact of such variation on primary production and the food web?
- How does variability in micronutrient and macronutrient availability affect the productivity of the Bering Sea?

A program of long-term observations is needed to identify and understand causes of climate and ocean variability.

The efforts required to track and understand the change in the Arctic can be broken into four main categories: Time Series Observations; Process Studies and Related Programs; Analysis, Modeling, and Application to Broader Questions; and Coordination.

2.1.4 Time Series Observations

Time series measurements are the backbone of the observational program. They are needed to track the change in the future. The crucial feature of these observations will be duration. Such a program may require a new approach in funding and operations, an approach in which investigators pool their efforts to obtain a community data set. Teaming of NSF with mission-oriented agencies such as NOAA is necessary to provide the ongoing support needed for long-time-series observations.

Ocean

The critical variables in the ocean include the hydrographic state, circulation, inflows, and outflows to the Arctic Basin. At the surface the key variables are the distribution, thickness, and motion of sea ice. In the atmosphere the circulation, moisture, and heat content are the primary variables.

It is convenient to think of the Arctic Ocean as a box with well-defined inflow and outflow regions, exchanging heat and momentum with the atmosphere. Primarily ocean temperature and salinity define the thermodynamic state of this box and, because it is essentially an ice bath, the mass of the ice cover. To assess the change in the Arctic we will need to measure this thermodynamic state. Inflows, outflows, and exchange with the atmo-

sphere must be monitored to explain the observed changes in the state.

Repeated Hydrographic Sections

Hydrographic sections of temperature and salinity reveal the thermodynamic state of the ocean. From them the baroclinic currents can be estimated as well. Ideally we would have a detailed, high-resolution CTD survey of the Arctic Ocean once per year for an indefinite period. A well-justified selection of chemical tracers should also be measured, because there are instances when temperature and salinity alone are inadequate to answer circulation questions essential to understanding the cause of observed changes. Examples include the distinction between sea-ice melt and river water and the distinction of halocline water mass contributions.

Such sequences of large-scale hydrographic observations were made by the former Soviet Union in the 1970s by means of airborne hydrographic surveys conducted in the spring months. The largest of these covered the whole basin with a resolution of about 200 km. These were augmented by data from some of 31 long-term ice stations. Repeating such intense sampling every year may not be practical. However, it would be feasible to establish a hierarchy of frequent surveys at a few locations and less-frequent large surveys at higher resolution. Recent developments facilitate hydrographic measurements. Recent icebreaker cruises have been able to penetrate far into the basin.

Drifting buoys measuring hydrographic parameters have been used by the U.S. to gather sections similar to those from a long-term drifting ice camp for a fraction of the cost. New icebreaker capabilities will make establishing such automated sites easier. In the 1990s the use of Navy submarines has provided a new tool for gathering hydrographic information.

These tools should be used to begin gathering a regular sequence of hydrographic sections. A minimum set of records should be obtained annually to observe changes at key locations. For example, aircraft making sections from shore stations across the topographically controlled boundary currents might perform these. Samples in the interior of the basin could be gathered by automated stations, submarine cruises, and aircraft staged from small ice camps. A complete survey measuring a wider array of hydrographic variables and at greater spatial resolution might be done every few years. The platforms mentioned above could be augmented by extended icebreaker cruises to make the deeper and

more detailed measurements, including tracers and biology. The recent results from SHEBA show that it is important to measure at least a few hydrographic variables seasonally; the thermodynamic exchange between the ocean and atmosphere is recorded in the differences between the fall and spring upper ocean condition. The automated stations can provide seasonal and greater time resolution.

Time Series of Ocean Inflow and Outflow

Monitoring of inflows and outflows to the Arctic Ocean is a large task, but it is important that it be done to understand the mechanisms of change. It is also crucial to assess the effect of Arctic change on lower latitudes, such as convection in the Greenland and Labrador Seas. There are four oceanic portals: the Bering Strait, the Canadian Archipelago, the Fram Strait, and the Barents–Kara throughflow. Bering Strait, Fram Strait, and the Barents–Kara throughflow are already the subject of international programs.

The Bering Strait has been continuously monitored since mid-1990, although not fully satisfactorily. For example, coverage of the western channel has been spotty, and there are years without salinity measurements. Nonetheless, an important time series is beginning to accumulate. When combined with earlier estimates based on a wind-driven flow algorithm, it appears that the last two decades have seen relatively low transport through the strait, and during the 1990s both the salinity and the amplitude of the annual cycle in salinity in the strait have decreased considerably. The former may represent a general freshening in the North Pacific. On the other hand, the decrease in the annual salinity cycle likely reflects a reduction in the amount of sea ice produced over the Bering Sea shelf in recent years. These changes have occurred over the same period in which the distribution of Pacific waters within the Arctic Ocean has changed. We also note that support for the accumulating time series in the Bering Strait is rather fragile, with short-term (typically 1–2 year) contributions thus far from NOAA, the Russian HydroMet Service, NSF, Canadian Department of Fisheries and Oceanography, and the Japan Marine Science and Technology Center. There is a distinct need to place this work on a firmer basis with a longer temporal perspective. An additional perspective on the Bering Strait throughflow is that it represents a key element in the global water balance, transporting excess fresh water from the Pacific to the Atlantic.

Considerable effort has gone into monitoring Fram Strait over the past decade, based primarily

on contributions from Germany, Norway, and the U.S. The strait is a large and complex area with a significant recirculation, but the main exchanges with the Polar Basin are concentrated over the continental slope on either side, and these slopes provide a natural focus for monitoring. The slope on the Spitsbergen side is ice-free and easily accessible; it provides the conduit through which the main warming signal discussed earlier propagated. Keys to identifying this mechanism were the annual hydrographic sections taken by the Marine Research Institute in Bergen, and the long-term monitoring program of this institute should be taken into account in future planning for work in this region. The emphasis on the Greenland side has been the outflow of ice from the Polar Basin, since it is variability in this buoyancy flux that has been implicated in causing the so-called Great Salinity Anomaly in the North Atlantic during the 1970s. The recent measurements over the Greenland slope suggest that interannual variability in the ice flux can in fact be large enough to create such anomalies. A European effort, Variability of Exchanges in the Nordic Seas (VEINS), to determine the fluxes through the Greenland–Norwegian Sea system is presently underway and includes Fram Strait, but the focus is on defining the mass budget, not on monitoring, and the program is of limited duration, with perhaps two years of field work. There is nevertheless a considerable base upon which to build a sustained monitoring program in Fram Strait, and enough is known to enable realistic planning.

It has recently been recognized that the flow of Atlantic waters into the Arctic Ocean has two branches of roughly equal volume: one that enters the Arctic through Fram Strait and one that transits through the Barents Sea. The European VEINS program will monitor the exchange between the Nordic and Barents Seas; it seems clear that further monitoring of the exchanges between the Barents and Kara Seas and the Arctic Ocean is also necessary. While the European VEINS program will monitor the entry of Atlantic waters onto the Barents shelf, the large and probably highly variable modification of these waters on the shelf argues strongly for the additional monitoring of the exchanges between the Barents and Kara Seas and the Arctic Ocean.

Though oceanographic data have been gathered at Fram Strait and Bering Strait, our knowledge of the flow through the Canadian Archipelago is more limited. The observed changes in Arctic Ocean circulation may be linked to two regimes: the typical

anticyclonic circulation pattern that favors flow out through Fram Strait, and a cyclonic circulation that enhances flow out through the Canadian Archipelago. Thus, these circulation regimes drive variations in the freshwater flux out of the Arctic that could be observable in data from current meter moorings deployed in the Canadian Archipelago. Variations in the freshwater flux rate between Fram Strait and the Canadian Archipelago are measurable and would provide evidence for the phasing of the two regimes.

Ice

To know the thermodynamic state of the Arctic Ocean, one must know the mass of ice present. This requires time series of ice extent and ice thickness. The ice extent has been monitored by remote sensing techniques for the past 20 years, and this will be continuing as part of existing programs. These techniques provide other useful parameters as well. The scanning multichannel microwave radiometer (SMMR) and special sensor microwave/imager (SSM/I) passive microwave satellite remote sensing systems have provided measurements of ice extent, concentration, and velocity for first-year and multi-year ice types to a resolution of about 25 km. The new advanced microwave scanning radiometer (AMSR) system is expected to provide improved measurements into the future. The advanced very high-resolution radiometer (AVHRR) system has provided measurements of surface temperature, albedo, and cloud properties to a resolution of 1–5 km. These measurements can also be used to estimate ice extent and velocity. The AVHRR type measurements will be continuing using the moderate resolution imaging spectroradiometer (MODIS) system. The new Canadian Radar Satellite (Radarsat) active microwave satellite images the ice with 100-m resolution. The data are being processed by the Radarsat geophysical processor system (RGPS) to produce ice velocities at 5- to 10-km resolution.

Measurement of ice mass or thickness is more problematic. This requires measurements of ice draft that must be provided by surface or in-water observations. The most obvious method is by surface observation, drilling holes in many random locations and measuring the ice thickness. However, the number of samples required for a meaningful average is substantial, and practical considerations probably lead to underestimates in thickness. The other approach is to measure ice draft and derive thickness and mass by assuming isostasy. Ice draft has been measured operationally as part of past submarine cruises. Many of these data are now being made available for scientific research. The

recent SCICEX submarine cruises for scientific research have provided detailed ice thickness profiles. In the future, autonomous underwater vehicles (AUVs) may duplicate this type of measurement currently being made by submarines. Moored upward-looking sonars (ULS) have also measured ice thickness. The upward-looking acoustic depth sounder measures the distance to the bottom of the ice. A sensitive pressure sensor measures the depth of the instrument, and this minus the distance to the bottom of the ice is the ice draft. The ULS approach relies on the ice drift to advect a wide range of ice types past the instruments. In the future a mix of these measurement techniques will be necessary. Direct sampling, submarine data, and AUV sampling will give snapshots of the spatial distribution of ice thickness. Moored ULSs, when placed in strategic locations and combined with measurements of ice velocity, can conceivably provide time series of ice thickness for large areas. This requires the thoughtful integration of various measurement types but may provide substantial insights into the mass balance of the basin.

Atmosphere

The atmosphere appears to be the driving force behind observed changes in the Arctic. Fortunately monitoring the Arctic atmosphere is part of ongoing programs. The International Arctic Buoy Program (IABP) network of drifting buoys measuring atmospheric pressure and temperature has observed changes in the atmosphere. These buoys tell us the surface wind field and thermodynamic forcing acting on the ice. Soundings into the upper atmosphere are conducted around the periphery of the Arctic Ocean by the various Arctic nations. Satellite remote sensing provides some profile measurements. The TIROS-N operational vertical sounder (TOVS) can yield vertical profiles of air temperature and vapor content to 100-km resolution over the whole basin. The atmospheric infrared sounder/advanced microwave sounding unit (AIRS/AMSU) systems will be continuing these types of measurements. AVHRR provides spatial maps of surface temperature, albedo, and cloud properties. What these satellite soundings lack in accuracy is compensated for by the statistical value of the large amount of data provided. These satellite systems work especially well when surface ground-truth measurements of air temperature are available from buoys. It would be beneficial if added atmospheric soundings were available at a few sites in the basin. The critical element for Environmental Arctic Change is that the existing atmospheric measurement programs continue.

2.1.5 Process Studies and Related Programs

As the time series measurements, analysis, and modeling progress, process-oriented questions are bound to arise. These will warrant process-oriented experimental programs.

These experiments may involve many investigators in complex multidisciplinary studies. Ideally many of these will already be part of active initiatives. Examples of such studies are the Surface Heat Budget of the Arctic (SHEBA) and the proposed Western Arctic Shelf Basin Interaction (SBI) program. SHEBA looked at the exchange of heat at the surface of the Beaufort Sea in a year-long observation program. The observations of thin ice and a fresh and warm mixed layer show a connection with other observed changes in the basin. The SHEBA process results will tell us if there is a feedback from the oceans to the atmosphere that might reinforce the changes.

The SBI is an NSF initiative that has important connections to Environmental Arctic Change. It aims to study shelf processes and their effects on the rest of the Arctic Ocean. Because some of the changes we see, such as the salinity increase in the Makarov Basin, may be connected to changes on the shelves, SBI process studies can contribute to our understanding of Arctic change.

Process studies will be needed for Environmental Arctic Change. Fortunately the logistics and operations efforts of a time series study will provide a significant base for the process studies.

Although Environmental Arctic Change is an atmosphere-ice-ocean oriented study, it has connections to other programs, such as the terrestrial transects of the International Geosphere/Biosphere Program. Proxies to extend our records back in time and look for evidence of changes in the past may be found in ice cores of the Greenland Ice Sheet Program (GISP) and the records of the Paleontology of Arctic Lakes (PALE) program. The results of the Arctic change work may affect the direction of the NSF Human Dimension of Arctic Climate Change (HARC) program.

2.1.6 Analysis, Modeling, and Application to Overarching Questions

Modeling will be an integral component of the study of Arctic environmental change. First, simu-

lations can be used to extend the field data in both space and time. In 1996, satellite and buoy data were assimilated into a model that predicts freshwater outflows from the Arctic Ocean. Another researcher found decadal-scale variability in an ocean circulation model using meteorological forcing data. Second, various geophysical scenarios can be tested using a model, such as the response to increasing CO₂ concentration. Third, models can assist in guiding field programs by identifying locations and/or seasons where measurements are most crucial. An example is the SHEBA project, which is driven by the need to more accurately measure the surface energy balance. Similarly, another study has identified regions of high variability in modeled sea ice thickness, which might be used to guide the placement of moored buoys.

2.1.7 Coordination

The cooperation of mission-oriented agencies such as NOAA and ONR will be critical for making long time-series observations.

The Science Plan, as it develops, will define the study objectives, measurement requirements, and modeling requirements. The Science Plan will allow funding agencies to consider budget commitments.

Special emphasis will be placed on encouraging international cooperation and cost sharing. This is already a facet of observations of the important inflow and outflow regions. The European community has a strong program in the Fram Strait. The U.S. and Russia are working cooperatively in the Bering Strait, and Canada and Japan have also been involved in recent work there. Observations to study the Canadian throughflow will involve substantial Canadian and U.S. cooperation. The Arctic Climate System Study (ACSYS) program is international and is meant to examine the role of the Arctic in global climate. Many of its activities will support the objectives and measurement requirements of Environmental Arctic Change. Close cooperation with ACSYS will be important. Similarly cooperation with other international groups monitoring the various inflows and outflows of the Arctic Ocean will be crucial. The new International Arctic Research Center (IARC) in Fairbanks, Alaska, is focused on long-term climate change and will, in particular, support modeling and data analysis goals.

2.2 Arctic Monitoring and Assessment

Recognizing the sensitivity of the Arctic to pollution by contaminants that are generated both in the Arctic and at lower latitudes, and conscious of the degree to which the human population of the Arctic depends on the health of the region's ecosystems, in June 1991, in Rovaniemi, Finland, the governments of the eight Arctic nations adopted the Arctic Environmental Protection Strategy (AEPS). In this strategy the Arctic nations committed themselves to international cooperation to ensure the protection of the Arctic environment and its sustainable and equitable development, while protecting the cultures of indigenous people. The stated objectives of the strategy were:

- To protect the Arctic ecosystems including humans;
- To provide for the protection, enhancement, and restoration of environmental quality and the sustainable utilization of natural resources, including their use by local populations and indigenous people in the Arctic;
- To recognize and, to the extent possible, seek to accommodate the traditional and cultural needs, values, and practices of indigenous people as determined by themselves, related to the protection of the Arctic environment;
- To review regularly the state of the Arctic environment; and
- To identify, reduce, and, as final goal, eliminate pollution.

Believing that there should be more governmental attention to Arctic issues, especially in the area of sustainable development, in 1996 the eight Arctic governments created the Arctic Council. This Council is to promote cooperation and coordination among the Arctic states, oversee and coordinate the programs that were established under the earlier AEPS, oversee and coordinate a sustainable development program, and disseminate information, encourage education, and promote interest in Arctic-related issues. The U.S. is chair of this Council for the period 1998–2000.

There are five working groups under the Arctic Council: Protection of the Arctic Marine Environment; Conservation of Arctic Flora and Fauna; Emergency Prevention, Preparedness and Response; the Arctic Monitoring and Assessment Program (AMAP); and Sustainable Development and Utilization.

The principal purposes of AMAP are to document levels and trends of environmental contaminants; assess the effects of contaminants on Arctic

biota and ecosystems; anticipate adverse biological, chemical, and physical changes in Arctic ecosystems; and evaluate potential risks from environmental contamination to Arctic residents and ecosystems and recommend actions required to reduce such risks. AMAP is also concerned with potential impacts on the Arctic region of climate change and increased ultraviolet radiation.

The first phase of AMAP (1991–1998) concluded with the publication of a comprehensive assessment of the effects on Arctic ecosystems of persistent organic pollutants, heavy metals, radioactivity, acidification and Arctic haze, petroleum hydrocarbons, climate change, ozone depletion, and ultraviolet radiation. AMAP also had a subgroup dealing with the subject of pollution and human health. The AMAP working group presented a summary report titled *Arctic Pollution Issues: A State of the Arctic Environment Report* to the Ministers of the Arctic nations in 1997. The text of this report is available at the web site <http://www.grida.no/amap/amap.htm> under the heading of Online Documents. The much larger and more technical *AMAP Assessment Report: Arctic Pollution Issues* was published in 1998. It is going to become available as a CD-ROM.

The 12th AMAP working group meeting in Helsinki, December 7–9, 1998, marked the effective beginning of the second phase of AMAP. During this phase, AMAP will not attempt to produce another comprehensive assessment of effects of contaminants on the Arctic environment. Instead, it will focus on producing a limited number of assessment reports on specific pollution issues, and these reports will be presented to Ministers and Senior Arctic Officials for their consideration. At the Helsinki meeting a timetable was agreed to for producing these reports, but, whenever possible, the timetable will be adjusted so that assessment reports can be presented at other relevant international environmental forums, such as the "Rio + 10" meeting planned for 2002 in connection with the 10th anniversary of the UN Conference on Environment and Development. The U.S. came out of the Helsinki meeting with the responsibility for leading the development of assessment reports on Arctic environmental effects of climate change (jointly with Norway), ultraviolet radiation, and heavy metals. The U.S. will also participate in preparing the other assessment reports where it does not have the lead.

It should be recognized that AMAP, and indeed

*Sockeye salmon habitat
preference research,
Nikolai Creek, Tustumena
Lake watershed, Alaska.*



all of the Arctic Council programs, do not operate in a vacuum. Many Arctic problems are components of global, hemispheric, regional, national, or local issues that are being addressed in other forums, and this fact must be taken into account in assessing the potential impacts of contaminants on the Arctic region. Assessment of the effects of climate change in the Arctic, for example, demands close cooperation between AMAP and the Arctic Council's working group on Conservation of Arctic Flora and Fauna, together with the International Arctic Science Committee and the Intergovernmental Panel on Climate Change.

Each Arctic nation is scheduled to develop a National Implementation Plan outlining the Arctic research activities that it intends to support and that will contribute to accomplishment of the general objectives of AMAP. The U.S. views its National Implementation Plan as something of a "loose leaf binder" rather than a hard-bound volume. That is, our plan will be a varying one, with new programs and projects being added as agencies in local, state, and Federal governments, together with private organizations, begin new projects on the effects of Arctic pollution and as completed activities are dropped. In line with this approach the information presented here is a selection of rel-

evant activities that agencies plan to pursue over the next few years. Other relevant projects and programs will be added in subsequent reports of this type.

2.2.1 Arctic Contaminant Research

Understanding the contaminant behavior within the Arctic's atmospheric, marine, terrestrial, and estuarine systems requires an in-depth examination of complex, interdependent natural processes. Quantifying these processes provides the foundation for developing a multi-faceted perspective and predictive understanding that contributes to the knowledge base used by management and policy decision makers in planning, development, pollution avoidance, remediation, and restoration activities. Such understanding is fundamental to appreciating and mitigating the impacts of contaminants on human physical and socioeconomic systems.

NSF encourages and supports a wide variety of special studies relevant to contaminants in the Arctic. These fundamental research projects focus either on aspects of individual systems or on fundamental interrelationships among multiple systems. They range from microscopic to global in scale and organization. A newly developed Arctic initiative will emphasize research on a wide variety of contaminants, including heavy metals, radionuclides, persistent organic pollutants, hydrocarbons, and aerosols. To encourage increased submissions of proposals on these topics, a special solicitation has been published in FY 99. For at least the next five years, the type of research encouraged in that publication will continue to be considered by existing Arctic science programs within NSF's Office of Polar Programs.

Non-exclusive examples of studies appropriate for consideration under NSF's Arctic contaminant emphasis include fundamental research projects on:

- Transport pathways, rates, processes, and reservoirs of contaminants—from microscopic to global scales—within atmospheric, marine, terrestrial, and estuarine systems;
- Impact on transport of molecular-scale interactions involving microbes, inorganic and organic compounds, and colloids;
- Influence of unique Arctic conditions (for example, temperature and light) on the transformation and fate of contaminants;
- Biomagnification of contaminants in marine and terrestrial foodwebs and the dynamics of change in contaminant concentrations;

- Effects of combined contaminants on biota;
- Influence of UV-B on contaminant behavior in aquatic systems;
- Development of novel chemical methods or sensors for determining contaminant levels under polar conditions;
- Socioeconomic impacts of contaminants on marine and terrestrial resources and their effects on human communities;
- Risk perception and risk assessment for environmental contaminants; and
- Role of traditional knowledge in contaminant studies.

2.2.2 Persistent Organic Pollutants and Heavy Metals

Most synthetic organic chemicals of concern within the Arctic are fat-soluble and break down slowly. This allows them to accumulate in the fat of animals and to pass through the food chain from prey to predator, thus increasing the burden of organic contaminants at each successively higher level of the foodweb. Biological effects of persistent organic pollutants (POPs) on Arctic animals include impairment of reproduction and growth, formation of cancerous tumors, and weakened immune systems. Examples of POPs are polychlorinated biphenyls (PCBs), dioxins, hexachlorobenzene, hexachlorocyclohexane, and a wide variety of pesticides. The transport and fate of POPs depend to a large extent on the physical and chemical properties of each chemical, but it is clear that atmospheric transport plays an important role in carrying many of them from temperate latitudes to and through the Arctic.

Certain forms of some metals are toxic and pose a threat to the health of animals and humans. There is concern, therefore, that human activities will increase the flux of metals that can be carried by wind and water into the Arctic environment and thus become available to the plants and animals there. Heavy metals can also enter the environment from waste incineration. The metals of primary concern here are mercury, cadmium, lead, and selenium.

Under the Marine Mammal Protection Act of 1972, the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) share responsibilities for managing marine mammal populations. FWS is responsible for the managing polar bears, walruses, and sea otters, while NMFS has management authority for cetaceans, seals, and sea lions. Because samples are often collected in conjunction with other

organizations and in remote locations, there is a high degree of cooperation between the two agencies in collecting and analyzing marine mammal tissue specimens.

Polar bears, walruses, and sea otters are all important resources for Native Alaskans, and FWS is obligated to protect and maintain the availability of these species for subsistence purposes. Consequently FWS plans to continue its polar bear bio-monitoring program, study the relationship between contaminant levels in polar bears and their prey, and contribute samples for long-term storage with the Alaska Marine Mammal Tissue Archival Project (AMMTAP) to use in future analyses as analytical techniques improve and to help us better understand spatial and temporal trends of Arctic contaminant levels. Similar studies have been carried out on walrus and sea otter populations and will continue in the future. The majority of polar bear, walrus, and sea otter specimens are collected by Native Alaskan hunters working cooperatively with FWS biologists.

FWS and NMFS also share the responsibility for administering the Endangered Species Act. Generally NMFS deals with those species that occur in marine environments, including anadromous fish, while FWS is responsible for terrestrial and freshwater species, anadromous fish in freshwater and brackish water areas, and migratory birds. Both agencies' efforts include protecting endangered and threatened species and restoring them to a secure status in the wild. For example, populations of the Arctic and American peregrine falcons in northern and interior Alaska declined dramatically following World War II as a result of contamination with organochlorine pesticides, particularly DDT. The use of DDT and other organochlorine pesticides such as aldrin and dieldrin were restricted in Canada and the U.S. in the early 1970s. Peregrine falcon populations began to increase during the late 1970s. The Arctic subspecies has now been delisted, and delisting of the American subspecies is being considered. FWS plans to continue its peregrine falcon monitoring, reflecting the important role of organochlorine contamination in their decline and subsequent recovery.

FWS has published a series of baseline contaminants reports for five National Wildlife Refuges (NWR) in Arctic Alaska. These publications reported on ambient concentrations of metals in water, freshwater sediments, and fish tissues at several sites within each refuge. Baseline sampling in the Arctic NWR also included terrestrial

vegetation, and the suite of contaminants was expanded to include hydrocarbons and persistent organic chemicals. Similar reports for two additional refuges will be prepared in the future.

NMFS is working with the North Slope Borough to study contaminants in the bowhead whale's foodweb and to conduct a health assessment. They are also working with the North Slope Borough and the National Institute of Standards and Technology (NIST) to conduct similar studies of beluga whale populations. Their contaminant monitoring of Steller sea lions is done in cooperation with the State of Alaska and the University of Alaska Fairbanks. A polar bear/ring seal trophic transfer and transport contaminant monitoring study is a multiagency effort involving NMFS, FWS, the U.S. Geological Survey/Biological Resources Division (USGS/BRD), the North Slope Borough, and NIST.

The Marine Mammal Health and Stranding Response Program (MMHSRP) facilitates the collection and dissemination of data on the health of marine mammals and health trends in marine mammals in the wild; correlates those trends with available data on physical, chemical, and biological environmental parameters; and coordinates effective responses to unusual marine mammal mortalities. NOAA and USGS/BRD will continue operation of AMMTAP for collection and long-term storage of tissues from Alaskan marine mammals. These samples are collected to determine the levels of contaminants in Alaskan marine mammals, and the data are used by public health organizations to examine circumpolar contaminant concentrations and to evaluate the risk to people who eat marine mammals as subsistence foods.

AMMTAP is a partnership between USGS/BRD, FWS, NMFS, and NIST, and it was initially funded by MMS. USGS and NMFS now provide funding and personnel for collection. NMFS is the manager of the overall project and provides analytical work, design, and interpretation. NIST provides banking of samples, some funding, and the overall lead for quality assurance associated with banking. FWS provides opportunities for sampling and data interpretation. AMMTAP is part of the National Marine Mammal Tissue Bank (NMFS), which is part of the National Biomonitoring Specimen Bank (NIST). The National Marine Mammal Tissue Bank and AMMTAP are part of the Marine Mammal Health and Stranding Response Program established through the 1992 amendments to the Marine Mammal Protection Act. This program is a partnership between DOI and DOC with NMFS having the lead for the overall program.

MMS also sponsors the preservation of a wide variety of wildlife tissues in its Alaska Frozen Tissue Collection and Database at the Coastal Marine Institute of the University of Alaska Fairbanks.

An interagency cooperative effort to develop methods for collection, handling, transport, and long-term storage of seabird eggs from the Bering Sea, Chukchi Sea, and Gulf of Alaska is being conducted by NIST, the Alaska Maritime National Wildlife Refuge, and USGS/BRD. Common and thick-billed murre eggs are the initial focus of this research. Protocols may also be developed for other tissue types (for example, liver, kidney, muscle, feathers, and blood) and additional bird species. This project should update our knowledge of seabird egg and tissue contamination within this region, in addition to archiving specimens for the future.

NMFS, FWS, and USGS/BRD have developed a coordinated sampling plan for FY 99 and FY 00 to conduct contaminant investigations and monitor marine mammals of the Arctic. A foodweb study of northern fur seals, bowhead whales, and Steller sea lions is ongoing, combining the resources of the Alaska Department of Fish and Game and NMFS's Northwest Center and supported by a grant from the National Fish and Wildlife Foundation. Data from this study will contribute to our knowledge about the presence and possible effects of anthropogenic contaminants in the Arctic marine environment.

Over the next few years, NOAA's National Ocean Service (NOS) plans to start collecting sediment cores from relatively undisturbed coastal areas of the Arctic to reconstruct the historical chronology of environmental contamination in the region. A large variety of contaminants from industrial, maritime, and urban activities have a strong affinity to adsorb onto particulate matter, and as such, they can settle to the bottom near their point of entry in the coastal zone. Thus, changes in the levels of contaminants due to local anthropogenic sources, such as oil and gas development and maritime activities, as well as hemispheric transport of contaminants and natural fluxes of certain toxic contaminants, may be recorded in accumulated sediments. Sediment cores will be collected at randomly selected sites in Elson Lagoon located near Barrow.

NOS's National Status and Trends (NS&T) Program, through NMFS's Northwest Center and contractors, supports measurements of the status and trends of environmental quality of U.S. coastal areas and the biological consequences of

pollutants and other stresses on living organisms and coastal ecosystems. NOS plans to resample NS&T sites in Alaska at least once during the next five years.

Surficial sediment and biological samples collected in the Beaufort Sea, Bristol Bay, and Norton Sound, as well as from sites in eastern Siberia, have been analyzed by NOS investigators for radionuclides, organic contaminants, and toxic metals. Some of the results have been published as program reports, as research papers, or in international conference proceedings. Further analyses of data and preparation of manuscripts are expected to continue.

NOAA will continue to support studies of atmospheric mercury in the Arctic environment through its Arctic Research Initiative. Continuous measurements are being conducted from the NOAA/CMDL Barrow Atmospheric Baseline Station. Scientists working on this topic will apply long-range trajectory techniques developed within NOAA's Air Resources Laboratory, together with mercury sampling methodologies developed by Oak Ridge National Laboratory, to provide definitive information on the sources of biologically active mercury that is accumulating in the Alaskan Arctic. The work will be done in cooperation with scientists who are addressing similar concerns in Canada at the Canadian Atmospheric Environment Service in Toronto. Special attention will be given to computing back-trajectories for occasions when mercury concentrations are found to be elevated.

NOAA's Arctic Research Initiative is supporting projects at the University of Alaska Fairbanks, NMFS, and the University of California-Davis to study the effects of organochlorine contaminants on immune system development in northern fur seals and the pathways and extent of organochlorine contamination in the Bering Sea ecosystem. A project at the North Slope Borough's Department of Wildlife Management, the University of Alaska Fairbanks, NMFS, and Texas A&M University is examining the potential use of the bowhead whale as an indicator species for monitoring the health of the Western Arctic/Bering Sea ecosystem. Finally, an Arctic Research Initiative project with the Barrow Arctic Science Consortium is attempting to assess how contaminants enter and move through the Arctic foodweb and reach top predators and humans, and also to assess how people respond to this information.

The Office of Naval Research is sponsoring a North Slope Borough study of contaminants in Arctic marine mammals. Scientists working on this

project will assess the levels and interactions of several heavy metals in tissues of bowhead and beluga whales, ringed seals, and polar bears. The project is expected to lead to recommendations on safe human consumption levels for these species.

During 1992 and 1993 the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) conducted a number of studies to characterize the extent of POPs and heavy metals contamination in the Arctic. These studies included analyses of lake sediment cores and fish and squirrel tissues. ORD is reviewing the data from this project for quality and is organizing the database to make it available to researchers on a CD-ROM some time in 2000. ORD is also sponsoring a study at the University of Alaska Fairbanks on the biochemical response of marine mammals to metals and inflammatory agents.

EPA's Office of International Activities is sponsoring a multilateral initiative to assist Russia in phasing out its production and use of PCBs and in developing environmentally sound PCB management and disposal practices. This is a three-phase project to estimate PCB production, use, storage, waste, and release rates; to study the feasibility of technology conversion/retrofit options; and to conduct pilot demonstration projects, such as the production and use of alternatives to PCBs as dielectrics in electrical transformers. Expertise and/or funding are being sought from other domestic and international entities such as the Department of Energy, the Edison Electric Institute, the World Bank, and the Nordic Environmental Finance Corporation. It is anticipated that this project can be expanded to other countries that produce or use PCBs and contribute to the long-range transport of PCBs to the Arctic.

For much the same reason as with PCBs above, EPA's Office of International Activities is developing a multilateral Arctic initiative on mercury. One objective of the initiative will be to monitor atmospheric levels of mercury at strategic locations in the Arctic and to identify and demonstrate promising mercury control technologies in key source countries. A second objective will be to examine the atmospheric chemistry and fate of mercury during the springtime return of sunlight to the Arctic. The photolytic reactions of this Arctic sunrise event cause large quantities of mercury to leave the vapor phase and deposit to land and water in particulate form. EPA is coordinating with NOAA, Canada, and Norway on instrumentation and methods for long-range atmospheric monitoring and modeling, and with DOE, the Tennessee Val-

ley Authority, and others on mercury control technologies. Trace element data and back-trajectory analysis and modeling will allow scientists to model the transport of mercury to the U.S. from sources abroad and, through international cooperation, to enhance international mass balance analysis for mercury. Arctic sunrise research will be done in coordination with ongoing U.S.–Canadian cooperative activities.

EPA's Office of Research and Development is supporting a project at Utah State University to conduct a detailed investigation of the reduction of trichloroethane and dichloroethane levels in groundwater by naturally occurring microbial bioremediation techniques.

*Beluga whale,
Beaufort Sea, Alaska.*



2.2.3 Radioactivity

Potential threats to human health and the environment from radioactive pollution in the Arctic appear to be associated with nuclear operations and activities; accidents during the removal, transport, and storage of spent fuels from power plants and nuclear vessels; accidents during nuclear operations; and radionuclides remaining from atmospheric and underground nuclear weapons testing.

A theme voiced by many Alaska Native communities is their belief that they live in the shadow of radiation from military practices of the former Soviet Union, underground nuclear tests on Amchitka Island, and activities at other former or active military sites within Alaska. In addition, communities report observations of changes or abnormalities in wildlife that they attribute to radioactivity, such as lesions in fish and caribou livers, loss of hair on seals, and tumors and sores on birds and mammals. Virtually every community

speaks of a deeply held concern over the diminished health of its members. The Alaska Native Science Commission and the Institute of Social and Economic Research, University of Alaska Anchorage, have received a grant from the EPA for a Radionuclides and Traditional Knowledge project to study this problem. The first year will be spent gathering traditional knowledge about radionuclide concerns across five major regions of Alaska. The second year will be dedicated to a series of regional meetings plus a synthesis meeting. The purpose of the regional meeting will be to enable communities to consider the implications of their own knowledge of environmental changes and scientific information. The purpose of the synthesis meeting will be to enable scientists and communities to identify common and divergent understandings of environmental change and the role of radionuclides and other contaminants. In the second and third years a community program will support Alaska Native grassroots action projects to address community concerns about radionuclides and other contaminants.

Recent revelations by the Russian government about past defense waste management practices have focused attention on waste management and environmental restoration at the Mayak site located near Kyshtym. Radionuclide releases there are greater than 2.5 times the amount released by the Chernobyl reactor accident in 1986, but they are dwarfed by recently revealed injection of at least one billion curies of radioactive waste at Tomsk and Krasnoyarsk into sandy aquifers 300–450 m below the surface. Mayak, Tomsk, and Krasnoyarsk are located on Paleozoic rocks that surface beyond the edge of the West Siberian Basin in topographically higher areas that serve as recharge sources for some of the waters flowing north into the basin. As a result they are sources of contamination for both local and regional surface and subsurface hydrologic systems—and ultimately the Arctic Ocean. With support from the U.S. Department of Energy, scientists at the Pacific Northwest National Laboratory plan to continue working with Russian colleagues on groundwater flow and radioactive contaminant transport studies at Mayak and Tomsk.

The Atomic Energy Commission, predecessor of the DOE, used Amchitka Island in the Aleutians for underground nuclear tests between 1965 and 1971. In preparation for the tests, intensive bioenvironmental studies were conducted. Follow-up radioecology studies were conducted during the 1970s, and EPA has been collecting surface and groundwater samples subsequent to those studies. Begin-

ning in 1997 DOE supported an expanded radioactivity sampling program in collaboration with the State of Alaska's Department of Environmental Conservation and the Aleutian/Pribilof Islands Association. Work is in progress to select and use a model to predict groundwater flow at Amchitka, and the model will be used to predict leaching and transport of radionuclides by groundwater. These data will enable DOE to predict where groundwater from the vicinity of the detonation cavities is likely to discharge on the ocean floor near the island. It will also predict concentrations and transport times. This information will then be applied to human health and ecological risk assessments.

2.2.4 Petroleum Hydrocarbons

The Arctic is very rich in petroleum and hard mineral resources. The North Slope of Alaska, Yamal Peninsula, Norwegian Sea, and Barents Sea have some of the largest oil-and-gas-producing fields in the world and a great potential for new untapped reservoirs. The National Petroleum Reserve-Alaska and the Arctic NWR may contain substantial and economically recoverable reserves of oil, natural gas, and coal. Thus, it is anticipated that fossil energy development and related industrial activities in the U.S. Arctic will continue in the foreseeable future and will require scientific studies to ensure safe and prudent development of the resources. In addition, studies will be required to protect fish and wildlife populations, critical habitats, and subsistence resources.

A substantial information base and extensive scientific data on the physical environment and biological resources of the U.S. Arctic already exist as a result of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), 1975-1992. The program, established as an inter-agency effort between NOAA and MMS, provided numerous topical and synthetic scientific reports, environmental atlases, a comprehensive digital database, various analytical and numerical models, and a contaminant baseline in the context of offshore oil and gas development in the seas around Alaska.

MMS continues to sponsor a program of environmental studies focused on outer continental shelf oil and gas development in the Beaufort and Chukchi Seas. The studies are funded either directly by MMS or indirectly under a cooperative agreement between MMS and the University of Alaska Fairbanks.

A study to determine the levels of metals, polycyclic aromatic hydrocarbons (PAHs), organo-

chlorine pesticides and industrial chemicals, and organotin compounds in the coastal Beaufort Sea is underway as a collaborative effort between NOAA/NOS and the University of Alaska Fairbanks. Earlier data of a similar nature, covering a much smaller area and based on fewer analytes, were published periodically since 1976. The overall purpose of the study is to determine if the levels of environmental contaminants can be attributed to increased industrial development and urbanization of the region. MMS is funding a portion of this study of petroleum hydrocarbons and metals associated with petroleum exploration and development. More site-specific monitoring in the vicinity of the Federal oil and gas lease area is underway.

PAHs, a group of complex organic compounds having two or more fused benzene rings, are components of petroleum, coal, peat, and pyrogenic residues, although some are biogenic. It is generally agreed that the vast majority of PAHs in the environment are derived from fossil fuels and combustion sources. They are widely distributed and are found in all components of Arctic ecosystems, particularly in association with sediment. Their abundance in the U.S. Arctic shows a distinctly regional pattern; concentrations in coastal Beaufort Sea sediment are generally much higher than elsewhere. A number of PAH compounds and their metabolites are known to be toxic, carcinogenic, or genotoxic. An assessment of potential source terms and environmental fate and effects of PAHs in the U.S. Arctic has not been made.

Photoactivation of several PAHs by ultraviolet (UV) radiation is known to affect genotoxicity (for example, DNA strand breakage), and new techniques to assess genetic damage have recently been developed. A number of studies have established that the toxicity of UV-activated PAHs results from activation of bioaccumulated PAHs. Such effects may be synergistic, that is, the combined effect of exposure to UV radiation and PAHs would be greater than the sum of their individual effects. As such, studies to examine the combined effects of increased UV radiation and PAHs in the coastal Beaufort Sea, particularly in view of the likely depletion of stratosphere ozone in the Arctic, should receive high priority. NOAA/NOS is currently examining the feasibility of conducting such a study.

EPA's Office of Research and Development is supporting a project at the University of Alaska to determine the role of oligobacteria in the degradation of environmental hydrocarbons.

Under the auspices of the U.S.–Russian Joint Commission on Economic and Technological Cooperation, EPA's Office of Research and Development is cooperating with the Russian government in a project to assure that oil and gas resources in the Siberian Arctic and the Arctic Ocean drainage basin are undertaken in an environmentally sound manner. The project also explores the potential of using information derived from classified intelligence sources of both Russia and the U.S. for environmental risk assessment. Phase 1 of the project was a risk assessment for the Priobskoye oil deposit, which is located beneath the ecologically sensitive Ob River floodplain. This phase has been completed and the results published. The final report is available on the Internet at <http://www.epa.gov/ncea.oilgas.htm>. Decisions on how to proceed next await discussions within both governments.

2.2.5 Climate Change

In the Alta Declaration of 1997, the Arctic ministers endorsed continued efforts by the working groups for AMAP and Conservation of Arctic Flora and Fauna (CAFF) to study and understand the impacts of climate change on the Arctic. Changes in the climate of the Arctic are expected to be among the largest anywhere in the world, and there is little room for doubt that major changes have occurred there in recent decades. Since climate affects all aspects of life on earth from species to ecosystems to humans, knowing the probable impacts of climate change is a crucial input to policy development, economic and environmental planning, and the well being of Arctic people.

Currently the international scientific community is planning (and in many instances, has already initiated) very large programs in climate research, prediction, assessment, and adaptation. These programs consider climate variability on time scales from seasons to years, along with both natural and anthropogenic climate changes from decades to centuries. Included in these efforts are foci on long-term observations/monitoring; physical, chemical, biological, and geophysical process studies of atmospheric, oceanic, terrestrial, and cryospheric systems; modeling and prediction of climate and its effects; and assessment of climate change and production of climate forecasts.

The international AMAP plan is to produce a circum-Arctic synthesis of climate change impacts, with the first report expected in the year 2000. The synthesis will be undertaken jointly by the International Arctic Science Committee, AMAP, CAFF, and possibly other parties. It is important to have partici-

pation by IASC, since that organization has already sponsored regional climate impact assessments in the Bering Sea and the Barents Sea, and a sound Arctic impact assessment will require involvement by some of the international teams of scientists who worked on those earlier studies, which include the Canadian MacKenzie Basin impacts assessment.

The Arctic Climate Impact Assessment—proposed by IASC and now under consideration by the Arctic Council, IASC, AMAP, and CAFF—will consist of periodic workshops that bring together the most knowledgeable people in climate research, physical and biological impacts assessment, and economic and social sciences, including representatives of indigenous people, to provide estimates of the effects of climate change and increased ultraviolet radiation on Arctic ecosystems and other aspects of life in the Arctic. AMAP, CAFF, and IASC have established an Assessment Steering Committee to guide these workshops and the production of impact assessments. A workshop organized by IASC at Tromsø, Norway, in April 1999 determined the needs and requirements for such an assessment.

NOAA/NMFS is leading the development of an Arctic Initiative within the Scientific Committee of the International Whaling Commission. The purpose of this initiative is to address pollution, contaminants, habitat, and climate change as they affect cetaceans in the Arctic.

The Department of Energy's Atmospheric Radiation Measurement (ARM) program is a multi-laboratory, interagency program designed to help resolve scientific uncertainties about global climate change, with a specific focus on improving the performance of general circulation models used for climate research and prediction. These improved models will help scientists better understand the influence of human activities on the earth's climate. In pursuit of its goal the ARM program establishes and operates field research sites called Cloud and Radiation Testbeds in several climatologically significant locations. One of these sites, the North Slope of Alaska/Adjacent Arctic Ocean Site, is providing data about cloud and radiative processes at high latitudes. These data are being used to refine models and parameterizations as they relate to the Arctic. Details on the ARM program may be found on the web site <http://www.arm.gov>.

2.2.6 Ultraviolet Radiation

Stratospheric ozone plays a critical role in blocking potentially harmful ultraviolet (UV) radi-

ation from reaching the earth. The amount of ozone in the stratosphere is currently decreasing, especially in the polar regions, and this has caused concern that plants and animals (including humans) may be damaged by increased ultraviolet radiation. During springtime, maximum UV levels are observed at a time when people and many biological systems are most sensitive to UV radiation.

Existing UV measurement programs focus mainly on the incoming UV radiation that affects human skin, for example, and that can be used to make inferences about ozone concentrations aloft. There is concern that increasing near-horizontal UV radiation is contributing to an increasing incidence of eye disease (cataracts and cancer). A new multi-agency program to concentrate on the issue of near-horizontal UV radiation and its biological consequences is being planned.

It is possible to use UV radiative transfer models to estimate UV exposure in regions where UV measurements do not exist. Such measurements are usually based on satellite data to provide relevant atmospheric parameters, but they are difficult to make in the Arctic because of the complexity of atmospheric and environmental conditions, including persistent but changing cloud cover and high and variable surface albedo. The use of ground-based UV measurements, therefore, is crucial for developing reliable algorithms for determining surface UV exposure in the Arctic from satellite data.

NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL), in collaboration with the Air Resources Laboratory, the National Weather Service, the University of Alaska Fairbanks, and the University of Colorado at Boulder, has recently deployed ground-based UV radiation instruments at Barrow, Nome, and St. Paul Island. At the CMDL Observatory in Barrow, one instrument is a broad-band UV spectrometer that measures total irradiance over the 280- to 320-nm spectrum and produces an output proportional to the biologically important UV-B or "erythemal" dose, which describes the response of human skin to solar radiation. The other instrument is a narrow-band (10-nm bandwidth) radiometer that measures UV irradiance at five discrete wavelengths and is useful for applications that require better resolution than is offered by broad-band instruments.

Over the next several years CMDL's UV research will focus on addressing four key objectives: assessing day-to-day, month-to-month, and year-to-year variability in UV irradiance in and near the Bering Sea; characterizing the effects of changes in ozone on UV reaching the surface and

studying the relationship between ozone and UV; determining the effects of Arctic haze and other particulate matter on UV transmission in the Arctic; and providing UV data to interested users in the biological scientific community so they can examine the effects of increasing UV on Arctic ecosystems.

NOAA is supporting the preparation of a research plan to examine the effects of increased UV radiation on marine and terrestrial species, ecosystems, human health, and anticipated UV dosages both regionally and seasonally. Participation in this planning process will be sought from other local, State of Alaska, and Federal organizations. The research plan will consider the multiple effects of contaminants, climate change, and water accessibility that may combine nonlinearly with stress from increased UV radiation. The resulting research plan will be widely circulated to scientists and local communities associated with the working groups on AMAP and Conservation of Arctic Flora and Fauna for their review and comment.

As part of its plan to establish or upgrade Environmental Observatories, the NSF expects to fund long-term measurements of UV radiation, in addition to the current observations at Barrow. Discussions with potential European partners may lead to UV observations at Summit, Greenland. Further collaboration is planned with NOAA regarding such observations, as well as research on UV effects.

2.2.7 Human Health

It is commonly recognized that environmental contaminants can have adverse impacts on human health. Major concerns are subtle long-term effects, including impaired reproductive ability, compromised defense against disease, retarded mental development in children, and increased risk of cancer. U.S. efforts to study the human health impacts of Arctic contaminants are led by the National Institutes of Health (NIH) in the Department of Health and Human Services.

NIH's National Institute of Environmental Health Sciences (NIEHS) plans to hold an international conference on biomarkers that could serve as early warnings of environmental impacts on the health of Arctic residents. The product of this conference will be a report containing recommendations for programs to better assess the health consequences of pollutants in the Arctic.

An Alaska Native Cord Blood Monitoring Program has been established in response to Alaska Native concerns about the effects of contaminants

that are accumulating in their subsistence food species and their potential effects on the health of mothers and infants. The program is a collaborative effort among tribal, Federal, and State of Alaska agencies. Tribal agencies involved in this effort include the Arctic Slope Native Association, the North Slope Borough, the Yukon-Kuskokwim Health Corporation, the Alaska Native Tribal Health Consortium, and the Alaska Native Health Board Epidemiology Center. Federal collaborators are the Alaska Area Native Health Service, the Environmental Protection Agency, the National Center for Environmental Health, and the Center for Disease Control's Arctic Investigations Program. State of Alaska agencies are the Department of Health and Social Services' Epidemiology Section and the University of Alaska Anchorage's Institute for Circumpolar Health.

The Alaska Native Cord Blood Monitoring Program will monitor the levels of selected heavy metals (including mercury) and persistent organic pollutants (including PCB congeners) in umbilical cord blood and maternal blood of indigenous groups in the Arctic, with an initial focus on Alaska Native American populations. The objective of this effort is to establish a sampling protocol that supports a statistically significant yearly number of maternal-infant blood samples at sites serving Alaska Natives with a Bering Sea exposure (Yup'ik Eskimo) and an Arctic Ocean exposure (Inupiat Eskimo). Data analysis will be carried out by participating agencies, and reports will be made to Alaska Native organizations and other interested groups. This program will be coordinated with similar ongoing programs in other Arctic nations.

NIEHS will continue to support projects dealing with the neurobiological effects of PCB exposure and the relationship of PCB exposure to thyroid function and development of the central nervous system in infants of Inuit populations in Canada and Greenland. In addition, the CDC's National Center for Environmental Health and the Alaska Native Health Board Epidemiology Center are looking at

a possible link between exposure to PCBs early in life and later development of cancer.

2.2.8 Multiple Stressors

Regardless of how well individual stressors in the Arctic are measured and their effects evaluated, our ability to adequately understand what impacts contaminants are having on the Arctic ecosystem will depend on how we address the combined and cumulative effects of multiple chemical and other stressors. As a step toward better understanding and research, EPA's Office of Research and Development is planning a special workshop to address multiple stressors impacting the Arctic-Bering Sea. The purposes are to identify the array of sources and stressors in relation to key ecological and human values of concern, to document known exposure pathways and effects, and to produce a set of conceptual models. These models will provide managers, scientists, and local communities with a framework for targeting resources and research, assessment questions, and management opportunities.

2.2.9 Outreach

EPA plans to develop an Arctic Marine Environmental Education Resource Guide for hands-on teacher and student activities centered on the Arctic and sub-Arctic regions. This guide will incorporate Western science together with indigenous knowledge and will enhance communication and understanding of physical processes in the environment, risks from contaminants, and the ecological and human health dimensions of environmental concerns. EPA's Office of International Activities, NOAA's Sea Grant College Program, the University of Southern Mississippi, and Arctic Perspectives will collaborate with the University of Alaska and public and private sector entities in Alaska and Canada to develop the materials. Initially workshops in Alaska will train teacher-trainers from the U.S. and Canada. Eventually EPA envisions broader outreach to contacts in all Arctic countries to identify existing educational materials, develop new ones, and train trainers in their use.

2.3 Assessment of Risks to Environments and People in the Arctic

The people of the Arctic, and the multitude of freshwater, terrestrial and marine ecosystems on which they depend, are at risk. As a nation and world partner, the U.S. faces an ever-more-urgent challenge as the Arctic environment and its human and wildlife inhabitants show troubling signs of change. To meet this challenge, policy makers and scientists must be deliberate in designing research programs that are linked to international commitments and management decision making and provide the basis for quality research and management strategies.

Assessing risks to people and ecosystems in the Arctic cannot be based solely on collecting more data on important stressors. To increase the effective use of available information and future research initiatives, the U.S. research program should be founded on an ecosystem perspective. Research initiatives must increasingly focus on interdisciplinary work that addresses the combined and cumulative effects of contamination, climate change, fishing pressure, habitat alteration, waste debris, and other stressors. Data should be collected so that information on stressors, exposure, and effects can be linked in meaningful ways to establish cause-and-effect relationships. Research partnerships should be formed with a specific intent to pull together data and information in formalized risk characterization. Finally, risk characterization should be based on recognized human and ecological values of concern so that an assessment of risk is possible and research can lead to change. Effective risk assessments are directly linked to the values, both human and ecological, that the world community can embrace.

These recommendations are a challenge to Arctic communities, agency managers, and scientists alike. However, a formalized process for interpreting research data into an assessment of risk provides a clear pathway and means to link values, both human and ecological, to research strategies, available data and information, and management opportunities.

Human health and ecological risk assessment processes are fundamentally the same. The process, described in the EPA Guidelines for Ecological Risk Assessment (USEPA, 1998), provides the framework for organizing current work in the Arctic and offers an opportunity for creating strategic research agendas. To facilitate understanding of

these elements, the following discussion is organized around a set of questions. Where agencies have existing or planned programs targeted toward a specific question, their program is featured. Where programs do not exist, research needs are highlighted. The questions to consider include:

- What are we trying to achieve in the environment?
- What are the problems we need to address?
- How are we establishing cause-and-effect relationships between stressors and human and environmental changes?
- How are we linking scientific investigations and risk assessment to management needs and achievement of desired environmental ends?

What follows is an outline of the elements needed in research agendas to provide the basis for assessment of risk to people and ecosystems of the Arctic. It is not a detailed description of specific studies. However, where research programs are in place for each element, these are highlighted.

2.3.1. Defining Environmental Ends

Assessment of risk to people and ecosystems is more than understanding ecosystem processes, contaminant fate, transport and loadings, and global change. Communities want to understand risk so they can reduce their risk. However, actions to reduce risk require two things: broad-based commitment, only possible if the community is engaged ("community" meaning the larger community of Federal, state, local, environmental, commercial and Native partners), and an agreement on the human and ecological values requiring protection.

To date, the interaction of scientific research planning in the Arctic has not been well connected to the concerns and values of the larger Arctic community. The Nation has a legitimate reason for investing in research to reduce risk. When scientists understand and respond to community needs, research is not compromised—it becomes more powerful. Then the values of the community—what they want to protect—provides the basis for developing a responsive interdisciplinary research strategy. However, for scientists to be responsive, they need to understand values and management questions of the larger Arctic community. Then the community can use scientific information effectively to work in concert to achieve environmental ends.

To address this need, EPA has established the Arctic Bering Sea as a Regional Geographic Initiative (RGI). The RGI, funded from FY 99 to FY 01, is intended to bring all interested parties together to identify the set of values held in common across diverse groups in the region. The work is founded on establishing partnerships across local, regional, national, and international interests. The intended result is a better understanding of the ecological, economic, cultural, and health values that diverse groups can endorse and act to protect.

Current work is designed to identify all interested parties in this region from the local to international level and includes Federal, state, environmental, commercial, Native, local community, academic, and other interests. In partnership with the Alaska Governor's Office, EPA is gathering information about organization missions, interests in the Bering Sea, potential common values, and conflicts. EPA, NMFS, and DOI supported the First International Summit, *Wisdom Keepers of the North: Vision, Healing and Stewardship for the Bering Sea*, in March 1999 to provide a forum for Native people of the Arctic to develop a shared vision for the Bering Sea. Other such forums will be established for developing visions or goals within each constituency group. A Bering Sea visioning summit is planned in FY 01 to bring all constituency groups together to identify common values. The values established in these forums will be fundamental for bringing available scientific and traditional knowledge together in a formal assessment.

2.3.2. Defining the Problem

Determining risk requires establishing a link between a potential cause and an observed effect. Even for a simple assessment of risk for one stressor, defining the problem is a critical first step. When trying to develop research to assess risk in an ecosystem the size of the Arctic, defining the problem in manageable ways is a decided challenge with which scientists continue to struggle. Investment in problem formulation, the first stage of a risk assessment, provides a process for integrating available information into conceptual models that identify multiple stressors, potential interactions, observed effects, and direct relationships to the values of concern to decision makers. The value of problem formulation, often overlooked in the press to conduct more research, can significantly increase the power of planned research by systematically defining what is known and not known, targeting work that will have the

greatest impact for decision makers, and providing a rationale for priority setting. Assessment endpoints and conceptual models, principal products of problem formulation, provide a framework for investigating cause-and-effect relationships by defining research for understanding stressors and their sources and linking these with effects on ecological and human values of concern.

As a first step toward problem formulation for the Arctic, EPA and the Alaska Department of Environmental Conservation are sponsoring an interagency, interdisciplinary case study on the Pribilof Islands within the Bering Sea that includes participants from USFWS, NMFS, USCG, other state agencies, and commercial and environmental interests. These islands provide a "microcosm" for developing conceptual models of a diverse set of stressors and values highly consistent with those of the Bering Sea and the Arctic. The work is being done in partnership with the Pribilof Island Native communities. EPA provided two grants to the St. Paul Tribal Council to engage in community visioning. The results of this effort and other community work will set the foundation for an integrated risk assessment that incorporates ecological, economic, cultural, and human health concerns.

In addition, EPA is planning a workshop in FY 00 to develop preliminary conceptual models for the Bering Sea and Arctic ecosystems for multiple stressors. The workshop will support the Arctic Council Arctic Monitoring and Assessment Program efforts to address combined effects (see Section 2.2) and will complement efforts underway within NOAA to understand the impacts of multiple stressors on marine mammals.

Using Available Information

The ability to develop an effective problem formulation depends, in part, on how much is already known about human patterns and ecosystem functions, stressors and their sources, and observed effects. The first stage of problem formulation is identifying and using all available information and processing it in a way to establish a series of risk hypotheses about relationships among processes, stressors, and effects. Going through the process engenders significant learning as diverse perspectives, expertise, and knowledge are brought together. Throughout this research plan are research activities that add significantly to our ability to do this work. Section 2.1 describes some of the changes or effects that are occurring in the Arctic, Section 2.2 on research under AMAP provides significant information about the extent of Arctic contamina-

tion, and Section 2.4 gives us fundamental information on how the marine ecosystem functions. All are critical areas of investigation. Our challenge is to bring this information together into a cohesive whole that allows us to establish relationships between human activities and environmental and health effects. Although this research plan is broad-based, there are many sources of existing information that can be used more effectively through better use or by accessing previously unused information.

Information Management, Data Preservation and Dissemination, and Data Synthesis

The amount of existing information on the Arctic is large and diverse, which presents specific challenges. Because of the diversity of investigators, organizations, and nations conducting research in the Arctic, just knowing about existing data is difficult. Even when known, data formats often differ widely and are challenging to compare or bring together. Thus, to use these data effectively, the data must be managed. There are significant cross-agency efforts to establish "metadata" that describe the characteristics of data sets, including data collection instruments, processing information, peculiarities in collecting or processing the data, known problems that have been solved, and comments from scientists who have used the data. To facilitate the use of available information, specific efforts are required to establish common data formats and perform necessary data conversions and connections. In June 1999, NOAA and DOI cosponsored a workshop on the Bering Sea where scientists from many Federal and state agencies and academia gathered to share knowledge about existing data and the formation and format of metadatabases.

For some data, preservation is urgently needed to prevent their permanent loss. As found in Russia during ANWAP, many data sets and much information are unknown or unavailable to the scientific community or exist in formats or files that are not easily accessed. Potentially significant data are slowly being destroyed by poor storage. Part of the problem is lack of coordination in the collection, storage, quality assurance, archiving, communication, and retrieval of pertinent information. When existing data sets are preserved and disseminated, they can be assessed for quality control and quality assurance and incorporated into problem formulation to analyze their implications and identify data gaps.

Traditional Knowledge

An entire body of existing knowledge on the Arctic is untapped. The knowledge of indigenous people of the Arctic is based on centuries of observation, covering all seasons and amassed over lifetimes. While the process of data collection and storage is very different, risk in the Arctic will be better understood using the knowledge and perspectives of Native people who depend on Arctic resources for their livelihood.

Part of the challenge is knowing how to collect the information and, once collected, how to use it. A pioneering effort to solve this problem is to address one of the major concerns voiced by Alaska Native communities who believe they live under the threat of nuclear radiation from military practices of the former Soviet Union, Project Chariot, Amchitka, and over 640 toxic military sites elsewhere in Alaska. In FY 99 the Alaska Native Science Commission and the University of Alaska Anchorage's Institute of Social and Economic Research were awarded a three-year grant from EPA to incorporate traditional knowledge in a study of radionuclides in Alaska Native communities. During the first year of research, traditional practices will be used to gather information about radionuclide concerns across all five regions of Alaska through a series of regional meetings. An ancillary benefit will be opportunities to document other environmental and health concerns and observed changes in the environment. The second and third years will be used to synthesize results and support Alaska Native efforts to address community concerns.

Traditional knowledge would be very useful in generating conceptual models during problem formulation. As a series of relationships about how a system is working, conceptual models provide an effective place for organizing information from all sources. This is an approach EPA would like to foster in the future.

2.3.3. Sources and Stressors

To evaluate risk in the Arctic, it is critical to understand the stressors and their sources. Among the more clearly recognized stressors in the Arctic are contaminants. Sources of contaminants include local contaminated sites (for example, old military operations and current waste sites) and regional or global activities. Long-range transport via streams, rivers, ocean currents, and atmospheric circulation is of increasing concern.

Sources

With the end of the Cold War, communications with the former Soviet Union (FSU) opened and led to the revelation of wide-scale dumping of nuclear and toxic waste materials by the FSU into the Arctic Ocean, its marginal seas, and many of the river systems. The Russian Federation Commission (commonly referred to as the Yablokov Commission) documented this history of dumping and discharges. The Yablokov Commission Report of 1993 provided evidence that, in violation of international law, the FSU dumped (or lost) in the marine environment more than 2.4 million curies of radioactivity. This represents about two-thirds of the total material dumped worldwide. Other reports indicate that at least 20 million curies are contained in submarines awaiting decommissioning or in temporary storage awaiting disposal. The FSU also released more than three billion curies into the Arctic watershed environment (lakes, rivers, and underground). The U.S. government response to the disclosure of dumping of radioactivity wastes was the funding of the Arctic Nuclear Waste Assessment Program (ANWAP) in the Office of Naval Research. Other regional sources are contributing as well. Detectable quantities of radioactivity from nuclear plants at Sellafield, United Kingdom, and Cap de La Hague, France, are found in the Barents and Kara Seas.

Disclosures from the FSU raised awareness of the potential for risk to the Arctic from an array of sources and contaminants including persistent organic compounds, trace and heavy metals, and hydrocarbons. Internationally, resource development, mining, and petroleum production have been long-term sources. Persistent organic compounds from North America, Asia, and Europe, coal combustion products from Europe and Asia, and globally dispersed pesticides are all arriving in the Arctic by long-range transport. Under the auspices of NATO's Committee on the Challenges of Modern Society, a recent cross-boundary environmental study evaluated environmental problems in the Arctic from defense-related facilities and activities (NATO 1998). Pilot studies were conducted on the impact of hazardous materials, defense-related activities, radioactive contamination of rivers and transport into the sea, and defense-related management of radioactive waste. In particular, an environmental risk assessment of non-defuelled, decommissioned nuclear-powered submarines was performed. Follow-on reports reviewed and characterized the problems of defense-related activities, assessed potential risk of specific cases, and

offered recommendations for future studies and remediation steps. The reports inventoried the range, extent, and magnitude of defense-related environmental problems. Many of these same contaminants are entering the environment by direct discharges from local sites, such as in Alaska, where the Defense Environmental Restoration Program identified more than 150 sites that require some level of environmental cleanup.

The importance of Arctic contamination is reflected in the recently published AMAP report *Arctic Pollution Issues: A State of the Arctic Environment Report* (AMAP 1997) and the follow-on U.S. research plan to support AMAP, summarized in Section 2.2. Questions that need to be addressed when describing sources include:

- Where does the stressor originate?
- What environmental media first receive stressors?
- How does the source influence stressor distribution in the environment?
- What other sources are there for the same stressor?
- Are there natural sources for the stressor?
- Is the source still active?
- Does the source produce a distinctive signature that can be detected in the environment, organisms, or communities?

What are not addressed in current research programs are sources of other kinds of stressors to which human and ecological receptors or values may be exposed. Stressors such as fishing pressure, waste debris, and habitat alteration are likely to compound the effects of contaminants and global change. Incorporating the array of stressors into conceptual models for the Arctic under problem formulation is an important first step in determining what additional research should be planned to assess risk from combined effects.

Exposure to Stressors

Characterizing exposure is based on describing the potential or actual contact or co-occurrence of stressors with receptors. This is based on measures of exposure and ecosystem and receptor characteristics used to analyze the sources of stressors, their distribution in the environment, and the extent and pattern of contact or co-occurrence (USEPA 1998). Wide evidence of sources of contamination has been the basis for further investigations to determine exposure through research to evaluate how contaminants move through the environment, their fate and transport, and evidence in receptors that exposure is occurring or has occurred.

A variety of research efforts relevant to fate and transport are described in Section 2.2 as part of the AMAP program. Some of the issues being addressed include:

- Change in sources over time;
- Transport of contaminants by ice, water, and air;
- Natural sources of contamination;
- Transport of contaminants by biota;
- Bioaccumulation of contaminants;
- Accumulation of contaminants in water, soil, and sediment; and
- Uptake by high trophic levels, including human consumption.

These studies will help identify key processes for exposure models and risk assessments. They provide a means to predict how fate and transport may change with time, particularly as more is learned about the marine environment, air and water circulation patterns, and the effect of global change. Research is needed to determine bioaccumulation mechanisms that may differ in Arctic organisms, unique Arctic contaminant transport mechanisms connected with ice formation, and transformation of contaminants in the Arctic environment.

The Alaska Marine Mammal Tissue Archival Project (AMMTAP) is providing important baseline information on exposure in organisms. The project is addressing contaminants in marine mammals relevant to issues identified by the Minerals Management Service for offshore oil and gas development in the Arctic. These issues address both DOI and Department of Commerce (DOC) trust resources. As such, USGS cooperates with the National Oceanic and Atmospheric Administration (NOAA) and the National Institutes of Standards and Technology (NIST) through the National Marine Mammal Health and Stranding Response Program (MMHSTRP). The cooperation involves sharing of field and laboratory resources and USGS funding for NIST (sample preparation, tissue banking, analyses) through an interagency agreement with NOAA. Since each organization (NOAA, NIST, and USGS) is contributing funds and personnel toward achieving common objectives, it represents collaborative research that also includes additional partners from many other organizations inside and outside government.

Under the program, tissues and sera from marine mammals are collected and analyzed to assess tissue contaminant levels. The program involves research to develop better techniques and tools. Wherever this effort is coupled with research that

evaluates animal health based on a variety of characteristics (for example, weight, age, parasite loadings, immune function, location captured, reproductive condition), it provides the necessary elements for an assessment of risk from contaminants and other potential stressors.

2.3.4 Effects

Changes in the Arctic are increasingly recognized and in many cases are profound. Evidence indicates that a shift in climate occurred in the North Pacific in the 1970s, leading scientists to believe that global climate change is a reality that must now be monitored and managed. At the same time many ecological resources are decreasing. Of the 25 marine mammals in the region, 11 are considered depleted, including the endangered Steller sea lion. The northern fur seal world population has dropped by approximately 50% since 1977. Seabird populations in the region, representing over 40% of breeding seabirds in the U.S., are changing. Important species such as kittiwakes, murres, and eiders have shown population decreases of up to 90%. A billion dollar industry, commercial fishing has shifted significantly toward a pollock-dominated fishery, and the famous salmon fishery has experienced catastrophic failures in the Bering Sea-Bristol Bay region for two consecutive years. In certain areas the people of the Arctic are increasingly unable to depend on underground permafrost cellars to preserve food. As the ice thins and moves farther offshore and as ecological resources become depleted or move elsewhere, their ability to obtain food is jeopardized. As contaminants collect in subsistence foods, their health and well-being are affected.

Documentation of change in the environment over time is critical for evaluating exposure and linking exposure to potential effects of stressors such as contaminants. NOAA's National Status and Trends (NS&T) program was initiated in 1984 to determine the status of, and to detect changes in, the environmental quality of the Nation's coastal waters. The program's activities focus on two long-term goals:

- Assess the status and trends of environmental quality in relation to levels and effects of toxic contaminants, radionuclides, and other sources of contamination in U.S. marine, estuarine, and Great Lakes environments; and
- Develop diagnostic and predictive capabilities to determine the effects of toxic contaminants, radionuclides, and other sources of environmental degradation on coastal and marine

resources and human uses of those resources. The program includes measuring pollutants from a nationwide network of 240 sites. Biological effects of contaminants are evaluated on the basis of sediment toxicity assessments, biomarker responses, and changes in benthic community structure. In 1997, sampling was conducted at eight coastal sites in the U.S. Arctic, extending from Nome to Barter Island. This work is important for looking at the distribution and collection of contaminants within the environment and the link to observed effects.



Native subsistence harvest of beluga whales, western Alaska. Tissue samples are collected for AMMTAP by USGS.

More fundamental research on effects is needed, especially attempts to understand the link between life history characteristics, population change, and alteration of individual health and reproductive potential, and sources and stressors. This research will provide the basis for evaluating the impact of contaminants and the combined effects of contaminants, global change, and other stressors. The establishment of cause-and-effect relationships between stressors and observed effects in risk assessments is the foundation for addressing management needs and understanding system dynamics. This is an area of critical research needed now.

2.3.5 Risk Characterization

Risk characterization is the final phase of a risk assessment. It is a process for integrating information obtained during planning, problem formulation, and analysis of exposure and effects, including the analysis of predicted or observed adverse effects related to human and ecological values of

concern. Results of risk characterization are intended to provide clear information to risk managers to support decision making.

A valuable example of an Arctic risk characterization was produced under ANWAP, a Congressionally mandated program, focused on evaluating the potential health and ecological risks associated with former Soviet Union nuclear waste discarded into the Arctic Ocean and possibly entering the Arctic (ONR 1997). This program provided \$30.0 million in support of over 80 domestic and international research projects. The assessment included:

- Characterization of the source terms;
- Screening to select the most significant radionuclides;
- Examination of release scenarios such as the breaching of dumped reactors in the Kara Sea and deterioration of dumped waste in the Sea of Japan;
- Transport pathways analysis;
- Bioconcentration in food webs; and
- Assessment of risk to both humans and marine organisms.

The final risk assessment report focused on Alaskan endpoints. Conclusions in the report included:

- FSU dumping activities will not cause elevated concentrations of radionuclides in Alaskan waters, based on the predicted low concentrations.
- It is highly unlikely that any significant ecological impact will occur outside of the immediate Russian dump sites.
- Potential human health risks associated with ingesting Alaskan seafood contaminated by dumping are extremely low.
- Russian wastes pose no threat to human health in Alaska.

In particular, Alaska Native communities do not need to alter any of their dietary habits associated with subsistence foods obtained from Alaskan waters.

ANWAP and its report are supplemented by the findings of 15 years of applied and integrated research by the Nuclear Energy Agency's Coordinated Research and Environmental Surveillance Program (CRESP) under the Organization for Economic Cooperation and Development (OECD). The risk assessment framework of the CRESP has been used to define the transport and fate of past radioactive materials disposed of in the northeastern Atlantic Ocean by the European community (OECD 1996). ANWAP built on the coordinated risk assessment approach of CRESP to conduct its Arctic assessment of marine radioactivity, and

together they provide a useful example. Much progress has been made on radiological issues, and this progress will lead to understanding of processes affecting other contaminants. Application of the process to address multiple diverse stressors can lead to greater understanding of combined and cumulative effects.

2.3.6 Risk Assessment and Risk Management

The link between risk assessment and risk management is through the translation of values identified by the management community into measurable endpoints in the risk assessment. To strengthen Arctic research, this connection must be addressed. Once done, research planning can focus on key missing information.

More work is needed, for example, on establishing a clearer understanding of Arctic contaminants and their interrelationship with the global environment and multiple stressors. This will require sophisticated conceptual models and sustained interdisciplinary studies. Studies that link human health, ecological, cultural, and economic effects are also needed. Human health risk assessment must incorporate issues of environmental equity to account for the potential higher risk to Native populations consuming large quantities of subsistence foods. The latency of effects is also an important consideration for both humans and ecosystem change. Future research programs will be most effective if they:

- Document temporal and spatial patterns of

stressors coupled with information on the health of biota, structure of community, or integrity of ecosystem function;

- Document indicators that exposure is occurring (including biomarkers);
- Identify processes that enhance transport and transformation or distribution of the stressor; and
- Establish relationships between exposure and potential effects of stressors.

To accomplish this, research plans should include:

- Planning with resource managers and communities;
- Data and information identification, including traditional knowledge, data management, preservation, and dissemination;
- Synthesis of available information in problem formulation and development of conceptual models;
- Observation and long-term monitoring and assessment;
- Process-oriented research;
- Model development; and
- Linkage of risk assessment to risk management.

By broadening research perspectives to consider interactions among multiple stressors, cumulative effects, and ecosystem-level thinking and by pulling diverse sources of information together within a risk assessment context, the data available will be more powerful and research in the future better designed to support decision makers with the information they need to achieve desired environmental results.

2.4 Marine Science in the Arctic

The marine Arctic is an integral part of the history of our planet over the past 130 million years. It contributes significantly to the present functioning of the earth and its life. The Arctic shows signs of variability that suggest that the future may be different from the present and the recent past, possibly including a reduced ice cover. Furthermore, the marine Arctic is intimately involved in global climate and in the earth's great biogeochemical cycles. An adequate understanding of the past and the present Arctic, and of the processes that shape it, is key to seeing the future of this unique region and its impact on society, including its health and commerce.

2.4.1 The Arctic Ocean and Global Climate

Two aspects of the interaction between the Arctic Ocean and global climate appear particularly important. The first involves sea ice and the surface heat and mass budgets. The polar regions are the primary global heat sinks, and the Arctic Ocean and its veneer of sea ice are major elements in the global climate system, in part because of the importance of the ice in controlling mass and energy fluxes at the surface.

Considerable effort has been invested in understanding sea ice as a geophysical material, and while the rheology, dynamics, and thermodynam-

ics of sea ice are probably as well understood as any part of the polar climate system, sizable problems remain. For example, there is not yet a clear understanding of the strong feedback mechanisms within the polar climate system involving ice, clouds, and radiation that is adequate for predicting changes in the system under anthropogenic forcing. Furthermore, the state of both the sea ice cover and the thermohaline structure and circulation of the ocean depends on interactions between the ice and the underlying ocean. The ice cover in turn provides a control on the surface heat and mass budgets and thereby on the global heat sink. From this perspective the critical issues relate to the means by which the upper ocean salinity stratification is maintained or altered, for on that depends both the turbulent vertical heat flux from the warm intermediate layer of the Arctic Ocean and the effectiveness of haline convection in stirring the ocean. Indeed, recent changes in the upper Arctic Ocean temperature and salinity structure suggest that this stratification may not be as robust as previously thought.

The second major connection between the Arctic Ocean and global climate that has come to the foreground during the past decade is the oceanic component of the global water cycle. Each year about 3000 km³ more sea ice is frozen within the Arctic Ocean than is melted. This surplus of low-salinity ice is largely exported through Fram Strait, and once into the convective gyres of the Greenland–Iceland Sea system, it has the potential to influence the overturning cell of the global ocean through a control on the dense overflows that feed the North Atlantic.

Atmospheric Hydrology and Controls on Upper-Ocean Salinity

The large-scale atmospheric circulation contributes to the Arctic Ocean's freshwater anomalies in several ways, including the direct fluxes of precipitation and evaporation at the ocean surface, and lateral inputs originating as precipitation and evaporation over terrestrial watersheds. The net terrestrial precipitation and evaporation eventually reach the Arctic Ocean as river runoff. Over the long term the Arctic Ocean balances this positive atmospheric influx of fresh water by a net advective export of fresh water (including sea ice) to the North Atlantic and the Canadian Archipelago. However, the variability of the various freshwater budget components is poorly documented.

The Arctic Oscillation

In an ongoing investigation a close connection

between variations in Arctic sea-level pressure, lower-troposphere temperature, and the strength of the stratospheric polar vortex has been observed. This large-scale mode of atmospheric variability, termed the Arctic Oscillation (AO), is centered on the Arctic and extends well southward into the North Atlantic and Pacific. It spans a range of time scales from monthly to interannual, and the well-known North Atlantic Oscillation (NAO) emerges as a subset of this broader mode.

Variations in atmospheric circulation corresponding to the AO have profound implications for the advective fluxes of heat and moisture into the Arctic and for the wind-forced motion of sea ice and the underlying ocean. The periodic strengthening and weakening of the anticyclonic sea ice and ocean circulation appears to be one manifestation of this.

Radiatively Active Trace Gases and Aerosols

Trace gases and aerosols play key roles in the forcing of Arctic climate and climate change. Measurements along the coast of the Arctic Ocean show that concentrations of carbon dioxide, methane, CFCs, and other trace gases have increased substantially over the past several decades. Because these are greenhouse gases, they are enhancers of downward long-wave radiation and potential triggers of feedbacks involving Arctic surface temperature, surface state, water vapor distribution, and clouds. Feedbacks among these various quantities must be understood and incorporated into climate models if future climate changes in the Arctic are to be predicted with confidence.

The importance of atmospheric aerosols in decade- to- century-scale climate change has become apparent in recent years. Globally the radiative forcing by anthropogenic aerosols is a large fraction of, if not equal to, the present forcing due to greenhouse gas accumulations since pre-industrial times.

Of particular importance to the Arctic is the forcing by sulfate aerosol particles, which are primary components of Arctic haze. Anthropogenic sulfate particles affect the atmosphere through the direct scattering of short-wave radiation and changes in the concentration of cloud concentration nuclei (CCN), which may, in turn, modify cloud formation, cloud lifetime, and the radiative properties of clouds.

There is the likelihood that the northern oceans may contribute significantly to the atmospheric sulfur budget. Evidence for such a contribution includes the relatively high levels of dimethyl sulfide (DMS) in seawater in northern latitudes, as

well as the high mixing ratios of DMS in the air above the northern oceans. A quantitative assessment of this contribution is needed, especially since the spatial and temporal gradients imply large variations in the radiative forcing by aerosols over the Arctic Ocean. Aerosols may also serve as important hosts for chemical reactions that destroy tropospheric ozone. Recent findings suggest that reservoirs of acidic chlorine and bromine compounds that are inactive in ozone destruction are converted to active chlorine and bromine gases on sulfuric acid aerosols.

Finally, modeling of polar trace gases and aerosols will require accurate simulations of the exchanges of aerosols (anthropogenic and natural), as well as their precursors, between the Arctic and middle latitudes. Since the middle latitudes are the sources of most of the anthropogenic gases and aerosols affecting the Arctic radiative budget, models must capture the pathways of trace gases and aerosols to the Arctic, as well as their eventual fate in the Arctic.

Arctic Variability and Sensitivity

Largely because global warming simulations suggest an amplified climate response in the Arctic, it has been argued that Arctic climate provides an early warning of global change. It has also been pointed out that climate variability in the Arctic is large, so that a weak signal-to-noise ratio may initially mask climate trends. It seems likely that both the amplified climate response and the large natural variability are connected with the strong feedbacks that characterize the Arctic climate system, feedbacks that involve sea ice

The past decade has seen a reduction in ice

extent within the Arctic Ocean, especially in the Nansen Basin during summer. There have also been large changes in the upper and intermediate layers of the ocean, as well as other changes with climatic implications. The deep Greenland Sea has continued its multidecadal trend toward warmer and saltier conditions, with a corresponding decrease in oxygen content. All in all, there is sufficient evidence to support the view that the present conditions in the Arctic Ocean and overlying atmosphere, including adjacent areas in the northern extensions of the North Atlantic, are unprecedented during this century. One cannot say that the Arctic is showing the early signs of global warming, but one can say that large changes in ocean circulation and structure, with long time scales, are a reality, and that it would be highly prudent to seek a mechanistic understanding and a prognostic capability.

There are also other issues of oceanic environmental sensitivity related to contaminants and pollutants. These include radionuclides, persistent organics, and metals. While radionuclides have received most of the attention, it seems likely that, barring catastrophic radionuclide releases, increases in organic loading constitute the more important long-term concern. For example, the Arctic seas appear to be concentrating certain persistent organics, an example of the so-called global distillation process, in which the reduced volatilization at low temperatures leads to semivolatile compounds being preferentially transported into the Arctic. While these issues are complex, involving variable atmospheric and oceanic sources, particulate fluxes within the ocean, and the marine food web, the pathways within the ocean are strongly conditioned by ocean circulation and mixing. The ability to predict the evolution of the material distributions of interest therefore depends to a considerable extent on improving our understanding of the governing physical processes and their variability.

These various changes in the high-latitude ocean and its ice cover, and in their material burdens, have major implications for the people who live and work in the Arctic, for commerce, for resource extraction, and for marine life. In addition to their global consequences, therefore, such changes argue strongly through their more local implications for acquiring a predictive capability for the Arctic marine system.

Sea Ice Variability and Trends

The decrease in sea ice extent of 2.9% per decade since 1980 is statistically significant. Sea ice

Three-story-high iceberg,
LeConte Bay, Alaska.



variability has further ramifications for climate modeling. Because variability provides some insight into the sensitivity of a particular model component, it is a valuable adjunct to the more usual mean-state comparisons between models and observations. Further, the intimate connection between sea ice and polar climate suggests that incorrect variability in the sea ice distribution will lead to unrealistically modeled variability in the coupled atmosphere and ocean. Identifying the principal processes that control sea ice variability and representing them adequately in global climate models are clearly important challenges for the coming years.

Tracer Results and Variability

Application of water mass tracers has been key to illuminating both circulation and changes in the Arctic Ocean and is therefore particularly important in the present context. The distributions of naturally occurring and anthropogenic chemical constituents help define water mass modes and delineate patterns and rates of circulation.

When combined with salinity, and in certain cases other tracers, oxygen isotopes can be applied to the problem of distinguishing between freshening due to sea ice melt and to runoff. Naturally and artificially occurring radionuclides and other transient tracers can provide the added dimension of time to the circulation constraints. The chemical signals tend to integrate smaller-scale processes and so have been used to estimate average water replacement or ventilation times for marginal seas and the major water masses of the Arctic.

While these contributions have broken new ground with respect to understanding Arctic circulation, the data sets on which they are based have been quite limited both in time and space. Many of the interpretations are based on an assumption of a steady-state circulation, and up to several decades of data have been combined to provide sufficient geographical representation to deduce pathways. As more evidence for decadal-scale variability in the Arctic is found, steady-state interpretations come into question. For further progress, it is necessary both to complete a first-order characterization of the tracer distribution in the Arctic and to carry out a set of strategically located repeat sections and stations that can characterize the variability. In addition to large-scale shifts of circulation within the Arctic, our understanding of the role of Arctic water mass products in global thermohaline circulation has come under renewed scrutiny. It has recently been suggested that the

primary source of Denmark Strait overflow water, which along with Iceland–Scotland overflow water ventilates the deep North Atlantic, is not necessarily or exclusively a local product of convection in the Nordic Seas, but rather it may also include Atlantic waters that have circuited the Arctic Ocean at middepth to exit with the East Greenland Current.

Arctic History in a Global Context

The history of the Arctic Ocean should be studied in the context of its global connections. Arctic history is essential for understanding past changes and predicting future change. Some processes or conditions that operated in the past are either not operating today or are operating at drastically different rates, such as ice sheets that covered the Barents Sea. Many natural systems operate in more than one mode, with rapid switches between modes when threshold conditions are reached. A dramatic example for this is found in the Greenland ice core record, where about half of the temperature change from the last glacial period is reported to have occurred in less than three years.

The paleoceanographic–paleoclimatic history of the Arctic is linked to its tectonic evolution. Tectonic control on narrow straits such as Fram Strait and eustatic control of other openings to the world ocean along with the geologic history of the surrounding continents define the history of the Arctic Ocean and to some extent adjacent seas to the south. During most of the Cenozoic the Arctic Ocean exchanged water with or received water from the Atlantic, Pacific, and continental runoff. The variation in these fluxes coupled with changes in sea ice extent and thickness over time has contributed to the complex history of this ocean basin. Thus, understanding its history will require elucidation of the linkages between tectonic, oceanographic, and climatic processes, a multidisciplinary undertaking that is perhaps unique in marine science.

The contrasting tectonic histories of the Eurasian and Amerasian Basins present the opportunity to examine the unique interaction of midocean ridges with continents, the microplate tectonics, and the sea-floor spreading process itself. The absence of a comprehensive plate tectonic history for the Cretaceous-aged Amerasian Basin has hampered our understanding of Arctic continental geology. The ultraslow-spreading Gakkel Ridge is unique in composition and structure, providing an end member to contrast with other midocean ridges and an excellent example of the interaction

between such ridges and continents where it intersects with the Russian continent at the Laptev Sea.

There are three major research thrusts dealing with and linking these Arctic history themes:

- The first is the interactions of the Arctic Ocean and its adjacent seas with global environmental dynamics in understanding the earth's changing climate, both on decadal and millennial time scales.
- The second is the nature and history of lithospheric dynamics in the Arctic and is focused on structural features such as the ridge complexes.
- The third covers shelf processes, sediment fluxes, and the complex land-sea interaction.

The Arctic Ocean is surrounded by the largest continental shelves on earth. Both broad and shallow, these shelves are sensitive to sea level fluctuations and large seasonal, fluvial discharges that influence sea ice cover and depositional environments. These shelves are of great importance to indigenous Arctic people and, because of the potentially vast economic resources on these shelves, to the entire U.S. future economy. The impact of Arctic shelves on global change is yet to be determined but will certainly involve sea ice production and export, geochemical and biochemical fluxes, biota, and sediments.

Land and Shelf Interaction and Sediment Fluxes

The Arctic shelves receive and interact with discharges from several large rivers, totaling 10% of the global discharge. The history of anthropogenic pollutants is most likely recorded in the marginal marine and shelf sediments. The impact of changes in these anthropogenic fluxes should also be recorded in the biogenic sediment archives (fossils and biochemical proxies). Reconstructing the sedimentation history on the shelves will facilitate understanding of the history of riverine discharge, which plays an important role in maintaining the low-salinity surface water layer and thus the sea ice cover in the Arctic Ocean. The sediment flux onto and across these shelves and slopes, both present and past, is an important part of the sediment budget in the Arctic because the central Arctic Ocean has much lower deposition rates than the shelves and slopes. Much more research on sediment fluxes across all Arctic shelves needs to be undertaken to understand the variability in processes among the different parts of the Arctic.

Sediment transport via sea ice has also been shown to be important, perhaps the most important process today. We still understand very little about

how sea ice entrains sediment, how it disperses it (today and in the past), and how variable these processes are.

Permafrost is an important and unique aspect of the Arctic coastal zone and even some offshore areas. The impact of the onset and temporal variations in the thickness and extent of permafrost is unknown. In addition, ice sheets have existed on some Arctic coastal areas continuously for more than 100,000 years, while in other areas (Baffin Island and Novaya Zemlya) ice sheets have developed only during the last 10,000 years. Even over the last 50 years some glacier termini have retreated rapidly while others have changed little. Also, little is known about the source and conditions of snow accumulation that eventually leads to ice sheets on Arctic land or marginal marine areas. As a consequence, predicting changes in sea ice extent and iceberg production that influence commercial sea routes and both Native and commercial fishing remains difficult. Because the shelves are the primary areas in the Arctic for new sea ice formation, understanding and predicting ice production and export from the Arctic Ocean, along with their potentially important role in global climate, depend on a better understanding of the interaction of the factors involved, such as river discharge, ocean currents, winds, etc. The sediment archive of sea ice cover over the different shelves should be useful along with paleoceanographic and paleoclimatic proxies in providing this understanding.

Continental Shelf Resources

The widest shelves in the world occur in the Arctic. The potential resources on and under these shelves are equally vast but remain largely unstudied, except for the North Slope of Alaska. The Arctic shelves potentially contain the largest methane hydrate deposits in the world, and these deposits are not only of economic interest but need to be identified and studied because of their potential importance to global warming. Mapping the geomorphologic features is essential to understanding sedimentological processes that form canyons, gravity slides, and slope sediment and that determine the final fate of sediments and the possible mineral resources as well as contaminants that they transport. This mapping could best be done by submarines equipped with a seafloor characterization and mapping pod (SCAMP) and other acoustical bottom-surveying equipment mounted on a submarine or surface vessels where ice conditions permit.

Tectonic History of the Arctic Basin

The opening of the Eurasian Basin was a major tectonic event that had profound effects on the world oceans because it allowed the fresh ice-laden waters of the Arctic a pathway to the south. The exact effect of this opening on both the Arctic Ocean and the North Atlantic is still uncertain. The resulting Gakkel Ridge is different in its petrology, morphology, and structure from any other mid-ocean ridge. As such it provides a superb test of the models and hypotheses developed from studies of faster-spreading ridges. Its uniqueness also makes it an excellent ridge for studying the petrology of the upper mantle and the processes involved in upwelling, melting, and crustal generation. The similar curvilinear form of the Gakkel Ridge and the continental Lomonosov Ridge suggest that studying the internal structure of this rifted continental ridge and its relationship to the Gakkel Ridge may help our understanding of how continents rift. The Laptev Sea is also of great importance for studying the processes of initial continental rifting. It is the southern terminus of the Gakkel Ridge and thus the location of structures resulting from the intersection of a spreading ridge and a continent.

Ultimately, deep sea drilling might provide the only resolution to these questions, but additional seismic and acoustical surveys, especially from submarines, aeromagnetic and aerogravity surveys, and giant piston coring in locations where slumping has uncovered the underlying pre-Tertiary strata or crust, would add tremendously to our understanding of the basin evolution.

Onset and Variability of the Perennial Sea Ice

The initiation of a perennial sea ice cover in the Arctic should have had a major impact on global climate, at least according to global change models (GCM). Knowledge of this event and correlation to global paleoclimate would be a major advance to understanding the interaction of the Arctic Ocean with global climate. Equally important is the understanding of how this ice cover has changed since its inception. Did it ever disappear only to re-form? If so, when and which sediment proxies recorded this? Our ability to determine the past thickness and extent of the pack ice cover is limited, and much research on sediment proxies for this change is needed.

Paleo-Proxies in the Arctic

The paleoceanographic record contained in Arctic sediments may provide details of the past

responses of the Arctic system to changes in climatic variables. A prerequisite to interpreting this record is a baseline understanding of the contemporary elemental cycles within the Arctic and their mode of incorporation in the sedimentary record. Only when the current spatial distributions of these tracers and their underlying biogeochemical cycles are better understood can variations of the abundances of these tracers in the geologic record be used to constrain theories concerning the nature and strength of past biogeochemical processes and paleocirculation.

2.4.2 Biogeochemical Cycles

Characterizing the Unique Arctic Marine Environment

Understanding the Arctic Ocean's present and past roles in global biogeochemical cycles requires a well-developed knowledge of the fluxes of materials into and out of the basin, as well as the type and rates of internal transformations that occur within the basin. Such information provides a background against which to assess the impacts of resource exploitation or climate change. It also provides the basis for interpreting sedimentary records of paleoarctic conditions.

The understanding of nearly every aspect of Arctic marine chemistry is hindered by seasonally biased or nonexistent observations of fluxes and internal transformation rates. Specific requirements involve the determination of the magnitude and time variability of riverine inputs, which deliver 10% of the global runoff to the Arctic Ocean; inputs from the Pacific through Bering Strait; inputs from the Atlantic through Fram Strait and the Barents Sea; and outputs through Fram Strait and the Canadian Archipelago. In addition to the water-borne fluxes, atmospheric fluxes into the Arctic via precipitation, particulate deposition, and gas condensation as well as outputs via gas evasion may be important for certain materials. Fluxes to and from the sediments and ice also need to be quantified.

Within the water column, rates of biologically and chemically driven transformation processes need to be ascertained. Significant progress can be expected if new technologies for remote and in-situ sampling, such as chemical sensors and water sampling devices, are adapted or developed for year-round use under Arctic conditions. Technologies specifically designed for Arctic deployments may be required for addressing certain problems, such as determining the influence of ice-rafted materials on sub-ice biogeochemical dynamics. The availability of versatile year-round platforms, including

moorings, autonomous underwater vehicles, aircraft-supported ice camps, and icebreakers to deploy such technological innovations in the Arctic, is essential for advancing this research area.

The Role of Continental Shelves

Since shelves constitute 30% of the area of the Arctic Ocean and can act as repositories for many materials over a range of time scales, the biogeochemical processes that occur on them have important consequences for attenuating and transforming the oceanic and terrestrial chemical signals. Shelf regions are subject to highly variable physical conditions, including fluctuating temperature and salinity regimes, changing current strength, and extremes in ice cover and light penetration. These factors make direct observations difficult but nevertheless essential for developing predictive capabilities.

Multidisciplinary process-oriented studies in shelf regions that cover a range of carbon export conditions are required for characterizing the rate of geochemical transformations and magnitude of carbon storage on the shelves.

The formation of sea ice in shelf regions leads to entrainment of resuspended sedimentary material within the ice. Natural and anthropogenic materials can also be deposited on the ice surface through atmospheric transport. The subsequent advection of this ice into the interior basin of the Arctic and its seasonal partial melting provide a unique mechanism for transporting a variety of chemical species. Since this transport phenomenon is unique to the polar seas, it is important to determine what role it plays, and has played, in supporting the biogeochemical processes of the interior Polar Basin and also in redistributing contaminants, along with the susceptibility of such a mechanism to climatic changes.

Biogenic Gases

The Arctic Ocean remains an important unknown in global atmospheric chemistry. For example, the largest natural source of sulfur for the atmosphere is the emission of DMS from biological activity in surface seawater. Once in the atmosphere this sulfur gas is oxidized to sulfate aerosols within days. Among the highest DMSP (dimethylsulfonium propionate, a precursor to DMS) production for any marine organism has been shown to occur in ice. A similar situation holds for the production of halogenated hydrocarbons such as methyl bromide and methyl iodide, which are greenhouse gases with breakdown products that consume ozone in the stratosphere.

Another greenhouse gas of importance in the Arctic is methane. Sizable reserves of methane in the form of ice-like methane hydrates, also known as clathrates, exist in onshore and offshore permafrost and underlying continental slope sediments in the Arctic. The global reserve of methane in hydrates is estimated to be twice as large as all other known sources of fossil fuels. The development of methane hydrates as a fuel source is the subject of major new research in the U.S. and abroad. There is speculation that Arctic hydrates will be the first to be exploited for reasons of accessibility and existing infrastructure.

Understanding Contemporary Biogeochemical Cycles

Determining the magnitude of particulate fluxes from surface waters is critical to constraining a range of issues in the Arctic Ocean, including carbon cycling and the health of the ecosystem, the fate of contaminants, and interpretation of paleodepositional records. To what degree the Arctic acts as a net sink for carbon and other materials will depend strongly on what fraction of primary production escapes remobilization in surface waters and is exported into subsurface waters, and how much of this material is preserved in the sediments. Particle export, which is a sporadic process, is best assessed by combining methods such as time-series sediment trap observations in a variety of locations with integrative approaches that involve interpretation of naturally occurring particle reactive radiotracers.

Any comprehensive understanding of sequestration of carbon and other materials within the Arctic requires estimates of the rate at which particulate matter is delivered to the deep waters; this information is also required for interpreting the sediment record. Although logistically challenging, long-term deployment of sediment traps and co-located cores could be accomplished at key locations in the major basins and on the continental shelves. Seasonal sampling for natural radionuclides and other related parameters of the water column should also be carried out along sections in the same areas.

2.4.3 Health of the Arctic Marine Ecosystem

Productivity, the Food Web, and Ecosystem Health

The studies of this past decade are markedly changing our understanding of the Arctic Ocean. Large-scale Arctic Ocean circulation appears sub-

ject to variability on a range of time scales that we are just beginning to appreciate. Chemical tracers have been essential in identifying shifts in circulation patterns over a range of spatial scales and in estimating time scales of water mass renewal. The long-held notion that the central Arctic Ocean is a biological desert due to light limitation by the ice and snow cover has changed dramatically in recent years. Substantial active in-situ carbon and nutrient cycling has been documented under the ice cover, which may provide a critical source of micronutrients. Certain shelf regions of the Arctic have recently been documented to support some of the highest primary and secondary production levels in the world's ocean.

The Arctic's remote location and relatively sparse population do not protect it from industrial and agricultural contaminants produced at lower latitudes. Chemical fingerprinting of ice, snow, seawater, and sediments have demonstrated delivery pathways that include the atmospheric as well as terrestrial and oceanic domains. The short, lipid-rich Arctic food chain renders the Arctic ecosystem particularly prone to biomagnification of organic herbicides and pesticides and certain heavy metals that ultimately impact human inhabitants of the north.

A key issue for biological studies in the Arctic is the need to be able to predict and understand marine ecosystem structure and function in the face of planetary change. There are also issues of general scientific interest embedded in the food chains of polar oceans, such as the regularity in plant growth driven by the annual insolation cycle. This characteristic affects evolution in the life cycles of marine organisms and adaptations in their physiology. Studies on primary and secondary production are essential for understanding trophic-level dynamics and the food web structure of biological systems, as well as biogeochemical cycling in the Arctic ecosystem. The following section outlines important issues related to trophic-level structure and function, contaminant input, and associated research tasks and strategies to better understand the health of the Arctic marine ecosystem.

Primary Production: Phytoplankton

Estimates of primary production and its fate in the Arctic marginal seas, and especially in the central basins, are severely limited by insufficient understanding of the controlling environmental factors on both temporal and spatial scales. Primary producers in the Arctic include phytoplank-

ton, ice algae, and benthic microalgae and macrophytes. Although ice algae have historically been considered of minor importance, recent studies indicate that it may be more important to total primary production rates in the Arctic Ocean Basin than previously estimated. Bottom ice communities are most concentrated on first-year ice with higher light penetration and nutrient supplies. By contrast, phytoplankton blooms are widespread in open waters and even in the perennial pack ice. The largest amount and variation in primary and secondary production occur over the continental shelves of the Arctic Ocean and surrounding marginal seas, which comprise an extensive area that is important to biological activity and carbon deposition or export.

The partitioning and cycling of organic matter into particulate, dissolved, and gaseous fractions is very important, and changes in ice cover will very effectively change the significance of the Arctic as a source or sink of several gases of climatic importance, as described earlier under Biogeochemical Cycles.

Secondary Production: Zooplankton and Bacteria

The pelagic food web in the Arctic Ocean may vary from large phytoplankton that are consumed directly by microcrustaceans to a microbial food web, as in most oligotrophic marine waters. Recent investigations indicate that heterotrophic bacteria and protozoans in the microbial loop typically dominate later in the growth season. The primary link between plants and higher trophic organisms in the sea (for example fish and some marine mammals) is zooplankton, which often have adaptations that allow them to exploit periodic or episodic availability of food. These adaptations, along with the food supply, are usually tied to regional water mass movements or other predictable physical aspects of the environment.

Bacteria consume dead organic matter and dissolved organic matter released by phytoplankton, and their role in structuring Arctic marine communities requires further study. Important topics related to zooplankton processes include the role of zooplankton in structuring food webs by preferentially consuming protozoans (microbial loop), diatoms (classical loop), or ice algae. In addition, a better understanding is needed of the role of predation in population and community dynamics. Zooplankton grazers can drive a food web toward fish and bird production, while the absence of such grazers leads to a food web dominated by the benthos. An important question is whether this

would change under reduced ice cover, causing a major shift in the relative importance of the benthic fauna and pelagic zooplankton, which in turn would have a dramatic cascading effect on higher-order food consumers.

Secondary Production: Benthos

Benthic fauna in polar regions are characterized by slow metabolic rates, long life spans, and large biomass levels. Short food chains characterize the Arctic, particularly on the continental shelves and in under-ice communities, emphasizing the tight connection and transfer potential of carbon and contaminants between lower and higher trophic levels (plants to marine mammals and humans). Benthic-feeding marine mammals (such as walruses, gray whales, and bearded seals) are common in the Arctic, and they would be affected directly by a reduced ice cover. Factors affecting lower trophic dynamics have the potential to cascade quickly to higher trophic levels (fish, seabirds, and marine mammals) and ultimately to humans. Changes should also be expected in the efficiency of carbon transfer between primary producers (water column, ice, and attached macrophytes) and benthic consumers. A reduction or loss of imported carbon from the euphotic zone could

directly impact benthic production, resulting in large disruptions in the migratory habits of endangered and commercially important marine fish and mammals.

The Arctic contains 35% of the world's continental shelves and some of the largest populations of seabirds, fish, and marine mammals that are consumed by humans. Recent studies suggest that ice algae may act as an early season carbon source to "jump start" the biological system prior to significant phytodetritus flux, although its influence probably depends on whether this production is over the shelf or the deep basin. Changes in carbon usage and transport over the continental shelves can influence the amount of carbon exported into the Arctic Basin, either to be used in surface waters or sequestered in deeper waters under the halocline of the Arctic Ocean. The timing, extent, and type of primary production (ice algae vs. open water phytoplankton) can influence water column and benthic faunal communities, so potential changes in these parameters may ultimately influence the relative importance of water column and benthic community dynamics.

Secondary and Tertiary Production: Higher Trophic Levels

Higher trophic animals are key indicators of the health of the Arctic marine ecosystem and ultimately have a direct impact on the indigenous populations that consume them. Arctic marine mammals have undergone large population fluctuations due to human hunting and climatic fluctuations. The consequences of ecosystem change in the Arctic (for example, as a response to future global warming) to population diversity and density of marine mammals and birds is of critical importance for the cultural survival of Native northern residents.

Numerous endemic and migratory species of marine mammals, seabirds, and fish are dependent on ice-edge systems and associated seasonal productivity. Changes in marine mammal seasonal distributions, geographic ranges, patterns of migration, nutritional status, reproductive success, and population dynamics may occur with Arctic warming and varying ice extent. Ice-associated seals may be especially vulnerable to changes in ice extent.

Human Impacts

Continental shelves are sensitive to environmental forcing, providing an indication of more widespread changes in the global environment, although the signal-to-noise ratios in these ecosys-

*Spring breakup at the Nikolai
Creek sockeye salmon
research site.*



tems may be low. Shelf regions are also the focus of human marine activity in the Arctic, including the culturally based hunting activities of indigenous people, resource development, and shipping. Recent studies indicate increased levels of anthropogenic contaminants (persistent organic contaminants, heavy metals, and radionuclides), along with significant resource development impacts (release of polycyclic aromatic hydrocarbons from oil production) in the Arctic.

Organic Contaminants and Heavy Metals

The short, lipid-rich Arctic food chain enhances biomagnification of many persistent organochlorine compounds (such as organic herbicides and pesticides) and certain heavy metals (lead, cadmium, and mercury) that are transported from lower latitudes via marine and atmospheric pathways. For instance, Arctic haze aerosols contain soot, trace elements of anthropogenic origin, and sulfate. Concentrations of pesticides in Arctic marine fog can be several times higher than in adjacent water or ice. In addition, modern or currently used pesticides such as triazines, acetanilides, and organophosphates were designed to be less stable than organochlorine pesticides; however, features of the Arctic environment (such as low temperatures and low solar radiation) slow down the destructive processes and enable these contaminants to persist.

Changes in trophic pathways and flux rates due to global change may affect the bioamplification and delivery of pollutants to consumers of Arctic fish, mammal, and bird populations, which may in turn jeopardize the health and/or economic future of traditional indigenous populations. A comprehensive understanding of Arctic ecosystem structure, including physical and biogeochemical interactions involved with shelf-basin exchange, would assist in analyzing global change impacts on contaminant transport, transformation, and fate in the polar north.

Radioisotopes

Once released to the environment, radioisotopes enter biogeochemical cycles as determined by associated chemical and physical properties of the radioisotope. Radioisotopes that are particle-reactive, such as cesium and plutonium, can be scavenged and deposited within short distances from their source. In contrast, elements that favor the dissolved phase, such as iodine and technetium, can travel long distances with ocean currents and can act as tracers of ocean circulation. The

early 1990s witnessed the release of classified information regarding the dumping of nuclear wastes by the former Soviet Union into the marginal seas and the watersheds of the Russian rivers emptying into the Arctic Ocean. Concern about the fate of this material provided the impetus for numerous physical and biogeochemical tracer studies over the past 20–30 years. Recent studies undertaken as part of the U.S. Office of Naval Research Arctic Nuclear Waste Assessment Program (ONR 1997) and the international Arctic Monitoring and Assessment Program (AMAP 1997) are evaluating anthropogenic radioisotope inputs to the Arctic system, including risk assessment analyses of biological components of the ecosystem. Data on radioactivity and other contaminants in the Arctic have recently been compiled in an Arctic Environmental Atlas (ONR 1999).

Effects of Ozone Depletion

Ozone depletion events have occurred in the Arctic over the past decade or two. Anomalies such as the 1996 ozone hole have developed over small areas of the Arctic periphery, typically lasting several days. In addition to the short-lived ozone depletion events, a general downward trend of Arctic ozone concentrations has been detected. Average concentrations of Arctic ozone were 10% lower in the 1990s than in the 1970s (AMAP 1997). Associated with the ozone decrease has been an increase in UV radiation reaching the surface. Environmental effects of UV on photosynthetic carbon fixation in marine autotrophs, and ultimately man, are of growing concern in polar regions. Marine organisms are sensitive to UV, and ozone depletion is known to have significant effects on phytoplankton productivity in the Antarctic, resulting in a reduction in the global carbon sink for anthropogenic carbon. Further disruptions of the marine food webs may occur because UV radiation can damage zooplankton and fish (particularly the egg stage in shallow waters), which would ultimately impact higher trophic levels, including humans.

Research Needs and Strategies

Research issues important to understanding Arctic ecosystem dynamics require knowledge of seasonal and interannual variations in ice cover and other physical aspects influenced by climate variation. Understanding the proximate and ultimate controlling factors of various trophic-level standing stocks and production rates is essential for interpreting ecosystem change occurring presently in

the Arctic, as well as interpreting past shifts in trophic-level importance, including paleontologic proxies from the sediment record. Major research issues include:

- The distribution, magnitude, and seasonal variability of primary production (total and new) and secondary production (bacteria, zooplankton, and benthic fauna);
- The biogeochemical cycling of organic sulfur and halogenated compounds among the various food chain compartments (phytoplankton, grazers, and bacteria);
- The causes and consequences of variations in abundance (space/time distributions) of higher trophic organisms (fish, seabirds, and marine mammals);
- The quantity of fixed carbon consumed, sequestered, and exported within each ecosystem (shelf, slope, and basin);
- The effects of human impacts on the Arctic marine ecosystem (individual species to ecosystem level), assessed from studies of increased UV radiation to organic contaminant cycling; and
- The small-scale physics and large-scale dynamics of air-sea-ice interactions.

It is clear that appropriate research strategies are needed for describing and understanding the Arctic marine ecosystem, including a mixture of retrospective analyses, time-series data, process studies, and modeling. Evidence of change in the Arctic environment is rapidly accumulating. Although the effects of these changes on physical and chemical dynamics are now being recognized, coincident effects on the biological systems are more difficult to assess.

More information is needed on the amounts and controlling factors of primary production (phytoplankton and ice algae) in the marginal seas and the central Arctic in order to assess and predict the effect of environmental changes on Arctic ecosystems and biogeochemical cycles. Estimates of primary production suffer from chronic spatial and temporal undersampling, as well as reduced efficacy of satellite data due to ice, snow, and cloud cover in the Arctic. Very few time series exist to establish seasonal patterns, and there are almost no observations during breakup, which may be a time of high primary and secondary production.

Both system-based and process-oriented studies are necessary for assessing biological production in the Arctic marginal seas and the central Arctic. System-based studies investigate geographical, spatial, and temporal variations of key biological

and environmental parameters. Process-oriented studies are necessary to determine the relationships between variations in environmental and biological parameters and the production and fate of fixed carbon through the ecosystem. Ice-capable ships, ice stations, submarines, moorings, and autonomous vehicles are major platforms projected for a coordinated study of the Arctic ecosystem. Key locations (such as Fram, Bering, and Barrow Straits, the broad western Arctic shelves, and the Canadian Archipelago) should be investigated intensively.

A useful approach to understanding the Arctic marine ecosystem may be through intensive studies of subsets that can be scaled up to regional and larger assemblies via coupled modeling. For example, the significance of the shelves to the larger Arctic marine ecosystem is currently being addressed through the NSF Western Arctic Shelf Basin Interactions (SBI) project. This effort is intended to illuminate the physical and biological shelf and slope processes that influence the structure and functioning of the Arctic marine ecosystem, with the larger goal of being able to predict the impact of global change on ecosystem function.

The use of the Arctic as a regional laboratory for questions in astrobiology is being planned by both NSF and NASA, with the ice-covered Arctic Ocean considered an analog of possible habitats for microbial life on other solar bodies, such as Jupiter's ice-covered moon Europa (AMES report 1998).

Understanding the forcing functions and ecosystem response to perturbations, be they natural oscillations, human-induced global warming, or anthropogenic contaminants, is critical to evaluating the past, current, and future environmental condition of the Arctic. Ultimately ecosystem modeling must be used in conjunction with field analyses to predict the effects of global and climate changes on the biological production and fate of organic carbon in the Arctic.

2.4.4 Strategic Considerations

The practical constraints on Arctic marine research are considerable, ranging from those imposed by a difficult working environment, through requirements for international arrangements in politically sensitive areas, to a need for significantly increased funding to increase our national capabilities. Given these constraints, we believe that an effective strategy must:

- View the Arctic in a global context;
- Move toward a symbiosis of measurement, modeling, and retrospective analysis;
- Provide access to the entire marine Arctic;

- Lead to effective international coordination;
- Develop and maintain efforts sufficient to create usefully long time series;
- Extract and use existing data in both the public and private sector;
- Recognize the dependence of Arctic coastal residents on the marine environment; and
- Consider existing and proposed industrial activities in the marine Arctic.

We recognize that while the marine Arctic is seriously underobserved and its simulation is deficient in major aspects, sufficient progress has been made during the past decade to believe that a useful predictive capability can realistically be achieved. Doing so, however, will require a considerable expansion of our present capabilities.

Scientific Access

Scientific access to essentially the entire Arctic Ocean and its peripheral seas is required during the next decade, as there are substantial limits to what can be achieved through piecemeal investigations. This will require stably funded and scientifically responsive logistics, but it will also require predictable scientific access to the exclusive economic zones that cover much of the Arctic. In particular, it will require mechanisms that can with some confidence provide access to the Russian shelf and slope regimes. This in turn will require commitments at levels of government far higher than is customary in arranging such work. It is also important that the large Canadian marine Arctic, including the major passages through the Canadian Archipelago, remain scientifically accessible in the face of changing regional governmental structures and responsibilities in Canada. The importance of the Arctic shelves and slopes looms very large in the research strategy of the next decade, and one cannot hope to fully meet the strategic goal of predictive capability without an understanding of all the major shelf areas. We note that scientific programs, including those involving deep drilling, have been successfully completed on other continental shelves around the world, and these programs may therefore provide a guide for the Arctic shelves.

Sustained Measurements

There is also a clear need to develop new methodologies that are workable in ice-covered waters. Much of the instrumentation and techniques that have come to the fore in open ocean research in recent years, or are contemplated, are difficult or impossible to apply to the Arctic. This includes

methodologies as diverse as Lagrangian profilers, sea surface altimetry from satellites, and expendable moorings that require surfacing to transmit their data.

For certain parameters, such as velocity, temperature, salinity, and ice thickness, moored measurements are possible anywhere within the Arctic Ocean, given the necessary logistical support, but such measurements are expensive, and new technologies, including acoustic ones, should be systematically explored. Other parameters, including a variety of tracers, are also important constituents in such a long-term measurement strategy.

We therefore recommend that a long-term dedicated effort be instituted to develop measurement techniques that with confidence can be applied to ice-covered seas. There may be special opportunities for forging new partnerships in this undertaking, both internationally and with other government agencies and industry, for example in developing and utilizing autonomous underwater vehicles.

New Methodologies

There is a further distinct need for sustaining key measurements over a long period of time (on the order of several decades). Guidance on the low-frequency variability of the physical system is obtainable both from studies of the paleorecord and from simulations and theory, but this does not obviate the need for direct measurements. Such long-term monitoring does not easily fit within the NSF-academic system, except perhaps for Environmental Observatory sites, which suggests that cooperation from other agencies must be sought, whether domestic or foreign. Highly successful examples of such international and interagency cooperation in the Arctic are the International Arctic Buoy Program, as well as numerous polar-orbiting satellites with special capabilities for the remote sensing of ice and other parameters of interest. For example, the multi-year satellite-derived geophysical data sets now available provide a rich store of information highly relevant to the principal research themes of this report. Important long-term international environmental monitoring programs, such as the Global Ocean Observing System (GOOS), and international marine paleoclimate investigations, such as the Ocean Drilling Program, have traditionally avoided the high latitudes, but a deliberate engagement of Arctic marine research with these planning efforts should be sought.

In general in the Arctic, one has relatively little understanding of the scales of variability, whether

spatial or temporal, but dynamical considerations suggest that at least the spatial scales are smaller than at the midlatitudes. This then places a special burden on both observational strategies and numerical simulation, and resolving these issues of scale and their importance will require a more focused research effort than has been the case.

Because of the large logistic expenses of Arctic Ocean field work, requiring either submarines or icebreakers, small individual research is far too inefficient. This does not mean that there should be no individual or small group research that is not part of a large coordinated effort because there always needs to be support for good ideas, but coordination of logistical support is essential and most easily accomplished with large, well-planned initiatives. There is no question that deep sea drilling in the Arctic Ocean will be required to resolve many of the important questions about the structure and evolution of the Arctic, but giant piston coring and acoustical surveys should be aggressively pursued immediately. At the same time a greater effort to obtain longer deep-sea drill core needs to be funded.

Indeed, the national interest addressed by Arctic marine research would be well served by such action because of the vital importance of the Arctic shelves to the national and global economies of the future and because of the importance of understanding the linkage between the Arctic and global climate. Every effort should be made to involve the petroleum companies in collaborative research and to share the wealth of geologic and oceanographic data on shelf areas like the North Slope. The indigenous people of these areas also have a vast knowledge of and interest in the coastal marine environment that should be tapped by direct involvement in research programs.

Interagency Cooperation

A multiagency effort is required to support the full range and depth of research required for carrying out the strategic goal of acquiring a predictive capability for the marine Arctic and its links with the global atmosphere-ocean system. Similarly, in recognition of the pan-Arctic nature of such marine research, an effective means of international cooperation is required. This may take a variety of forms, including joint funding, bilateral agreements, sharing of research infrastructure, and close logistical coordination. Within the international research community, Canada provides a natural partner with whom to initially develop such systematic and sustained cooperation, as amply dem-

onstrated by the successes of the 1994 Canada-U.S. Arctic Ocean Section and the recently concluded field phase of the Surface Heat Budget of the Arctic Ocean study (SHEBA). The experience gained can then be used to develop similar arrangements with other nations, especially Russia. Existing international programs such as the Arctic Climate System Study of the World Climate Research Programme and the Ocean Drilling Program can contribute additional experience and networking potential.

Cooperative arrangements of this nature share with large coordinated science projects the ability to effectively leverage and use resources, including logistics, and to promote multidisciplinary approaches, but they need to be considered within the context of an overall balance that also encourages fresh insights and innovative approaches. The NSF has a special role to play in this regard, safeguarding and promoting the opportunities to test new ideas and approaches.

Resources and Logistics

Just as new ways of working are required to achieve these goals for an effective scientific presence in the Arctic in support of national needs, substantial new resources are also required. Predictable availability and known paths to these resources are important elements in their effective use. Furthermore, individual investigators should be encouraged to form partnerships whenever practical to best utilize resources. Means should also be found to share financial resources, facilities, and logistics internationally. The participation of NSF in the international Ocean Drilling Program may provide a useful model for using international scientific infrastructure to achieve long-term and complex goals, such as drilling in the Arctic Ocean.

Arctic marine research in the U.S. has been severely limited by the absence of a surface vessel capable of carrying into the ice on a regular basis the complex array of scientific facilities that are an essential part of modern science. The advent of the USCGC *Healy* into the U.S. research fleet creates the opportunity for the U.S. for the first time to support its science community with a dedicated and suitable platform available throughout the year. It also provides the opportunity for the U.S. to become a full international partner with other nations who have earlier made such an investment. To convert these opportunities to working realities will require that administrative and operational practices and cultures be developed that are capable of bridging the gap between the military opera-

tor (the Coast Guard) and the largely civilian users. We believe that this development will require support at the highest level within the cognizant organizations and a sustained and creative effort by one or more knowledgeable working groups with clear mandates. To make the *Healy* a working reality in support of science will also require stable funding that does not place the working scientist in the untenable position of having to secure operational funds. We further believe that the scientifically most effective funding mechanism is one that provides support for the scientists themselves on a competitive basis and that may be funded by a variety of agencies and sources, including foreign. Finally, effective use of the *Healy* will require a long-term planning process to assess regional, seasonal, and programmatic emphases on a multiyear basis and to identify and coordinate schedules with escort or companion vessels on deep penetrations of the Arctic Ocean. This may not comfortably fit the short proposal cycle of NSF and other agencies, and it may therefore require ingenuity in adapting agency practice to the realities of Arctic planning.

We consider it unlikely that the *Healy* will be able to meet all the science requirements for work in or near ice-covered waters, in part because of the anticipated priority use of the vessel in areas more difficult to reach, and in part because the vessel will be expected to cover the entire Arctic. We therefore foresee the need for an ice-strengthened research vessel of medium size to work in the marginal ice zone of the western Arctic in summer and fall and in the Bering Sea throughout the winter. This issue is best addressed by a panel, building upon present and past deliberations.

The use of submarines as scientific platforms in the Arctic dates back to the 1930s, but only recently, through the SCICEX (Submarine Science Ice Exercise) program, has a sustained and broadly based experiment in such use been performed. SCICEX employs a U.S. Navy nuclear attack submarine whose seven-week mission is devoted to scientific measurements in the ice-covered Arctic Ocean. The five dedicated SCICEX submarine cruises have provided an unprecedented opportunity to observe the ice cover, upper ocean, and seafloor, and an evaluation of that program is underway in the form of a SCICEX 2000 workshop report. Published results to date point to the considerable scientific potential of submarines, especially in a survey mode, where submarines can truly excel. For certain other applications, such as benthic sampling, the limitations appear

severe. This suggests that the maximum scientific return will be had when programs carried on submarines and other platforms, such as icebreakers, are carefully coordinated both scientifically and operationally. We also strongly encourage the continued release of both past and future submarine data, which provide the only large-scale measurements of ice thickness in the Arctic.

The principal shore facility in the U.S. in support of Arctic marine science has been the former Naval Arctic Research Laboratory at Barrow, now owned by the Ukeagvik Inupiat Corporation and used in support of both education and research. For marine science in the nearshore zone and for work requiring field camps and aircraft support, shore support stations are essential. We consider it likely that aircraft operating from such shore bases will prove a mainstay of future work on the continental shelves during winter. We further believe that providing satisfactory shore support will require international investments in infrastructure at a circumpolar series of sites, perhaps six to eight sites altogether. In addition to the laboratory at Barrow, diverse models for such stations range from the Canadian bases in Tuktoyaktuk and Resolute Bay to the NSF facilities in the Antarctic and New Zealand, although with respect to the latter model the Arctic presents special problems, primarily associated with political and administrative boundaries.

Coordination

Given that patterns of Arctic climate change, for example, are nonuniform, it is important to integrate U.S. programs with other national and international ocean science programs to obtain a pan-Arctic perspective. For example, the Arctic is a very large ecosystem indeed, and full understanding of the levels and controlling factors for biological production will require coordinated international efforts to attain enough spatial and temporal coverage. In particular, parallel research programs in the marginal seas and basins of the eastern and western Arctic will be necessary to assess biological production in the pan-Arctic system.

International coordination with Canada, Russia, Germany, Sweden, Norway and Denmark/Greenland is both essential and efficient. For example, Canada has excellent shore-based logistic capabilities in the Arctic, and arrangements for regular use by U.S. investigators should be initiated. We note also that it was international efforts that succeeded in carrying out scientific traverses of the

deep Arctic basins by icebreakers and that are currently promoting broad initiatives in climate (the Arctic Climate System Study of the World Climate Research Programme) and solid earth sciences (the Nansen Arctic Drilling Program). Furthermore, if one is to understand how the Arctic is or is not changing, long-term studies are essential. These efforts will also require international cooperation.

International collaboration is essential for working over the Arctic continental shelves. Multi-national agreements for scientific studies need to be raised as critical issues in effective political forums. Leaving requests for access to foreign waters up to the principal investigator is not adequate for collaborative work, particularly within the Russian EEZ. It would likely also prove valuable to establish a U.S. government liaison in collaborating countries to support Arctic research and operations.

Finally, to encourage international collaboration, funds should be provided for both invited workshops and symposia and for participation of foreign scientists in field work and collaborative planning efforts with NSF-funded scientists.

2.4.5 Recommendations

In support of national research needs in the marine Arctic, IARPC recommends the following:

- Expand support of basic research on the Arctic marine system, with a particular emphasis on improving predictive capabilities;
- Include in the emphasis on predictive capabilities both a global perspective and a regional one with application to more local problems and opportunities;
- Initiate a sustained effort to acquire marine environmental time series, including the estab-

lishment of a marine Environmental Observatory in the Arctic and a set of strategically located repeat hydrographic sections;

- Initiate a program of giant piston coring and support the expansion of International Ocean Drilling Program efforts into the Arctic Ocean;
- Support continued seafloor mapping and integrated geophysical measurements by submarines and other appropriate means;
- Initiate a sustained effort to develop instrumentation and measurement techniques suitable for ice-covered seas;
- Seek release from the petroleum industry of geophysical and coring data from the continental shelves;
- Immediately pursue international cooperative agreements for planning and supporting Arctic marine science, particularly with Canada as a natural first partner with which to initially develop such systematic and sustained cooperation;
- Facilitate scientific access to the Russian EEZ and continental shelves through a high-level bilateral agreement with Russia;
- Use a balanced and complementary logistical system that includes icebreakers, smaller coastal vessels, aircraft, shore support stations, and submarines where feasible;
- Ensure scientific control of expeditionary planning, scheduling, and scientific operation of the *Healy*, in the manner of UNOLS vessels; and
- Evaluate the logistical needs of Arctic research every three to five years, including the need for a smaller vessel suitable for work in the marginal ice zone.

3. Agency Programs

3.1 New Opportunities for Arctic Research

3.1.1 U.S. Chairmanship of the Arctic Council

The U.S. chairmanship of the Arctic Council (1998–2000) offers significant new opportunities for expanded national and international cooperation in the field of Arctic research. U.S. agencies are examining how best to contribute data to ongoing research programs being conducted through the Arctic Council's working groups and also whether there is scope for new research on issues relating to environmental contaminants, pollution, human health, and biodiversity. Given the Council's mandate with respect to sustainable development, there is also scope for renewed emphasis on research in the social sciences.

3.1.2 Remote sensing

High-latitude satellite observations continue to expand with unprecedented broad coverage monitoring conditions across the Arctic. This capability has been established as part of a multiagency mandate to provide tactical support to weather forecasting, shipping, and other operational activities and to provide a network of observations in support of space, climate, and ecosystem-related research.

A 20-year, cross-calibrated record of conditions across the Arctic has now been generated by space-borne passive microwave sensors operated through the auspices of the Defense Meteorological Satellite Program. The data have provided early indications of unusual ice conditions that have prompted much research and have assisted in seasonal forecasts, as well as providing a robust source of daily information on ice conditions across the whole Arctic. Wide-coverage data have recently been expanded considerably through the addition of synthetic aperture radar (SAR) data from the Radarsat program (Canada), with the "Arctic Snapshot" providing coverage of most of the Arctic every few days. This is a collaborative program between NASA and the Canadian Space Agency. The resolution of these data is sufficient to enable detection of subtle lead openings and pressure ridge formation in the ice while at the same time providing this information over a wide area of the Arctic. This promises to revolutionize our knowledge of the nature of the interaction

between the ocean and the atmosphere, taking us one step nearer to understanding the role of the Arctic in the climate system. Recent improvements in ground processing of data have also resulted in newly enhanced capabilities for monitoring sea ice drift, with associated benefits to models of the Arctic ocean–ice–atmosphere system.

Operational monitoring of the Arctic at the National Ice Center (NIC) has been revolutionized recently by the addition of wide-coverage SAR observations to the suite of available data sets, and by migration of operations to a fully digital data analysis environment, with efficient use of the Internet to support data ingestion and product dissemination. Operational monitoring at the NIC has also been aided by support from the Fleet Numerical Modeling and Oceanography Center and NOAA/NWS Ocean Modeling Branch, with data archived by the NOAA/NESDIS Satellite Active Archive. The NIC has also been involved in implementing the Environmental Working Group initiative to provide digital climatology data for the Arctic in support of science research and has established a science team to improve links between the scientific research and operational ice monitoring communities.

Remote sensing data have also played a key role in recent investigations of the state of the Greenland ice sheet, as part of the Program for Arctic Regional Climate Assessment (PARCA). This massive body of ice, with a maximum thickness of about 3 km, has the potential to have a significant impact on sea level. Recent studies using satellite radar altimetry and airborne laser altimetry have demonstrated significant regional differences in rates of thickening and thinning, indicative of a complex evolving system. These intriguing results will be studied further through the Geoscience Laser Altimeter System, due to be launched in 2001 on ICESAT. Future research in Greenland, as well as in other Arctic icecaps and glaciers, will also be enhanced through the application of SAR interferometry, which is able to map ice velocities and detect subtle changes in surface form and conditions. SAR interferometry has application to the study of glacier motion, as well as to crustal deformation and volcanic swelling.

Remote sensing of the Arctic will enter a new

generation with the launches of NASA's Earth Observing System suite of sensors, AM-1 in 1999 and PM-1 the following year. This will provide an integrated observing system that includes sensors from a wide range of the electromagnetic spectrum. With observations recorded from the same platforms, geophysical phenomena can be studied using a wide range of sensors without the time lapses in observations that, in the past, have limited their synergistic value. For example, the advanced microwave radiometer sensor (AMSR) will provide information on continental snow cover distributions and thicknesses, land surface wetness, sea surface temperature, and sea ice concentrations and temperatures. The planned convergence of the DOD-NOAA-NASA weather program, with the launch of NPOESS, continues this philosophy. There has been, and will continue to be, international cooperation to make efficient use of research resources, this being particularly important for the monitoring and study of major components of the Arctic system.

3.1.3 *In-situ Sensing*

Ground-based observations are being revolutionized by emerging new technologies. Precision navigation from portable low-power receivers is possible from the satellite-based global positioning systems. A number of options for data telemetry are evolving, including specialized communication microsatellites, an ionospheric-path HF radio frequency with digital packet switching, and a ground-plane MF radio frequency over ice. Advances in low-power microprocessors and mass storage media (optical disk, digital audio tape, video tape) have provided a new generation of programmable, high-capacity dataloggers for field experiments. Innovative sensors and signal processing techniques based on acoustic and optical propagation have opened up new dimensions in probing the structure of the atmosphere, ice, and ocean. New materials and high-density energy sources have spawned a new generation of remote platforms, such as buoys and autonomous detectors. Instruments based on such new technology will enable radically new adaptable and interactive observational strategies for process studies, as well as provide the means for long-term, real-time monitoring of primary variables at remote sites.

3.1.4 *Fisheries Management*

Bering Sea stocks cannot be fished indiscriminately without irreversible changes in the popula-

tion structure and yield. Agreements between the Presidents of the U.S. and Russia reflect the heightened consciousness regarding the rich fishery, wildlife, mineral, and heritage resources of the Bering Sea region.

Representatives of the State of Alaska have called for a study of the Bering Sea aimed at understanding the fishery dynamics and devising appropriate management options. The Arctic Research Commission has concurred with these concerns and has recommended a study of the Bering Sea as an ecosystem.

The NOAA/National Marine Fisheries Service (NMFS) conducts an extensive program of ecological and stock assessment research in support of its fisheries and marine mammals conservation mandates. These research programs include fisheries oceanography to understand how environmental changes affect resource production, stock assessments to determine resource status, and recruitment research to understand and forecast new entrants to fisheries and mammal populations. The agency and the groundfish industry carry out large-scale observer programs to monitor at-sea catch and bycatch of the fleet. This information is used to set harvest levels and to allow wise use of the resources.

3.1.5 *Cultural Exchange*

Work continues on planning for the Russia-United States International Beringian Park in the Bering Straits region based on agreements reached by the NPS in 1990. This park would preserve the unique environmental and cultural heritage adjacent regions of Alaska and Siberia. Current plans call for continuing the highly successful past efforts on research, cultural exchanges, and publication projects.

The Smithsonian Institution's recent projects in the greater Beringian region include completion of its Russian Far East tour of the "Crossroads" exhibition, including publication of a Russian-language catalogue. New exhibits on Alaska and the Aleut region have been opened at the National Museum of Natural History, and new special exhibits on Ainu and Alutiiq cultures will open in 1999-2000. A major millennium exhibition, "Vikings: the North Atlantic Sagas," will also open in 2000. In addition to catalogues for these exhibitions, new publications will include an English translation of a material culture atlas of Siberia, a Native history of the Bering Strait region, and archival studies of the Jesup North Pacific Expedition.

3.1.6 Data

Common to all programs is the need for consistent data management among the Federal agencies. The Arctic Data and Information Program describes this activity (see Section 4.2).

3.1.7 U.S.–Russia Collaboration

The ending of the Cold War and the opening of relations with the former Soviet Union offer an unprecedented opportunity to develop bilateral research programs on Arctic scientific issues of common concern to the U.S. and Russia. Several bilateral agreements already exist to promote cooperative efforts in the areas of environmental protection, oceans research, basic science, fisheries management, and energy technology. An extensive amount of data has been exchanged with the former Soviet Union and now Russia over the last several years, which include data from north of the Arctic circle. These data are distributed among the U.S. national data centers. A steady stream of Russian scientists and science officials have visited the U.S., offering plans and proposals for collaborative work. Proposals for specific projects with Federal agencies have resulted. Many agencies have taken the initiative to develop their own contacts and programs in Russia. Revelations about environmental contamination in the Russian Arctic and efforts to preserve and disseminate scientific data from the former Soviet Union have been the principal motivations behind much of this activity.

Studies of Russian, U.S., and Canadian Arctic history continue to demonstrate the ties that have linked Arctic people, cultures, and regions for the past 15,000 years.

Under the Environmental Working Group (EWG) of the U.S.–Russian Joint Commission on Economic and Technological Cooperation, the U.S. and Russia have developed methods and procedures for using national security data for environmental problems of mutual interest. A key success of the EWG has been the creation of a series of Arctic climatology atlases using information derived from both Russian and U.S. national security data. The winter and summer oceanographic CD-ROM atlases of a 40-year gridded time-history have been released. Production of sea ice and meteorological atlases is underway. The oceanographic atlases have more than doubled the Arctic oceanographic information available to the world's scientific community.

3.1.8 Oil Pollution Control

Title V of the Oil Pollution Act of 1990 established the Prince William Sound Oil Spill Recovery Institute (OSRI), with broad interagency participation led by NOAA and including the Department of Interior, Department of Defense, Department of Transportation, and Environmental Protection Agency. The State of Alaska is working to coordinate with OSRI's development of an Arctic–sub-Arctic oil spill research plan. The plan has \$5 million in research support from the State of Alaska and authority to receive up to \$23 million from an account to be established in the National Pollution Fund.

3.1.9 Permafrost Degradation

Renewed concern for the potential damage to infrastructure and the environment due to permafrost degradation has been sparked by ongoing initiatives to provide access to the National Petroleum Reserve in Alaska (NPR–A) for nonrenewable resource development, as well as increased DOD interest for potential National Missile Defense facilities in Alaska and other Arctic regions.

Roads, airfields, buildings, and pipelines founded on permafrost are at risk of damage when the ground warms or thaws. This degradation causes frozen ground to lose its strength, with consequences ranging from a reduced service life to outright structural failure. The thawing of ice-rich permafrost produces irregular settlement and slope instabilities that permanently alter the terrain and have catastrophic consequences on the infrastructure.

Significantly, permafrost degradation is not a hypothesized outcome of global warming: engineers have been dealing with the effects of permafrost degradation for some time, and there are documented cases of the resulting damage to the infrastructure. Although a link with global climate change is intuitive, factors such as microclimate, local hydrology, glacial history, geomorphology and materials, and increased snow depth can promote, and in some cases control, degradation at specific sites.

In addition to the impact to infrastructure, permafrost warming and thawing have dramatic effects on vegetation, topography, and hydrologic processes, which in turn have serious ecological and land use implications. Warming may increase the release of trapped methane and CO₂ as a greenhouse gas. The degradation process may

result in a dramatic increase in the mobility of contaminants locked in existing permafrost deposits. The impact is initially localized and is highly dependent on the nature of the contaminants and the geological and hydrological conditions of the site. The contaminants become more widespread as warming proceeds, increasing the probability of their introduction into the food chain and large-scale groundwater contamination.

Historically the presence of contaminants in solidly frozen ground has not been considered a problem because they were thought to be relatively immobile. Disposal practices in the Arctic still allow for wastes to be buried and back-filled in cold permafrost. However, since climate warming scenarios indicate that seasonal thawing will occur to progressively greater depths, and much permafrost will thaw completely, the opportunity increases for contaminants to spread laterally and reach deeper layers. This circumstance motivates our present concerns. Although the effects from any individual site may be confined, the need to address this issue on a broad scale is justified by the potential number of sites that are of concern.

The issue of permafrost degradation impacts virtually all elements of the existing infrastructure and future Arctic building programs, land use, and con-

taminant mobility, and raises concerns regarding the exposure of other cold-regions nations to this threat. Although this problem has been recognized by the engineering community, knowledge of the extent of permafrost areas at risk, predictions of the rate of degradation and the resultant damage to specific structures, and a strategy for dealing with progressive damage are all lacking.

3.1.9 Contaminant Behavior and Impact in Northern Polar Regions

This new program of the National Science Foundation has as its goal to encourage research on the physical and biological routes, rates, and reservoirs of Arctic contaminants to develop baselines for natural systems. This research will provide a better understanding of the behavior of contaminants among the Arctic's atmospheric, marine, terrestrial, and estuarine systems and their impacts on human populations and ecosystems. It is a component of the research program described in Section 2.2, Arctic Monitoring and Assessment, and Section 2.3, Assessment of Risks to Environments and People in the Arctic. A complete description of this program is located at <http://www.nsf.gov/pubs/1999/nsf9997/nsf9997.htm>.

3.2 Arctic Ocean and Marginal Seas

3.2.1 Ice Dynamics and Oceanography

A prominent feature of the Arctic Ocean is its permanent, dynamic ice cover. This marine cryosphere significantly impacts the environment on all scales, from climatic to molecular. Critical processes governing this impact occur in the atmosphere and oceanic boundary layers above and below the ice. A major priority is the development of the next generation of operational ice forecasting tools and models. A systematic program of oceanographic, cryospheric, and atmospheric measurements by conventional technologies, as well as new technologies such as autonomous underwater vehicles (AUVs), is needed to support the objectives of this research and the interagency program.

Among the specific SCICEX studies are investigations of the water masses in the Arctic, their sources, and the nature of their modification by the Arctic environment. Over the five years of

SCICEX the Atlantic inflow from the eastern Arctic has been seen to penetrate even farther into the western Arctic and has produced considerable (approximately 2°C) warming at intermediate depths. This warming has been accompanied by a thinning and warming of the insulating layer between the Atlantic inflow and the ice pack, causing concern about the fate of the permanent ice pack. Measuring this trend is a key need of future Arctic environmental monitoring efforts. The structure, distribution, and draft of the ice pack over large portions of the Arctic are analyzed to investigate the properties of the ice and to predict ice thickness distributions. Very detailed bathymetry and shallow sub-bottom profiling are also part of the SCICEX program, employing the seafloor characterization and mapping pod (SCAMP) developed by the National Science Foundation. Obtaining high-quality bathymetry in the Arctic has been extremely difficult until the advent of SCICEX. SCAMP now promises to produce

unparalleled high-resolution views of a largely obscure ocean basin. Particular emphasis will be placed on the Mid-Ocean and Lomonosov Ridges and the Chukchi Borderland regions. In particular, a portable swath bathymetric imaging system, first used in 1998, promises to revolutionize our knowledge of the geology of the Arctic Ocean.

To increase our understanding of the large-scale behavior of Arctic sea ice, NASA has been sponsoring the development of the Radarsat geophysical processor system (RGPS). This system, due to be installed for operational use at the Alaska SAR Facility during 1999, is able to monitor ice drift over a large portion of the Arctic using data from the Canadian Radarsat satellite. By maintaining a Lagrangian database of these observations, the RGPS is also able to maintain information on ice age and deformation and, through use of an ice growth model, ice thickness. The system promises to significantly enhance our knowledge of atmosphere-ice-ocean interactions.

Objectives

- Determine the processes, history, dynamics, and mechanisms of ice production, deformation, advection, and decay;
- Determine the processes of renewal and mixing of Arctic and sub-Arctic water masses from large to small scales;
- Determine the large-scale circulation of the Arctic Ocean and circulation variability and dynamics, including the role of shelf seas, boundary currents, and exchanges with adjoining seas; and
- Determine the mean and natural range of variability of currents and hydrographic features in the nearshore region of the Bering, Chukchi, and eastern U.S. Beaufort Seas.

3.2.2 Ocean and Coastal Ecosystems and Living Resources

The biota of marine and coastal ecosystems are influenced by physical processes, including seasonal extremes of light and temperature. Arctic marine ecosystems are dominated by sea ice, while coastal ecosystems are influenced by freshwater input and seasonal sediment loads, as well as by seasonal sea ice. There is a need to quantify the resulting variability in the rates of biological production of marine living resources through long-term and well-designed interdisciplinary research.

Objectives

- Determine the status and trends of fish, bird,

and marine mammal populations and identify their habitat requirements;

- Monitor coastal ecosystems to detect and quantify temporal changes in nutrient and energy exchange and their effect on biota;
- Determine the magnitude and variation of marine productivity in Arctic areas through studies of the structure, dynamics, and natural variability of the ecosystems;
- Consider the influence of ice and human activities on both the biotic and abiotic components of the Arctic environment;
- Study the influence of Arctic marine productivity on the global cycling of biologically active materials, including carbon and nitrogen; and
- Understand the physical and biological processes that affect fisheries recruitment in the U.S. waters of the Bering, Chukchi, and Beaufort Seas.

3.2.3 Marine Geology and Geophysics

The Arctic continental margin and deep ocean basin constitute one of the least understood geological regions of the world, partly because much of the offshore area is covered with sea ice. A better understanding of the tectonic history, geologic structure, sediment processes and distribution, and climatic and glacial history of the deeper basin will require extensive geophysical and geological research and the integration of newly collected data on an international scale.

Objectives

- Develop and perfect new techniques for deployment of instruments in the harsh Arctic environment (for example, seismic tomography, geophysical arrays, hydraulic piston coring, and scientific deep drilling);
- Initiate Arctic marine geological and geophysical studies to provide information on past and present climate change and the history of the ice cover, support rational development of natural resources, and address fundamental questions of global geologic history and regional tectonic development;
- Define the geologic framework, deep structure, and tectonic history and development of the Bering Sea region;
- Develop the capability for systematic and comprehensive collection of geologic data in the ice-covered offshore regions using remote sensing and other technologies, such as the nuclear submarine; and

- Determine modern sediment transport by sea ice, icebergs, and other processes; characterize the seafloor sediments by coring and reflection methods; and establish a well-dated stratigraphy.

3.2.4 Underwater Research

Marine scientists working in the Arctic are severely limited by vessel capability and other logistical problems. The development of submersible technology, especially remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), may significantly improve our ability to study and understand the physical and biological processes of the polar seas. The increased U.S. policy interest in the Arctic and the biological and physical data accumulating about it challenge undersea technology.

NOAA's National Undersea Research Program's (NURP) West Coast and Polar (WC&P) Center, located at the University of Alaska Fairbanks, has supported many projects in recent years, including studies of beluga whale feeding habitats in the Arctic and benthic response to early season deposition of algae in the Chukchi Sea. During the Chukchi Sea expedition the Coast Guard Cutter *Polar Sea* cut a path through the Arctic ice and provided openings so that an ROV provided by WC&P could obtain seafloor samples. The underside of the ice pack was found to be home to dense mats of algae that fall to the bottom and feed a thriving seafloor community. Bacteria were collected in a search for new drugs. Water, biota, and ice samples provided data on carbon dioxide sea-air exchange to help understand the global carbon cycle and climate change. Pictures and additional information on this cruise can be found on the *Polar Sea*'s web site at <http://www.oz.net/~polarsea>.

In April 1998 the WC&P, NASA, and the Coast Guard convened a workshop on undersea research in polar regions. The initial objective was to

develop opportunities to employ NASA's shallow-water ROVs equipped with telepresence capabilities in science operations using Coast Guard vessels in Arctic, Antarctic and Pacific Basin sites. The use of those vehicles would enhance the capability of the WC&P to support scientific research in those demanding environments. Conversely, through the use of telepresence techniques for data transfer and remote operation of robotic vehicles, NASA could hone its ability to conduct science on other worlds while supporting significant research opportunities on or under the Earth. Workshop participants and agency representatives are in the process of developing an interagency partnership and initiative to enhance undersea research in polar regions.

Objectives

- Increase our understanding of the relationship of finfish and shellfish to particular habitats and improve population estimates;
- Study shelf and slope ecology, particularly important biological processes and the physical and biogeochemical processes that accompany them;
- Study tectonic environments, such as hot spot effects, fracture zones, and propagating rifts, including the ecology and chemical characteristics;
- Study the fishery potential of seamounts, where unique biological communities have developed due to a combination of isolation, bathymetry, and ocean current regime, and search for clues to the causes of intra- and interannual variability of fish stocks; and
- Using acoustic propagation, perform physical oceanographic studies of biological activity under the ice in the Arctic, particularly light and chlorophyll studies, coupled with studies of the biological communities and ecosystem dynamics under ice and in areas covered seasonally by ice.

3.3 Atmosphere and Climate

3.3.1 Upper Atmosphere and Near-Earth Space Physics

The goal of this research is to study upper atmospheric and near-Earth space phenomena unique to the Arctic regions. These include the aurora, particle precipitation, auroral convection and currents, polar mesospheric clouds, Joule heating, and geo-

magnetic storms and substorms. These phenomena are intimately linked to the Arctic environment and culture, particularly as Arctic inhabitants become more dependent on modern technology and the Arctic economy becomes more firmly planted in technical systems.

Many of these phenomena are driven by parti-

cles and fields originating on the sun. Particles from the sun impact Earth's magnetosphere, which is connected to the upper atmosphere and ionosphere through magnetic field lines that converge in the polar regions. A large fraction of the energy entering the magnetosphere is deposited in the polar upper atmosphere with dramatic consequences. Strong currents can disrupt electrical power systems and cause accelerated erosion in oil pipelines. Magnetic perturbations jeopardize the accuracy of mining exploration technology. Arctic ionospheric disturbances interrupt the performance of GPS navigation systems, surveillance systems, and high-frequency radiowave propagation.

The state of the space environment near Earth and its response to solar inputs has come to be known as space weather. The National Space Weather Program (NSWP) is a multi-agency program created to develop the capability to produce timely, accurate, and reliable space environment observations, specification, and forecasts. The study of Arctic phenomena represents a critical element in understanding the way the space weather system works.

The Arctic region is also extremely sensitive to atmospheric changes associated with global warming. Ongoing research is showing that the sensitivity of the Arctic upper atmosphere to climate change provides an effective means to monitor long-term variations of the atmosphere. Warming of the atmosphere at lower altitudes occurs in conjunction with cooling of the upper atmosphere, a change that is believed to be manifested in the increasing occurrence rate of polar mesospheric clouds. Changes in the thermal structure of the upper atmosphere have also produced a measurable change in the height of ionospheric layers. These effects are being studied intensively as part of the U. S. Global Change Research Program.

Objectives

- Observe the global-scale response of the polar regions through a coordinated program involving a polar network of ground-based optical, radio, and magnetic observatories and space-based measurements;
- Develop special research tools to address key problems, including establishing a Relocatable Atmospheric Observatory and upgrading the existing incoherent scatter radars, the array of HF radars in the Arctic, and the arrays of optical, radio, and magnetic remote sensors, and also including establishing a coordinated rocket program, promoting the

use of special facilities, and making use of research aircraft;

- Maintain active theoretical programs and promote the evolution of models to describe the unique physics of the atmosphere and ionosphere in Arctic regions;
- Understand solar phenomena that affect the Earth's environment;
- Understand electromagnetic waves, fields, and particles in near-Earth space; and
- Develop an understanding and the ability to make long-term predictions of radio-wave propagation in and through the Earth's ionosphere.

3.3.2 Climate and Weather

The outstanding characteristic of the Arctic climate and weather is its dramatic variability in clouds, radiation, and surface heat exchange. Most projections of future climate change suggest that high-latitude regions will incur the greatest temperature fluctuations. Research is needed to clarify the impact of potential change and to address Arctic weather problems occurring on a variety of spatial and temporal scales that range from micro-scale to global. A major need is for accurate regional and local weather forecasts, especially to predict such hazardous weather phenomena as Arctic lows, storm surges, icing conditions, and fog, which can affect human activities.

Objectives

- Develop an Integrated Arctic Climate Studies Program as part of the USGCRP, including studies of climate effects on Arctic indigenous people and biological resources, and a systematic program of intercomparison between observations and modeling results, focused on the Arctic radiative balance, cloud processes, and their effects on local, regional, and global climate;
- Understand the extent to which Arctic climate variations are amplified signals derived from elsewhere or are generated locally as a result of the sensitivities of the regional environment;
- Understand whether, how, and with what result Arctic climate anomalies propagate to middle and lower latitudes;
- Quantify snow cover and ice feedback mechanisms that amplify climate change at high latitudes, quantify high-latitude terrestrial ice and snow changes, and consider their effects;
- Quantify land and sea surface-atmosphere

momentum and both sensible and latent heat exchanges, and model the role of surface-atmosphere interactions in influencing mesoscale tropospheric and stratospheric dynamics; and

- Develop a “testbed site” on the North Slope of Alaska for making atmospheric radiation measurements to improve mathematical simulations of cloud and radiative transfer processes in general circulation models (GCMs) as part of the USGCRP.

3.3.3 Tropospheric and Stratospheric Chemistry and Dynamics

The chemistry of the Arctic atmosphere is dynamic, changing in response to natural and human-induced disturbances. Stratospheric ozone depletion is a global process accentuated at the poles. Ice core chemistry reveals current and historic trends in global natural and anthropogenic gas and aerosol concentrations. Expected warming trends could have a significant influence on biosphere-atmosphere interactions, trace gas emissions and retention, and atmospheric photochemical processes. In addition, an annual average of 1.7 million acres of wildfire in Alaska has an impact on airborne particulates and atmospheric chemistry.

Objectives

- Establish the correlation, if any, among the chemistry of polar stratospheric clouds in the Arctic, the ozone concentration at northern midlatitudes, and the incident ultraviolet radiation reaching the earth’s surface;
- Develop a database for determining long-term regional trends in climate and air chemistry, including solar radiation levels and anthropogenic contaminant levels (organics, metals, radionuclides, greenhouse gases, and ozone-depleting gases), across the circumpolar regions of the globe;
- Conduct periodic sampling of the Arctic stratosphere and troposphere to understand ozone depletion, atmospheric transport phenomena, and the role of anthropogenic airborne pollutants in the Arctic;
- Conduct theoretical and experimental research to understand the chemical and dynamical processes that deplete stratospheric ozone in the Arctic region; and
- Establish regional and seasonal variations in sources and sinks of carbon, nitrogen, sulfur, atmospheric gases, and aerosol species and assess the importance of local emissions.

3.4 Land and Offshore Resources

3.4.1 Energy and Minerals

The geologic framework of the Arctic is very poorly known because of the complexities of its geologic setting, its remoteness, and its relative lack of exploration. The remote frozen environment requires long lead times for energy and mineral development. Additional information is necessary to allow the discovery, assessment, and mapping of new and dependable sources of oil, gas, coal, and strategic minerals. These resources are important for national security and independence, as well as for local use and economics.

Objectives

- Continue systematic mineral appraisal activities and expand programs to provide periodic assessments of the undiscovered oil and gas and strategic mineral resources in the Arctic on both broad and local scales;
- Evaluate unconventional energy resources (for example, heavy oil, tar sands, gas hydrate, solar, and wind);

- Identify energy and mineral resources for local use;
- Use new technologies to develop a more modern and complete geologic database, increase geologic mapping, expand modeling efforts, and design derivative maps to address broader earth-science questions; and
- Evaluate the economic, environmental, cultural, and social implications of resource extraction and transport.

3.4.2 Coastal and Shelf Processes

Erosion rates are extremely high along the Alaskan Arctic coast, where sea ice and permafrost are common. Specific questions about where to build causeways, man-made islands, and other structures can be answered only after basic process information is collected, interpreted, and analyzed carefully. Studies of coastal erosion and sediment transport in the Arctic are needed to understand the long-term history of the coastal area in order to intelligently manage the coastal region. Study of

archeological sites can provide important information on the history of coastal platforms, erosion rates, and land-shelf interactions.

Objectives

- Map beach, littoral, and nearshore sediment and subsea permafrost and determine its associated physical and chemical properties;
- Define the processes controlling the formation and degradation of the seasonally frozen sea floor;
- Implement long-term measurements of tides, winds, waves, storm surges, nearshore currents, sediment distribution patterns, and archeological sites to understand coastal erosion and sediment transport processes; and
- Investigate the direct and indirect effects of ice on coastal erosion (the influence on waves and currents) and on sediment transport (contact with beach sediments, keel gouging, entrainment in frazil ice).

3.4.3 Terrestrial and Freshwater Species and Habitats

The Arctic supports many unique species of birds, mammals, fish, and plants, which are important resources to the Nation, as well as to Alaska Natives. Some of these resources are harvested commercially or for subsistence purposes (for example, food, shelter, fuel, clothing, and tools),

Sockeye salmon fry outmigration and overwinter survival research, Tustumena Lake watershed, Alaska.



and others provide recreation. To assure that biological resources are protected for future generations, management agencies must have adequate data and information on the biology and ecology of these species, as well as information on environmental attributes of importance to vital biological processes (for example, feeding and breeding).

Objectives

- Determine the history, abundance, biodiversity, and distribution of fish and wildlife populations and identify their habitat requirements;
- Develop new techniques and technologies for studying and managing biological resources in the often-remote and cold-dominated Arctic environments, including recovery of ecosystems damaged by wildfires and other natural and human-induced causes; and
- Improve methods for detecting and determining the effects of human activities on the environment and identify measures to mitigate the declines of Arctic biological resources and the destruction of habitats.

3.4.4 Forestry, Agriculture, and Grazing

Increased knowledge of ecosystem processes and the current and potential productivity of Arctic and sub-Arctic forests and soils will lead to improved management practices for increasing sustainability and the productivity of renewable resources. The goals are to promote self-sufficiency among local inhabitants and to accrue economic benefits.

Objectives

- Continue and enhance a sustained program of research into ecosystem processes of northern boreal forest ecosystems, focusing on issues of forest landscape and stream ecosystem sustainability and productivity over long time periods; ecosystem stability in the face of episodic disturbance and global climate change; and interactions among atmosphere, landscape, forest, and stream ecosystems and ecosystem management for societal goals;
- Enhance soil and crop science research to develop effective management practices under conditions of permafrost, low temperatures, wildfire, and development impacts;
- Prepare coordinated soil resource information (maps and databases) of the Arctic circumpolar region; and
- Provide technology for enhancing the economic well-being and quality of life at high latitudes.

3.5 Land–Atmosphere–Water Interactions

3.5.1 Glaciology and Hydrology

Documentation of seasonal, interannual, and long-term trends in the physical environment of the Arctic requires attention to the special features of seasonal and perennial snow and ice cover and glaciers, especially as they relate to and record climatic change. Also, reliable information is needed on surface water quality and quantity. Collection of this information will help provide a climatic and hydrologic baseline for the Arctic. The Arctic is expected to be especially sensitive to the effects of possible global changes, including possible greenhouse warming, on terrestrial, atmosphere, and marine environments.

Objectives

- Continue to develop paleoenvironmental records from ice caps, ice sheets, and mountain glaciers; conduct research on the incorporation of global, hemispheric, and regional climate signals in snow and ice records; conduct research on the processes by which gases, aerosols, and particulates are incorporated into the snow and ice; and support interpretation of results from existing records and correlation of these records with adjacent records from other sources and proxy records;
- Document the relationships among glaciers, sea ice, and global hydrology, including the relationship to world sea-level changes and climatic fluctuations, and continue to develop models for glacier mechanisms;
- Determine the consequences of specific renewable and nonrenewable resource development and harvest practices on ground and surface water, and develop predictive models for stream flow and water quality;
- Forecast future sea-level fluctuations attributable to greenhouse-gas-induced changes in polar glaciers and ice caps;
- Establish the role of land–water interactions in the control of nutrient cycling; and
- Investigate the hydrology and biogeochemistry of the Arctic drainage basin from a systems perspective, and study linkages between the land and water components of the Arctic system, with emphasis on the water resources in this system (water quality, bioaccumulation, sediment, and dissolved material pathways and flux rates).

3.5.2 Permafrost, Landscape, and Paleoclimate

Additional knowledge is needed about the temperature, distribution, thickness, and depth of permafrost throughout all geomorphic provinces of the Arctic, including the continental shelf. Modern geologic processes that are responsible for the present morphology and land surface need to be better understood.

Objectives

- Undertake a comprehensive program to extract paleoclimatic records from permafrost terrains and lake sediments;
- Reconstruct the late Glacial and Holocene climate history in the Arctic via borehole monitoring and other technology;
- Improve the ability to assess and predict the degree and rate of disturbance and recovery of permafrost terrain following natural or human-induced changes;
- Improve our understanding of the effects of thawing of permafrost on the hydrology, ecosystem characteristics, and productivity of boreal forest ecosystems;
- Model the response of the hydrologic and thermal regimes of the active layer and permafrost to greenhouse-gas-induced warming in the Arctic and sub-Arctic at different locations;
- Provide information on the moisture and thermal regime of the active layer and on degradation of permafrost due to climate warming;
- Develop results leading to the ability to predict future climate-induced changes to the Arctic landscape;
- Understand how possible climate-induced alterations to permafrost systems may influence carbon metabolism, turnover, and storage; and
- Reconstruct the late Glacial and Holocene climate history in the Arctic.

3.5.3 Ecosystem Structure, Function, and Response

The Arctic is expected to be especially sensitive to the effects of possible global changes and contaminant transport and deposition on terrestrial, freshwater, marine, and atmosphere environments. Research is needed to improve our understanding of the influence of climate on land and freshwater processes and vice versa. Resource managers and

decision makers need reliable environmental impact and health risk assessments.

Topics of particular importance include heat balance relationships, landscape alteration, impacts of wildfire, identification of biological indicators of change, development of a basis for (and clarification of) current and recent contaminant levels, sources and sinks of carbon and trace gases, and long-term trends in biological diversity.

Objectives

- Distinguish ecological changes due to natural causes from changes due to human activities and evaluate management techniques for the conservation and restoration of ecosystems;
- Identify and evaluate the responses of key biological populations and ecological processes to increased CO₂ and to different climatic conditions; monitor the changes in ecotone bound-

aries, which might serve as integrative indicators of change; and select biological indicators for use in a monitoring program designed to detect, measure, and predict the extent of change;

- Provide opportunities for international cooperation at Long-Term Ecological Research sites and biological observatories in the Arctic;
- Identify factors contributing to reductions in regional and global biological diversity;
- Integrate process, community, ecosystem, and landscape features into a dynamic description that is realistically linked to both finer and coarser scales of resolution;
- Determine the CO₂ flux from tundra and the responses of vegetation to elevated levels of CO₂; and
- Determine the environmental factors controlling methane fluxes.

3.6 Engineering and Technology

Engineering and technology provide one of the best and possibly most direct avenues for improving and extending the infrastructure so critical to quality of life in the Arctic. In addition, enhanced engineering capabilities and advanced technologies can make crucial contributions to addressing environmental quality challenges and achieving environmentally sustainable development of natural resources. The harsh and unique environment of the Arctic makes advancement in these areas particularly difficult and limits the ability to simply borrow or evolve the engineering and technology advances developed for nonpolar conditions. Only concentrated, specific efforts will produce the advanced technical capabilities the Arctic requires. Engineering and technology development programs that address the priority Arctic engineering research needs are necessary to support these efforts.

Recent concerns of Arctic infrastructure damage due to permafrost degradation have highlighted the inability of current engineering and technology design criteria to address changes in the permafrost foundation over the life-cycle of these structures. These deficiencies impact the existing infrastructure in Alaska (where warming is occurring at a faster than expected pace), and future Arctic building programs, including structures such as roads, pipelines, buildings, airfields, and hazardous material storage tanks. These same concerns

have been raised regarding the exposure of other cold-regions nations to this threat, particularly in the former Soviet-block countries.

In this time of scarce resources, cooperation between government agencies, academia, and the private sector provides an excellent opportunity to leverage resources and assure that the advanced technologies developed by government and academia can be practically and effectively applied. Development of goals that meet both commercial and technological interests will help assure that technologies developed will move rapidly into the marketplace.

The Arctic Research Commission, in its report *Goals and Priorities to Guide United States Arctic Research*, provides clear priorities for Arctic engineering and technology. In this document the Commission found that to achieve the basic principles of the U.S. Arctic policy and to achieve the desired national competitiveness in the Arctic, the Nation's Arctic engineering capabilities must be improved through a balanced and coordinated continuing program of cold-regions engineering research at universities and national laboratories. The Commission recommended that the IARPC develop an Arctic engineering research plan with special emphasis on the following items:

- Improved methods for the continued performance of existing transportation and public facilities in cold regions;

- New and more cost-effective construction technologies and materials for Arctic purposes;
- Design of maintainable and affordable rural sanitation facilities for Arctic villages;
- Capabilities for testing the performance of outdoor material and equipment;
- Methods for waste disposal and local air pollution control under Arctic conditions; and
- Small-scale power generation and energy storage technologies.

The Commission also recommended that the Interagency Coordinating Committee on Oil Pollution Research support research for an adequate and thoroughly tested oil spill prevention technology and response capability for the Arctic. Three specific types of research were recommended: perfection of in-situ burning techniques, development of alternatives to combustion, and policy analysis and information transfer activities related to testing and accepting new pollution abatement processes.

The recommendations given above are consistent with those presented in *Findings and Recommendations of the Arctic Research Commission, Arctic Engineering Research*. The report of the Commission also recognized the following critical areas of scientific research, the results of which are of major importance and will be crucial for successful technology development and transfer:

- Physical properties of snow and ice;
- Physical and chemical behavior of Arctic soils;
- More extensive communications and cooperation between government agencies and the professional societies, conferences with specialized Arctic engineering activities, and more effective mechanisms for technology transfer; and
- New engineering courses and programs specializing in Arctic engineering topics.

Objectives

- Develop engineering data and criteria for building, operating, and maintaining strategic and operational facilities and infrastructure in the Arctic, including the effects of permafrost degradation;
- Ensure that current engineering practices include assessment of potential impacts of warming climate on permafrost and other Arctic systems commensurate with the design life of the projects;
- Provide the capability to conduct logistics operations and research support and development in the Arctic;

- Undertake assessment of the potential impact of weather changes associated with climate warming on transportation and maintenance of lines of communications;
- Develop environmentally compatible engineering technologies for the Arctic;
- Develop enhanced understanding of cold-regions performance of new structural materials and systems;
- Provide design criteria for ship operations in ice-infested waters;
- Provide mapping and prediction of ice conditions, along with GIS-based monitoring systems, for port and harbor management;
- Provide engineering data and criteria for water resources activities and environmental impact permitting;
- Provide GIS database and mapping capability for land use, water resources, and monitoring of environmental degradation;
- Ensure that the best available, safest, and pollution-free technologies are used in the development of oil and gas in the Arctic and outer continental shelf;
- Ensure, through technology transfer and retrospective case studies, that future resource exploration and development in the Arctic take advantage of both tried and proven methods, as well as incorporating innovative new technology with minimal environmental impact;
- Provide enhanced engineering criteria and techniques to use naturally occurring materials, such as snow and ice, for ice road and island construction, reducing costs and minimizing environmental impacts;
- Develop methods for mining and mine closure that are environmentally compatible in Arctic environments;
- Advance the technology for recovering fossil fuels in the Arctic, including onshore extraction and production methods;
- Develop criteria for exploitation of frozen ground conditions to minimize environmental impact (tundra snow/ice roads) and enhance system performance (for example, ground-penetrating radar);
- Prevent the discharge of oil, chemicals, and other hazardous materials into the marine environment;
- Ensure the quick, effective detection and cleanup of pollution discharges;
- Provide the ability to predict and map movement of pollutants in ice-infested waters;

- Develop Arctic-appropriate cleanup technologies for contaminants and remediation of sites resulting from past military and resource development;
- Evaluate enhanced marine transportation for resupply of coastal and Arctic villages;
- Develop and maintain effective surface transportation and air support facilities in the Arctic; and
- Develop mechanisms for technology transfer between government, academia, and private industry.

3.7 Social Sciences

The historic, current, and future presence of human populations in the Arctic has made the social sciences a top priority and a valuable tool for Arctic research. How have various groups adapted to environmental, economic, and social change? What predictions about future adaptations can be made on the basis of the historic and prehistoric record? These are just a few examples of questions that arise when considering the role of societies in Arctic research. In addition, Arctic communities have themselves become partners in research projects responding to local needs and concerns.

The Arctic Research and Policy Act of 1984 emphasizes the need for social, behavioral, and health research (Section 102b). Soon after the Act was passed, the Polar Research Board established a Committee on Arctic Social Sciences and charged this body with reviewing existing research, identifying research needs, and recommending future directions for social science research in the North. The committee published its final report, *Arctic Social Science: An Agenda for Action*.

The report identifies three substantive themes for social research: human/environment relationships, community viability, and rapid social change. These themes have guided the agencies' support of social and behavioral research in the Arctic. The report also led to the establishment of the Arctic Social Sciences Program within the Office of Polar Programs at the National Science Foundation. In an effort to coordinate research plans among Federal agencies, an Interagency Arctic Social Sciences Task Force was established within the Interagency Arctic Research Policy Committee (IARPC). As one of its first projects, the Task Force prepared and implemented a *Statement of Principles for the Conduct of Research in the Arctic*, which addresses the need for improved communication and increased collaboration between Arctic researchers and northern people. The principles have fostered greater awareness of local concerns among Arctic researchers and have helped to place a high value on the input of Arctic

residents in research and environmental issues. Given the U.S. chairmanship of the Arctic Council and the Council's mandate with respect to sustainable development, there is scope for renewed emphasis on research in the social sciences.

International Arctic Social Science and Health Research

International scientific organizations have recognized the importance of Arctic social sciences, such as the International Arctic Social Sciences Association (IASSA), the International Arctic Science Committee (IASC), and the International Union for Circumpolar Health (IUCH). The U.S. has actively participated in these organizations. The Arctic Council established a Sustainable Development Working Group consisting of Senior Arctic Officials and Permanent Participants. The Sustainable Development Working Group will consider a number of issues touching upon health, social sciences, economic development, and the environment.

Social and Health Sciences

NSF continues to provide support for peer-reviewed research projects dealing with decision, risk and management frameworks, risk and health perceptions, co-management of resources, and collaborative research with indigenous communities.

Arctic social scientists have identified the need to work with Arctic communities in a collaborative fashion. For example, NSF's Arctic Social Sciences Program contributed to the establishment of the Alaska Native Science Commission, an organization that provides essential linkages between researchers and local communities, facilitating communication and cooperation. Other NSF-supported projects have linked Alaska Native corporations and nonprofits with social science researchers. Examples include:

- Social scientists, community leaders, local educators, and rural Alaska high schools collaborated to collect data on student attitudes, expectations, and aspirations from high school

students in nineteen rural Alaska schools. The data will be used for planning and curriculum development.

- A social scientist, a biologist, and indigenous people documented traditional ecological knowledge about beluga whales in Alaska and the Russian Far East. Here, the indigenous residents often led the researchers in new and unexpected directions to attain a holistic, complex picture of beluga ecology.
- Yup'ik elders and a social scientist traveled to Berlin to identify and describe the Yup'ik artifacts collected by Johan Adrian Jacobsen in 1882–1883, the largest unresearched and unpublished group of Yup'ik artifacts anywhere in the world. This “visual repatriation” has generated enormous interest among young and old alike in Yup'ik culture and lifeways.
- NSF plans to continue to emphasize the partnership approach in the Arctic through enhanced outreach to Arctic communities, recognizing that cooperative community relations and education form a central tenet of responsible research conduct.

Human Dimensions of Global Change

The NSF supports opportunities for research on the Human Dimensions of Global Change (HDGC). HDGC research focuses on the interactions between human and natural systems, with emphasis on the social and behavioral processes that shape and influence those interactions.

NOAA's Economics and Human Dimensions program supports research investigating human responses to variations in the climate system. The program currently focuses on the potential use and constraints to the use of climate forecast information for decision making across a range of sectors. Although NOAA's Economics and Human Dimensions program does not focus on any particular region, the role of indigenous knowledge and how it might interact with newly developed climate forecast information, as well as the ways in which Native communities adapt to their regional climate, is of interest to the program.

The Human Dimensions of the Arctic System (HARC) initiative, launched under the NSF Arctic System Science program, will focus on the dynamics of linkages between human populations and the biological and physical environment of the Arctic, at scales ranging from local to global. HARC research will examine current and potential impacts on human activity that may be expected to occur in response to global change.

The Beringian Systems Program

Regional interdisciplinary assessments of impacts due to global change are a high priority on the international global change agenda. Two programs of special interest are being developed: the Bering Sea Impact Study (BESIS) and the Barents Sea Impact Study (BASIS).

Education, Training, and Outreach

NSF and Federal agencies are committed to developing educational components that link social scientists with students and other members of Arctic communities and to training young scientists. Program such as NSF's Faculty Early Career Development (CAREER) program supports research and teaching by junior faculty members. Dissertation Improvement Grants, available through the Arctic Social Sciences Program, support graduate students in their Ph.D. research projects. Research Experience for Undergraduate (REU) supplements provide on-site research training to college and university students. The Teachers Experiencing the Arctic (TEA) program links secondary school teachers with Arctic scientists to form research teams and bring Arctic research experiences into the secondary school classroom.

NSF encourages community outreach and education through supplements to visit local communities and schools, develop and share instructional materials, involve students in research projects, and disseminate research results to a large audience. Small Grants for Exploratory Research (SGER) can be used for exploratory or high-risk projects that require community endorsement before researchers can make definite plans.

The RAPS (Resource Apprenticeship Program) of the Department of Interior has provided summer jobs for Alaska Natives through the NPS, BLM, and FWS. Other programs, such as the Cooperative Education Program and the NOAA Sea Grant Program, also support students in Alaska. The BLM Heritage Education National Program is developing materials on archaeological and historical places in Alaska to support education of America's children and to foster a sense of stewardship of cultural heritage. The USDA Forest Service has participated in an increasing number of programs within the region to promote Alaska Archaeology Week activities (lectures and field trips) and other opportunities for education that foster stewardship and the conservation of heritage resources. The Forest Service is continuing a comprehensive program of cultural resource presentations, subsistence awareness sessions, and site

monitoring and protection, in cooperation with the University of Alaska Southeast, Ketchikan Campus. The Forest Service will continue to sponsor multicultural educational opportunities involving Native and local communities, as well as the diverse range of National Forest visitors. The Smithsonian Institution conducts educational programs in the North Pacific and Russian Far East and provides museum and exhibit training in Washington, D.C., Anchorage, and Fairbanks.

In the Iqaluit Declaration of September 18, 1998, Ministers of the Arctic states announced the establishment of an international University of the Arctic, a "university without walls," as proposed by a working group of the Circumpolar Universities Association. The University of the Arctic will operate using the Internet, as well as student and faculty exchanges. Finland has offered to support the university's interim secretariat.

Resources Management

Over 66% of the area of Alaska is managed by Federal agencies. Cultural and natural resources are protected by law, and good management can only be built on accurate baseline data. Although cultural resources, historic and prehistoric sites, artifacts, and landscapes require documentation and protection, renewable resources, especially fish and game, are also culturally defined through subsistence needs. In 1989, Alaska State subsistence laws were declared unconstitutional because they discriminated against non-rural residents. As a result, Federal land management agencies assumed responsibility for subsistence management on Federal lands. The DOI Fish and Wildlife Service (and its Office of Subsistence Management) is the lead Federal agency in this responsibility. Subsistence is defined as fulfilling both household economic needs and cultural needs, including social communication, food sharing, and maintenance of cultural knowledge and identity. Management of marine resources, such as fish and most species of marine mammals, is led by the DOC National Marine Fisheries Service.

3.7.1 Cultural Resources

The Arctic is a major repository of human experience. Archaeological remains go back some 15,000 years, providing a record of human adaptation to environmental change of unparalleled richness. The Arctic is also home to numerous indigenous cultures, some of which are rapidly losing their traditional lifeways, languages, and cultural heritage. This traditional and local knowledge base

can provide long-term information about northern ecosystems and wildlife, of considerable value in resource management.

The fact that many agencies have similar administrative and management structures and mandates suggests that excellent opportunities exist for interagency cooperation. The opening of the Smithsonian's Arctic Center office in Anchorage offers possibilities for cooperation between land-managing agencies and the Smithsonian in a wide variety of research and programmatic activities. The National Park Service and the Smithsonian have been working together in Anchorage for several years on regional archeological assessments, and NSF-SI cooperation in education and exhibition has begun. With tighter budget restraints, interagency collaboration is not only preferable but will increasingly become necessary.

A number of agencies support research on archaeology, history, and Native culture (BIA, BLM, USFS, NPS, SI, NSF). Finds of artifacts and bones give evidence of past economies and baseline data for pollution monitoring, and historical and ethnographic descriptions tell of more recent conditions. Coastal resources (fish, seals, walrus, whales) supported the largest human populations in Alaska, and changing shorelines



Sockeye salmon spawning in Glacier Flats Creek, Tustumena Lake watershed, Alaska.

and maritime conditions are reflected by these sites.

To maximize the effectiveness of research sponsored by Federal agencies, there needs to be increased initial planning and coordination of projects, pooling of technical resources, and use of existing databases. The results of such research should also be made public through popular publications, and special efforts should be made to make results accessible to residents potentially affected by the research.

Objectives

- Document and analyze the origins and transformations of Arctic cultural systems, ethnic groups, and languages;
- Study and analyze traditional knowledge systems, resource uses, and subsistence economics;
- Research paleoenvironmental changes, including ancient sea levels, in concert with cultural historical investigations; and
- Help develop explanatory models integrating cultural systems with local, regional, and global environmental changes.

Repatriation

Repatriation has become a major priority for museums and research institutes since the passage of NAGPRA (Native American Graves Protection Act) in 1990. This act requires Federal agencies to document Native American human remains, associated grave goods, and items of "cultural patrimony." Agencies must report their holdings of such materials to Native American groups and consult about their repatriation. The National Park Service has a major role in NAGPRA for coordination and guidance at the national level. It can be expected that repatriation will be a major effort for at least a decade.

Repatriation of Alaskan collections at the Smithsonian has led to several major collection

returns during the past several years, with more to follow in the future. Consultation in this process has opened new channels of communication between the Smithsonian and Alaska Native people that offer potential for future program development in research, education, and exhibition development.

3.7.2 Rapid Social Change and Community Viability

The impacts of technological and economic development on northern societies, both Native and non-Native, have been profound. While standards of living have often been improved, there has been a concurrent loss of traditional cultural values. Chronic unemployment, family violence, substance abuse, and societal breakdown in general have reached epidemic proportions. One key to recovery is the facilitation of increased local control of land, resources, social institutions, and education. All across the Arctic, including Alaska, there are demands for greater political autonomy. While this will add greatly to northern community empowerment, success will ultimately depend on economic viability and the balancing of development with ecologically sound policies. Within these contexts, subsistence hunting and fishing is a major factor in northern socioeconomics.

Objectives

- Gain insight into the short-term and long-term effects of rapid social change on Arctic cultures and societies;
- Develop culturally relevant educational programs;
- Develop practical applications of social and behavioral science to benefit Arctic residents;
- Determine linkages between social and behavioral science and health; and
- Determine ecological thresholds as they relate to economic development and community viability.

3.8 Health

Health can be defined as a combination of physical, psychological, social, and spiritual well-being. Unique cross-cultural interdependencies due to harsh environmental conditions in the Arctic highlight this definition. Consequently Arctic health research must take into account complex human and environmental interactions. Health issues have

been identified by the U.S. as a key priority for its chairmanship of the Arctic Council.

Health research in the Arctic focuses on basic and applied biomedical topics (such as molecular biology and genetics), the effects of cultural change on Native populations, the epidemiology of disease, adaptations of humans to extreme environ-

mental conditions, environmental health risks, contamination, and health care delivery in remote and isolated communities. Health concerns in the Arctic are intimately linked to international health issues. Western culture (and potentially Asian culture) can impact Native people adversely by introducing lifestyle and dietary changes and new infectious agents. Research designed to study these effects and techniques for disease prevention is urgently needed. Health research in the Arctic is done, individually or collaboratively, by the Centers for Disease Control and Prevention, the Indian Health Service, the National Institutes of Health, and the Department of Defense. Nonclinical research on social and behavioral aspects of health is supported by the National Science Foundation's Arctic Social Sciences Program.

Among the ongoing and planned activities in Arctic health research is the continuation of studies on cancer epidemiology by the National Cancer Institute's SEER (Surveillance, Epidemiology, and End Results) program and through the Alaska Native Tumor Registry. Of special interest are colon cancer, nasopharyngeal carcinoma, and hepatocellular carcinoma, which have a high incidence in Native Alaskans.

The National Institute of Environmental Health Sciences (NIEHS) will continue to support studies on anthropogenic pollutants, such as the effect of polychlorinated biphenyls (PCBs) on thyroid function and central nervous system development. The NIEHS will be a primary participant in the Arctic Council AMAP activities, including sponsorship of an international Biomarkers Conference and of the Maternal and Umbilical Cord Blood Monitoring Study being conducted in Alaska. The lead agency for U.S. participation in AMAP activities is the National Oceanic and Atmospheric Administration (NOAA).

The National Institute on Aging (NIA) is planning a major collaboration with the Iceland Heart Association for a study of genetic susceptibility to various diseases of old age, using data from the Reykjavik Study cohort. This unique database will allow examination of genetic and environmental factors in an aging population examined for neurologic, ophthalmologic, cardiovascular, pulmonary, and body composition changes.

The National Institute of Mental Health (NIMH) will support mental health services and delivery research, including a five-year large-scale assessment of prevalence rates for the major mental disorders among Native Americans. The National Center for American Indian and Alaska Native

Mental Health Research will continue to receive support. The fourth annual research conference focusing on comorbid alcohol, drug, and mental (ADM) disorders was held in FY 99. The NIMH also has an interest in the application of telemedicine in the delivery of mental health care to isolated and remote communities in Alaska.

The National Institute on Drug Abuse (NIDA) has initiated a program of community-based research at the University of Alaska Anchorage dealing with the relationship of substance abuse in active drug users to infectious diseases, including human immunodeficiency virus (HIV), hepatitis B and C, and pneumonia. NIDA plans to expand these efforts to include the development of telemedicine through a series of "research at a distance" projects. In cooperation with the National Institute of Allergy and Infectious Diseases, NIDA has actively promoted discussions between the U.S. and Russia on emerging and re-emerging infectious diseases, including participants from Siberia and the Russian Far East. Meetings organized by NIDA/NIAID/Russian staff in St. Petersburg were recognized as an important component of the Gore-Chernomyrdin/Primakov accords.

The National Institute on Alcohol Abuse and Alcoholism (NIAAA) is continuing data collection on male and female Native Alaskans undergoing treatment for alcoholism. Researchers are studying cultural and other factors that contribute to alcoholism in this population, with the goal of improving prevention and treatment methods. Previous data suggest that alcohol-related policies, such as those governing beverage taxes and driving, influence alcohol abuse. The NIAAA supports a study of such policies, the results of which can assist criminal justice officials and legislators in considering sanctions and laws that regulate alcohol use.

The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) will support research that disproportionately affects Alaska Native populations, such as type 2 diabetes, obesity, and end-stage renal disease. The Diabetes Prevention Program (DPP) includes collection of data from Alaska.

The National Library of Medicine (NLM), a component of the NIH, will continue to provide free access by Arctic Health researchers to the relevant health literature via on-line databases, such as MEDLINE, accessible through the Internet. As of January 1999, there were 20,000 citations to such research. The NLM is supporting special projects to develop a field manual for outreach to rural underserved areas (such as in the Arctic) and to

upgrade Internet connectivity for selected Alaska Native villages. These projects are related to the sustainable development theme of the Arctic Council. In addition, NLM is a primary participant in the DHHS support of Alaska telemedicine activities.

The Alaska Area Native Health Service of the Indian Health Service (IHS) is spearheading the Maternal and Umbilical Cord Blood Monitoring Study, with contributing resources provided by the CDC and the EPA Office of International Activities. Contaminants to be analyzed include heavy metals and persistent organic pollutants, such as PCB isomers. Cooperating organizations also include the Alaska Native Tribal Consortium, the Yukon-Kuskokwim Health Corporation, the North Slope Borough Health Department, and the Arctic Slope Regional Health Corporation.

The Centers for Disease Control and Prevention (CDC) Arctic Investigations Program (AIP) has a new initiative in the prevention and control of emerging infectious diseases in the Arctic. This initiative follows U.S. government interagency recommendations established by the Committee on International Science Engineering and Technology (CISET), which direct the CDC, DOS, DOD, USAID, FDA, and NIH to partner with governments of other countries, the World Health Organization, and other international organizations to improve world-wide infectious disease surveillance, reporting, and response. The CDC's AIP will build on existing circumpolar health alliances to create an International Circumpolar Surveillance (ICS) infectious disease network to monitor the emergence of antimicrobial resistance, infectious diseases of childhood, hepatitis, tuberculosis, and HIV and other sexually transmitted diseases of concern among circumpolar communities. A workshop on infectious disease concerns of Arctic communities is planned as part of the CDC's second International Conference on Emerging Infectious Diseases to be held in Atlanta in July 2000. The CDC's Arctic Investigations program will continue prevention and control activities for diseases caused by *Hemophilus influenzae*, *Streptococcus pneumoniae*, *Helicobacter pylori*, respiratory syncytial virus, and hepatitis A, B, and C.

The CDC's National Center for Environmental Health's Division of Environmental Hazards and Health Effects will continue studies on human exposure to environmental persistent organic pollutants in the Arctic. In addition to providing laboratory support and consultation for the AMAP interagency monitoring of environmental persistent organic pollutants, nonpersistent pesticides,

and trace metals in maternal and umbilical cord blood of Alaska Natives, studies of environmental contaminants as co-factors in nasopharyngeal cancer and breast cancer in Alaska Natives, as well as an assessment of arsenic exposure and associated health effects in rural Alaska communities, will be undertaken together with the Alaska Native Health Board and the State of Alaska's Division of Public Health.

The CDC's National Institute for Occupational Safety and Health's Alaska Activity, in collaboration with the Indian Health Service, the State of Alaska, the Alaska Native Tribal Health Consortium, and the Alaska Native Health Board, will continue studies on the epidemiology, risk factors, and prevention strategies for occupational injuries in Alaskan communities. The NIOSH Alaska Activity will coordinate two new Arctic initiatives:

- The development of an integrated surveillance system for disease and injury in the Arctic. This activity will link existing CDC's Alaska surveillance systems for infectious diseases, injuries, and birth defects with other systems monitoring chronic diseases and malignancies and behavioral risk factors, as well as a broader spectrum of injury events, to provide a more seamless comprehensive picture of current health status and trends, by partnering with the Alaska Division of Public Health, the Alaska Native Medical Center, and the Alaska Native Health Board's Epidemiology Center. Emerging event and mortality data should also be compiled for comparison purposes from other circumpolar nations to detect trends and enable timely response to emerging health problems.
- The development of a human health emergency preparedness and response plan. While the specter of new nuclear, biologic, and chemical hazards has become more prominent recently, these add to the list of serious natural hazards in the Arctic requiring preparedness and response to protect human health. While the lead in the strategic and security management of these events resides with the DOD, Nunn-Lugar-Domenice requires Federal interagency partnerships, including the Public Health Service, the Federal Emergency Management Administration, and other agencies, to prepare for these events.

Objectives

- Ensure interagency communication and coordination in health research priority setting, resource management, infrastructure, and pro-

3.8 Health

gram development to ensure that health research translates into prevention and control activities that benefit all Arctic people;

- Establish, enhance, and maintain surveillance systems of health events impacting Arctic populations to allow timely and focused interventions and the monitoring of intervention effectiveness;
- Establish, enhance, and support basic and

applied research for the purpose of improving health through biomedical and behavioral research programs; and

- Establish, enhance, and maintain health communication systems to facilitate timely dissemination of basic and applied research information on the etiology, pathogenicity, diagnosis, prevention, and treatment of diseases of concern to people of the Arctic.

4. Research Support, Logistics, Facilities, Data, and Information

4.1 Research Support and Logistics

IARPC, in cooperation with the National Science Foundation, will use new resources targeted for Arctic logistics to enhance the leadership role of the U.S. in Arctic research. The focus on logistics entails:

- Establishment, development, and maintenance of national Environmental Observatories;
- Technology and instrument development;
- Expansion of marine platforms and aircraft support capabilities;
- Integration of research, education, and Arctic community interests; and
- Further international collaboration in the support of research.

Use of the new resources will be guided by the Arctic Research Commission report *Logistics Recommendations for an Improved U.S. Arctic Research Capability*. The general recommendations of the report are:

- Ensure access to the Arctic over the entire year;
- Increase availability and use of remote/autonomous instruments;
- Protect the health and safety of people conducting research in the Arctic;
- Improve communications and collaboration between Arctic people and the research community; and
- Seek interagency, international, and bilateral logistics arrangements.

Planning will be done in partnership with Native groups and other advisory bodies and will respond to merit-reviewed proposals.

The development of additional Environmental Observatories (EOs) is a major component of the proposed plan for logistics enhancement and is also an identifiable component of the NSF theme "Biocomplexity." Candidates for Arctic Environmental Observatories include:

- Toolik Lake, Alaska, an NSF LTER site where the agency has already supported upgrades;
- Barrow, Alaska, Environmental Observatory, where NSF has initiated a cooperative agreement with the Barrow Arctic Science Consortium; and

- Summit, Greenland, a site for which NSF has had three planning meetings with Denmark and other European countries on joint funding of a year-round EO.

As proposals are received for these sites, they will provide the core of an Arctic network for use in distance learning programs, science projects, and related logistics support. By working through the International Arctic Science Committee (IASC), the U.S. hopes to link its EOs with those of other countries (for example, Abisko, Sweden; Svalbard, Norway; and Zackenberg, Kangerlussuaq, Denmark/Greenland) to assure that scientists have access to the full range of Arctic environments and to promote distance learning on an international scale.

The NOAA/CMDL Barrow Observatory, in continuous operation since 1973, conducts research relating to atmospheric constituents that are capable of forcing change in the climate of the earth through modification of the atmospheric radiative environment and those that may cause depletion of the ozone layer. This manned facility conducts scores of continuous monitoring activities, including 21 cooperative programs with universities and other government agencies. The Barrow Observatory has expanded its research activities over its lifetime and expects to be monitoring climate change in the Arctic through the next century. Information on CMDL and the Barrow Observatory can be found at <http://www.cmdl.noaa.gov>.

In response to concerns about Arctic ozone loss and increased UV-B radiation, NSF is considering establishing Ultraviolet International Research Centers in the Arctic, probably at the same three EO sites. These centers would provide long-term information on ecosystem and human exposure and would combine physical with social sciences research to examine human aspects of such environmental change. Also, the atmospheric and space weather observatories at existing U.S. facilities at the Sondrestrom Radar (Greenland) and Spitsbergen and Bear Island (Norway) may be upgraded.

Another major logistics issue in the Arctic is

developing full access and capability to conduct research on all aspects of the Arctic Ocean. The U.S. plans to facilitate this by funding:

- Research use of the new USCGC *Healy*;
- Tomographic arrays; and
- Improved sensors for the Arctic drifting buoy program, instruments for the SCICEX program on Navy submarines, moorings, and autonomous underwater vehicles.

For both marine and terrestrial research the U.S. will improve basic health and safety by providing access to a pool of emergency beacons, satellite phones, and GPS receivers. There is also a need to better integrate traditional knowledge of Arctic residents with research to broaden our capability in the Arctic. The U.S. plans to increase the duration of measurements (especially during the winter) by providing remotely operated instruments linked with individual researchers in their labs, with other Environmental Observatories, and with distance learning centers at community colleges and elementary schools involved with the Alaska Rural Systemic Initiative and the College of Rural Alaska.

4.1.1 Ships and Ice Platforms

Vessels supporting research in ice-covered areas fall into five categories, based on their ice-going capability:

- Icebreakers operated by the Coast Guard;
- Ice-capable and ice-strengthened vessels for research and survey purposes;
- Nuclear submarines provided by the U.S. Navy;
- Manned drifting ice stations; and
- NOAA's National Undersea Research Program (NURP) capabilities and expertise with unmanned deep-diving vehicles.

The Coast Guard maintains icebreaking facilities with due regard to national defense and for icebreaker support to other Federal agencies pursuant to interagency agreements. The Coast Guard's mandate, operational competence, and existing capital make it the appropriate agency to undertake this mission. The Federal Oceanographic Fleet Coordination Council (FOFCC) 1990 report supports the need for the Coast Guard to maintain and operate a fleet of icebreakers for polar ice escort, logistics support, and research support. It reaffirms that an ice-capable research ship should be operated as a national facility for both the Federal and academic communities. The 1999 report by the Interagency Task Force on the Roles and Missions of the United States Coast Guard reaf-

firmed that the Coast Guard is the appropriate Federal service to operate the polar icebreaking fleet.

The Arctic Research and Policy Act (ARPA) confirms the Coast Guard's role as manager of the Nation's icebreaker fleet to serve the Nation's interests in the heavy ice regions of the Arctic. This includes security, economic, and environmental interests. Research in support of those interests is specified in ARPA. Coast Guard icebreakers support research in these regions in two general ways: on dedicated science deployments and, as opportunities arise, in conjunction with other missions. The Coast Guard has two icebreakers and is acquiring a third. A design and construction contract was awarded to Avondale Industries, Inc., of New Orleans in July 1993. The vessel is scheduled to be delivered in FY 00 and operational in FY 01. This ship is being outfitted as a fully equipped research vessel with missions planned exclusively for the Arctic region. Coast Guard icebreakers are available to users on a partial-reimbursable basis. Daily fuel costs and a portion of the helicopter and ship maintenance costs are charged to users, as mandated by OMB. The Arctic Icebreaker Coordinating Committee (AICC) of UNOLS, the University-National Oceanic Laboratory System, was established in 1996 to coordinate science community and Coast Guard planning for science missions.

Drift stations and other ice platforms including Russian and Canadian opportunities will be utilized as research needs dictate.

As has been documented in recent revisions of this Plan, the Science Ice Exercise (SCICEX) series of research/data collection cruises using a nuclear submarine started with a demonstration cruise in 1993 aboard USS *Pargo*. The *Pargo*, with five civilian scientists aboard, deployed under the sea ice in the Arctic Ocean for 19 days. The cruise, conducted as a proof-of-concept, determined that a nuclear submarine could effectively serve as a data/sample collection platform, meeting the needs of the science community. Perhaps more importantly the unique Arctic attributes of a nuclear submarine were revealed to science. Capabilities such as platform quietness, ability to achieve precise positions in the Arctic, and all-season access had not before been available to researchers of the Arctic Ocean. Also, because the nuclear submarine can transit at good speed wherever is desired (water depth permitting), scientists are able to obtain a synoptic picture of the Arctic Ocean for the first time.

Following the demonstration cruise, both the science community and the Navy deemed the

SCICEX concept to be viable. This led the Arctic Research Commission to coordinate the preparation and approval of a Memorandum of Agreement (MOA) among NSF, NOAA, USGS, and ONR, plus the Chief of Naval Operations and Submarine Force Commanders. In the MOA the Navy agreed to provide a nuclear submarine for an annual cruise to the Arctic Ocean dedicated to civilian science. Science would pay for science-associated costs. As of 1999 these cruises have enabled scientists to collect data in the Arctic for a total of 211 days covering over 57,000 miles of track.

In the 1998 cruise, new data horizons were opened to science through the seafloor characterization and mapping pod (SCAMP) system installed aboard USS *Hawkbill*. The SCAMP system is composed to two elements: a swath bathymetry system and a subbottom (chirp sounder) profiler. The former is enabling the first-ever 3-D bathymetry of the Arctic Ocean, while the latter, enhanced by the submarine's inherent silence, is collecting subbottom profiles of sediments down to 200 m.

Other data collected (on all cruises) has been similar in its unique quality and quantity, benefiting science in the near term and the Navy in the long term. In summary, it may be conservatively stated that the total store of Arctic Ocean data (of the parameters measured) has more than doubled thanks to the SCICEX program.

The SCICEX program in its current form will end in 1999. Continuing high levels of military commitments for our Navy's submarines, coupled with the continuing retirement of the aging, Arctic-capable SSN-637 Class units, make it more difficult each year to free the time for a civilian science cruise.

At the SCICEX 2000 Workshop, held in the fall of 1998, various ideas for continuing some form of Arctic submarine science cruises were put forward. There is little question that new paradigms for data collection, cruise execution, and Navy-science cooperation must be developed. There is also little question that the program has yielded valuable and previously unobserved information and that the submarine, particularly with SCAMP installed, offers great potential for gathering more unique knowledge.

The NOAA National Undersea Research Program has extensive expertise and experience in conducting deep-diving efforts in all types of aquatic environments. The National Undersea Research Center in Fairbanks, Alaska, can provide

vehicles for seafloor exploration or experiments. The center can also work through the ice with ROVs, as was done in Antarctica.

4.1.2 National Ice Center

The U.S. Navy/NOAA/Coast Guard National Ice Center (NIC) provides world-wide sea ice, Great Lakes ice, and Chesapeake/Delaware Bay ice information to the U.S. armed forces, U.S. government and international agencies, and civil interests. NIC staffing and fiscal resources are provided through a cooperative agreement between the Department of the Navy, the Department of Commerce (NOAA), and the Department of Transportation (U.S. Coast Guard). Weekly global and regional-scale ice extent and coverage products are produced in support of mission planning, vessel operations, and scientific research. More frequently produced tactical-scale ice analyses and forecasts are tailored to customer-specified spatial and temporal requirements. Sea ice features of most frequent interest to operations include ice edge position, ice thickness, ice concentration, areas of compression or heavy deformation, and the location and orientation of open water or thin-ice-covered leads and polynyas. All NIC ice extent and coverage products are derived from a blend of remotely sensed and in-situ oceanographic and meteorological data.

Routine data sources for ice analyses include Radarsat synthetic aperture radar (SAR), DMSP operational linescan system (OLS) fine visible/infrared imagery, NOAA TIROS advanced very high resolution radiometer (AVHRR) local area coverage (LAC) visible/infrared imagery, DMSP special sensor microwave/imager (SSM/I) passive microwave data, aerial reconnaissance visual and side-looking airborne radar (SLAR) observations, drifting buoy observations, and ship/shore reports.

NIC ice analyses are crucial to both the safety of navigation in ice-covered waters and as a U.S. contribution to international global climate and ocean observing systems. Real-time raster and digital ice products are distributed via the Internet using the NIC home page (<http://www.natice.noaa.gov>) and over military networks comprising the Defense Information Infrastructure. NIC legacy (1972–1994) Arctic and Antarctic ice information are available on CD-ROM in the international sea ice archival (SIGRID) format from the World Data Center–A and the National Snow and Ice Data Center (NSIDC). Arctic and Antarctic ice information for 1995–96 will be available for distribution in 1999. All sea ice data (including 1997–present)

are also available in an ARC/INFO geographic information system (GIS) format. Weekly regional-based ice extent and coverage statistics (in square kilometers) are also available on the NIC home page. Moderate resolution (12.5-km resolution) monthly multiyear ice climatologies highlighting median ice concentration and maximum, median, and minimum ice extents will be available from NIC in the summer of 1999. The U.S. Interagency Arctic Buoy Program (USIABP), managed by NIC, collects and distributes surface meteorological and ice drift data. A historical quality-controlled archive of these data is available for the World Data Center-A or via the Internet (<http://iabp.apl.washington.edu>) from the Applied Physics Laboratory of the University of Washington.

During the past year, NIC has established a new science program with fiscal support from ONR, NOAA, and NASA. This program is aimed at expanding the use of NIC's products within the science community and providing a route for migration of scientific techniques (such as algorithms) into the operational environment. The program is presently staffed by a senior research scientist but was expanded in March 1999 to include two additional post-doctoral research fellows. The NIC Science Plan (available at <http://www.natice.noaa.gov>) summarizes the activities, interests, and goals of this polar science program. Current areas of in-house research include the improvement of SSM/I-derived ice concentrations through the derivation of mapping functions that incorporate ice chart data derived from higher-resolution sensor data. The science program also involves oversight of external activities, such as the University of Kansas ARKTOS ice classification system for Radarsat data, which is undergoing evaluation prior to operational implementation.

4.1.3 Land-Based Facilities

Under contract to NSF, the Polar Ice Coring Office provides logistics support for research in Greenland. The logistics support for the NSF facilities in Søndrestrom have changed dramatically since Greenland was granted Home Rule and since September 1992, when the U.S. Air Force terminated operations at Søndrestrom. The logistics support, which was provided by the Air Force, is now done through arrangements negotiated with the Greenland Home Rule Government and the Danish Polar Center.

The Polar Ice Coring Office (PICO) provides logistics support as required for NSF and NASA in Kangerlussuaq (formerly Søndrestrom AB), Green-

land. The New York Air National Guard ski-equipped LC-130s operate from Kangerlussuaq.

U.S. investigators have access, on a cooperative or reimbursable basis or both, to land-based facilities in Canada and Nordic countries. Cooperative arrangements with the Polar Continental Shelf Project Office in Canada provide for logistics support in the Canadian High Arctic. Facilities in Svalbard are available through the Norwegian Polar Institute, Norwegian universities, and other national programs.

Small seasonal camps are maintained in the Alaskan Arctic by individual agencies or groups of agencies to support field programs. The Toolik Field Station, operated by the University of Alaska and now being upgraded with NSF/PICO support, and the privately operated facilities at Barrow and Prudhoe Bay provide fixed bases for land-based research (DOC/NOAA, DOE, DOI/FWS/NPS/GS, NSF).

DOC/NOAA has available hangar facilities for two H-1N helicopters at Fort Richardson, Anchorage, Alaska. These facilities have some additional space for field equipment, scientific instruments, and Arctic gear. NOAA fleet ships have previously worked above latitude 60°, ice and weather permitting. NOAA aircraft have flown Arctic research projects while basing out of Elmendorf AFB, Eielson AFB, and Thule AFB. NSF, ONR, and the New York Air National Guard have taken over the SPAWAR Arctic Logistics infrastructure at Thule AB.

A memorandum of understanding between the National Science Foundation and the U.S. Army Corps of Engineers has been implemented which allows NSF-supported engineering and scientific researchers to use USACE laboratory facilities. Many of these state-of-the-art facilities are dedicated to cold-regions research and engineering thrusts and are described below.

An aggregation of unique facilities that are nationally and internationally recognized exist at the Cold Regions Research and Engineering Laboratory (CRREL). The main complex is in Hanover, New Hampshire. In addition, a permafrost research tunnel and additional coldrooms are located near Fairbanks, Alaska. Industry and academia often use CRREL's unique experimental facilities. This is evidenced by the high number (80) of cooperative research and development agreements that the laboratory has put in place over the last seven years.

At the Hanover campus the main laboratory houses 24 low-temperature research laboratories capable of achieving temperatures as low as -50°F, special-purpose ice test facilities, clean-

rooms, a chemical laboratory, and two specialty low-temperature materials laboratories. The Material Evaluation Facility can simulate snow and icing conditions and can simulate static and cycling temperatures ranging from -50° to 120°F and has the capability to conduct full-scale tests on automotive vehicles. The High Performance Materials Laboratory is used for strength and thermal testing of many types of materials, including construction, road, bridge, and composite materials. Specialized testing machines, such as the Split Hopkinson Pressure Bar, enable low-temperature, high-strain materials evaluation to temperatures as low as -80°C . Other equipment include thermal cycling chambers that allow for thermal cycling from -100° to 100°C and a specially fabricated UV-radiometry system for exposing testing materials to controlled doses of radiation.

The 73,000-square-foot Ice Engineering Facility has three special-purpose research areas: a large low-temperature towing tank, a 100-foot-long refrigerated flume for modeling rivers, and a large hydraulic-model room for studying ice effects on civil works facilities, primarily locks and dams. The Ice Engineering Facility also houses a snow-drift wind tunnel.

The Frost Effects Research Facility (FERF) allows full-scale research on the impact of freeze-thaw cycles on pavements, foundations, and utility systems. This 29,000-square-foot facility contains a 182- by 75-ft soil testing area that can be maintained at temperatures below 30°F and 12 large test cells where soil can be frozen and thawed at temperatures ranging from as low as -35°F to as high as 120°F . Six to eight natural freeze-thaw cycles can be simulated in a single year. The newest addition to the CRREL's experimental capability, the Heavy Vehicle Simulator (HVS), is housed in this facility. The HVS can simulate the effect of heavy vehicles on roads and pavements.

A Geophysical Research Facility serves the needs of the Navy for sensing and understanding the behavior of sea ice. It has become the focus of experimental work for ONR accelerated research initiatives, as well as research for NASA and NSF, drawing students and faculty from numerous universities for coordinated experiments each year.

The Remote Sensing/Geographic Information Systems Center is involved in flood mapping, emergency management, water resource management, as well as large-area environmental assessments critical to emergency response efforts. This 16,400-square-foot state-of-the-art facility is used to develop technologies that measure and monitor

environmental conditions over land and water surfaces and provide RS/GIS data and overlays to a diverse collection of research projects.

At the Alaska campus in Fairbanks, CRREL has a research permafrost tunnel and maintains a 133-acre permafrost research site. The CRREL facilities in Alaska include two coldrooms capable of -30°F temperatures, a heavy equipment maintenance shop, a woodworking shop, a soils laboratory, a shock laboratory, and several Small Unit Support Vehicles (SUSVs) used as research vehicles.

The Technical Information Analysis Center (TIAC) serves DOD and the Nation as the most comprehensive source of cold-regions information in the world. The 24,000-square-foot TIAC provides a gateway to the world's information and research resources for cold-regions science and engineering. The Cold Regions Science and Technology Information Analysis Center (CRSTIAC), serves as the Nation's corporate repository for cold-regions science and engineering data. This center houses the CRREL library, which contains 30,000 books, 160,000 reports, 450 journals, 450 rolls of microfilm, 250,000 pieces of microfiche, 40 CD-ROM reference titles, and topographic maps of all 50 states. The Bibliography on Cold Regions Science and Technology, comprising 53 volumes dating from 1951, is prepared for CRREL by the Library of Congress and contains approximately 250,000 citations, including cumulative author and subject indexes.

4.1.4 Atmospheric Facilities and Platforms

Because of the strategic location of the Arctic for observing space-related phenomena, an extensive infrastructure has been established over the past four decades to observe the Arctic upper atmosphere and ionosphere. The Arctic is the site of many ground-based radio, radar magnetic, and optical observing sites. These sites and many other smaller facilities have been an important aspect of the Arctic social structure, providing economic benefits in remote regions and educational opportunities for indigenous people.

Among the major upper atmospheric research facilities in the Arctic are the Sondrestrom Radar in Greenland, the High Frequency Active Auroral Research Program (HAARP) radar in Alaska, the Poker Flat Rocket and Research facility near Fairbanks, the Resolute Bay Observatory in Canada, the Longyearbyen Optical Station in Norway, and the SuperDARN radar network with sites spanning

the Western Hemisphere Arctic. These and other smaller sites are operated in collaboration with international partners, including academic and research institutions in Canada, Denmark, Norway, and Japan.

NASA is establishing a Network for Detection of Stratospheric Change (NDSC) program at Thule and Sondrestrom, Greenland, to provide long-term data on a variety of stratospheric constituents.

NASA and NSF are cooperating in a program called the Program for Arctic Regional Climate Assessment (PARCA). This involves satellite and airborne surveys of different regions of the ice sheet to establish patterns of ice sheet thickening and thinning along with ground-based surveys to establish reference data for interpreting airborne and satellite observations. Ground observations include the deployment of automatic weather stations and the analysis of shallow snow pits and deep ice cores. The results have, for the first time, shown clear regional patterns in the mass balance of the ice sheet.

4.1.5 Central Coordination and Logistics Information Clearinghouse

The Department of the Interior supports an Alaska Office of Aircraft Services (OAS), which coordinates aircraft services on a reimbursable basis.

An electronic bulletin board, ALIAS, is available on the Internet (<http://www.nsf.gov:80/od/opp/arctic/logistic/start.htm>). The IARPC and NSF are coordinating this effort.

4.1.6 Data Facilities

Archiving and distribution functions for data required in support of Arctic research are distributed among all the U.S. national data centers. Disciplinary data for the Arctic are held in global archives at the National Climatic Data Center (climatology and meteorology), at the National Oceanographic Data Center (oceanography), at the National Geophysical Data Center (seismology, geomagnetism, marine geology and geophysics, solar and ionospheric studies, ecosystems, topography, and paleoclimatology), and at the National Center for Atmospheric Research (upper atmosphere and ionospheric studies). Global satellite data archives for polar-orbiting satellites are held by NOAA/NESDIS/National Climatic Data Center (NCDC) in Asheville, NC. Included in these archives are:

- Global infrared and visible digital imagery from the advanced very-high-resolution radio-meter (AVHRR) instruments;

- Atmospheric temperature and moisture data and derived soundings from the high-resolution infrared radiation sounder (HIRS) instruments; and
- Global passive microwave data from the special sensor microwave/imager (SSM/I).

Electronic access to recent AVHRR and HIRS data is available through the NESDIS Satellite Active Archive (<http://www.saa.noaa.gov>). Global satellite data archives for the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) data are held by the National Geophysical Data Center. The National Oceanographic Data Center (NODC)/World Data Center-A for Oceanography (WDC-A) is the lead agency in the United Nations Intergovernmental Oceanographic Commission (IOC) Global Oceanographic Data Archaeology and Rescue Project (GODAR). The goal of this project is to locate and rescue historical oceanographic data that are in jeopardy of being lost, including Arctic oceanographic data.

There is a particular Arctic focus at two facilities, the National Snow and Ice Data Center (NSIDC) at the University of Colorado at Boulder and the Alaska SAR Facility at the Geophysical Institute at the University of Alaska Fairbanks. The NSIDC provides access to cryospheric data for both northern and southern hemispheres, with the present emphasis on the Arctic. NSIDC is chartered and funded by NOAA, through the Cooperative Institute for Research in Environmental Sciences (CIRES), to provide snow and ice data services. The center is under contract to the NASA Earth Observation System Data and Information System (EOSDIS) project as a Distributed Active Archive Center (DAAC), providing data services for snow and ice, including products from passive microwave remote sensing instruments, such as SSM/I and SMMR, and in-situ data.

The Alaska SAR Facility (ASF) also operates a DAAC under contract to NASA/EOSDIS. The facility receives and processes polar imagery from SARs onboard Canadian (Radarsat) and European (ERS-2) satellites. The ASF also carries out a range of tasks in support of the data, including calibration and the development of data analysis tools. A major data analysis project underway at the ASF involves implementation of the Radarsat geophysical processor system (RGPS), which is designed to generate high-level products from Radarsat, including ice drift, ice deformation, and ice thickness histograms using a novel Lagrangian tracking system. This system, developed by a team including the Jet Propulsion Laboratory and the University

of Washington Applied Physics Laboratory, is due for implementation at ASF during 1999.

Without archives, Arctic data would in time be lost. Without a method to locate data in the archives, scientists would have no access to the data required for Arctic and other research. Both the Arctic Environmental Data Directory (AEDD),

with its Arctic focus, and the Global Change Master Directory (GCMD) and NOAA Environmental Services Data Directory (NESDD), each having a broader mandate, are vital windows into the U.S. national data archives, providing a means for scientists to locate the data they require.

4.2 Arctic Data and Information

4.2.1 Arctic Data

The Arctic Environmental Data Directory (AEDD) is a collection of information that describes the major Arctic data holdings of the IARPC agencies. With more than 350 entries, AEDD also identifies selected Arctic data sets managed by the state and local agencies in Alaska, various universities, and a few other Arctic nations. AEDD is managed by the U.S. Geological Survey (USGS) on behalf of IARPC science agencies. All data set descriptions in AEDD are reviewed prior to entry for completeness, consistency, and accuracy. AEDD resides on a World Wide Web server in offices of the USGS in Anchorage, Alaska, and is accessible over the Internet using standard WWW search and browsing tools and the Wide Area Information Service (WAIS). The complete collection of on-line U.S. and international Arctic data and information is indexed worldwide by commercial services.

AEDD has taken advantage of recent developments and technology, most notably the WWW. During 1995–1996, AEDD has established a WWW home page (<http://www.ak.wr.usgs.gov/aedd/aedd.html>) that provides powerful tools for exploring all data and information in the AEDD and ADD (the U.S. and international directories). As a service the AEDD home page also links directly to more than 50 other Arctic data and information sources on the WWW. Because this cross-reference tool is frequently updated, a researcher may connect to virtually every known Arctic data and information resource in the world from the AEDD home page with the click of a mouse.

The Arctic Research Consortium of the U.S. (ARCUS) is working with the NSF Arctic System Science (ARCSS) program to identify and explore the human dimensions of Arctic science (HARC). AEDD has participated in two workshops sponsored by HARC to help guide social scientists into the use of AEDD as their metadata repository for socioeconomic data and information.

International Arctic Data

The IARPC challenged the AEDD Working Group to make the directory circumpolar in scope, including descriptions for data sets residing in all Arctic nations. To this end the AEDD Working Group has formed an effective working relationship with the United Nations Environment Program (UNEP) Global Resources Information Database (GRID) office in Arendal, Norway. The two groups sponsored a series of workshops with circumpolar participation with the objective of establishing contacts in all countries with Arctic science programs to create an international Arctic Data Directory (ADD). Participants from all of the Arctic countries, plus several other countries, the European Community, and international organizations with significant Arctic science programs, have agreed in concept to assemble compatible directories with the idea that, using the WWW, researchers can access all of the directories as if they were one directory.

Based on the model that AEDD initiated, an ADD node was established at UNEP/Grid–Arendal in 1994. This directory holds information about Arctic data for the Nordic countries and portions of western Russia. ADD is a network cooperation between major Arctic environmental data holders. This cooperation is making Arctic data available to circum-Arctic users. ADD assesses the quality and reliability of data set descriptions by means of a set of internationally agreed-upon criteria. ADD provides worldwide access to Arctic environmental data via the Internet. ADD identifies and works actively to form working relationships with institutions holding Arctic environmental data. ADD's network cooperation ensures feedback mechanisms to establish and maintain its relevance by addressing key environmental issues.

Through the ADD workshops the AEDD Working Group has also established contacts within Denmark, Germany, Italy, Japan, the Netherlands,

New Zealand, Poland, and the United Kingdom. Each of these countries is being encouraged to consider sponsoring a node of ADD. Eventually ADD will contain, and make available to the research community, descriptions of all major Arctic data holdings worldwide.

At a workshop in Moscow in September 1995, Russia agreed to initiate a Russian ADD node that will contain information about the Russian Arctic. The Russian node will be affiliated with the UNEP/GRID. All three nodes have agreed to identify and use certain standards that will make it easier for researchers to use the directory. For example, the structure and content of all ADD nodes are based on the Directory Interchange Format (DIF), which is used by the Global Change Master Directory, the Master Directory of the International Geosphere/Biosphere Programme, the Antarctic Data Directory, and the NASA Master Directory. The use of DIF simplifies the task of researchers who must access many data sources. All ADD nodes will use the WWW as their primary means of access, with obvious benefits to the research community. All ADD nodes will use Netscape Navigator (or equivalent WWW browsers) and standard search engines such as WAIS as primary search and retrieval mechanisms.

ADD has also taken advantage of the new technology available on the WWW. The ADD home page is maintained by UNEP/GRID-Arendal. In its second generation of design, it is incorporating the concept of "Gateway to the Arctic Environment" as part of the ADD support to the international Arctic Council. The AEDD and ADD home pages are closely linked and share considerable content. Together they provide a state-of-the-art and very complete guide to Arctic data and information in support of Arctic research. Because these directories are linked electronically, users can search on a specific theme to gain information on how to obtain relevant data sets worldwide.

The AEDD Working Group and UNEP/GRID-Arendal are working closely with the Russian State Committee on Environment Protection (SCEP) to establish the third ADD node in Moscow, Russia. Changes in the organization of the former Ministry of Environment Protection and Natural Resources have slowed the process of establishing the UNEP/GRID-Moscow node, but progress has been made. The objective is to facilitate the process of making information about Russian Arctic data more readily known and available to researchers in all countries. More than 80 Russian institutes holding Arctic data and information have already been identified. A

quick schedule to establish the node by 1996 has led to the preliminary identification and documentation of 40 Russian institutions. The Moscow node has found a home at the Center for International Projects (CIP) at Moscow State University, with sponsorship by the SCEP. This endeavor requires close cooperation between scientists in Western nations and those in the Russian Federation and a commitment to apply equivalent review and quality standards to the data set descriptions from all sources.

Arctic Contamination Data

Issues of Arctic contamination are of great concern in the international community, but there is little knowledge of the sources or content of data sets that might help in understanding these issues. The Japan Foreign Ministry participated as an observer at the ADD Steering Council meeting in Arendal in November 1996. Negotiations are underway to explore establishing an ADD node in Japan, sponsored by the Japan Foreign Ministry or other interested Japanese agencies or universities, to house and manage environmental contamination data from the marginal seas of the Russian Far East.

With headquarters in Oslo, Norway, AMAP is identifying and using data sets from the Arctic nations. AEDD and ADD are both being used as key resources to be accessed and used by AMAP researchers. The USGS, as the AMAP data manager for North American data, is supporting AMAP activities with AEDD. In this regard an effort is being made to add descriptions of data sets that relate to Arctic contamination and to incorporate links to data sources of others. Data sets that measure contaminants in the marine and freshwater environments, on land surfaces, in the atmosphere, and in the flora and fauna will be added to AEDD. Of particular interest will be HARC data sets on medicine, human health, marine biology, socioeconomic information, demographics, and the physical measurements of radionuclides, persistent organics, and heavy metals in the Arctic environment.

National Snow and Ice Data Center

The National Snow and Ice Data Center (NSIDC), University of Colorado at Boulder, was chartered in 1982 by NOAA/NESDIS to provide data and information services to the cryospheric community. NSIDC is affiliated with the NOAA/NESDIS/National Geophysical Data Center through a cooperative agreement between NOAA

and CIRES. The World Data Center-A for Glaciology is located at NSIDC. NSF, NASA, and NOAA fund major data management activities at NSIDC. The NSF Arctic System Science (ARCSS) Data Coordination Center at NSIDC has expanded its efforts to provide the most up-to-date means of data accessibility to the scientific community.

An ARCSS World Wide Web home page (<http://arcss.colorado.edu/>) developed at ADCC for access to data and information has become a tool for integration within ARCSS. Direct accessibility is the fundamental feature of this service, where data and information can be downloaded easily. Contact information for each ARCSS investigator, NSF ARCSS managers and staff, upcoming meetings and proposal deadlines, and information on each ARCSS component are included. A listserver provides electronic mail and information access to the ARCSS component communities and for each component working group and advisory committee.

NSIDC's data holdings include a wide range of data sets funded by NASA and NOAA in addition to those funded by NSF. NSIDC operates as a Distributed Active Archive Center (DAAC) for cryospheric data of the NASA EOSDIS program (Section 4.1.6). The continuing increase in the very large volume of satellite data acquired over high latitudes has led NASA to establish two major Distributed Active Archive Centers for polar data. The Alaska SAR Facility (ASF) in Fairbanks, Alaska, is responsible for receiving, archiving, processing, and distributing data from the many SAR satellites and for scheduling data-acquisition requests. NSIDC is primarily responsible for polar data from other instruments. A major NASA emphasis has been towards extracting information from the large volume of satellite data in a form that is both useful and intelligible to a broad community. As data volume grows, user-friendly data facilities consume an increasing proportion of available rescues, stressing the need to seek innovative approaches to data management. Data managed by these facilities are referenced in AEDD.

NSIDC holds many in-situ data sets that are maintained through NOAA support. The NOAA Environmental Services Data and Information Management program in particular has been responsible for the rescue and development of numerous snow, sea ice, and glacier data sets from the former Soviet Union.

Nongovernmental Organizations

AEDD is also working with nongovernmental

organizations that have mutual interest in Arctic environmental data and information. For example, the International Permafrost Association (IPA) is working to identify and rescue frozen-ground data that may be at risk of being lost by agencies in various countries, including the U.S. As organizations succeed in building data sets of interest, whether in the U.S., Russia, or other countries, they are using AEDD and the international ADD to document the results. Through associations with such organizations, descriptions in the international ADD of larger numbers of Arctic data sets will be realized with minimal cost and effort to the AEDD working group.

The AEDD will continue to work closely with nongovernmental organizations to compile extensive new collections of Arctic data and information.

Planned Interagency and International Data Activities

- Increase the value-added content of AEDD by increasing the number of entries and WWW links in AEDD, with an increased focus on Arctic contamination issues and socioeconomic data and information related to Arctic inhabitants, and provide a link to the Arctic Council web site at <http://www.arctic-council.usgs.gov>;
- Improve access to AEDD by continuing to adopt up-to-date tools on the WWW, including expansion of the WWW home page and compatibility with commercial browsers and standards-based search engines;
- Work with IARPC agencies to support the Arctic Council and its programs, including AMAP and the Conservation of Arctic Flora and Fauna, to provide information about and access to Arctic data of the U.S.;
- Seek expansion of international member and nonmember participation in ADD, with near-term potential for a new node in Japan and longer-term plans for Canada, Germany, the United Kingdom, Denmark, and perhaps Poland;
- Continue to work with UNEP/GRID to establish and populate the international ADD node in Russia to document and provide access to greater amounts of Russian Arctic data and information;
- Investigate new technologies that will make it as easy as possible to identify and use Arctic data sets while maintaining the high quality and reliability of AEDD and its contents and links;

- Help identify, rescue, and document Arctic data sets at risk of being lost, in conjunction with other organizations that share common interests; for example, the National Climate Data Center is cooperating with Russia in data exchange to help identify, rescue, and document the extensive set of precipitation data at risk of being lost, including data for north of the Arctic Circle;
 - Develop and distribute tools that will help scientists and data managers document Arctic data sets properly, such as a "DIF template on a diskette" for use on desktop computers;
 - Conduct workshops in conjunction with the Japanese scientific community to develop Japanese cooperation and an ADD node in Japan; and
 - Expand cooperation with the Antarctic data and information communities through links to ICAIR and related organizations.
- International Permafrost Association;
 - World Data Center—A for Glaciology and the Institute of Arctic and Alpine Research at the University of Colorado at Boulder;
 - Byrd Polar Research Center at the Ohio State University;
 - Dartmouth College; and
 - U.S. Army Cold Regions Research and Engineering Laboratory.

Electronic Access to Polar Information

The American Geological Institute completed a project to provide an electronic version of the *Arctic Bibliography*. This multi-volume set of over 100,000 abstracted works on Arctic regions was last published in the mid-1970s. It is expected to find greatly increased usage in an electronic format, which will ease considerably the task of finding material in this very useful reference work.

In late 1998 the Western Libraries Network (WLN) published PolarPac5, containing nearly 700,000 bibliographic records from 81 libraries. New collections of Canadian and Scandinavian libraries are included, the largest (20,000 titles) coming from McGill University. PolarPac5 comes in DOS, Windows, and Macintosh versions.

Arctic and Antarctic Regions is available for Windows, DOS, and Internet use from NISC. Comprehensive polar coverage on this CD offers over 800,000 records compiled by the major polar regions research organizations in the U.S., Canada, and the UK.

A Polar web site, a collaborative project of the Polar Libraries Colloquy and others, provides a guide to Internet resources. The address is <http://www.urova.fi:80/home/arktinen/polarweb/polarweb.htm>

4.2.2 Arctic Information

The U.S. Polar Information Working Group (USPIWG) is an independent body of U.S. polar information specialists associated with the international Polar Libraries Colloquy. The objective of USPIWG is to offer a single service to the U.S. Arctic and Antarctic scientific communities for matching information resources with information needs in a user-based context. Institutions and organizations currently represented are:

- University of Alaska Fairbanks;
- University of Alaska Anchorage;
- Environment and Natural Resources Institute of the University of Alaska Anchorage;
- Alaska State Library;
- Arctic Research Consortium of the U.S. (ARCUS);

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Appendix A: Glossary of Acronyms

ACSYS	Arctic Climate System Study	AUV	Autonomous underwater vehicles
ADAMHA	Alcohol, Drug Abuse and Mental Health Administration	AVHRR	Advanced very high resolution radiometer
ADD	Arctic Data Directory	BASIS	Barents Sea Impact Study
ADEOS	Advanced Earth Observation System	BERPAC	Program for Long-Term Ecological Research in Ecosystems of the Bering and Chukchi Seas and the Pacific Ocean
ADI	Arctic Data Interactive		
AEDD	Arctic Environmental Data Directory	BESIS	Bering Sea Impact Study
AEPS	Arctic Environmental Protection Strategy	BIA	Bureau of Indian Affairs
AFB	Air Force Base	BLM	Bureau of Land Management
AFES	Agriculture and Forestry Experiment Station	BOM	Bureau of Mines
		BRD	Biological Resources Division (USGS)
AFN	Alaska Federation of Natives	CAFF	Conservation of Arctic Flora and Fauna
AGASP	Arctic Gas and Aerosol Sampling Program	CAPS	Circumpolar Active-layer Permafrost System
AHAP	Alaska High-Altitude Photography	CAREER	Faculty Early Career Development program (NSF)
AICC	Arctic Icebreaker Coordination Committee	CART	Cloud and Radiation Testbed
AIP	Arctic Investigations Program	CCN	Cloud concentration nuclei
AIRS/AMSU	Atmospheric infrared sounder/advanced microwave sounding unit	CDC	Centers for Disease Control
		CD-ROM	Compact disk-read-only memory
		CFC	Chlorofluorocarbon
ALERT	Arctic Long-term Environmental Research Transects	CIP	Center for International Projects (Moscow State University)
AMAP	Arctic Monitoring and Assessment Program	CIRES	Cooperative Institute for Research in Environmental Sciences
AMEC	Arctic Military Environmental Cooperation	CISER	Committee on International Science Engineering and Technology
AMMTAP	Alaska Marine Mammal Tissue Archival Project	CMDL	Climate Monitoring and Diagnostic Laboratory (formerly GMCC) (NOAA)
AMSR	Advanced microwave radiometer sensor		
AMSU	Advanced microwave sounding unit	CMIS	Conical Microwave Imager Sounder
ANILCA	Alaska National Interest Lands Conservation Act	CONRIM	Council on Northern Resources Information Management
ANWAP	Arctic Nuclear Waste Assessment Program	CRESP	Coordinated Research and Environmental Surveillance Program
AOSB	Arctic Ocean Science Board		
ARC	Arctic Research Commission	CRREL	Cold Regions Research and Engineering Laboratory
ARCSS	Arctic Systems Science		
ARCUS	Arctic Research Consortium of the United States	CSRS	Cooperative State Research Service
ARM	Atmospheric Radiation Measurement program (DOE)	CTD	Conductivity, temperature, depth sensor
ARPA	Arctic Research and Policy Act	DA	Department of Agriculture
ASF	Alaska SAR Facility	DAAC	Distributed Active Archive Center

DDAC	Distributed Data Archive Center	GPS	Global positioning system
DHHS	Department of Health and Human Services	GS	Geological Survey
		HAARP	High Frequency Active Auroral Research Program
DIF	Directory Interchange Format		
DIRWOG	Data and Information Resources Working Group	HARC	Human Dimensions of the Arctic System (NSF)
DMS	Dimethyl sulfide	HCFA	Health Care Financing Administration
DMSP	Defense Meteorological Satellite Program	HDGC	Human Dimensions of Global Change program
DMSP	Dimethylsulfonium propionate	HF	High frequency
DOC	Department of Commerce	HIRS	High-resolution infrared radiation sounder
DOD	Department of Defense		
DOE	Department of Energy	HRSA	Health Resources Services Administration
DOI	Department of Interior		
DOS	Department of State	HVS	Heavy vehicle simulator
DOT	Department of Transportation	IABP	International Arctic Buoy Program
DPP	Diabetes Prevention Program		
EEZ	Exclusive Economic Zone	IAMSLIC	International Association of Aquatic and Marine Science Libraries and Information Centers
EM	Environmental Management (DOE)		
EML	Environmental Measurement Laboratory	IARC	International Arctic Research Center
EO	Environmental Observatory		
EOSDIS	Earth Observation System Data and Information System	IARPC	Interagency Arctic Research Policy Committee
EPA	Environmental Protection Agency	IASC	International Arctic Science Committee
EPPR	Emergency Prevention, Preparedness and Response	IASSA	International Arctic Social Sciences Association
ER	Energy Research		
ERS-1	European Remote-sensing Satellite	ICS	International Circumpolar Surveillance
ESDD	Earth Science Data Directory	IGBP	International Geosphere-Biosphere Program
EWG	Environmental Working Group	IHP	International Hydrological Program
FAS	Fetal alcohol syndrome	IHS	Indian Health Service
FDA	Food and Drug Administration	IOC	Intergovernmental Oceanographic Commission
FE	Fossil energy		
FERF	Frost Effects Research Facility (CRREL)	IPA	Intergovernmental Personnel Act
FHWA	Federal Highway Administration	IPA	International Permafrost Association
FIRE	First ISCCP Regional Experiment		
FOFCC	Federal Oceanographic Fleet Coordinating Council	ISCCP	International Satellite Cloud Climatology Program
FS	Forest Service		
FSU	Former Soviet Union	ITEX	International Tundra Experiment
FWS	Fish and Wildlife Service	IUCH	International Union for Circumpolar Health
FY	Fiscal year		
GCM	General circulation model	JCCM	Joint Coordinating Committee for Environmental Management Contaminant
GCMD	Global Change Master Directory		
GGD	Global Geocryological Database		
GIS	Geographic information system	JERS-1	Japanese Earth Resources Satellite
GISP	Greenland Ice Sheet Project		
GODAR	Global Oceanographic Data Archaeology and Rescue Project	JPL	Jet Propulsion Laboratory
		LAC	Local area coverage
GOOS	Global Ocean Observing System	LTER	Long-Term Ecological Research

*Appendix A:
Glossary of Acronyms*

MAB	Man and the Biosphere	NOS	National Ocean Service (NOAA)
MARC	Machine readable record	NPOESS	National Polar-Orbiting Operational Environmental Satellite System
MF	Medium frequency		
MMHSRP	Marine Mammal Health and Stranding Response Program	NPS	National Park Service
MMS	Minerals Management Service	NS&T	National Status and Trends program
MOA	Memorandum of agreement		
MODIS	Moderate Resolution Imaging Spectroradiometer	NSB	National Science Board
		NSF	National Science Foundation
NAD	Nansen Arctic Drilling program	NSIDC	National Snow and Ice Data Center
NADP/NTN	National Atmospheric Deposition Program/National Trends Network	NSN	Northern Sciences Network
NAGPRA	Native American Graves Protection Act	NSWP	National Space Weather Program
		NTS	Nevada Test Site
NAS	National Academy of Sciences	NURP	National Undersea Research Program (NOAA)
NASA	National Aeronautics and Space Administration		
		NWR	National Wildlife Refuge
NATO	North Atlantic Treaty Organization	NWS	National Weather Service (NOAA)
NCCOS	National Centers for Coastal Ocean Science	OAI	Ocean-Atmosphere-Ice Interactions
NDSC	Network for Detection of Stratospheric Change	OAR	Office of Oceanic and Atmospheric Research (NOAA)
NESDIS	National Environmental Satellite Data and Information Service	OAS	Office of Aircraft Services
		OCSEAP	Outer Continental Shelf Environmental Assessment Program
NEWNET	Neighborhood Environmental Watch Network	OECD	Organization for Economic Cooperation and Development
NGO	Non-governmental organization		
NIA	National Institute on Aging	OES	Bureau of Oceans and International Environmental and Scientific Affairs (DOS)
NIAAA	National Institute on Alcohol Abuse and Alcoholism		
		OIES	Office of Interdisciplinary Earth Sciences
NIC	National Ice Center		
NIDA	National Institute on Drug Abuse	OLS	Operational linescan system
NIDDK	National Institute of Diabetes and Digestive and Kidney Diseases	OMB	Office of Management and Budget
NIEHS	National Institute of Environmental Health Sciences	ONCO	Office of NOAA Corps Operations
NIGEC	National Institute of Global Environmental Change	ONR	Office of Naval Research
NIH	National Institutes of Health	OPP	Office of Polar Programs (NSF)
NIMH	National Institute of Mental Health	ORD	Office of Research and Development (EPA)
NIOSH	National Institute of Occupational Safety and Health	OSRI	Oil Spill Recovery Institute
		PAH	Polycyclic aromatic hydrocarbons
NISC	National Information Services Corporation	PAME	Protection of the Arctic Marine Environment
NIST	National Institute of Standards and Technology	PARCA	Program for Arctic Regional Climate Assessment
NLM	National Library of Medicine	PCB	Polychlorinated biphenyls
NMFS	National Marine Fisheries Service	PICES	Pacific International Council for the Exploration of the Sea
NOAA	National Oceanic and Atmospheric Administration	PICO	Polar Ice Coring Office
		PMEL	Pacific Marine Environmental Laboratory (NOAA)
NODC	National Oceanographic Data Center		

Appendix A:
Glossary of Acronyms

POP	Persistent organic pollutants	TCP/IP	Transmission control protocol/ Internet protocol
PRB	Polar Research Board	TEA	Teachers Experiencing the Arctic program (NSF)
Radarsat	Canada's imaging satellite	TOPEX	Poseidon Ocean Topography Experiment
RAPS	Resource Apprenticeship Program (DOI)	TOVS	TIROS-N Operational Vertical Sounder
REU	Research Experience for Under- graduates program	UCAR	University Corporation for Atmospheric Research
RGI	Regional Geographic Initiative (EPA)	ULS	Upward-looking sonars
RGPS	Radarsat Geophysical Processor System	UNEP/GRID	United Nations Environmental Program/Global Resources Information Database
ROV	Remotely operated vehicle	UNESCO	United Nations Educational, Scientific and Cultural Organiza- tion
SAR	Synthetic aperture radar	UNOLS	University National Oceano- graphic Laboratory System
SBI	Western Arctic Shelf Basin Interaction program (NSF)	USACE	U.S. Army Corps of Engineers
SCAMP	Seafloor Characterization And Mapping Pod	USCG	United States Coast Guard
SCEP	State Committee on Environment Protection (Russia)	USDA	United States Department of Agriculture
SCICEX	Submarine Scientific Ice Expedi- tions	USFS	United States Forest Service
SCS	Soil Conservation Service	USGCRP	United States Global Change Research Program
SEARCH	Study of Environmental Arctic Change	USGS	United States Geological Survey
SeaWiFS	Sea-viewing wide-field sensor	USIABP	United States Interagency Arctic Buoy Program
SEER	Surveillance, Epidemiology, and End Results program (NCI)	USPIWG	United States Polar Information Working Group
SGER	Small Grants for Exploratory Research (NSF)	UV	Ultraviolet
SHEBA	Surface Heat Budget of the Arctic Ocean program	VEINS	Variability of Exchanges in the Nordic Seas
SI	Smithsonian Institution	WAIS	Wide area information server
SIGRID	Sea ice archival format	WC&P	West Coast and Polar Center (NOAA)
SLAR	Side-looking airborne radar	WLN	Western Libraries Network
SMMR	Scanning multichannel micro- wave radiometer	WWW	World Wide Web
SPAWAR	Space and Naval Warfare Systems Command		
SSM/I	Special sensor microwave/imager		

Appendix B: Seventh Biennial Report of the Interagency Arctic Research Policy Committee to the Congress

February 1, 1996, to January 31, 1998

Background

Section 108(b) of Public Law 98-373, as amended by Public Law 101-609, the Arctic Research and Policy Act, directs the Interagency Arctic Research Policy Committee (IARPC) to submit to Congress, through the President, a biennial report containing a statement of the activities and accomplishments of the IARPC. The IARPC was authorized by the Act and was established by Executive Order 12501, dated January 28, 1985.

Section 108(b)(2) of Public Law 98-373, as amended by Public Law 101-609, directs the IARPC to submit to Congress, through the President, as part of its biennial report, a statement "detailing with particularity the recommendations of the Arctic Research Commission with respect to Federal interagency activities in Arctic research and the disposition and responses to those recommendations." In response to this requirement, the IARPC has examined all recommendations of the Arctic Research Commission since February 1996. The required statement appears in Appendix A.

Activities and Accomplishments

During the period February 1, 1996, to January 31, 1998, the IARPC has:

- Prepared and published the fifth biennial revision to the United States Arctic Research Plan, as required by Section 108(a)(4) of the Act. The President transmitted the Plan to Congress on July 29, 1997.
- Published and distributed four issues of the journal *Arctic Research of the United States*. These issues reviewed all Federal agency Arctic research accomplishments for FY 94 and 95 and included summaries of the IARPC and Arctic Research Commission meetings and activities. The Fall/Winter 1997 issue contained the full text of the fifth biennial revision of the U.S. Arctic Research Plan.
- Consulted with the Arctic Research Commission on policy and program matters described

in Section 108(a)(3), was represented at meetings of the Commission, and responded to Commission reports and recommendations (Appendix A).

- Continued the processes of interagency cooperation required under Section 108(a)(6), (7), (8) and (9).
- Provided input to an integrated budget analysis for Arctic research, which estimated \$183 million in Federal support for FY 96 and \$172 million in FY 97.
- Arranged for public participation in development of the fifth biennial revision to the U.S. Arctic Research Plan as required in Section 108(a)(10).
- Continued to maintain the Arctic Environmental Data Directory (AEDD), which now contains information on over 400 Arctic data sets. AEDD is available from Alaska as a resource on the World Wide Web on the Internet.
- Continued the activities of an Interagency Social Sciences Task Force. Of special concern is research on the health of indigenous people and research on the Arctic as a unique environment for studying human environmental adaptation and sociocultural change.
- Continued to support an Alaska regional office of the Smithsonian's Arctic Studies Center in cooperation with the Anchorage Historical Museum to facilitate education and cultural access programs for Alaska residents. The Smithsonian's Arctic Studies Center circulated its "Crossroads Alaska/Siberia" exhibition to cities in the Russian Far East from December 1996 to November 1997.
- Supported continued U.S. participation in the non-governmental International Arctic Science Committee, and the Committee's International Conference on Arctic Research Planning.
- Participated in the continuing National Security Council/U.S. Department of State review of U.S. policy in the Arctic. U.S. policy for the

Arctic now includes an expanded focus on science and environmental protection and on the valued input of Arctic residents in research and environmental management issues.

- Participated in policy formulation for development of the Arctic Council. This Council incorporates a set of principles and objectives for the protection of the Arctic environment and for promoting sustainable development. IARPC's Arctic Monitoring Working Group serves as a U.S. focal point for the Council's Arctic Monitoring and Assessment Program (AMAP).
- Focused attention within the U.S. Government on the disposal of nuclear waste and other toxic waste materials by the former Soviet Union on land and into the Arctic Ocean, seas and rivers; provided assistance to the Department of Defense's Arctic Nuclear Waste Assessment Program (ANWAP); and increased attention on such other Arctic environmental and human health stressors as land use and land cover change, and losses of habitat and biodiversity.
- Approved a coordinated Federal agency research initiative on Assessment of Risks to Environments and People in the Arctic. The initiative is designed to augment individual agency mission-related programs and expertise and to promote the resolution of key unans-

wered questions about Arctic environmental protection. The initiative is intended to help guide internal agency research planning and priority setting. The goal of the initiative is to disclose specific management questions and goals that should drive assessments and to gather credible information about the sources, transport, fate, effects and cumulative risks of Arctic contaminants and other human health and environmental stressors. This initiative proposes development of an integrated, comprehensive assessment including: 1) data rescue-and synthesis; 2) observations; 3) process-oriented research; 4) model development; 5) impacts analysis and estimation of risk; and 6) information management. It is expected that funding for the initiative will be included in agency budget submissions, as its objectives and potential value are of high relevance to the mission and responsibilities of each IARPC agency.

- Convened two formal meetings of the Committee, in November 1996, to receive public comments on the U.S. Arctic Research Plan, and June 1997, to approve the U.S. Arctic Research Plan; and held twenty-six meetings of IARPC staff committees, working groups and task forces to accomplish the above.

Appendix C: Arctic Research Budgets of Federal Agencies

Dept/Bureau	Program name	Budget (dollars in thousands)		
		FY 98 actual	FY 99 planned	FY 00 proposed
DOD	Arctic Engineering	2,515	1,819	1,900
DOD	Permafrost/Frozen Ground	523	316	350
DOD	Snow and Ice Hydrology	2,056	1,513	1,650
DOD	Oceanography	3,836	3,439	3,000
DOD	Lower Atmosphere	110	81	100
DOD	Upper Atmosphere	0	0	0
DOD	High-Freq Active Auroral Prog	5,000	12,500	0
DOD	Medical and Human Engr	1,210	993	783
	DOD TOTAL	15,250	20,661	7,783
DOI/MMS	Technology Assessment/Research	3,480	3,200	3,200
DOI/MMS	Environmental Studies	3,335	3,700	3,800
DOI/USGS	Energy and Minerals	3,500	3,500	3,500
DOI/USGS	Natural Hazards	3,500	3,500	3,500
DOI/USGS	Global Change	1,000	1,000	1,000
DOI/USGS	Marine and Coastal Geology	250	250	250
DOI/USGS	Geomagnetism	250	250	250
DOI/USGS	Ice and Climate	250	250	250
DOI/USGS	Hydrology	130	130	130
DOI/USGS	Mapping	750	750	750
DOI/USGS/BRD	Marine Mammals	1,660	1,660	1,660
DOI/USGS/BRD	Migratory Birds	2,390	2,390	2,390
DOI/USGS/BRD	Fisheries Research	360	360	360
DOI/USGS/BRD	Cooperative Research	330	330	330
DOI/USGS/BRD	Terrestrial Ecology	1,130	1,130	1,130
DOI/USGS/BRD	Park Research	1,140	1,140	1,140
DOI/USGS/BRD	Basic Marine Research/N. Pacific Ocean	0	6,600	0
DOI/BLM	Natural Ecology	2,700	1,700	2,000
DOI/BLM	Minerals Research	115	115	115
DOI/BLM	Cultural Resources	250	200	200
DOI/BLM	Pipeline Monitoring	550	550	550
DOI/BLM	Fire Control	350	380	380
DOI/BLM	Mining Administration	300	300	350
DOI/NPS	Cultural Resources	1,400	1,400	1,400
DOI/NPS	Natural Ecology	2,486	2,486	2,486
DOI/BIA	Cultural	600	600	600
DOI/BIA	Subsistence	1,250	1,250	1,250
DOI/FWS	Migratory Birds	2,889	3,484	3,884

Dept/Bureau	Program name	Budget (dollars in thousands)		
		FY 98 actual	FY 99 planned	FY 00 proposed
DOI/FWS	Fisheries	3,879	3,894	4,068
DOI/FWS	Marine Mammals	1,568	1,568	1,768
DOI/FWS	Conservation of Flora and Fauna (CAFF)	185	185	200
DOI/FWS	U.S.-Russia Environmental Agreement	0	75	150
	DOI TOTAL	41,977	48,327	43,041
NSF/OPP	Arctic Natural Science	10,494	11,650	11,750
NSF/OPP	Arctic System Science Prog	12,827	16,000	16,250
NSF/OPP	Arctic Social Sciences Prog	1,317	1,830	1,850
NSF/OPP	Arctic Education research	0	310	310
NSF/OPP	Arctic Research Support	1,897	1,780	1,780
NSF/OPP	Arctic Data/Info/Coord	95	290	290
NSF/OPP	Arctic Research Commission	500	680	700
NSF/OPP	Arctic Logistics/Instrumentation	4,500	17,000	17,000
NSF/OPP	Sub-total OPP	31,630	49,540	49,930
NSF	Other NSF Science Programs	17,383	17,500	17,600
	NSF TOTAL	49,013	67,040	67,530
NASA	Polar Ice Interactions	5,100	5,500	5,500
NASA	Ecology	2,100	2,225	1,605
NASA	Solid Earth Science	480	480	480
NASA	Arctic Ozone	2,900	5,600	12,700
NASA	Clouds and Radiation	2,000	1,500	1,500
NASA	Sub-orbital Science	2,800	2,300	2,300
NASA	Iono/Thermo/Mesospheric SR&T	1,000	780	780
NASA	Magnetospheric SR&T	400	400	400
NASA	FAST Auroral Snapshot	2,600	1,000	2,400
NASA	Solar Terrestrial Theory	400	400	400
NASA	Arctic Data Systems	11,800	11,225	12,500
NASA	Research Balloon Program	750	750	750
NASA	Sounding Rocket Program	1,413	1,700	950
	NASA TOTAL	33,743	33,860	41,765
DOC/NOAA	Atmos Trace Constituents	34	40	300
DOC/NOAA	Fisheries Assessment/Management	5,984	7,374	7,220
DOC/NOAA	Marine Mammal Assessment	2,300	3,050	3,050
DOC/NOAA	Coastal Hazards	50	50	0
DOC/NOAA	Ocean Assessment	95	160	150
DOC/NOAA	Stratospheric Ozone	2	2	120
DOC/NOAA	Satellites/Data Management	292	325	350
DOC/NOAA	Remote Sensing	208	279	275
DOC/NOAA	Aircraft/Vessels	1,515	1,515	2,410
DOC/NOAA	Climate and Global Change	382	416	0
DOC/NOAA	Arctic Ice	150	150	150
DOC/NOAA	Weather Research	0	165	175
DOC/NOAA	Western Arctic/Bering Sea Ecosystem	2,072	2,114	2,148
DOC/NOAA	Barrow Observatory	250	300	900
DOC/NOAA	Undersea Research	134	0	0
DOC/NOAA	Arctic Research Initiative	1,500	1,650	1,300
	DOC/NOAA TOTAL	15,070	17,590	18,548

Dept/Bureau	Program name	Budget (dollars in thousands)		
		FY 98 actual	FY 99 planned	FY 00 proposed
DOE/SC	Nat Inst Global Env Change	186	186	186
DOE/SC	Carbon Balance/Tundra Ecosystem	132	132	0
DOE/SC	Atmos Radiation Project	3,200	3,200	3,200
	DOE TOTAL	3,518	3,518	3,386
DHHS	National Institutes of Health	13,575	12,999	13,630
DHHS	Centers for Disease Control/Prevent	2,550	3,490	3,990
	DHHS TOTAL	16,125	16,489	17,620
SMITHSONIAN	Anthropology	450	400	400
SMITHSONIAN	Arctic Biology	50	50	50
	SMITHSONIAN TOTAL	500	450	450
DOT/USCG	Test and Evaluation	3,400	3,400	12,025
DOT/USCG	Extramural Science Support	30	30	30
DOT/FHA	Stream Crossings/Hydrological	100	100	50
DOT/FHA	Pavement Problems	800	800	800
DOT/FHA	Soils/Subbases (Permafrost)	200	100	50
DOT/FHA	Weather Monitoring/Storm Forecasting	500	500	500
DOT/FHA	Air/Water Quality Impacts	1,250	1,400	800
DOT/FHA	Snow Control/Pavement Treatment	300	1,300	300
	DOT TOTAL	6,580	7,630	14,555
EPA	Research and Development	300	200	450
EPA	Regional Activities	80	825	230
EPA	International Activities	100	100	100
	EPA TOTAL	480	1,125	780
USDA/FS	Forest Service – Environment	700	700	700
USDA/CSRE&ES	Cooperative State Res – Environ	725	725	725
USDA/CSRE&ES	Cooperative State Res – Food/Saf	793	793	793
USDA/NRCS	Natural Resources Cons Svc S – Global	560	560	560
USDA/ARS	Agricultural Research Service	650	2,000	2,000
	USDA TOTAL	3,428	4,778	4,778
STATE	MAB: Arctic Directorate	20	20	20
	STATE TOTAL	20	20	20
	GRAND TOTALS	185,704	221,488	220,256

Appendix D: Federal Arctic Research Program Descriptions

Department of Defense

- Arctic Engineering: The study and development of technologies for construction and maintenance of facilities and equipment in Arctic environments.
- Permafrost/Frozen Ground: The study of the formation, structure, characteristics, and dynamics of permafrost and frozen ground.
- Snow and Ice Hydrology: The study of the snowpack and river, lake, and sea ice, their formation, structure, and dynamics.
- Oceanography: The study of Arctic Ocean features and processes including sea ice dynamics.
- Lower Atmosphere: The study of Arctic weather with an emphasis on heat budget.
- High-Frequency Active Auroral Research Program (HAARP): The use of radiowave energy to study basic physical response and composition of the ionosphere and upper atmosphere.
- Medical and Human Engineering: The study of human response to cold climates and methods to mitigate those effects.

Department of the Interior

Minerals Management Service

- Technology Assessment and Research Program: Research to support Minerals Management Service offshore operations. Studies address operational needs for permitting of drilling and production operations, safety and pollution inspections, enforcement action, accident investigations, and well control training requirements.
- Environmental Studies Program: Research to provide information needed for prediction, assessment, and management of impacts from offshore natural gas and oil and mineral development activities on human, marine, and coastal environments of Alaska.

U.S. Geological Survey

- Energy and Minerals: Research to assess the distribution, quantity, and quality of energy and mineral resources with an increasing emphasis on characterizing the environmental

impact of resource occurrence and use. This information assists the Nation in managing its land, formulating environmental policies, and ensuring stable and safe supplies of resources.

- Natural Hazards: Research to forecast and delineate hazards from earthquakes, volcanoes, landslides, and related phenomena. Losses from future natural hazard events can be significantly reduced through studies of past and potential events applied to disaster mitigation and response planning.
- Global Change: Research to investigate the impact that potential global change, such as global warming, would have on our planet. This is part of the U.S. Global Change research program, which provides the scientific basis for developing policy relating to natural and human-induced changes in the global earth system.
- Marine and Coastal: Research to address issues of national, regional, and local concern that involve marine and coastal geology. These issues involve natural hazards, natural resources, and environmental quality and restoration; they span the full continuum from coastal wetlands and seashores to the deep ocean.
- Geomagnetism: Research to measure, map, and model the earth's magnetic field within various time scales and to publish and disseminate this information for use in navigation and orientation by Federal, state, local, and international groups. Eleven magnetic observatories are operated, and repeat magnetic field surveys are performed to determine how and how fast the earth's magnetic field is changing.
- Ice and Climate: Research to understand the causes, characteristics, and effects of changes in glacier conditions over annual to decadal time scales, as well as of changes in snow conditions in mountainous areas over monthly to seasonal time scales.
- Hydrology: Research to monitor and assess the sensitivity of surface water and wetland hydrology to variations and changes in climate.
- Mapping: Program to develop geologic and environmental maps of Arctic Alaska.

*U.S. Geological Survey—Biological
Resources Division*

- Marine Mammals: Research on marine mammals to provide information needed for USGS to fulfill its stewardship responsibilities under the Marine Mammal Protection Act.
- Migratory Birds: Research on migratory birds to provide basic biological information needed for responsible implementation of the Migratory Bird Treaty Act.
- Fisheries: Research related to land management responsibilities on National Wildlife Refuges and National Parks or focusing on treaty issues involving the U.S. and Canada.
- Cooperative Research: Research addressing issues relating to short-term or site-specific resource management issues.
- Terrestrial Ecology: Research related to land management, emphasizing potential effects of resource development on National Wildlife Refuges.
- Park Research: Research related to land management, emphasizing issues specific to National Parks.

Bureau of Land Management

- Natural Ecology: Inventorying and monitoring of the quantity and status of waters, soils, vegetation, fish and wildlife populations, and habitats in Arctic Alaska. This is a major effort to support lands and resources management in this unique area.
- Cultural Resources: Studies of man's prehistoric activities in the Arctic. Recent findings in northern Alaska have helped in understanding man's migration into North America.
- Pipeline Monitoring: Program to ascertain that permittees are in compliance with the agreement and grant right-of-way for the Trans-Alaska Pipeline in Arctic Alaska. There is constant monitoring of pipeline integrity and the status of the natural resources in and adjacent to the right-of-way.
- Fire Control: Studies of fuels, ignition, burning, fire spreading, and methods of control of wild fires in the Arctic. A network of remote automatic weather stations has been established. The primary purpose of this network is to help understand the influence of weather on wildfires.
- Mining Administration: Monitoring of placer mining on public lands in Arctic Alaska. The goal is to assure compliance with the approved plan of operations and minimize the

impact of mining on the riparian wetland resource.

National Park Service

- Cultural Resources: Research and investigation of cultural resources as they pertain to historic places in National Parks. The Shared Beringian Heritage Program promotes international cooperation in multidisciplinary studies of Beringia.
- Natural Ecology: Research to monitor and understand natural resources in National Parks.

Bureau of Indian Affairs

- Cultural: Research and investigation of learned and shared behaviors as they pertain to historic places and cemetery sites applied for under the provisions of the Alaska Native Claims Settlement Act (P.L. 92-203).
- Subsistence: Research on the customary and traditional uses of fish, game, and plant resources.

National Science Foundation

- Arctic Natural Sciences: Research in atmospheric, space, ocean, biological, earth sciences, and glaciology that is primarily investigator-initiated; this is basic research that is concerned with processes and phenomena in the entire Arctic region, including Alaska, Canada, Greenland, Svalbard, Russia, the Arctic Ocean and adjacent seas, and the upper atmosphere and near space.
- Arctic System Science (ARCSS): An interdisciplinary program that examines the interactions within and between the climatic, geologic, biologic, and socioeconomic subsystems of the Arctic. ARCSS is a regional component within the U.S. Global Change Research Program.
- Arctic Social Science: A multidisciplinary and interdisciplinary program focused on issues of human-environment interactions, rapid social change, and community viability.
- Arctic Science Support: Support for Intergovernmental Personnel Act (IPA) personnel assigned to the Arctic Sciences Section of the Office of Polar Programs (OPP), and scientific meeting, panel, and publication support.
- Arctic Data and Information, and Advisory and Coordination: Support for a program of Arctic data and information research and

advisory services, including support for the Interagency Arctic Research Policy Committee, and conferences, workshops, and studies to further develop and implement Arctic research planning and policy.

- Arctic Research Commission: Support for the Commission staff and members. Funding for the Arctic Research Commission is included in the NSF budget for administrative convenience.
- Other Sciences: Research supported in divisions and programs outside the OPP in atmospheric, ocean, biological, earth sciences, and glaciology that is primarily investigator-initiated basic research.
- Engineering: Engineering research that is related to the Arctic.
- Education: Education research that is related to the Arctic.

National Aeronautics and Space Administration

- Polar Ice Interactions: Program focused on Arctic ice cover and its interactions with the oceans and atmosphere. Long-range goals are to significantly improve our ability to represent high-latitude processes in models of global climate and climate change, and to implement a program to monitor important high-latitude phenomena that are likely to respond to climate change, with particular emphasis on the mass balance of the Greenland ice sheet and its effect on sea level.
- Ecology: Program focused on the function of high-latitude terrestrial ecosystems and their interactions with the atmosphere and hydrosphere, with particular emphasis on carbon cycling and land-atmosphere interactions.
- Solid Earth Science: Program focused on improving our understanding of the Earth gravity field, oscillations in the length of day, and tilting of the axis of rotation. It also contributes to other polar studies by providing a frame of reference with which to monitor changes, such as the volume of the ice sheets.
- Arctic Ozone Studies: Program supporting a number of tasks related to measuring and understanding chemical and dynamical processes in the Arctic stratosphere in order to measure and understand changes in Arctic stratospheric ozone.
- Arctic Data Systems: Support for two Distributed Active Archive Systems (DAACs) for

high-latitude data: one at the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, and one at the Alaska SAR Facility (ASF), in Fairbanks, Alaska. The ASF is responsible for the acquisition, processing, archiving, and distribution of synthetic aperture radar (SAR) data from several non-U.S. spacecraft, and the NSIDC handles most other satellite data over high latitudes. In addition, NASA supports the development of several high-latitude "Pathfinder" data sets, comprising higher-level information derived from various satellite data.

- Space Physics Division: Support for a vigorous program of experimental and theoretical studies of the upper atmosphere of the Arctic regions, including the ionosphere, thermosphere, magnetosphere, and the Aurora Borealis. It includes these programs listed in the NASA budget table: Sounding Rocket Program, Suborbital Science, Iono/Thermo/Mesospheric Science and Technology, Clouds and Radiation, FAST Auroral Snapshot, Magnetospheric Science and Technology, and Solar Terrestrial Theory.

Department of Commerce

National Oceanic and Atmospheric Administration

- Atmospheric Trace Constituents: Continuous and discreet measurements of atmospheric trace constituents (for example, greenhouse gases) that are important to understanding global change.
- Marine Fisheries Assessment: Assessment by the National Marine Fisheries Service (NMFS) of U.S. living marine resources in Arctic waters.
- Marine Mammal Assessment: Long-term research by NMFS's National Marine Mammal Laboratory on the population biology and ecology of Arctic marine mammals. NMFS also participates in the Marine Mammal Health and Stranding Response Program, which oversees the Arctic Marine Mammal Tissue Archival Program (AMMTAP) in collaboration with Department of Interior (FWS, BRD, and MMS) and the National Institute of Standards and Technology (NIST). The AMMTAP collects, analyzes, and archives tissues for contaminants and health indices to provide a database on contaminants and health in marine mammal populations in the Arctic.
- Coastal Hazards: Activities directed towards

developing a better understanding of the effects of tsunami propagation and run-up.

- **Ocean Assessment:** A wide range of programs and activities directed toward NOAA's environmental stewardship responsibilities, including environmental monitoring and assessment, technology transfer, and education and outreach. Ocean assessment includes the National Status and Trends Program, the Coastal Ocean Program, and other pertinent activities of the recently formed National Centers for Coastal Ocean Science (NCCOS), National Ocean Service.
- **Stratospheric Ozone:** Program that is developing an understanding of the dynamics and chemistry of the potential for Arctic ozone depletion, as part of activities directed to understanding the global depletion of stratospheric ozone.
- **Satellites/Data Management:** Research addressing NOAA's responsibilities for collecting, archiving, processing, and disseminating environmental data and providing specialized data analyses and interpretations.
- **Remote Sensing:** A substantial program (jointly with NSF and DOE) for developing, testing, and using ground-based remote sensors for Arctic meteorological research. The emphasis is on prototypes for future operational systems that can operate in the Arctic with minimal attention. The scientific issues include boundary layer turbulence and structure, cloud macro- and micro-physical properties, and cloud-radiative coupling relevant to Arctic climate.
- **Aircraft/Vessels:** Support from the Office of NOAA Corps Operations (ONCO) for the platforms needed to conduct the research and observations associated with NOAA's Arctic research program.
- **Climate and Global Change:** Studies that are assessing Arctic processes as forcing functions of climate and global change and as "barometers" of global change.
- **Arctic Ice:** Support of NOAA's Pacific Marine Environmental Laboratory (PMEL) investigations of the influence of sea ice on weather and climate systems, oceanographic stratification, and marine biota. The National Ice Center, jointly operated by NOAA, the U.S. Navy, and the U.S. Coast Guard, provides analyses and forecasts of ice conditions in all seas of the polar regions, the Great Lakes, and Chesapeake Bay. The National Snow and Ice Data

Center (NSIDC), affiliated with NOAA's National Geophysical Data Center (NGDC), archives many new and rescued ice data sets.

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

Department of Energy

- **Climate-Related Atmospheric Radiation Research:** Operation of an Atmospheric Radiation Measurement (ARM) research ("testbed") site on the North Slope of Alaska to improve mathematical simulations of cloud and radiative transfer processes in general circulation models (GCMs).
- **Carbon Balance/Tundra Ecosystems:** Investigation of the response of tundra ecosystems to changes in the levels of available carbon, with an emphasis on determining the flux of CO₂ from tundra and the responses of vegetation to elevated CO₂.
- **National Institute of Global Environmental Change:** Multiple projects that relate to the measurement of carbon fluxes and "greenhouse" gases.
- **Environmental Measurements of Radioactivity in the Atmosphere:** Continuous measurements of long-term levels and trends of anthropogenic and natural radionuclides in the Arctic atmosphere. Investigations of the use of radionuclides as atmospheric tracers are part of this project. Sites include Alaska, Greenland, and northernmost Canada and Norway.
- **Neighborhood Environmental Watch Network (NEWNET):** An Alaskan network (Fairbanks, Kotzebue, Nome, Point Hope, Seward) of public-accessible environmental gamma-radioactivity monitoring stations and data storage/processing systems, based on concepts devel-

oped by the DOE for the Community Monitoring Program at the Nevada Test Site (NTS) Nuclear Testing Facility.

- Joint Coordinating Committee for Environmental Management Contaminant (JCCEM) Transport Studies: Assessment of the hydrogeologic framework and radioactivity contamination status of the West Siberian Basin from past and ongoing releases of commercial and defense-related nuclear and hazardous waste disposal operations at the former Soviet Union Mayak, Tomsk, and Krasnoyarsk sites.
- Amchitka Island, Alaska, Studies: DOE participation in human health and ecological risk assessments and hydrogeological modeling related to potential leaching and transport of radionuclides from three underground nuclear tests conducted on the island between 1965 and 1971.
- North Slope of Alaska Methane Hydrate Resource Assessment: DOE is assisting the U.S. Geological Survey (USGS) in an assessment of the recoverability and production characteristics of permafrost-associated methane hydrates and related free-gas accumulations in the Prudhoe Bay–Kuparuk River area of the North Slope of Alaska.
- Wind Electricity Generation Activities in Alaska: To better understand the role that renewable energy can play, the DOE's Wind Energy Program is engaged in collaborative efforts with Alaskan organizations at the state and local levels to explore ways in which wind can make a greater contribution in the production of electric power. These efforts are occurring in several Alaskan locations including Kotzebue, Wales, Yukutat, Deering, Naknek, and Unalaska.

Department of Health and Human Services

National Institutes of Health

- Basic and applied research that relates primarily in the areas of rheumatic diseases, cancer, drug and alcohol abuse, and coronary heart disease that affect Arctic residents.

Centers for Disease Control and Prevention

- A program designed to evaluate infectious disease prevention strategies in the Alaska Native population.
- An occupational injury research program focusing on the Nation's geographic area with

the highest risk of occupational-related injury.

- A program to provide technical assistance to the State of Alaska to develop a surveillance system for fetal alcohol syndrome (FAS) and to develop and evaluate model programs for FAS prevention.

Smithsonian Institution

- Anthropology: Research and interpretation of Arctic cultures and natural history. Training of Arctic residents and Natives in museum studies, collections care, conservation, and cultural heritage programs. Studies of the origin and history of northern cultures and their interactions with their environment and with European cultures are central features of this research.
- Arctic Biology: Basic research on biological and evolutionary studies in botany, zoology, and other natural history fields. Interactions of Arctic flora and fauna with human cultures are emphasized.

Department of Transportation

U.S. Coast Guard

- Arctic Science/Logistics Support: The costs of providing and maintaining polar icebreakers for use in the Arctic.
- Test and Evaluation: The cost of tests designed to evaluate polar icebreakers in the performance of Arctic missions. (Previously, unreimbursed Arctic science mission costs were included in this category.)
- Extramural Science Support: Funding provided to other agencies for Arctic science studies, research, or vessel availability studies.

Federal Highway Administration

- Stream Crossing/Hydrological: Investigations directed toward dealing with highway stream crossings, bridges, and covered culverts; anomalies found in Arctic conditions, including frozen ground and related subfreezing conditions and permafrost, can cause icing blockages and highly variable stream discharges.
- Pavement Studies: Investigations of the effects of the Arctic and its extremely low and highly variable temperatures on behaviors of portland cement and asphalt concrete pavements.
- Soils/Sub-bases (Permafrost): Investigations dealing with the control of unpaved road sur-

faces and appropriate measures to attain stable road conditions in Arctic areas typified by poor drainage conditions and permafrost.

- **Air/Water Quality Impacts:** Investigations directed toward forecasting the environmental impacts of highway construction.
- **Snow Control/Pavement Treatment:** Investigations dealing with the interception and diversion of snow and ice, the disbonding from pavements and removal of snow and ice from pavements, the prevention of snow and ice covering and melting of snow and ice by chemical (salt) applications, and the covering of ice and snow on pavements by abrasive materials such as coarse angular sands to improve traction by vehicles on pavements.

Environmental Protection Agency

- **Research and Development:** Intramural and extramural basic and applied research based on the risk assessment/risk management paradigm. EPA research interests in the Arctic include air quality, land use, habitat, bioremediation, and environmental engineering and social science research.
- **Regional Activities:** Activities of EPA's Region 10 (Pacific Northwest and Alaska office) conducted with the State of Alaska and local communities, Alaskan indigenous people, and others to resolve specific Arctic environmental issues.

Department of Agriculture

Forest Service

- Research directed toward improving the understanding, use, and management of Alaska's natural resources, especially the northern boreal forest. Research centers on the dynamics of mixed stands and the cumulative effects of management activities on hydrology, soils, vegetation, wildlife, carbon reserves, insects, and fire in boreal ecosystems.
- Important portions of the boreal ecosystems research are conducted at the Bonanza Creek Long-Term Ecological Research Site near Fairbanks, AK.

Cooperative State Research, Education and Extension Service

- Research in plant sciences emphasizing propagating and cultivating Alaska native plants and domestic crops.
- Research in animal sciences investigating gen-

etic parameters for growth and reproduction of pink salmon and the chemical composition, nutritional value, and utilization of animal feeds.

- Research in natural resources and forestry addressing forest floor organic matter reserves, ecosystem sustainability, soil classification, wildlife habitat, quantification of timber productivity, and disturbance revegetation in wetlands.

Natural Resources Conservation Service

- Research in support of the National Cooperative Soil Survey program addressing soil cryogenic processes, soil reduction and oxidation properties, temperature, water status and gas flux in wetlands, reindeer and caribou grazing needs, and vegetation trends.
- Research on vegetation, landform, and carbon sequestration relationships in support of the Global Change Research Program.
- Research in support of the snow survey program. Snowfall measurement techniques are being studied to support the snow survey, which continues to be used to predict snow-melt, water availability, river breakup timing, and wildlife movements.

Agricultural Research Service

- Research on plant sciences emphasizing germplasm preservation to protect native and Russian plant species with emphasis on medicinal value and utility for erosion control.
- Research in animal sciences to investigate Alaska fisheries byproduct use (especially for feed stocks), integrated pest management for grasshopper control in Alaska's central basin, and the biosystematics of Holarctic ruminant parasites to assess pathogen distribution in food resources of northern communities.

Department of State

- **Man and the Biosphere Program:** Research as part of the U.S. Man and the Biosphere Program. Working with indigenous communities, the program seeks to ensure sound management of key renewable resources such as caribou.
- **Coordination of U.S. involvement in the Arctic Council and its working groups,** including support by U.S. agencies for the U.S. chairmanship of the Council (1998–2000).
- **The State Department chairs regular meetings of the interagency Arctic Policy Group and has overall responsibility for the coordination and formulation of U.S. policy in the Arctic.**

Appendix E: Arctic Research and Policy Act, As Amended

PUBLIC LAW 98-373 - July 31, 1984; amended as
PUBLIC LAW 101-609 - November 16, 1990

An Act

To provide for a comprehensive national policy dealing with national research needs and objectives in the Arctic, for a National Critical Materials Council, for development of a continuing and comprehensive national materials policy, for programs necessary to carry out that policy, including Federal programs of advanced materials research and technology, and for innovation in basic materials industries, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled:

TITLE I-ARCTIC RESEARCH AND POLICY

SHORT TITLE

SEC. 101. This title may be cited as the "Arctic Research and Policy Act of 1984, as amended".

FINDINGS AND PURPOSES

SEC. 102.(a) The Congress finds and declares that—

- (1) the Arctic, onshore and offshore, contains vital energy resources that can reduce the Nation's dependence on foreign oil and improve the national balance of payments;
- (2) as the Nation's only common border with the Soviet Union, the Arctic is critical to national defense;
- (3) the renewable resources of the Arctic, specifically fish and other seafood, represent one of the Nation's greatest commercial assets;
- (4) Arctic conditions directly affect global weather patterns and must be understood in order to promote better agricultural management throughout the United States;
- (5) industrial pollution not originating in the Arctic region collects in the polar air mass, has the potential to disrupt global weather patterns, and must be controlled through international cooperation and consultation;
- (6) the Arctic is a natural laboratory for research into human health and adaptation, physical and psychological, to climates of extreme cold and isolation and may provide information crucial for future defense needs;
- (7) atmospheric conditions peculiar to the Arctic make the Arctic a unique testing ground for research into high latitude communications, which is likely to be crucial for future defense needs;
- (8) Arctic marine technology is critical to cost-effective recovery, and transportation of energy resources and to the national defense;

(9) the United States has important security, economic, and environmental interests in developing and maintaining a fleet of icebreaking vessels capable of operating effectively in the heavy ice regions of the Arctic;

(10) most Arctic-rim countries, particularly the Soviet Union, possess Arctic technologies far more advanced than those currently available in the United States;

(11) Federal Arctic research is fragmented and uncoordinated at the present time, leading to the neglect of certain areas of research and to unnecessary duplication of effort in other areas of research;

(12) improved logistical coordination and support for Arctic research and better dissemination of research data and information is necessary to increase the efficiency and utility of national Arctic research efforts;

(13) a comprehensive national policy and program plan to organize and fund currently neglected scientific research with respect to the Arctic is necessary to fulfill national objectives in Arctic research;

(14) the Federal Government, in cooperation with State and local governments, should focus its efforts on the collection and characterization of basic data related to biological, materials, geophysical, social, and behavioral phenomena in the Arctic;

(15) research into the long-range health, environmental, and social effects of development in the Arctic is necessary to mitigate the adverse consequences of that development to the land and its residents;

(16) Arctic research expands knowledge of the Arctic, which can enhance the lives of Arctic residents, increase opportunities for international cooperation among Arctic-rim countries, and facilitate the formulation of national policy for the Arctic; and

(17) the Alaskan Arctic provides an essential habitat for marine mammals, migratory waterfowl, and other forms of wildlife which are important to the Nation and which are essential to Arctic residents.

(b) The purposes of this title are—

(1) to establish national policy, priorities, and goals and to provide a Federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials, physical, biological and health sciences, and social and behavioral sciences;

(2) to establish an Arctic Research Commission to promote Arctic research and to recommend Arctic research policy,

(3) to designate the National Science Foundation as the lead agency responsible for implementing Arctic research policy, and

(4) to establish an Interagency Arctic Research Policy Committee to develop a national Arctic research policy and a five year plan to implement that policy.

ARCTIC RESEARCH COMMISSION

SEC. 103. (a) The President shall establish an Arctic Research Commission (hereinafter referred to as the "Commission").

(b)(1) The Commission shall be composed of seven members appointed by the President, with the Director of the National Science Foundation serving as a nonvoting, ex officio member. The members appointed by the President shall include—

(A) four members appointed from among individuals from academic or other research institutions with expertise in areas of research relating to the Arctic, including the physical, biological, health, environmental, social and behavioral sciences;

(B) one member appointed from among indigenous residents of the Arctic who are representative of the needs and interests of Arctic residents and who live in areas directly affected by Arctic resource development; and

(C) two members appointed from among individuals familiar with the Arctic and representative of the needs and interests of private industry undertaking resource development in the Arctic.

(2) The President shall designate one of the appointed members of the Commission to be chairperson of the Commission.

(c)(1) Except as provided in paragraph (2) of this subsection, the term of office of each member of the Commission appointed under subsection (b)(1) shall be four years.

(2) Of the members of the Commission originally appointed under subsection (b)(1)—

(A) one shall be appointed for a term of two years;

(B) two shall be appointed for a term of three years; and

(C) two shall be appointed for a term of four years.

(3) Any vacancy occurring in the membership of the Commission shall be filled, after notice of the vacancy is published in the Federal Register, in the manner provided by the preceding provisions of this section, for the remainder of the unexpired term.

(4) A member may serve after the expiration of the member's term of office until the President appoints a successor.

(5) A member may serve consecutive terms beyond the member's original appointment.

(d)(1) Members of the Commission may be allowed travel expenses, including per diem in lieu of subsistence, as authorized by section 5703 of title 5, United States Code. A member of the Commission not presently employed for compensation shall be compensated at a rate equal to the daily equivalent of the rate for GS-18 of the General Schedule under section 5332 of title 5, United States Code, for each day the member is engaged in the actual performance of his duties as a member of the Commission, not to exceed 90 days of service each year. Except for the purposes of chapter 81 of title 5 (relating to compensation for work injuries) and chapter 171 of title 28 (relating to tort claims), a member of

the Commission shall not be considered an employee of the United States for any purpose.

(2) The Commission shall meet at the call of its Chairman or a majority of its members.

(3) Each Federal agency referred to in section 107(b) may designate a representative to participate as an observer with the Commission. These representatives shall report to and advise the Commission on the activities relating to Arctic research of their agencies.

(4) The Commission shall conduct at least one public meeting in the State of Alaska annually.

DUTIES OF THE COMMISSION

SEC. 104. (a) The Commission shall—

(1) develop and recommend an integrated national Arctic research policy;

(2) in cooperation with the Interagency Arctic Research Policy Committee established under section 107, assist in establishing a national Arctic research program plan to implement the Arctic research policy;

(3) facilitate cooperation between the Federal Government and State and local governments with respect to Arctic research;

(4) review Federal research programs in the Arctic and recommend improvements in coordination among programs;

(5) recommend methods to improve logistical planning and support for Arctic research as may be appropriate and in accordance with the findings and purposes of this title;

(6) recommend methods for improving efficient sharing and dissemination of data and information on the Arctic among interested public and private institutions;

(7) offer other recommendations and advice to the Interagency Committee established under section 107 as it may find appropriate;

(8) cooperate with the Governor of the State of Alaska and with agencies and organizations of that State which the Governor may designate with respect to the formulation of Arctic research policy;

(9) recommend to the Interagency Committee the means for developing international scientific cooperation in the Arctic; and

(10) not later than January 31, 1991, and every 2 years thereafter, publish a statement of goals and objectives with respect to Arctic research to guide the Interagency Committee established under section 107 in the performance of its duties.

(b) Not later than January 31 of each year, the Commission shall submit to the President and to the Congress a report describing the activities and accomplishments of the Commission during the immediately preceding fiscal year.

COOPERATION WITH THE COMMISSION

SEC. 105. (a)(1) The Commission may acquire from the head of any Federal agency unclassified data, reports, and other nonproprietary information with respect to Arctic

research in the possession of the agency which the Commission considers useful in the discharge of its duties.

(2) Each agency shall cooperate with the Commission and furnish all data, reports, and other information requested by the Commission to the extent permitted by law; except that no agency need furnish any information which it is permitted to withhold under section 522 of title 5, United States Code.

(b) With the consent of the appropriate agency head, the Commission may utilize the facilities and services of any Federal agency to the extent that the facilities and services are needed for the establishment and development of an Arctic research policy, upon reimbursement to be agreed upon by the Commission and the agency head and taking every feasible step to avoid duplication of effort.

(c) All Federal agencies shall consult with the Commission before undertaking major Federal actions relating to Arctic research.

ADMINISTRATION OF THE COMMISSION

SEC. 106. The Commission may—

(1) in accordance with the civil service laws and subchapter III of chapter 53 of title 5, United States Code, appoint and fix the compensation of an Executive Director and necessary additional staff personnel, but not to exceed a total of seven compensated personnel;

(2) procure temporary and intermittent services as authorized by section 3109 of title 5, United States Code;

(3) enter into contracts and procure supplies, services and personal property;

(4) enter into agreements with the General Services Administration for the procurement of necessary financial and administrative services, for which payment shall be made by reimbursement from funds of the Commission in amounts to be agreed upon by the Commission and the Administrator of the General Services Administration; and

(5) appoint, and accept without compensation the services of, scientists and engineering specialists to be advisors to the Commission. Each advisor may be allowed travel expenses, including per diem in lieu of subsistence, as authorized by section 5703 of title 5, United States Code. Except for the purposes of chapter 81 of title 5 (relating to compensation for work injuries) and chapter 171 of title 28 (relating to tort claims) of the United States Code, an advisor appointed under this paragraph shall not be considered an employee of the United States for any purpose.

LEAD AGENCY AND INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

SEC. 107. (a) The National Science Foundation is designated as the lead agency responsible for implementing Arctic research policy, and the Director of the National Science Foundation shall insure that the requirements of section 108 are fulfilled.

(b)(1) The President shall establish an Interagency Arctic Research Policy Committee (hereinafter referred to as the "Interagency Committee").

(2) The Interagency Committee shall be composed of representatives of the following Federal agencies or offices:

(A) the National Science Foundation;

(B) the Department of Commerce;

(C) the Department of Defense;

(D) the Department of Energy;

(E) the Department of the Interior;

(F) the Department of State;

(G) the Department of Transportation;

(H) the Department of Health and Human Services;

(I) the National Aeronautics and Space Administration;

(J) the Environmental Protection Agency; and

(K) any other agency or office deemed appropriate.

(3) The representative of the National Science Foundation shall serve as the Chairperson of the Interagency Committee.

DUTIES OF THE INTERAGENCY COMMITTEE

SEC. 108. (a) The Interagency Committee shall—

(1) survey Arctic research conducted by Federal State, and local agencies, universities, and other public and private institutions to help determine priorities for future Arctic research, including natural resources and materials, physical and biological sciences, and social and behavioral sciences;

(2) work with the Commission to develop and establish an integrated national Arctic research policy that will guide Federal agencies in developing and implementing their research programs in the Arctic;

(3) consult with the Commission on—

(A) the development of the national Arctic research policy and the 5-year plan implementing the policy;

(B) Arctic research programs of Federal agencies;

(C) recommendations of the Commission on future Arctic research; and

(D) guidelines for Federal agencies for awarding and administering Arctic research grants;

(4) develop a 5-year plan to implement the national policy, as provided in section 109;

(5) provide the necessary coordination, data, and assistance for the preparation of a single integrated, coherent, and multiagency budget request for Arctic research as provided for in section 110;

(6) facilitate cooperation between the Federal Government and State and local governments in Arctic research, and recommend the undertaking of neglected areas of research in accordance with the findings and purposes of this title;

(7) coordinate and promote cooperative Arctic scientific research programs with other nations, subject to the foreign policy guidance of the Secretary of State;

(8) cooperate with the Governor of the State of Alaska in fulfilling its responsibilities under this title;

(9) promote Federal interagency coordination of all Arctic research activities, including—

- (A) logistical planning and coordination; and
- (B) the sharing of data and information associated with Arctic research, subject to section 552 of title 5, United States Code; and

(10) provide public notice of its meetings and an opportunity for the public to participate in the development and implementation of national Arctic research policy.

(b) Not later than January 31, 1986, and biennially thereafter, the Interagency Committee shall submit to the Congress through the President, a brief, concise report containing—

(1) a statement of the activities and accomplishments of the Interagency Committee since its last report; and

(2) a statement detailing with particularity the recommendations of the Commission with respect to Federal interagency activities in Arctic research and the disposition and responses to those recommendations.

5-YEAR ARCTIC RESEARCH PLAN

SEC. 109. (a) The Interagency Committee, in consultation with the Commission, the Governor of the State of Alaska, the residents of the Arctic, the private sector, and public interest groups, shall prepare a comprehensive 5-year program plan (hereinafter referred to as the “Plan”) for the overall Federal effort in Arctic research. The Plan shall be prepared and submitted to the President for transmittal to the Congress within one year after the enactment of this Act and shall be revised biennially thereafter.

(b) The Plan shall contain but need not be limited to the following elements:

(1) an assessment of national needs and problems regarding the Arctic and the research necessary to address those needs or problems;

(2) a statement of the goals and objectives of the Interagency Committee for national Arctic research;

(3) a detailed listing of all existing Federal programs relating to Arctic research, including the existing goals, funding levels for each of the 5 following fiscal years, and the funds currently being expended to conduct the programs;

(4) recommendations for necessary program changes and other proposals to meet the requirements of the policy and goals as set forth by the Commission and in the Plan as currently in effect; and

(5) a description of the actions taken by the Interagency Committee to coordinate the budget review process in order to ensure interagency coordination and cooperation in (A) carrying out Federal Arctic research programs, and (B) eliminating unnecessary duplication of effort among these programs.

COORDINATION AND REVIEW OF BUDGET REQUESTS

SEC. 110. (a) The Office of Science and Technology Policy shall—

(1) review all agency and department budget requests related to the Arctic transmitted pursuant to section 108(a)(5), in accordance with the national Arctic research policy and the 5-year program under section 108(a)(2) and section 109, respectively; and

(2) consult closely with the Interagency Committee and the Commission to guide the Office of Technology Policy’s efforts.

(b)(1) The Office of Management and Budget shall consider all Federal agency requests for research related to the Arctic as one integrated, coherent, and multiagency request, which shall be reviewed by the Office of Management and Budget prior to submission of the President’s annual budget request for its adherence to the Plan. The Commission shall, after submission of the President’s annual budget request, review the request and report to Congress on adherence to the Plan.

(2) The Office of Management and Budget shall seek to facilitate planning for the design, procurement, maintenance, deployment and operations of icebreakers needed to provide a platform for Arctic research by allocating all funds necessary to support icebreaking operations, except for recurring incremental costs associated with specific projects, to the Coast Guard.

AUTHORIZATION OF APPROPRIATIONS; NEW SPENDING AUTHORITY

SEC. 111. (a) There are authorized to be appropriated such sums as may be necessary for carrying out this title.

(b) Any new spending authority (within the meaning of section 401 of the Congressional Budget Act of 1974) which is provided under this title shall be effective for any fiscal year only to such extent or in such amounts as may be provided in appropriation Acts.

DEFINITION

SEC. 112. As used in this title, the term “Arctic” means all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering and Chukchi Seas; and the Aleutian chain.

Appendix F: Principles for the Conduct of Research in the Arctic

Introduction

All researchers working in the North have an ethical responsibility toward the people of the North, their cultures, and the environment. The following principles have been formulated to provide guidance for researchers in the physical, biological, behavioral, health, economic, political, and social sciences and in the humanities. These principles are to be observed when carrying out or sponsoring research in Arctic and northern regions or when applying the results of this research.

This statement addresses the need to promote mutual respect and communication between scientists and northern residents. Cooperation is needed at all stages of research planning and implementation in projects that directly affect northern people. Cooperation will contribute to a better understanding of the potential benefits of Arctic research for northern residents and will contribute to the development of northern science through traditional knowledge and experience.

These "Principles for the Conduct of Research in the Arctic" were prepared by the Interagency Social Science Task Force in response to a recommendation by the Polar Research Board of the National Academy of Sciences and at the direction of the Interagency Arctic Research Policy Committee. This statement is not intended to replace other existing Federal, State, or professional guidelines, but rather to emphasize their relevance for the whole scientific community. Examples of similar guidelines used by professional organizations and agencies in the United States and in other countries are listed in the publications.

Implementation

All scientific investigations in the Arctic should be assessed in terms of potential human impact and interest. Social science research, particularly studies of human subjects, requires special consideration, as do studies of resources of economic, cultural, and social value to Native people. In all instances, it is the responsibility of the principal investigator on each project to implement the following recommendations:

1. The researcher should inform appropriate community authorities of planned research on lands, waters, or territories used or occupied

by them. Research directly involving northern people or communities should not proceed without their clear and informed consent. When informing the community and/or obtaining informed consent, the researcher should identify—

- a. all sponsors and sources of financial support;
 - b. the person in charge and all investigators involved in the research, as well as any anticipated need for consultants, guides, or interpreters;
 - c. the purposes, goals, and time frame of the research;
 - d. data-gathering techniques (tape and video recordings, photographs, physiological measurements, and so on) and the uses to which they will be put; and
 - e. foreseeable positive and negative implications and impacts of the research.
2. The duty of researchers to inform communities continues after approval has been obtained. Ongoing projects should be explained in terms understandable to the local community.
 3. Researchers should consult with and, where applicable, include northern communities in project planning and implementation. Reasonable opportunities should be provided for the communities to express their interests and to participate in the research.
 4. Research results should be explained in non-technical terms and, where feasible, should be communicated by means of study materials that can be used by local teachers or displays that can be shown in local community centers or museums.
 5. Copies of research reports, data descriptions, and other relevant materials should be provided to the local community. Special efforts must be made to communicate results that are responsive to local concerns.
 6. Subject to the requirements for anonymity, publications should always refer to the informed consent of participants and give credit to those contributing to the research project.
 7. The researcher must respect local cultural tra-

- a. Use of local and traditional knowledge and experience.
 - b. Use of the languages of the local people.
 - c. Translation of research results, particularly those of local concern, into the languages of the people affected by the research.
8. When possible, research projects should anticipate and provide meaningful experience and training for young people.
9. In cases where individuals or groups provide information of a confidential nature, their anonymity must be guaranteed in both the original use of data and in its deposition for future use.
10. Research on humans should only be undertaken in a manner that respects their privacy and dignity:
 - a. Research subjects must remain anonymous unless they have agreed to be identified. If anonymity cannot be guaranteed, the subjects must be informed of the possible consequences of becoming involved in the research.
 - b. In cases where individuals or groups provide information of a confidential or personal nature, this confidentiality must be guaranteed in both the original use of data and in its deposition for future use.
 - c. The rights of children must be respected. All research involving children must be fully justified in terms of goals and objectives and never undertaken without the consent of the children and their parents or legal guardians.
 - d. Participation of subjects, including the use of photography in research, should always be based on informed consent.
 - e. The use and disposition of human tissue samples should always be based on the informed consent of the subjects or next of kin.
11. The researcher is accountable for all project decisions that affect the community, including decisions made by subordinates.
12. All relevant Federal, State, and local regulations and policies pertaining to cultural, environmental, and health protection must be strictly observed.

13. Sacred sites, cultural materials, and cultural property cannot be disturbed or removed without community and/or individual consent and in accordance with Federal and State laws and regulations.

In implementing these principles, researchers may find additional guidance in the publications listed below. In addition, a number of Alaska Native and municipal organizations can be contacted for general information, obtaining informed consent, and matters relating to research proposals and coordination with Native and local interests. A separate list is available from NSF's Division of Polar Programs.

Publications

Arctic Social Science: An Agenda for Action.

National Academy of Sciences, Washington, D.C., 1989.

Draft Principles for an Arctic Policy. Inuit Circumpolar Conference, Kotzebue, 1986.

Ethics. Social Sciences and Humanities Research Council of Canada, Ottawa, 1977.

Nordic Statement of Principles and Priorities in Arctic Research. Center for Arctic Cultural Research, Umea, Sweden, 1989.

Policy on Research Ethics. Alaska Department of Fish and Game, Juneau, 1984.

Principles of Professional Responsibility. Council of the American Anthropological Association, Washington, D.C., 1971, rev. 1989.

The Ethical Principles for the Conduct of Research in the North. The Canadian Universities for Northern Studies, Ottawa, 1982.

The National Arctic Health Science Policy. American Public Health Association, Washington, D.C., 1984.

Protocol for Centers for Disease Control/Indian Health Service Serum Bank. Prepared by Arctic Investigations Program (CDC) and Alaska Area Native Health Service, 1990. (Available through Alaska Area Native Health Service, 255 Gambell Street, Anchorage, AK 99501.)

Indian Health Manual. Indian Health Service, U.S. Public Health Service, Rockville, Maryland, 1987.

Human Experimentation. Code of Ethics of the World Medical Association (Declaration of Helsinki). Published in *British Medical Journal*, 2:177, 1964.

Protection of Human Subjects. Code of Federal Regulations 45 CFR 46, 1974, rev. 1983.

Appendix G: Acknowledgments

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Back Cover *Hanging glacier and fireweed, Portage Arm, Alaska.*

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