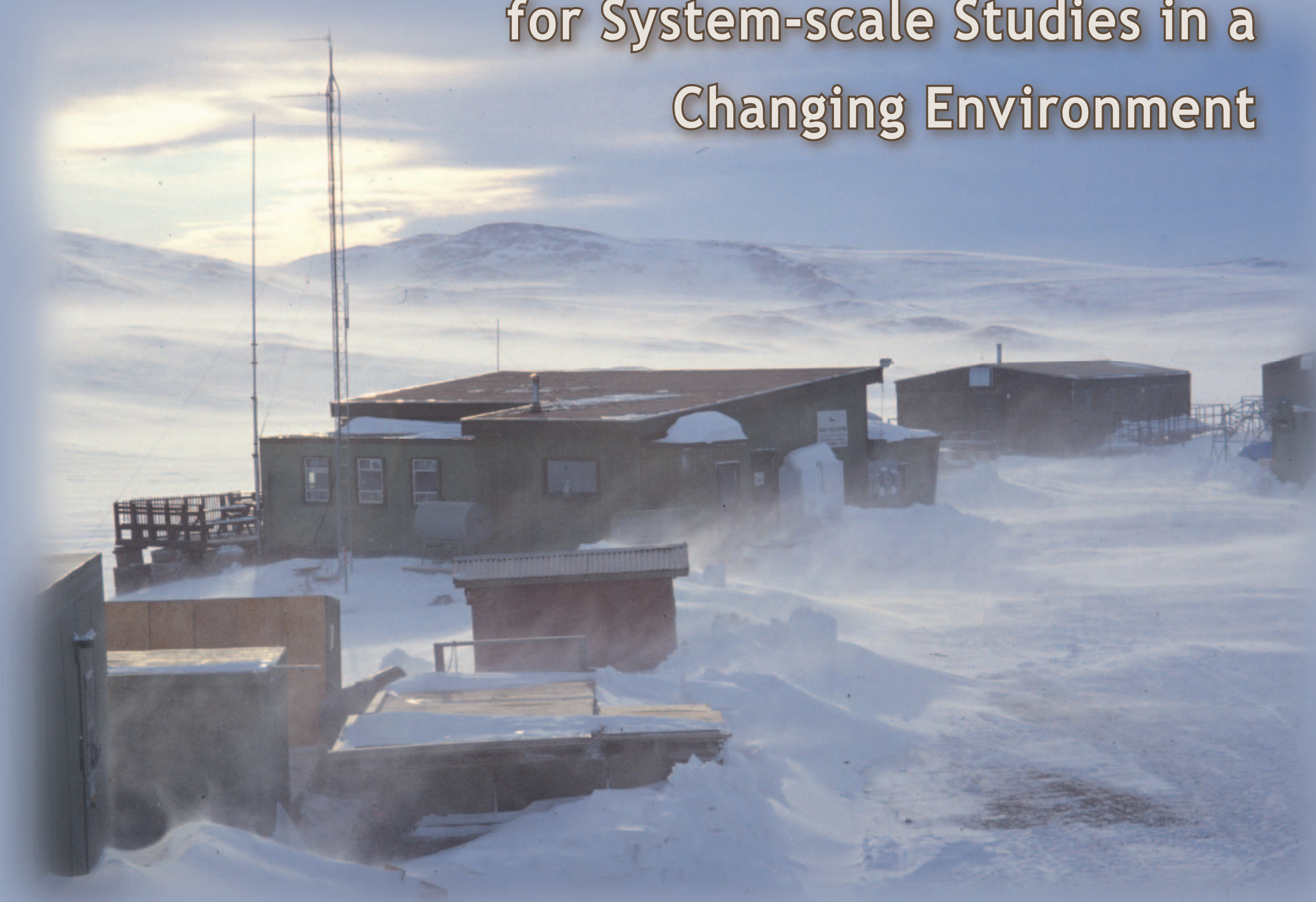
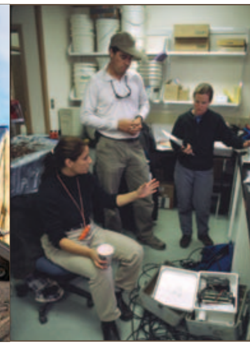
Arctic Research Support and Logistics

Strategies and Recommendations for System-scale Studies in a Changing Environment

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Cover photo: Toolik Field Station in an April snowstorm. Photo by James H. Barker, © 2002, courtesy of University of Alaska Fairbanks Institute of Arctic Biology.

Overleaf photos, left: The Barrow Arctic Science Consortium (BASC) provides logistical support to scientists working in the Barrow area. Photo courtesy of VECO Polar Resources. Center: Diane Sanzone, Adrian Green, and Kevin Barnes discuss their plans for deploying a data logger at their field site in the Arctic National Wildlife Refuge. Photo by James H. Barker, © 2002, courtesy of University of Alaska Fairbanks Institute of Arctic Biology. Right: Lou Codispoti recovers a rosette during the spring 2002 Shelf-Basin Interactions cruise on the USCGC Healy. *Photo by Robert Palomares, courtesy of Scripps Institution of Oceanography, University of California San Diego. Bottom: On Iglosiatik, an island south of Nain, Labrador, Bowdoin College undergraduate Ned Searles waits for a boat charter. Searles worked on an excavation of an Inuit sod house on the island. Photo by Susan Kaplan.*

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Above: Patrick A'hearn skirts melt ponds on the sea ice during the Surface Heat Budget of the Arctic Ocean (SHEBA) project. Photo courtesy of University of Washington. Facing page, left: Barrow Arctic Science Consortium (BASC) logistics coordinator Dave Ramey tows a disabled boat back to Barrow. Photo courtesy of VECO Polar Resources. Center: Karina Clemmensen and Martin Sommerkorn pick and sort plant roots and mycorrhizae from soil cores taken in tussock tundra at Toolik Field Station. The experiment depends on the infrastructure available at the station, including electricity and instruments such as liquid scintillation counters and gas chromatographs. Photo by Richard Flanders. Right: A C-130 Hercules delivers a new generator module to the camp at Summit, Greenland, in 2001. Photo courtesy of VECO Polar Resources.



Foreword

This document updates a report published in 1997, *Logistics Recommendations for an Improved U.S. Arctic Research Capability* (Schlosser et al., 1997). The update summarizes the progress made in improving research support since 1997 and responds to changing needs for arctic logistics and research support since the earlier report was published. The recommendations were assembled by the members of the Research Support and Logistics Working Group (Appendix D), with input from the arctic research community in the form of survey responses (Appendix C), discussions at meetings and workshops, and comments on a draft of this report.

This document is intended for use by all federal agencies with interests in the Arctic, as well as by Congress, in helping to develop and improve arctic research support. We intend this to be a continuation of a living document that will require future updates as research priorities change and logistics and research support assets continue to improve.

The arctic research community has made many contributions that have improved each version of this report. ARCUS Executive Director Wendy Warnick has been a guiding force in the report's development, and the skillful editing and science insight of Alison York and design and technical assistance from Sue Mitchell are much appreciated. The active participation and important contributions of the working group included soliciting information from the broader research communities that each member represented. Finally, we are grateful to the National Science Foundation for sponsoring ARCUS to produce this report and providing the opportunity for the arctic research community to articulate its research support needs.

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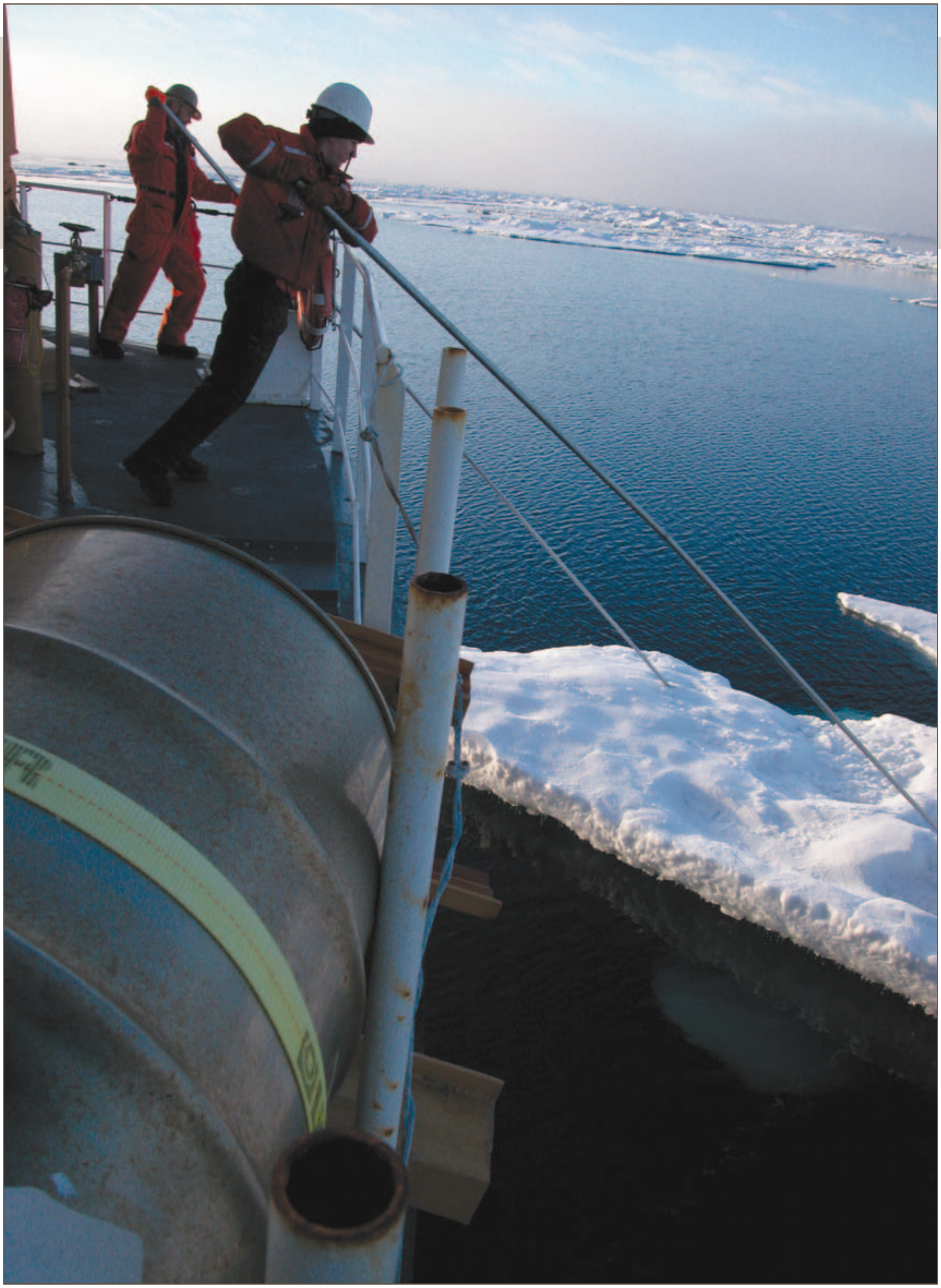
October 2003



Above: Peter Lane (University of Miami) and Suzanne Scriven (USCG) push an ice floe away from the stern of the Healy *during a plankton tow on the 2002 Shelf-Basins Interaction (SBI) project. Photo by Carin Ashjian. Facing page, left: Researchers from Louisiana State University collect data on a bowhead whale harvested by residents of Barrow. Photo by Daniel Hillman. Center: A load of cargo for the summer 2002 field site at Ivotuk on Alaska's North Slope. Photo courtesy of VECO Polar Resources. Right: Mike Abels drills through the ice in May 2002 to collect water samples from Toolik Lake. Photo by Richard Flanders.*



Executive Summary

The Arctic contains vast amounts of frozen water, much of which is close to melting. In the form of sea ice, snow, glaciers, and permafrost, this water defines both the character of the region and the physical limits of arctic plant, animal, and human life. Changes in the delicate thermal balance of the Arctic will have dramatic consequences for life in the region as well as global ramifications through changes in the reflection of solar radiation, the freshwater cycle, patterns of ocean circulation, and the cycling of greenhouse gases.

Both arctic residents and scientists have observed considerable environmental change in the region over the past several decades, including warming air temperatures, shrinking sea ice cover, thawing permafrost, decreasing snow cover, and melting arctic glaciers. These physical modifications have resulted in biological changes, including changes in types of vegetation, northward migration of the tree line, and declines in fisheries and marine mammal populations, all of which affect subsistence hunting and gathering. The associated potential increases in high latitude marine transportation and exploitation of natural resources are likely to have large social and economic impacts in and outside the Arctic.

Because much of the region is remote and subject to extreme climatic conditions, carrying out research on these issues in the Arctic requires substantial resources. Access is often expensive and entails detailed planning. Safety is a paramount issue. Concerns about the adequacy of logistics support for arctic research resulted in a 1997 report, *Logistics Recommendations for an Improved U.S. Arctic Research Capability* (Schlosser et al., 1997), which elucidated the arctic logistics needs of the academic research community and presented appropriate recommendations to meet those needs. This document is an update of the 1997 report. Since then, substantial progress has been made in year-round access for researchers, in protecting health and safety, and in improving collaboration and communication between researchers and arctic residents. Indeed, this progress is partially responsible for the scientific evidence documenting the rapid environmental changes occurring in the Arctic. Improved research support also has facilitated substantially more process studies, observations, and surveys. Despite improvements, however, research support has not kept pace with the demand for and nature of the research required to adequately document and understand the rapidly changing arctic environment.

Model studies indicate that the Arctic will be especially sensitive to global change and may indeed be a harbinger of climate change. The region may also provide important indicators of the impacts of human activities on climate and the environment. Understanding arctic change and its links to the global environment will require increases in long-term observational capabilities. It also will require process-oriented research designed to understand specific features or functions of the system; for example, the Arctic Ocean remains the least studied of the world's oceans, and little is known of its geologic origins and history. In addition, paleoenvironmental data is required to understand and place modern environmental change into the context of past changes.

The need to monitor change, to understand the causes of change and their links to the global system, and to fill scientific gaps such as our limited knowledge of the geophysics of the Arctic Basin has led to new logistics and research support requirements. An expansion of research support and logistics is needed to enable research in the Arctic that entails large-scale, long-term observational components and system-scale synthesis and modeling activities. This expansion includes beginning to organize and connect a distributed pan-arctic observing network. Coordination, planning, and resources will be needed to develop such a network. At the same time, traditional logistics support continues to be the critical underpinning of successful arctic research, and sustaining it remains paramount. The range of research support and logistics needs identified during the development of this report can be served by three broad strategies:

- supplying critical components for development of a pan-arctic perspective,
- supporting the basic infrastructure for safe and efficient research, and
- maximizing resources and cooperation.

The associated major recommendations to implement these strategies and meet the arctic research community's support and logistics needs are:

1. Supplying critical components for development of a pan-arctic perspective

Plan, implement, and support an arctic observing network. An international arctic observing network is the best means of linking current and new resources and existing networks to maximize long-term observations over a broad geographic area and disciplinary spectrum. A distributed network of long-term observation sites is essential to determining how change is affecting the natural and social aspects of the environment. The network is necessary to establish patterns of change, evaluate the magnitude of the change, provide understanding of individual processes, and determine linkages to other global systems.

Facilitate access to distributed systems of hardware, software, information bases, and automated aids for data management, synthesis, interpretation, and modeling. Enabled by information technology, a qualitatively new and different scientific infrastructure has developed in recent years. This infrastructure allows researchers to use advanced data assimiliation and curation, networking, and simulation tools. It allows modeling efforts, which are crucial to understanding the context of observations, to be more closely integrated with observations. Access to these tools is critical for modern arctic research.

Improve communication and data transmission capabilities, remote field power options, and access to satellite observations. The severe environment and high latitudes continue to make communication and data transmission a major issue. Remote locations need clean, portable, dependable power sources with increased capacity. Better access to satellite observations will enhance science and improve safety and efficiency of field operations.

2. Supporting the infrastructure for safe and efficient research

Continue to improve access by supporting, expanding, and upgrading marine and terrestrial facilities. Continued investments in existing platforms, new facilities, and improved access are necessary to accommodate the increased level of research associated with climate change as well as fundamental research efforts. Year-round access is especially important for a clear picture of seasonal variation of parameters and processes and for establishing and maintaining manned and autonomous observation stations. Access to remote terrestrial and marine locations is necessary for research on many issues, including the geological evolution of the arctic region. Scientific oversight of fixed instrumentation and data collection and analysis can add significantly to available high-quality observations.

Support safety training and planning. Providing researchers with proper training, equipment, and contingency plans to handle emergencies is crucial.

3. Maximizing resources and cooperation

Facilitate international coordination and cooperation. Collaboration with international colleagues and their sponsoring agencies is the only means by which an arctic-wide observation network can be established. International collaboration is also essential in developing an understanding of individual elements of the Arctic through process studies.

Pursue interagency collaborations. Since support for long-term observations in the Arctic exceeds the capacity of a single agency, this responsibility must be balanced appropriately among arctic research agencies. Shared use of platforms and facilities among agencies can foster collaborations and increase efficiency.

Enhance communication and partnerships with arctic communities. Arctic research activities focus on and improve understanding of their surroundings, and arctic residents are stakeholders in many arctic research projects. Local residents contribute vital knowledge and skills to the planning, execution, and relevance of research programs.

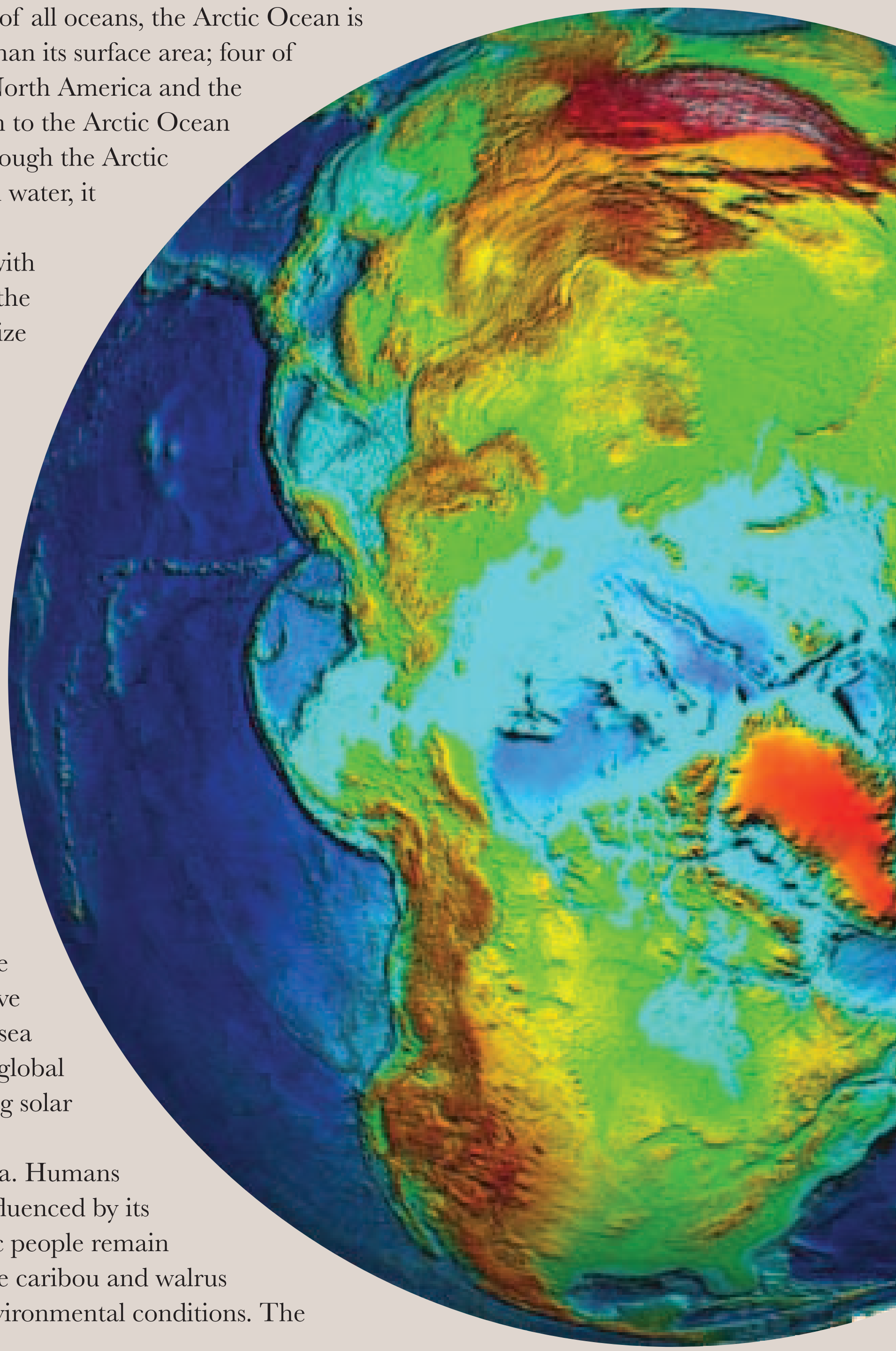
Maintain and disseminate arctic expertise and train the next generation of arctic field experts. Experienced arctic field scientists, engineers, and technicians are critical to assure the success of a field program.

These recommendations, which are discussed in more detail in Chapter 3, will strengthen needed research capabilities in the Arctic and foster the development of essential research support infrastructure.

The Arctic Region

Subject to extreme seasonal cycles of photoperiod and temperature, the northernmost region on Earth centers on a cold, ice-dominated ocean surrounded by continental land masses and islands. The least studied of the world's oceans, the Arctic Ocean's geologic origins and history are not well understood. The Arctic Ocean is connected to the global ocean by narrow straits. Water flows in and out of the Arctic Ocean through the Fram Strait between Greenland and Norway, through the Bering Strait, and through the Canadian Archipelago.

The most river-influenced and landlocked of all oceans, the Arctic Ocean is the only ocean with a drainage area greater than its surface area; four of the world's major rivers—the Mackenzie in North America and the Lena, Ob, and Yenisei in Eurasia—flow north to the Arctic Ocean through the northern continental plains. Although the Arctic Ocean contains only 1% of the world's ocean water, it receives 11% of world river runoff.



The interactions of arctic ocean currents with the atmosphere influence climate patterns in the Northern Hemisphere. Scientists now recognize a repeated swing between high and low atmospheric pressure over the Arctic. Called the Arctic Oscillation, this may be a "master switch" for northern climate, similar to the widespread effects of El Niño at lower latitudes.

Frozen water in various forms is prominent in the Arctic; these include sea ice, snow, glaciers, ice sheets, and permafrost (permanently frozen ground). The arctic system's thermal state is nearly centered on the critical threshold of the freezing point of water. When this threshold is crossed, many components of the system change fundamentally. Changes in the balance of time during which the thermal state of the arctic environment is above and below this threshold will dramatically alter the functioning of the system and are likely to have significant global ramifications. For example, sea ice and snow cover have major effects on the global climate because they reflect much of incoming solar radiation.

People have lived in the Arctic for millennia. Humans both affect the arctic environment and are influenced by its physical and biological processes. Many arctic people remain dependent on keystone subsistence species like caribou and walrus that are extremely vulnerable to changing environmental conditions. The circumpolar Arctic contains natural resources significant to the world economy, including oil, gas, diamonds, coal, gold, zinc, and other minerals. Changes in arctic climate could substantially affect resource extraction, shipping, and other development. These in turn could have profound implications for the arctic environment and people.

Solar wind particles and solar-terrestrial electric fields cause the aurora borealis, which can result in loss of communications, loss of networked electric power, and irregular behavior of global positioning systems (GPS) systems in the Arctic during energetic geomagnetic storms.

Studies have shown that arctic climate and ecosystems have changed substantially over the past several decades. Among the most obvious changes are warming air temperatures and a shrinking sea ice cover. Both scientists and arctic residents have observed these changes. Over the Arctic Ocean these significant changes include westward migration and intensification of warm Atlantic water, a substantial shift of normal ice drift patterns, thinning of the ice cover, a decrease in atmospheric pressure, and changing wind patterns. Observations on land have revealed reductions in snow cover, warming and thawing permafrost, and shrinking arctic glaciers. These modifications of the physical environment are also causing biological changes. They include changes in vegetation (e.g., more shrubs), northward migration of the tree line, and declines in fisheries and marine mammal populations with a concomitant impact on subsistence hunting. The physical and biological changes affect arctic and subarctic residents directly through changes in income, traditional subsistence harvesting methods, and quality of life. Potential increases in marine transportation and more feasible exploitation of natural resources will have large societal and economic impacts both in and outside of the Arctic.

Paleoenvironmental records from arctic ice cores and other sources tell a story of a region that has repeatedly undergone profound changes in the past. Modern environmental changes must be placed into the context of paleoenvironmental data and the Arctic's geologic history to develop an understanding of the region's role and response to natural global change.

Changes occurring in arctic climate will have global consequences through the ocean circulation, the ice cover, the freshwater cycle, and the cycling of greenhouse gases, especially carbon dioxide, methane, and carbon monoxide. The physical changes observed in the Arctic and the processes underlying those changes are closely connected to changes in the Northern Hemisphere and may have cascading effects in lower latitudes. Moreover, since the Arctic is predicted to be especially sensitive to global warming, it may be the harbinger of climate change and one of the best places on Earth to detect the effects of human activities on climate and the environment.

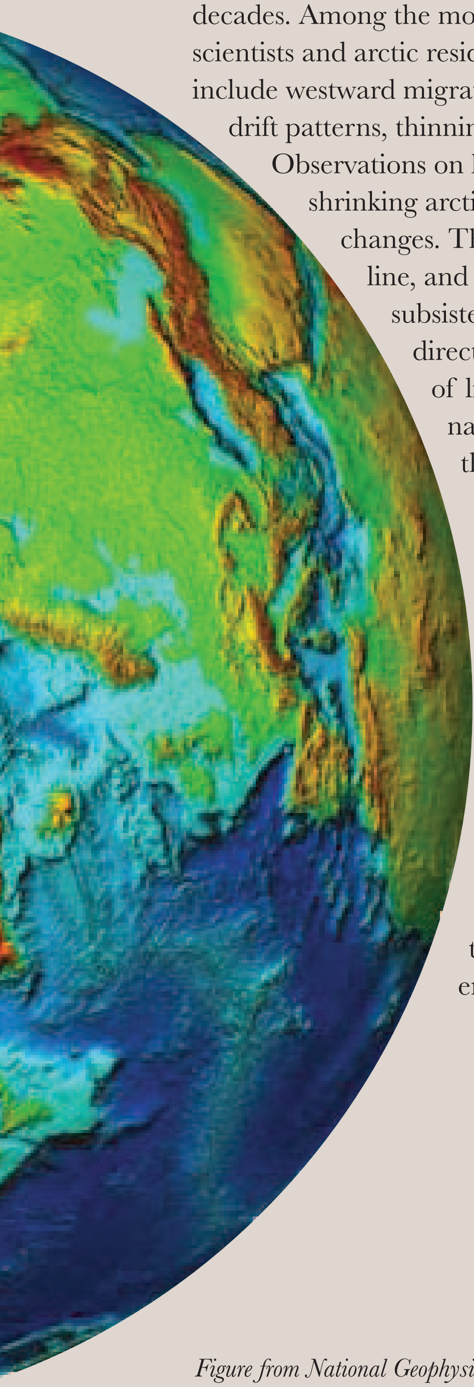
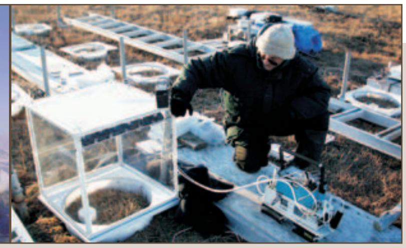


Figure from National Geophysical Data Center, National Oceanic and Atmospheric Administration.

Above: Historic Black Rapids roadhouse provides a staging area for Keith Echelmeyer's project on the motion of Black Rapids Glacier. VECO Polar Resources arranged for over 30,000 pounds of gear to be flown to Echelmeyer's field site in the Alaska Range. Photo courtesy of VECO Polar Resources. Facing page, left: Housed in this drill tent, the University of Utrecht's drill took a 60-meter core on Lomonsovfonna summit, Svalbard, in May 2000. Photo by Kathryn Matthews. Center: the USS Hawkbill *surfaces at the North Pole during the 1998 SCICEX expedition. Photo by Bernard Coakley. Right: Dmitri Karelin works at the San Diego State University tundra manipulation site in Barrow. Photo by Rommel C. Zulueta.*





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Logistics Support for Arctic Research

In addition to basic science costs, arctic research projects typically require significant logistics support to provide investigators with safe access to some of the most remote places on Earth. In the past, logistics costs consumed approximately 30% of the National Science Foundation (NSF) funding available to support arctic research. In most cases, individual investigators included the logistics costs as part of their research proposal budget and made their own arrangements to meet each project's logistics needs. Although scientists funded by NSF managed to carry out a tremendous amount of high-quality arctic research under this funding structure, the often ad hoc logistics arrangements and assets were limited and fairly inefficient.

With the FY 1999 budget, the funding level and structure for arctic research logistics at NSF changed. Responding in part to the 1997 publication of *Logistics Recommendations for an Improved U.S. Arctic Research Capability* (box page 6), Congress provided NSF with new ongoing funding for arctic logistics ($22 million in FY 1999, gradually increasing to $29 million by FY 2003), and the Arctic Sciences Section of the NSF Office of Polar Programs developed a program in Arctic Research Support and Logistics (RSL) to complement its science programs (pages 4–5 and Appendix B).

The significant investments in arctic research support and logistics made by NSF with these funds have allowed substantial progress on many of the scientific issues outlined in *Logistics Recommendations for an Improved U.S. Arctic Research Capability.* For example, improved access to the central Arctic Ocean has supplied fundamental knowledge of the Arctic's tectonic origins and wealth of natural resources. Notably, the logistics improvements helped investigators as they acquired a growing body of evidence indicating rapid changes in the arctic environment. Evidence from many sources has revealed significant changes over the past two decades across the arctic environment—in the arctic seas (including chemical composition, biological productivity, and ice cover), in the permafrost, and in the vegetation. These changes are strongly linked to, and may be caused by, climate change and shifts in atmospheric circulation and have resulted in changes in the health and population size of organisms in arctic environments.

The changes are already affecting arctic residents, their livelihoods, and their food resources, and are likely to ultimately affect other regions of the globe. This in turn has led to many pressing new questions; addressing these has stimulated more research, requiring investigators to work in new and more places and at more frequent intervals. The need to understand the rapidly changing arctic environment has led to a substantial increase in both long-term studies that monitor aspects of the arctic system and process-oriented research that investigates fundamental features or functions of the system. A better scientific understanding of the arctic system depends on contributions from both long-term studies and process-oriented research. Observations of change are limited in their usefulness without knowledge of the processes underlying the change. This two-pronged research strategy is essential to understanding the nature and the cause of the observed changes and appropriate adaptation or mitigation strategies. Modern observations also must be placed in context through paleoenvironmental studies, which allow us to reconstruct the evolution of the system.

Above all, the evidence of rapid change in the Arctic points to an urgent need for continuous, long-term, and spatially complete observation records from which rates of change and variability can be derived. Paradoxically, the scientific demand for such records has arisen as agency and governmental support for sustaining existing long-term observations has dropped. Examples include declining resources to support upper-air observational networks in Canada, ice stations in Russia, and hydrological monitoring (box page 13). Key measurements have been discontinued, compromising our ability to understand processes operating at longer temporal and larger spatial scales and to make progress in prognostic modeling. Many of the existing long-term datasets are unavailable. Some submarine-gathered data remain classified, much oil industry data is proprietary, and other long-term datasets are relatively inaccessible.

We are now at a critical juncture: there is a clear path toward understanding processes and the cause-and-effect relationships that will allow us to inform policy makers on likely future developments of the arctic system and their social and economic consequences, but the basic observations needed to drive and test simulations by models are not available at the required spatial and temporal resolution and scope. Because the arctic research community

A Definition of Research Support and Logistics

Research support and logistics refers to activities that contribute to the research endeavor, but are not normally considered actual research. Logistics, derived from military terminology, is understood as moving personnel, equipment, and supplies to a research site, and lodging and supplying researchers while they are in the field or at sea. In addition to this “traditional” definition of logistics, a number of related activities are required for effective arctic research support. These activities tend to be difficult or impossible for individual investigators to address and include:

- instrument, technology, and platform development;
- project coordination and planning;
- training for field operations and safety;
- improving access to computing capacity, datasets, and modeling results;
- developing international and interagency agreements and relationships to improve access to specific regions within the Arctic and to share resources;
- responding to permitting processes;
- providing power and communications to remote locations; and
- public outreach—particularly to arctic communities.

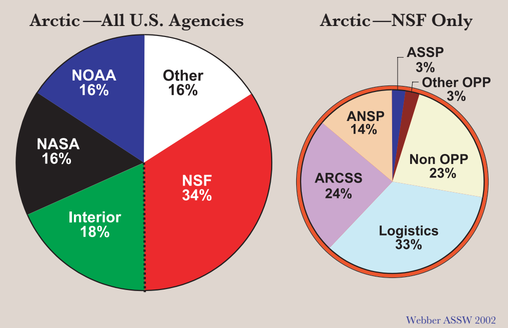
identifies this as primarily a research support and logistical problem (Appendix C), we recommend that the development and long-term maintenance of a distributed arctic observing network be one of the chief goals of future investments in arctic research support and logistics.

At the same time, we recognize that access and safety remain fundamental to successful arctic research and need attention now more than ever. Access to the Arctic is expensive and requires both detailed planning and flexibility. Safety in extreme environmental conditions remains a paramount issue. Because of the increased activity level, science needs have overwhelmed current research support capabilities and have forced limitations on the implementation of some high-priority U.S.-based programs. The demand and responsibility for long-term observations and a larger observation network cannot be met by the NSF alone. Other U.S. agencies must join with the NSF in supporting the sustained observations and research necessary to better understand the arctic region and its relationship with the rest of the world. In addition, the U.S. must be able to contribute to and collaborate in international arctic programs, including reciprocal logistics support as appropriate.

NSF's Role in Arctic Research

Investigators supported by many federal, state, and local agencies perform work that could be termed arctic research. The 1984 Arctic Research Policy Act designates the National Science Foundation (NSF) as the lead federal agency for arctic research. Within NSF, arctic research interests are concentrated in the Office of Polar Programs (OPP). Since 1995, OPP has included an Arctic Sciences Section. Other NSF divisions and programs also support arctic research as part of their overall funding. In 1998, for example, NSF provided a total of $49.01 million to fund 362 arctic research projects; $31.6 million of this came from the Arctic Sciences Section of OPP. In 2002, total NSF funding for arctic research was $85.99 million; $62.43 million of this was funded by the OPP Arctic Sciences Section.

United States Federal Funding for Arctic Research (estimates for 2002)



The National Science Foundation (NSF), Department of the Interior, National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA) provide the majority of federal funds for arctic research. Within the NSF Office of Polar Programs (OPP), the Arctic Sciences Section includes the Arctic Natural Sciences Program (ANSP), Arctic System Science Program (ARCSS), Arctic Social Sciences Program (ASSP), and the Arctic Research Support and Logistics (RSL) Program. Figure courtesy of Pat Webber.

Summary: Progress in Arctic Research Support and Logistics since 1997

In 1999, the U.S. Congress appropriated $22 million for the NSF to establish an Arctic Research Support and Logistics (RSL) Program. The first priority of the RSL program is to support the science projects reviewed and recommended for funding by the NSF Arctic Sciences Section, other NSF programs that support arctic research, and those of other agencies. Other priorities are to build research support infrastructure, improve access to all parts of the Arctic, foster investigator safety, and invest in coordination and communication.

Currently, approximately one third of the RSL program's funds are distributed over more than 100 grants to support logistics costs of research projects. Approximately half of the remaining resources fund developments in safety, facility improvements, and third party logistics providers to provide project support, including use of research vessels, field stations, and regional logistics providers. The remainder is used for organizational research support and coordination. Additional details on the following topics can be found in Appendix B.

Major platforms and access. Access to the Arctic Ocean improved greatly with the start of operations of the U.S. Coast Guard research icebreaker *Healy* in 2001. In October 1998, researchers completed a full year of field work on the pack ice during the Surface Heat Budget of the Arctic Ocean (SHEBA) project. The High Latitude Dynamics Program of the Office of Naval Research offered time in April 2003 at a Navy ice camp north of Prudhoe Bay, Alaska. NSF supported the establishment of a North Pole Environmental Observatory in 2000.

Winter work has been possible at the Summit field camp in Greenland since 1997, and the camp will operate year-round for at least the next three years. Toolik Field Station added winter accommodation in 1998. VECO Polar Resources (VPR) has established and operated temporary field camps in Alaska, Russia, and Greenland; VPR's inventory of camp equipment is available to NSF projects. In the Barrow area, the Barrow Arctic Science Consortium (BASC) provides NSF researchers with year-round logistics support and excellent connections to the local community. Helicopters are now routinely used on the North Slope of Alaska to support groups based out of Barrow, Toolik, and more remote sites.

In Russia, the Northeast Science Station, under contract to VPR, is a base for U.S. researchers working near the mouth of the Kolyma River. Kangerlussuaq continues to be a base for NSF and NASA projects in Greenland. The Canadian Forces base at Alert on Ellesmere Island supports an increasing number of U.S. projects. NSF and other agencies are developing agreements with international counterparts to provide access to other non-U.S. stations and facilities.

Instrumentation and technology. Two special OPP competitions, Long-term Observatories (1999) and Polar Instrumentation (2001), addressed the development of instrumentation and technology for polar research. Funded projects through this and other programs are developing and deploying innovative ways of collecting data, including autonomous underwater vehicles (AUVs), ocean gliders, ice and bottom anchored moorings, an autonomous cloud observing lidar, new autonomous meteorological stations, and a small, light-payload unmanned aerial vehicle (UAV).

Communications and information technology. The RSL Program has supported improvements to meet the increasing information technology needs of the arctic research community, including collecting and accessing high-precision spatial data, high-speed data transmission, and networking capability. Improvements by BASC in the Barrow area include a differential GPS system, a high speed Internet link (extended on a wireless radius of nearly 25 miles), and a web-based mapping interface with locations of over 2,100 research sites. The Toolik Field Station completed a major communications upgrade in 2001, providing phone and both wireless and hard-wired Internet access. Since 2001, a full-time GIS manager has been assembling spatial data and products for the Toolik area. The Summit, Greenland, site now has Internet and phone service and a wireless local-area network. Through VPR, SRI International can provide field communications services to projects, including VHF and HF radios, data collection and transmission systems for autonomous instruments, satellite telephones and mobile ISDN units, and VSAT systems for large field camps.

The Arctic Logistics Information and Support (ALIAS) project, developed by ARCUS, provides an online source of logistics information for research in the circumpolar Arctic (www.arcus.org/alias).

Safety. VPR offers free field safety courses at a variety of locations. VPR contracts with Medical Advisory Systems to provide researchers with remote medical services, including access to physicians and a field first aid kit. By 2002, VPR made satellite telephones available to all teams working in remote areas. Safety equipment and local expertise are available on Alaska's North Slope through BASC and in Chukotka, Russia, through the Chukotka Science Support Group.

Community relations. The *Principles for the Conduct of Research in the Arctic* (www.nsf.gov/od/opp/arctic/conduct.htm) establish standards of communication and collaboration with local communities for arctic researchers. NSF has tasked BASC and the Alaska Native Science Commission to help researchers make contacts and carry out the principles. Draft *Guidelines for Improved Cooperation Between Arctic Researchers and Native Communities*, under development by NSF, will help researchers work with local communities to avoid impacts to subsistence activities and to threatened or endangered species

International cooperation. In partnership with the U.S. Civilian Research and Development Foundation, NSF has established an office in Moscow to provide on-site support of NSF-sponsored cooperative activities in Russia. NSF has agreements for shared access to research facilities and coordination of research efforts with the Norwegian Polar Institute, Norwegian Research Council, Iceland, and the European community. New agreements with Denmark, Greenland, and Russia are in progress. The International Arctic Science Committee has supported the development of a Forum of Arctic Research Operators (www.faro-arctic.org/) to optimize logistics and operational support for scientific research in the Arctic through international collaboration.

Interagency collaboration. Examples of interagency collaboration include the planning process for scheduling *Healy* between the Coast Guard and NSF, NOAA, and other agencies. NSF and NASA share logistics resources in Greenland, including use of the 109th Air National Guard flight support.

History of Recommendations

In 1995, concerns about the adequacy of logistics support for arctic research resulted in an assessment sponsored by the U.S. Arctic Research Commission (USARC) and the National Science Foundation (NSF). This effort was organized by the Arctic Research Consortium of the United States (ARCUS). ARCUS formed a Logistics Working Group (LWG) made up of scientists representing a broad spectrum of arctic research disciplines. The LWG gathered information from the U.S. arctic academic research community to:

- assess the resources available to support U.S. arctic research,
- determine the degree to which arctic science was limited by inadequate logistical support,
- describe the science-driven logistics needs for the next decade, and
- develop specific recommendations to improve logistical support for U.S. arctic research.

ARCUS published *Logistics Recommendations for an Improved U.S. Arctic Research Capability* in 1997 (box this page). The report was intended for use by all federal agencies with research interests in the Arctic, with an emphasis on the National Science Foundation Office of Polar Programs (NSF-OPP). The Arctic Sciences Section of OPP is the primary sponsor of arctic research among the federal research agencies (box page 3).

The report had a significant impact on the opportunities for new and ongoing arctic research in a wide range of disciplines. Congress responded to the report by adding $22 million in new funding, specifically designated for arctic research logistics support, to the FY 1999 NSF budget. The funding increment, which has increased gradually in subsequent years to $29 million by FY 2003, enabled OPP to develop the Arctic Research Support and Logistics Program (RSL) to organize and supply the support necessary for its arctic science programs (pages 4–5, Appendix B).

The 1997 Logistics Report

Logistics Recommendations for an Improved U.S. Arctic Research Capability (Schlosser et al., 1997) elucidated the science-driven arctic logistics needs of the academic research community and presented recommendations to meet those needs (Appendix B). The 1997 report outlined five general recommendations that have guided the overall development of the RSL Program. These five recommendations are:

- Ensure access to the Arctic over the entire year.
- Increase availability and use of remote and autonomous instruments.
- Protect the health and safety of people conducting research in the Arctic.
- Improve communication and collaboration between arctic peoples and the research community.
- Seek interagency, international, and bilateral logistics arrangements to efficiently use all available resources and to reduce costs by avoiding duplication of efforts.

Logistics Recommendations for an Improved U.S. Arctic Research Capability is available in hard copy and electronic form from ARCUS: www.arcus.org.

Updating the 1997 Report

The ARCUS Logistics Working Group envisioned the 1997 report as a living document that would require periodic updating as scientific priorities shifted and technology improved. Within a few years of the publication of the 1997 report, science priorities had shifted significantly, and an update of the assessment of arctic research support and logistics was required. The environmental changes that have been observed in the Arctic and the scientific programs to investigate those changes present pressing research needs that cannot be adequately addressed with the current research support and logistics infrastructure. In addition, continuing difficulties in accessing key areas of the Arctic have slowed scientific progress in some disciplines. A relevant example is current understanding of the geophysics of the Arctic Basin, discussed in Chapter 2 of this report.

This document represents an update of the 1997 report on arctic logistics, developed in response to changing needs for arctic research support and logistics. In this report we describe the logistics and research support that will be needed to address the important science issues that the arctic research community will be investigating over the next decade. The report provides background information on arctic research support and logistics (Chapter 1), considers the major challenges and opportunities facing arctic scientists (Chapter 2), and outlines strategies and specific recommendations (Chapter 3) for effective support of arctic research.

This report was produced following a process similar to that used for the previous assessment of arctic logistics needs. ARCUS again formed a working

Guiding Principles

The present update follows two fundamental principles:

Logistics development must be science-driven. As in the 1997 report, scientific issues and the support required to address those issues should determine research support and logistics recommendations. Although this report cannot provide a comprehensive assessment of arctic science priorities, Chapter 2 identifies and summarizes the science issues that are likely to be important for the next decade. While some topics are similar to those identified in the 1997 report, others reflect an evolution in scientific questions and the approaches taken to address them. For instance, the significant increase in observational evidence of environmental change in the Arctic across a number of disciplines has intensified scientific emphasis on documenting change and variability in the context of previous observations. Recognizing patterns or cyclic behavior related to change has also become more urgent.

Investments must include research support as well as traditional logistics. While traditional logistics concerns, such as access to research platforms, retain their fundamental importance to the success of arctic research, other types of research support are needed for the development of a more complete understanding of a process or system. Research support includes such activities as providing access to data distribution, archiving, and management systems. The results of our community survey (Appendix C) indicate that investigators consider many of these issues critical to effective research support. This expanded definition of research support is directly related to the increased scientific emphasis on issues of environmental change and variability, and augments the need for traditional logistics support.

During the summer of 1998, SHEBA investigators had to float instruments and structures on barrels when the ice melted out from under them. Photo courtesy of University of Washington.

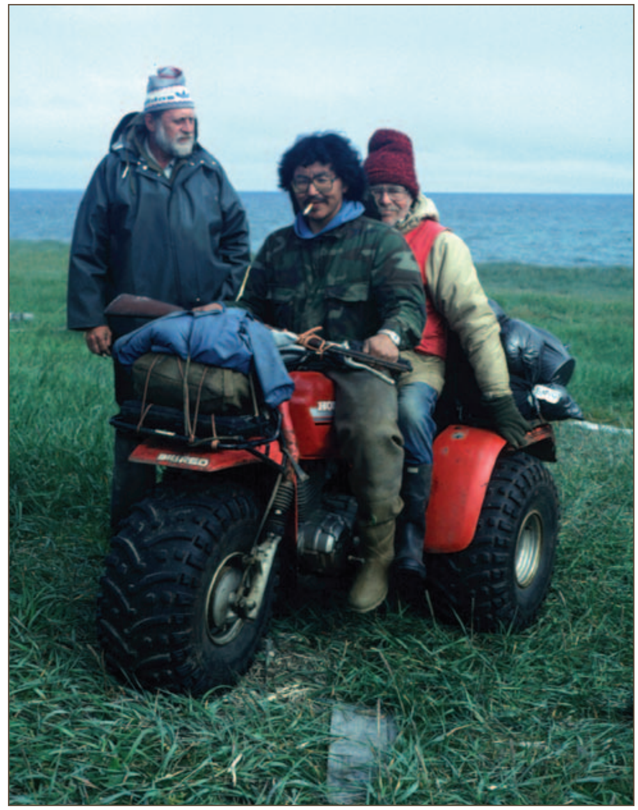
group consisting of arctic scientists spanning a broad range of research disciplines. The membership of the Research Support and Logistics Working Group (RSLWG), as well as other key contributors to the process of developing this report and recommendations, is listed in Appendix D. The group solicited input on current science issues and research support and logistics needs from the community through a web-based survey, open discussions at several scientific meetings, and direct input to group members. Recent planning documents produced by various steering committees and meeting reports were important to the process of identifying pressing science issues and support needs. Community review of previous drafts of this document provided essential information.

Community input to this report clearly pointed out that long-term, integrated research is essential to understand the causes and effects of the rapid changes occurring in the Arctic. This report, therefore, differs significantly from the previous report in three major ways. First, this report outlines science issues and concomitant research support and logistics needs from a thematic perspective, rather than the disciplinary point of view used in the 1997 report. This perspective generally follows themes identified in the 1998 report *Opportunities in Arctic Research* (ARCUS, 1998). Second, the scope of the report encompasses a broader definition of research support, consistent with the changing nature of the present issues in arctic research (box previous page). While traditional logistics remain fundamentally important in successful arctic research, other types of research support are needed to integrate our understanding of scientific questions into a systems perspective. High-speed data access, geographic data infrastructure, sustained time-series observations, and access to modeling results are among the essential types of support identified in this report. Third, the need to observe and understand the temporal evolution of the arctic system is reflected in the recommendation to institute a circumarctic observing network. Establishing such a network will require a major effort to convert the sparse patchwork of existing observation sites into a coordinated system capable of resolving the primary features of

Sergei Zimov finishes installing instruments on an eddy flux tower near the Northeast Science Station in Cherskii, Siberia. Photo courtesy of VECO Polar Resources.

the arctic system with adequate temporal and spatial resolution and scope. This effort will require significant enhancement of data assimilation and simulation capacity in addition to new observing devices and technologies and international collaboration.

While substantial progress has been made in arctic research support and logistics since the 1997 report, we reemphasize here some of the same areas of support that were identified in the earlier report. Two areas that remain critically in need of improvement are international collaboration and interagency cooperation. These areas are important for successfully conducting arctic research over large spaces and long time scales. With a major focus of arctic research on the understanding of arctic environmental change, interagency support is crucial, since neither NSF, nor any individual agency, can be expected solely to support the necessary long-term observations. Likewise, international collaboration has become increasingly important to supporting circumarctic observations, to improving access to critical areas not currently accessible, and to maximizing the use of precious logistical resources of all interested nations.



Research in remote areas often requires assistance with transportation from local villagers. Robert Tungiyan of Gambell, St. Lawrence Island, Alaska, helps transport David Hopkins of the University of Alaska Fairbanks and Victor Ivanov of Magadan, Russia. Photo by Julie Brigham-Grette.

Above: University of Washington graduate students Bethanne Zelano and Daniel Froehlich set up mist nets to catch hoary and common redpolls following a snowfall on the North Slope of Alaska. Photo by James H. Barker, © 2002, courtesy of University of Alaska Fairbanks Institute of Arctic Biology. Facing page, left: Noctilucent clouds over Valkeakoski, Finland. Photo by Tom Eklund. Center: Blaine Anderson and Brian Dunphey excavate a midden at a 16th century Inuit sod house site on Iglosiatik Island in Labrador. Photo by Susan Kaplan. Right: A diver in Stefansson Sound in the Beaufort Sea sets up a system to measure light and kelp photosynthetic activity under 2 m of fast ice. Photo by Ken Dunton.

2

Scientific Questions in the Arctic

Given the size and global importance of the Arctic, U.S. research in the region has been comparatively sparse. Because of its small, scattered human population and the logistical difficulties inherent in working in remote, cold areas, basic observations and information about many aspects of the Arctic remain limited. Thanks in part to the improvements in logistical support mentioned in Chapter 1, scientists working in the Arctic in recent years have been able to collect new data and make considerable progress in our understanding of the region. The significant and, at times, surprising findings of recent years, spanning the full scope of arctic science from upper atmospheric processes and space weather to the geophysics of the Arctic Basin, reveal many gaps in our knowledge and demonstrate an urgent need for more information.

The need for more information is particularly urgent in studies of environmental change. Both arctic residents and scientists have observed considerable change in the region over the past two decades. Much of the Arctic is undergoing pronounced warming, which has caused substantial changes in many components of the regional system, such as permafrost, sea ice, and vegetation cover (figure page 12). All these changes also have major impacts on the people who live in the northern latitudes. An overwhelming majority of arctic researchers cite environmental change in the context of the region's climatic evolution and geologic record as the most important arctic science priority for the coming decade (Appendix C). The imperative to study arctic environmental change has increased the emphasis the research community places on:

- detecting, understanding, and predicting change,
- crossing disciplinary boundaries,
- understanding the Arctic as a whole and its links with the rest of the world,
- describing feedbacks in the Arctic and their significance both in regional change and in global processes, and
- international cooperation and collaboration—to observe as much as possible of the Arctic and to maximize the use of precious logistical resources.

Observing variability in the arctic system. The general public and the scientific community are increasingly concerned about the effects of human activities on the global environment, including the global climate system. Modern observations of the Arctic reveal strong variability in the behavior of many components of the regional system. Examples include the widespread decrease in glacial mass balance and the lower pressure mode of the Arctic Oscillation (AO). Research is needed to develop a more fundamental understanding of this variability in the context of natural and anthropogenic forcing, including the questions of:

- whether the large amplitudes in the variability of the arctic environment contain an element of anthropogenically triggered long-term change, and
- how such a possible change might be driven by and feed back onto the global climate system.

Most modern observational records of the arctic system are inadequate to test hypotheses on the processes that govern observed variability or even to reveal the fundamental nature of the variability. In many cases the observational records are too short; other records, particularly those in the Russian Arctic, are no longer being maintained, and there are too few of the records even when they are long enough. A considerable part of the data on the Arctic is limited to specific seasons when a particular location is relatively easy to access, but increasing evidence suggests that year-round data are critical in the development of a predictive understanding.

The need for long-term, large-scale observations poses new challenges in designing innovative observing strategies and systems, developing technology that allows efficient monitoring in the scientific context, and coordinating with ongoing process-oriented studies, which in themselves can be large and complex. Simultaneous system-wide observing of multiple components of the Arctic elevates the magnitude of this challenge in terms of observing system design, access to remote locations for deployment and recovery of instruments, and availability of human resources. These challenges require

A systematic comparison of photos of Alaska's North Slope taken in the mid-20th century with current photos of the same locations reveals an increase in shrub vegetation over time (Sturm et al., 2001). In 2002 alder shrubs cover more of the landscape along the Nimiuktuk River, a tributary of the western Noatak River, compared to conditions in 1950. The vegetation of the western Brooks Range and North Slope appears to be responding to changes in climate, with implications for surface energy exchange and carbon flux. Photos courtesy of Ken Tape.

Rescuing Existing Observations

At the very time when observed climate signals in the Arctic may indicate anthropogenically induced change, many long-standing monitoring and research programs have been eliminated or severely curtailed. Examples include the Soviet North Pole drift stations, upper air measurements around the Arctic Basin, Canadian climate stations, weather stations in Alaska, hydrological monitoring (e.g., major river discharge) in Russia and North America (figure below), and weather ship observations in the regions south of the Arctic. It is critically important to ensure that arctic sites that already have long-term records are not lost due to lack of funding or changing governmental structures or policies. Critical endangered sites and programs must be identified and efforts undertaken to prevent future losses. Data from these sites must be archived and made compatible with current database technology. The possibility of reviving key stations and measurement programs that have been eliminated should be assessed.

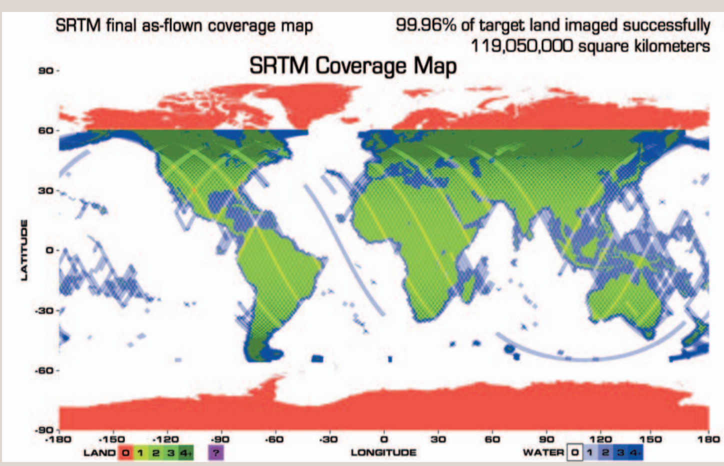
This figure illustrates the widespread decrease in hydrological monitoring throughout the Arctic in recent years. The monitored portion of the Arctic (red outline) is shown with the density of river discharge gauges in the regional Roshydromet office responsibility zones in Russia, the provinces in Canada, and Alaska. Values within each administrative unit represent the number of active discharge gauges in 1986 and 1999. The red-hatched areas show the loss in monitored areas from 1986 to 1999 (Shiklomanov et al., 2002).

considerable attention to planning of the necessary long-term observing systems, as well as additional resources for their development and support. The current array of observation platforms is insufficient. Further closures of long-term observation sites should be prevented.

Because our observational base has a limited time length, we also must continue to develop ways of projecting change over longer periods, extending records back into the past, and testing future predictions. Existing tools must be tested and their limitations determined quantitatively; examples include methods such as space-for-time substitution, in which investigators compare sites of different ages as an alternative to long-term studies. Similarly, active efforts must be made to integrate paleo-records, which are being developed at increasingly high temporal resolution, with the results of modern process studies. This will help determine the extent to which our understanding of causal processes, developed largely from modern process studies, are robust and sufficient explanations of dynamics observed on longer time scales (PARCS, 1999).

Sparsity of Data in the Arctic

Basic information that is taken for granted in other regions of the globe is often difficult to obtain in the Arctic. For example, accurate maps are fundamental to field research in every discipline. In recent years, major national and international efforts have significantly improved mapping products for the majority of the globe, but have not included the Arctic (Nolan and Fatland, 2003). The U.S. Geological Survey offers digital elevation models (DEM) data for the coterminous U.S. at a scale of 1:24,000, but only at the 1:63,360 scale in Alaska, and the data there are of poorer quality, particularly in glaciated regions. The quality of DEMs in the rest of the Arctic varies by country, and often these data are not freely available for scientific use. Although several federal agencies are aware of the problem, no topographic mapping mission is currently planned for Alaska or the Arctic.



The figure shows the coverage of radar elevation measurements taken from the space shuttle Endeavour *in 2000 during the Shuttle Radar Topography Mission. These measurements provide publicly available high resolution Digital Terrain Elevation Data for most of the globe. Note the absence of data in the Arctic. Similar data are available for the Antarctic region from the 1997 Radarsat Antarctic Mapping Project. Map from www.nima.mil/cda/article/0,2311,3104_10579_112959,00.html.*

Integrated approaches to arctic research. Studies of the role of the Arctic in the global context of environmental change are intrinsically complex, requiring long-term observations of the individual components of the arctic system and the processes that link these components together, as well as modeling studies to improve our understanding of processes and test the possibilities of predictability. Such studies cross the boundaries between physical, biological, geochemical, and social systems and involve a new level of interdisciplinary work in terms of project design, synthesis of complex datasets, and evaluation of results. The multifaceted scientific goals of these projects demand large, coordinated programs and a shift from a traditional disciplinary approach to theme-driven research, where each theme requires expertise from several disciplines.

In response to these challenges, research in the Arctic has become increasingly cross-disciplinary and integrated. This integration has been stimulated by our increased understanding of cause-and-effect relationships in the natural and social sciences, which has been assisted by model studies. Because significant change observed in a natural variable, parameter, or process is almost certain to have ramifications across disciplinary boundaries, effective research on environmental change in the Arctic requires an integrated approach to address cause and effect and feedback issues.

Modern arctic research requires spatial, temporal, and disciplinary integration as researchers elucidate process dynamics at local and regional scales and compare results from different locations around the Arctic. Scientific projects increasingly encompass the circumarctic region as a whole, requiring better year-round access to remote locations and stimulating international collaboration.

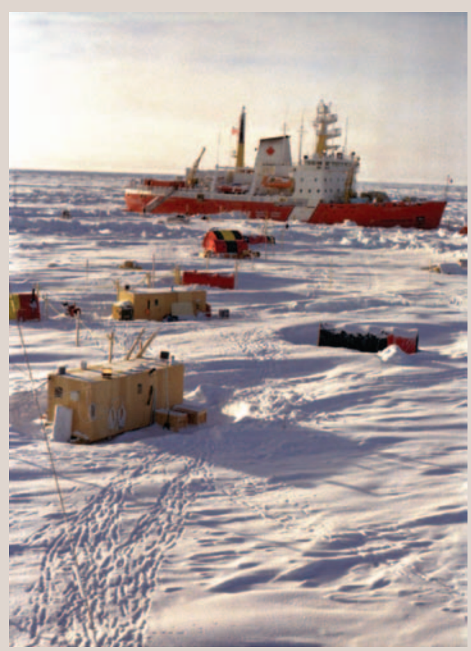
Modeling has become central to arctic research. Scientists increasingly use models to incorporate small-scale process information and improve estimates of regional and global processes. Modeling also is helpful in identifying the critical areas, processes, and regions where measurements and data collections must be made (observing network design) and in transferring research results to different spatial and temporal scales. In certain situations, models can provide real-time guidance for ongoing collection of field data (box this page).

The long-term objective of many arctic research programs is to develop mechanistic and predictive understanding of the processes, feedbacks, and effects of future changes in the arctic environment. Modeling not only helps us to better understand the linkages between various components within the arctic system (e.g., links between the atmosphere, the ocean, the ice, and the land), but also helps us to understand the sensitivity of the system to change and how the Arctic is coupled to the global climate system.

Model Guidance of Data Collection

During the Surface Heat Budget of the Arctic Ocean (SHEBA) field program in 1997–98 (photo), modeling guided several data collection efforts; for example, daily water-column data were transmitted to modelers, who incorporated it into model runs and helped to plan the data collection for the following days.

In addition, model outputs often are needed to interpolate datasets between field stations. Because the geographical spread of arctic meteorological stations is sketchy at best, for example, simulated temperature grid data are the only data available for some locales. Other examples include hydrologic models driven by precipitation and temperature that can be used to estimate evapotranspiration and runoff, or time series of river discharge from ungauged catchments for which observations are generally not available.



The Canadian Coast Guard icebreaker Des Groseilliers *was the heart of Ice Station SHEBA. The SHEBA project observed the ice, the atmosphere, and the ocean over a full annual cycle covering physical variables in all three systems. Photo courtesy of the University of Washington.*

Working with Community Organizations

Cooperation and full partnership between researchers and arctic communities is vital. Examples of the benefits of this approach include a joint project by the Alaska Eskimo Whaling Commission (AEWC), OPP, the North Slope Borough, and the Barrow Arctic Science Consortium (BASC). AEWC represents ten whaling villages in Alaska and is allied with Native groups in Russia. The project, which is designed to foster better communications and planning between shipborne researchers and coastal communities, facilitates face-to-face contact between researchers and community members. An important part of the work includes development of GIS-derived products such as the Bowhead Whale Subsistence Sensitivity Map, a map showing sensitive times and locations for other marine species, and a terrestrial sensitivity map.

In another example, Toolik Field Station on Alaska's North Slope has begun a partnership with Anaktuvuk Pass, the closest community. This effort includes mapping historic sites and developing an Iñupiaq dictionary of common plant, animal, and place names for the area.

Although process studies are the main building block for improving our knowledge, a good database with ongoing long-term observations must be allied with proven models to assess the significance of processes or observed events.

Research increasingly depends on accessibility to model results. As models become more widely used in observing system design, data synthesis, and interpreting results, and as researchers increasingly work in teams where they exchange data and results, ensuring access to model output becomes more and more important.

This integrated approach to arctic research includes the development of partnerships among researchers and arctic communities. People living in the Arctic have accumulated outstanding bodies of data on various aspects of the arctic environment, including sophisticated local indicators of ecosystem change. Arctic residents seek to document environmental change in the North, including depletion of biological resources, contamination of food webs, increased ultraviolet (UV) radiation, and climate warming. Local communities are pursuing ways to be more informed on the planning and outcomes of academic research.

Integrating local and traditional knowledge and establishing collaborations that include arctic residents as respected partners in new cooperative projects will be a critical link to successful interdisciplinary opportunities in arctic research. The Alaska Native Science Commission was formed in 1994 to help facilitate these partnerships in Alaska, and the Chukotka Science Support Group performs similar services in Russia. Improved dissemination of research goals and results to communities, including electronic communication, public and visual programs, and distance education, will boost public awareness. Fostering closer ties with arctic communities will benefit research efforts as well as local residents.

A long-term cooperative effort is needed to enable arctic communities to become involved in research as full partners, not just as data gatherers or consultants. This will require commitments from many entities in addition to NSF—including the communities themselves, tribal governments, educational institutions, researchers, and funding agencies—to support arctic communities in setting their own research agendas, participating in the research conducted in and around their communities, enhancing educational programs in the North that embrace local schools and teachers, and inviting non-resident researchers into their communities (box this page).

People in the Arctic

In recent years, research in arctic social sciences has increased rapidly in terms of the amount of research being conducted, the range of disciplines and topics involved, the geographic areas where projects are being done, and the degree of collaboration both among social science disciplines and with researchers from the natural sciences. These trends are likely to continue. Future support and logistical needs will range from extensive field support for remote archeological studies, to intensive efforts to create partnerships with local communities, to the coordination of planning, field research, and analysis involving disparate disciplines. Looking at recent developments in funding and research in arctic social sciences illustrates these and other needs, giving an indication of what will be needed in the future.

Subsistence activities such as gathering wild plants remain economically and culturally important in many northern communities. Gladys Pungowiyi picks roseroot (Sedum rosea) *on St. Lawrence Island. Roseroot leaves and stem can be eaten raw or cooked. Medicinal uses include making the root into a paste or tea to help wounds heal. Photo by Caleb Pungowiyi.*

Recognizing the exceptional and pressing opportunities in the Arctic for investigating social, cultural, political, and economic topics, including their relationship to environmental phenomena, the Arctic Sciences Section of the Office of Polar Programs established the Arctic Social Sciences Program (ASSP) in 1990, which is currently funded at about $1.9 million a year. The substantial body of work produced by social scientists supported by ASSP and other programs has greatly expanded our understanding of human populations in the North, particularly through the prehistory of the Arctic and the lifeways of indigenous peoples. The Arctic Social Sciences Program has supported important collaborations and partnerships, including cooperative work among U.S. and international scientists, researchers and indigenous peoples, social and natural scientists, and social scientists and schools. Research areas explored in the most recent ASSP publication (ARCUS, 1999a) include culture and the environment, resources and economic change, development of social and political institutions, ethnic and regional identities, and knowledge systems. Researchers and communities have identified additional research priorities, including the effects of environmental change on both the culture and livelihood of indigenous groups, the impacts of Western culture on indigenous populations, intellectual property rights in the use of Native stories and traditional knowledge, self-governance movements across the Arctic, and contaminants in traditional foods.

Issues of cultural, social, economic, and political survival and stability drive many research questions in arctic social sciences. Because much of this research has direct relevance to the well-being of northern residents and can have an immediate impact on their lives, the Social Science Task Force of the U.S. Interagency Arctic Research Policy Committee developed *Principles for the Conduct of Research in the Arctic* (IARPC 1990). These principles include involving northern residents in the planning and conduct of research, where possible. Such inclusion may change the traditional social science relationship between the people being studied and the people doing the studying—subjects and researchers often become less distinct as research becomes a more collaborative venture, with arctic communities as full partners and often the drivers of research.

Arctic residents today are actively involved in debates over resource development and environmental change in the region. In Alaska, for example, Native corporations have gained considerable economic and political influence, although governmental centers at lower latitudes continue to control access to most arctic resources. At the same time, changes in world markets for hydrocarbons, minerals, forest products, and marine resources have far-reaching consequences for local and regional subsistence activities and commercial production. Research on human-environment relationships has documented the efficacy of co-management, a relatively new approach to managing natural resources that involves both professional managers and traditional users.

Social scientists need to identify and explore responses to social, political, cultural, and economic changes generated by and affecting arctic communities. This research can increase understanding of the dynamics of past and current changes and test hypotheses about the impacts of possible future changes on social systems. Sources of information include historical records and oral traditions. Work modeling the effects of rapid change in arctic societies over the last century, for example, has shown that arctic residents increasingly combine elements of traditional cultures with the educational and employment opportunities that are found both at home and elsewhere.

From the first groups to cross the Bering Sea into the new world to modern arctic residents, humans have been integral to arctic ecosystems, both affecting their environment and being influenced by physical and biological processes. Climate and ecological changes influence the ways in which humans react and adapt to their environment, with strong implications for the futures of communities in the Arctic and at lower latitudes. The Human Dimensions of the Arctic System (HARC) initiative supports research that examines these interactions (ARCUS 1997a). A component of the Arctic System Science (ARCSS) Program supported by the NSF Office of Polar Programs, HARC offers valuable opportunities for collaboration among social, natural, and physical scientists. Relevant issues include the human dimensions of environmental changes such as increased storm surges, reduced snowfall, reduced glacial mass, elevated sea levels, thawing permafrost, and declining fisheries (SEARCH SSC, 2001). For example, the presence and characteristics of shore-fast ice has a significant effect on coastal communities, subsistence hunting, and shoreline erosion. Indigenous residents and western researchers have noted changes in shore-fast ice conditions in recent years, including a decrease in ice thickness, decreased ice stability, and changes in formation dates. Changes like these are recorded in the memories of the elders, and many efforts are being made to document this information (e.g., Krupnik and Jolly 2002).

Many types of changes to human-environmental systems that occurred over centuries—or centuries ago—in other regions were compressed into the last few generations in the North. Archaeological sites in most sectors of the Arctic tend to be well preserved and easily found and are often linked directly to current populations. DNA data has recently been used to link modern populations with archeological records in order to trace the descendents of the people who crossed the Bering Land Bridge and the relationships among modern groups. The combination of archeological records, genetic data, and historical information and oral histories offers rich documentation of processes of social change (ARCUS 1999a). A picture is emerging of resilient people whose cultures emphasize adaptation to their environment.

The recent Soviet past remains visible in Cherskii, a town of 8,500 in northeast Siberia. The rapid economic, social, and cultural transitions underway in the Russian Arctic offer numerous research opportunities. Photo courtesy of VECO Polar Resources.

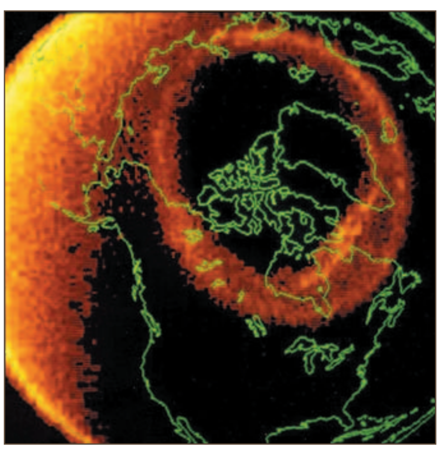
In many ways, the rate of change is more of a challenge to arctic cultures than the amount of change; as changes in the environment combine with external cultural impacts the complexity of the issues increases, and new responses may be required. Threats to the survival of distinct local cultures and traditions throughout the Arctic need to be understood and addressed. The Russian North has especially pressing needs for research to address the social and economic problems that residents currently face (ARCUS 1999a). The opening of Russia to the West offers researchers unprecedented opportunities to work with Russian colleagues and in Russian northern communities.

In addition to its actual and potential applications, arctic social science makes major contributions to the advancement of social science theory, methodology, and the cumulative body of social science knowledge. The ability to have access to many and varied archaeological sites; to study cultural, economic, social, and political processes as they occur; to examine the effects of extreme environments; and to conduct comparative work that covers different nations, different cultures, and different social, economic, and political systems gives researchers working in the Arctic opportunities to make significant advances in virtually every area of social science.

Physical Processes in the Arctic

The processes that determine the physical state of the atmosphere, marine, and terrestrial systems in the Arctic are intrinsically interlinked. Events or processes occurring in one element of the physical system propagate into the others and frequently have profound impacts on biogeochemical and social systems. In some respects the arctic physical environment is a well-defined regional system; the Arctic is strongly coupled to the global system, however, through links that include the freshwater cycle, thermohaline ocean circulation, albedo feedback, and possibly greenhouse gas release, as well as upper atmospheric processes through auroral activity and meridional circulation cells.

The coupling between the upper and lower atmosphere and the lower atmosphere and the sea ice/ocean/land surface is a central issue in long-term and short-term climate change. The recent increasing temperatures and longer melt seasons decrease overall albedo and increase tropospheric cloudiness, impacting the snow/ice albedo feedback and poorly understood cloud-radiation feedback processes. Important questions remain about the modes and variability of atmospheric circulation that appear to have pronounced effects on the Arctic, including the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO, also known as the Arctic Annular Mode). The positive mode of the AO is accompanied by decreasing surface pressure and warmer temperatures, and evidence is mounting for even more far-reaching effects on terrestrial and ocean systems. The North Atlantic Oscillation has been speculated to have stratospheric ties. Historically, the arctic atmosphere has been under-sampled, and current support is declining for many existing long-term upper-air networks, especially those operated by Russia and Canada. The chemical and associated dynamic linkages between the Arctic and the upper atmosphere represent potentially important avenues for arctic-global interactions. Atmospheric chemistry studies should include both extended time-series sampling of this unique environment and targeted studies for process-oriented understanding of coupling of the lower atmosphere with the surface and upper atmosphere.



The close coalignment of the axis of the Earth's geomagnetic field with the axis of its rotation results in the transfer of energy and momentum from the solar wind and interplanetary space into polar regions. The aurora, shown here from space, is the most commonly known example of this phenomenon (image from NASA's Dynamics Explorer satellite, courtesy of Louis Frank).

The Arctic is important for upper atmospheric research in terms of investigating both the atmosphere's response to its proximity to the geographic pole and effects related to the geomagnetic pole. In addition, the arctic upper atmosphere has global impacts through auroral activity and meridional circulation cells. Noctilucent clouds have been shown to be harbingers of global change (CEDAR, 1998), and over the past one hundred years, their occurrence has more than doubled, indicating that the mesopause region is getting colder during late summer. Since chemical reaction rates are temperature sensitive, atmospheric composition changes are occurring at the same time, affecting the concentrations of important minor constituents such as nitric oxide and ozone. There has been a general downward trend of arctic ozone concentrations: average values were 10% lower in the 1990s than in the 1970s (Arctic Monitoring and Assessment Program, 1998).

Studies of the aurora contribute to the fairly new field of space weather, which is concerned with the many interactions between the Sun and the Earth. Space weather research depends on observations of the ionosphere, near-earth plasmas, the Sun, and associated computer models. Auroral observations in support of space weather studies are conducted using a combination of ground-based arctic sites and space-based observatories. There is a continuing need for improved prediction of space weather due to the increasing use of space technology for navigation, communication, and remote sensing.

Arctic lands are closely linked to both atmosphere and ocean through the hydrologic cycle. The very short summer and prolonged winter produce extreme contrasts in physical processes on arctic lands, contributing to the fluxes of mass and energy. Increasing surface temperatures, thawing permafrost, and retreating glaciers are leading to increased erosion, vegetation redistribution, and sea level rise. If released by increased soil temperatures, large stocks of carbon sequestered in permafrost in the form of peat are likely to have significant impacts on the global carbon cycle. In addition, infrastructure built on permafrost, such as the Trans-Alaska Pipeline, could be threatened by thawing.

The discharge of fresh water from the surrounding land masses greatly influences the Arctic Ocean and affects global climate. The major fraction of the freshwater flux to the Arctic Ocean occurs over the shallow shelves. The fresh water is essential to the maintenance of the cold halocline, which effectively prevents heat contained in the warm Atlantic layer from reaching and thinning or even removing the sea ice cover. Excessive freshwater output from the Arctic Ocean in liquid and solid form to the Nordic and Labrador Seas can significantly reduce convective overturning with possible impact on the formation of North Atlantic deep water, a key element driving the global thermohaline circulation. Recent observations have confirmed that significant changes are occurring in the central Arctic Ocean. The halocline has thinned, and the Atlantic water has penetrated deeper into the Arctic Basin, reducing the size of the Pacific water pool in a smaller Beaufort Gyre. The sparse datasets for both ocean and atmosphere limit fundamental understanding of the processes causing the observed changes.

Permafrost coasts are vulnerable to thaw subsidence and subsequent wave-induced erosion. Coastal erosion problems are an extraordinary challenge to arctic communities such as Barrow, Wainwright, Kivalina, and Shishmaref (above). Photo courtesy of Luci Eningowuk and Native Village of Shishmaref.

The volume of sea ice in the Arctic Basin is maintained by dynamic and thermodynamic forcing. In addition to the decline in sea ice extent observed over the past two decades, the ice has been thinning. Recent evidence indicates that observed large changes in sea ice thickness over the past three decades may have been caused primarily by changes in ice drift patterns responding to shifts in atmospheric circulation which can occur in a very short time. A major change in the sea ice balance in the Arctic is likely to have as profound an impact on social and economic dimensions as any other change. Longer melt seasons are causing decreased sea ice extent in the nearshore regions. These longer open water seasons, the sea ice retreating further offshore, and particularly changes in fast ice adjacent to shore are accelerating coastal erosion, which in some cases is so serious that coastal villages may have to be relocated (photo).

The current understanding of the physical environment is largely limited to a few decades of data collected by instruments, supplemented by an additional few decades of recorded observations plus long-term but largely untapped traditional knowledge. To compare the changes currently being experienced with those that occurred during the past several centuries requires paleoclimatic information; past climate reconstruction from proxies including tree rings, lake sediments, ice cores, and marine sediments can establish the range of natural variability of the arctic physical environment (PARCS, 1999).

Geology and Geophysics in the Arctic

In the geosciences, the Arctic Basin and surrounding terrains remain one of the last regions where we still lack fundamental knowledge of Earth's history and evolution. The region is key to understanding the dynamics of Earth's crust and the nature of the sedimentary basins. First-order geoscience problems for the near future include:

- the geologic framework and tectonic evolution of the Arctic Ocean, including the structure and rheology of its crust and upper mantle, and
- the sedimentary history and paleoenvironmental evolution of the arctic region.

Recent indications of an unexpected number of active hydrothermal vents along the slowly spreading Gakkel Ridge in the Arctic Ocean (Edmonds et al., 2003) demonstrate just how much remains to be accomplished in understanding the geology and geophysics of the arctic region. This work has implications for heat and mass fluxes from Earth's crust and mantle and offers new opportunities for studies of seafloor spreading and the biogeography of vent-endemic organisms.

Linking modern and instrumental observations of the arctic system (described in other parts of this report) with historical and paleodata over a range of geologic time scales also is crucial to placing in proper perspective the magnitude and systemic consequences of future changes in the world's atmosphere and oceans.

Geologic Framework and Tectonics

The modern configuration of the Arctic Ocean is a consequence of over 130 million years of crustal evolution. A National Research Council report of the Committee on Solid-Earth Geosciences (1991) argued that the Arctic Ocean and its margins should be the next priority focus of geologic and geophysical research. In the twelve years since that report, only some of its recommendations have been carried out due to a lack of funding and logistical limitations. While the geologic history of the Arctic Ocean is fairly clear in the Eurasian Basin, which formed by northern propagation of the mid-Atlantic Ridge, numerous questions remain concerning the bathymetrically complex Amerasian Basin. The Alpha and Mendeleev ridges, and their relationship to the Chukchi Borderland and Northwind Ridge, remain among the most poorly understood of the major ridge systems. How the various gateways to the Arctic Ocean have opened and closed over time due to tectonic and other geological processes raises important questions with implications for paleoceanographic, paleontological, and tectonic studies.

Closely related to the crustal structure of the Arctic is the major subduction boundary between the Pacific and American plates, which skirts the northern boundary of the Pacific, resulting in tremendous seismic and volcanic activity. Prediction of earthquakes and volcanoes remains a key issue.

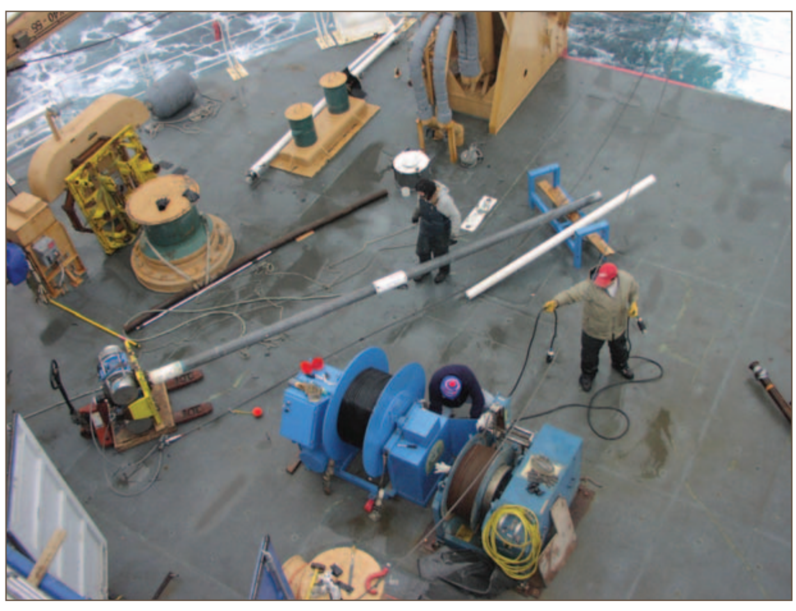
Large deposits of gas hydrates or clathrates underlie many of the world's continental shelves, including the extensive arctic shelves. Estimates of the volume of methane contained in these regions raise concern over the climatic and environmental consequences of their possible instability and release during interglacials and other climatic optima. Kennett et al. (2003) suggest that episodic methane releases from unstable marine sedimentary hydrate reservoirs to the atmosphere/ocean system provided crucial amplification to "jump-start" rapid warmings at stadial and glacial terminations. As arctic sea ice continues to thin and warmer Atlantic waters penetrate deeper into the Arctic Ocean from Fram Strait, it is important to note that little is known of the geothermal gradients and presence or absence of subsea permafrost beneath many arctic shelves.

Sedimentary Record and Environmental History

The Mesozoic tectonic history and early evolution of the Arctic Ocean provide the backdrop to the Cenozoic history of the high latitudes. The sedimentary records of the deep basins and continental shelves contain the paleoclimatic and oceanographic history of the Arctic, including the history of sea ice. Investigators have identified sites on many continental margins where sedimentation rates are likely high enough to test theories concerning the environmental history of the Arctic. For example, existing Arctic Ocean cores are missing much of the Cretaceous and Tertiary record; patchy fossiliferous sedimentary records on the surrounding landmasses, however, indicate that the Arctic Ocean probably lacked sea ice, and adjacent landscapes lacked tundra, until nearly 3 million years ago (Ma). The late Cenozoic, especially post-mid Pliocene, is thought to have been a time of significant environmental change in the Arctic, marked by the initiation of glacial/interglacial change some 2.6 Ma, yet no depositional sequence has been found with continuous records of this phase of climate evolution with adequate fidelity.

High-resolution records of recent climate change characterizing variations during the Holocene and previous interglacials are important for understanding both the stability of present climate and the vulnerability of the earth system to rapid climate change. While the arctic region is thought to be exceptionally sensitive to climate change and to amplify changes in the global system, little is known of the spatial variability of this amplification and consequences outside of the Arctic. At the same time, a growing body of paleoclimatic evidence suggests that changes in tropical climate may drive climate change at high latitudes, emphasizing the importance of considering global teleconnections

Neal Gielstra and Paul Gayes of Coastal Carolina University prepare the vibracorer for deployment on the aft deck of the Healy *during the 2002 seismic mapping and coring cruise in the Bering and Chukchi Seas. The vibracorer is used to sample sandier sediments. Photo by Julie Brigham-Grette.*



and feedbacks. Different natural recording systems such as lake and marine cores, glacier ice, and tree rings capture evidence of at least millennial-scale variability, and a subset of these archives has sufficient temporal resolution to detect change at decadal to annual timescales using a portfolio of geochemical, biological, and fossil proxies now standard in the earth sciences (PARCS, 1999). Access to these sedimentary and biological archives is a high priority in the paleoenvironmental sciences, and the archives contained in glacial ice and permafrost are themselves in danger of being lost through modern climate changes.

An understanding of paleoenvironmental change must go hand in hand with modern process research on environmental systems. As much as possible, modern change and process studies need to include interdisciplinary studies and proxy development for linking the work beyond the range of instrumental data. Because the dynamics and direction of modern arctic change cannot be compared with itself, modern change can only be placed in context using data on historical and paleo-time scales from decades to millennia.

The prospect of a rapidly warming Arctic places new importance on baseline studies needed to monitor this change and perhaps to provide engineering solutions to threatened coastal communities. A decrease in the duration of seasonal sea ice along arctic coasts composed of sedimentary rock or unconsolidated sediments and permafrost will likely result in dramatic increases in erosion and coastal retreat.

Biological Systems in the Arctic

Investigations of arctic ecosystems are yielding insights into a wide range of basic and applied issues in biological science. Compared with temperate and tropical regions, arctic ecosystems tend to be relatively simple and low in biological diversity. The Arctic is characterized by resident species, species with unique genetic variation, species adapted to extreme variations in climatic and feeding conditions, and migrating species that spend only part of their life cycle in the Arctic to take advantage of seasonally favorable conditions. Because many species share a circumarctic distribution, researchers can effectively scale ecological models from small plots and laboratories to whole watersheds and regions.

The Arctic is an excellent model system for study of biophysical interactions and feedbacks among atmosphere, biota, soils, water, ice, and permafrost, in part because it is generally simpler than many lower-latitude systems and less modified by the direct impact of human activities. Investigators can effectively combine process-based models with environmental data such as climate information to scale to a river basin or watershed level. Process studies at a few intensive sites are needed to allow investigators to create such generalizable models. This process-based modeling is key to scaling ecological knowledge from the small scale to whole landscapes, river basins, and regions of the Arctic. The models must then be tested by measurements at other sites and by long-term manipulation experiments.

The Arctic also is a valuable system in which to consider humans as components of a regional system because of the large proportion of its inhabitants who rely on subsistence resources and are, therefore, tightly

Jack Duman of Notre Dame University observes the melting and freezing points of insect hemolymph ("blood") at Toolik Field Station. Access to lab facilities near his field location is critical to the success of Duman's work on overwintering mechanisms. Photo by Richard Flanders.

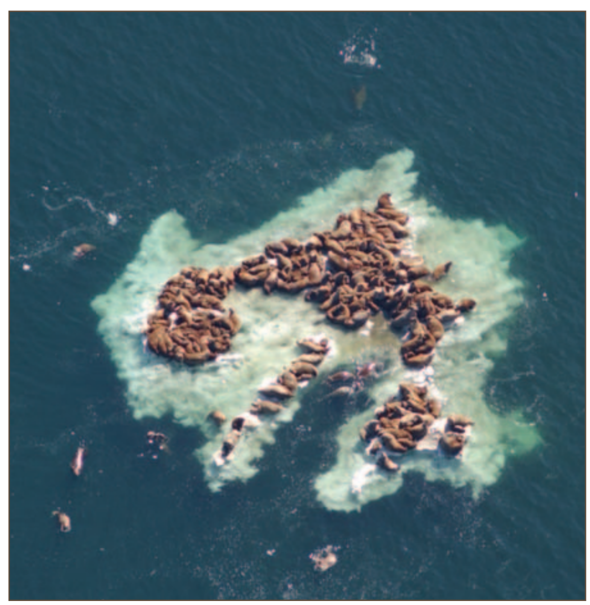
coupled to the changes that occur in their environment. The use of biological resources is fundamental to the economic and sociocultural well-being of many northern societies and cultures. While the economic, nutritional, and cultural importance of harvestable animals in the Arctic provides an adequate mandate for applied research on these species, the evidence of accelerating ecosystem change is prompting additional efforts. Research is needed to describe how environmental changes are affecting indicator species and whether these changes are responsible for declining populations. Investigations of the population dynamics of animals in ecosystems affected by environmental change and industrial development are of both basic and applied scientific interest. Health assessments of subsistence and sentinel species are critical, and factors such as disease, contaminants, and other stressors are influenced by environmental change.

Climate change in the Arctic is leading to observable changes in plant and animal communities that provide an important ongoing scientific opportunity for investigating how organisms respond to their environment. Predicting ecosystem responses to global change scenarios requires understanding controls over structure and function of individual species. This predictive understanding depends on process studies at a few intensive research sites, which are used to develop generalizable models that can be scaled up from small scales to whole landscapes and regions.

Organisms' evolutionary adaptations to the arctic environment also are important from a fundamental science perspective. The evolution of life in high latitudes has been influenced by pronounced seasonality, including wide temperature ranges, a short growing season, and low rates of nutrient cycling, making arctic and Antarctic environments valuable laboratories for understanding the capacities and limitations of physiological systems. These studies seek to identify molecular, physiological, and behavioral traits associated with adaptations to high-latitude environments, including extremes in photoperiod, temperature, short breeding seasons, and overwintering conditions. Individual variation in these traits can be linked to differences in survivorship and measures of fecundity, building toward predicting population response to environmental change. Many of the potential discoveries to be made in the adaptations of these organisms will make important contributions to basic biological science, as well as offering opportunities for advancing biotechnology and biomedicine—for instance in the development of protocols for cryopreservation of biological materials (NRC, 2003).

A major issue in studying biological systems in the Arctic is the variation in conditions that occurs from year to year and at longer time scales. Understanding how arctic systems respond to global change therefore requires long-term studies of how plants, animals, communities, and ecosystems respond to normal variations in the physical environment. Long-term studies need to include many seasons to incorporate data from all the

The U.S. Fish and Wildlife Service in Anchorage, Alaska, collaborated with the NSF-sponsored Shelf-Basin Interactions project to survey marine mammals and seabirds during a cruise on the Healy. *In mid-June 2002, wildlife biologist Marc Webber took high resolution digital photos of more than forty groups of walrus. Analyses of the aerial photos will be used to develop correction factors for future surveys using remote sensing systems. Photo by Marc Webber, U.S. Fish and Wildlife Service.*



potential combinations of conditions to permit identification of critical factors that influence individual organisms, populations, communities, and ecosystems. Many animal species undergo regular population fluctuations related to carrying capacity of the environment around them. These processes are somewhat conjectural for animals with short life cycles such as lemmings and hares, and are largely unknown for species with longer cycles such as caribou, geese, eiders, ringed seals, and polar bears. It is important to study arctic species over enough time to monitor and understand natural fluctuations in their populations.

Accumulating evidence indicates that it is also important that biological processes be studied over the life of the process in question and not just when it is logistically convenient. Many biological processes in the Arctic have been studied only during the summer season.

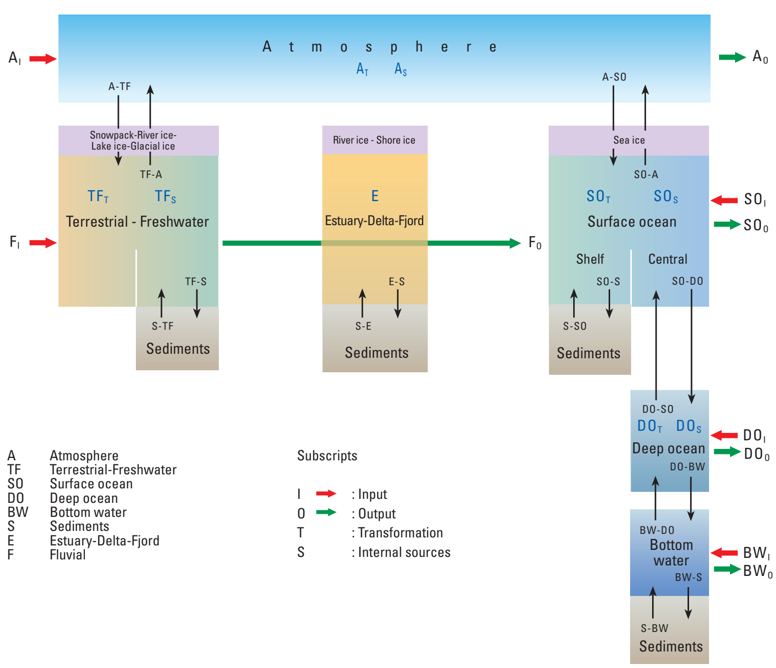
Biogeochemical Cycling and Contaminants in the Arctic

It is becoming increasingly clear that the Arctic plays a major role in global biogeochemical cycles, that the cycles within the Arctic are particularly sensitive to change, and that we do not understand these processes well enough to predict how they may operate in the future. An example is the potential importance of the vast boreal and tundra wetlands; currently they serve as a significant global sink for carbon (C) but are postulated to become a large source for C if the climate warms. Much of the plant growth in the Arctic is nitrogen-limited. In one possible scenario, warming and drying not only promote greater carbon efflux through decomposition, but also increase nitrogen mineralization, promoting a shift in plant community composition toward more productive functional groups.

Investigators recognize that the Arctic Ocean has a much more active carbon cycle than might be expected in a predominantly ice-covered sea. Because 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 are important in transforming oceanic and terrestrial chemical signals. These processes are vulnerable to change, especially over the enormous shallow shelves, where ice cover is likely to alter dramatically. The flow of waters from distinct sources into the Arctic Ocean (e.g., through the Bering Strait) is another crucial influence on large-scale arctic biogeochemical cycling.

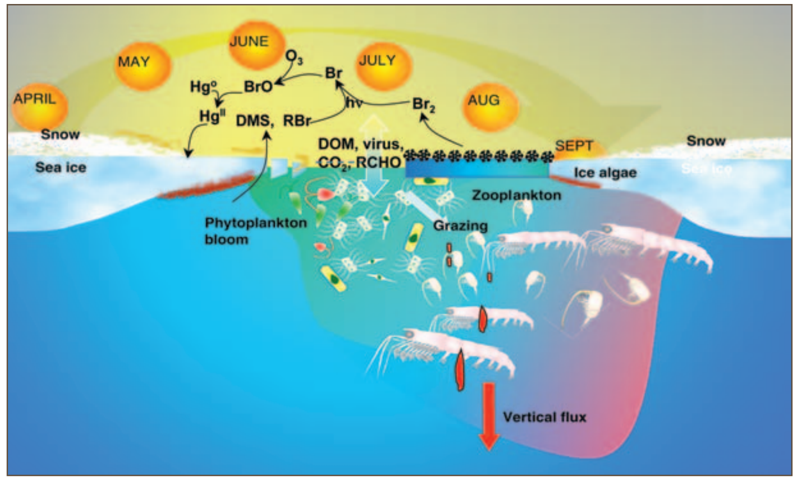
In terrestrial systems, climate warming has affected permafrost structure and stability, the distribution of arctic vegetation, and soil processes. A major challenge will be to monitor the impact of successional changes on hydrologi-

A multicompartment schematic diagram of the major pathways of contaminants into and within the arctic environment (Arctic Monitoring and Assessment Programme 1998). Figure courtesy of GRID-Arendal.



cal and biogeochemical processes and surface energy exchange, especially since vegetation changes occur on decadal time scales that are long relative to observational records and, thus, difficult to detect.

Substantial evidence refutes the idea of a pristine Arctic protected from contamination by its geographic isolation. Arctic haze, an annual feature of the arctic troposphere, demonstrates the rapid atmospheric connection between industrialized areas in northern Eurasia and the high Arctic. Numerous northward flowing rivers connect much of the surrounding landmass to the Arctic Basin, while exchanges with the Pacific and Atlantic oceans are controlled by ocean currents. These transport mechanisms carry fresh water, nutrients, and contaminants into and out of the Arctic. The formation and transport of sea ice also plays a role in potential transport of contaminants, and perhaps their concentration or dilution. This applies to local situations such as effects on oil spills, as well as broader effects such as transport of contaminants across the Arctic Basin from Siberia to the North Atlantic. The dominant sources and quantities of nutrients and contaminants that are reaching the Arctic need to be identified, and how their delivery is controlled by large-scale circulation of the atmosphere and hydrosphere needs to be understood.



Gases, particles, and particle precursors are exchanged between the ocean, snowpack, frozen ocean surface, and atmosphere. The exchange of photochemically reactive halogen gases leads to free radical consumption of atmospheric gases such as ozone, mercury, and volatile organic compounds. This chemistry can lead to particle production (a part of arctic haze), and subsequent deposition of the products to the surface. Many of these processes are known in qualitative terms, but are poorly understood quantitatively. Redrawn by P. Shepson from a figure by M. Fukuchi and P. Wassmann.

Within the Arctic, our understanding of transport, and especially transformation, of chemical compounds is too limited presently to allow the construction of realistic models (figure page 26). Contaminants are not simply deposited as a dilute drape over the arctic land and seascape; instead, biogeochemical pathways in both terrestrial and marine ecosystems provide specific routes of exposure of toxins, especially for organisms higher in the food chain (including indigenous human populations). Continued reduction of atmospheric ozone (O_3) will lead to increased ultraviolet (UV) flux, which may have adverse impacts on biota on land and in shallow water. On the other hand, enhanced UV in early spring is likely to accelerate photochemical processing in the melting snowpack, possibly oxidizing an increasing fraction of contaminants delivered through the winter (figure this page). In another example of the complexity of these transport mechanisms, new techniques have revealed the importance of small headwater streams in controlling the transformation and export of nutrients such as nitrogen to rivers, lakes, and estuaries. Research into the processes that control the distribution of chemical compounds within the Arctic is required, especially for developing reasonable predictive models.

Above: Ken Irving prepares to mount the radio antenna on the tower at the University of Alaska Water and Environmental Research Center's 10 meter meteorology station on the upper Kuparuk River. Photo by James H. Barker, © 2002, courtesy of University of Alaska Fairbanks Institute of Arctic Biology. Facing page, left: Mike Apfelbaum, Bernd Wagner, and Frank Neissen, part of an international team studying El'gygytgyn Crater Lake in Siberia, collect water samples for geochemistry. Photo by Julie Brigham-Grette. Center: Researchers arrive at the Big House, the main camp and galley building at Summit camp, on top of the Greenland ice sheet. Photo courtesy of VECO Polar Resources. Right: The U.S. Coast Guard Cutter Healy *began scientific missions in the Arctic in 2001. Photo courtesy of U.S. Coast Guard.*

3 Strategies and Recommendations

The array of scientific issues described in Chapter 2 will require interdisciplinary research to document and increase understanding of the changes being observed in the Arctic and to clarify their global ramifications. At the same time, we must continue to improve our basic knowledge of the Arctic through process studies that are limited in space and time. To enable the members of U.S. arctic research community to make the best possible use of existing and new research support and logistics assets as they address these challenges, we need updated strategies for the most effective ways to support arctic researchers in their efforts. In this chapter we outline three of these strategies and provide recommendations to advance them.

An expansion of the Arctic Research Support and Logistics Program (RSL) is needed to accommodate research that requires a large-scale, long-term observational component, as well as significant system-scale synthesis and modeling activities. Beyond a linear scaling up of traditional logistics support, this expansion includes beginning to organize and connect a distributed pan-arctic observing network. Coordination, planning, and resources will be needed to develop such a network. Because logistics in the Arctic are so expensive, care must be taken to identify locations where long-term data can be collected efficiently, and current observation series must continue if at all feasible.

At the same time, traditional logistics support continues to be the critical underpinning of successful arctic research, and sustaining it remains paramount. Investigators need safe access to remote locations via reliable transportation for themselves and their tools in order to carry out their research. They need adequate housing, communications, and laboratory facilities. To maximize broader research impacts, they need to strengthen connections to local communities and to participate in effective education programs.

We believe that the following strategies for improving arctic research support and logistics will contribute to efficient development of new capacity and will maximize infrastructure capabilities and the resources required to address future arctic research needs.

Supplying critical components for development of a pan-arctic perspective

- Plan, implement, and support a circumarctic observing network.
- Facilitate access to distributed systems of hardware, software, information bases, and automated aids for data management, synthesis, interpretation, and modeling.
- Improve communication and data transmission capabilities, remote field power options, and access to satellite observations.

Supporting the infrastructure for safe and efficient research

- Continue to improve access by supporting, expanding, and upgrading marine and terrestrial facilities.
- Support safety training and planning.

Maximizing resources and cooperation

- Facilitate international coordination and cooperation.
- Pursue interagency collaborations.
- Enhance communication and partnerships with arctic communities.
- Maintain and disseminate arctic expertise and train the next generation of arctic field experts.

Supplying Critical Components for Development of a Pan-Arctic Perspective

Plan, Implement, and Support an Arctic Observing Network

To elucidate the pace and scale of arctic environmental change, the research community needs to document changes in a wide set of interconnected variables over long periods with high spatial resolution. Local observations and regional observing networks will need to be integrated, expanded, and optimized to improve our collective understanding and allow us to predict and respond to changes that affect human and ecosystem welfare in the Arctic and elsewhere. To support coordinated observations of critical elements of the arctic system with reasonable spatial and temporal coverage, the arctic RSL program should plan for the development of a circumarctic observing network and begin its implementation. This network would link existing arctic research assets and add new ones to fill observational gaps. The network would integrate multiple sources of data, including:

- manned, autonomous, and cabled long-term observation sites,
- drifting sensors and instruments,
- retrospective analyses,
- autonomous vehicles such as aircraft, submersibles, and surface rovers,
- one-time and repeated surveys, and
- satellite measurements.

The network should be designed to link with other national and international research networks in order to contribute critical arctic resources to the development of regional, continental, and global perspectives (box next page). The ultimate goal is to harness existing and new arctic research logistics resources as efficiently as possible to address many of the science issues spelled out in Chapter 2.

Other Planned or Proposed Observing Networks

Several organizations support, plan, or propose to develop environmental observatory networks that complement the recommended arctic observing network. These include:

The **National Integrated Ocean Observing System** (IOOS) will begin operation over the coming decade under the National Ocean Planning Partnership (NOPP) and Ocean.US. The coastal component of IOOS will be a federation of regional observing systems nested in a federally supported backbone of observations, data management and modeling, research and education. Designed to be analogous to the National Weather Service for the ocean, the IOOS will provide information and infrastructure to support academic, nonprofit, industry, and government activities. The NSF **Ocean Observatories Initiative** (OOI) will contribute to basic research objectives in the IOOS effort through three elements: a network of regional cabled observatories, relocatable deep-sea buoys, and enhanced coastal observatories. As part of IOOS, a consortium of users are beginning efforts to develop the **Alaska Ocean Observing System** (AOOS); AOOS would be the umbrella association for three regional observing networks (Gulf of Alaska, Bering Sea, and Arctic Ocean). See www.ocean.us.

For the past few years, NSF has supported a broad planning effort to develop and link existing facilities to form a **National Ecological Observatory Network** (NEON), with the goal of providing an integrated network of regional research platforms. The proposed NEON would include up to seventeen regional observatories; each observatory would involve a regional consortium of appropriate ecological and environmental research facilities. The members of each consortium are likely to include field stations, marine labs, Long Term Ecological Research (LTER) sites, universities, natural history museums, public lands, and state and federal agencies, complemented by high-speed communications links, computing resources, and data management systems. See www.nsf.gov/bio/neon/start.htm.

The National Oceanic and Atmospheric Administration (NOAA) has begun planning for a **Global Environmental Observation and Data Management System** to develop global-to-local environmental observations and data management for comprehensive, continuous monitoring of coupled ocean/atmosphere/land systems. As part of building this capability, NOAA is taking inventory of its observing and data management capabilities, designing a process for evaluating the efficiency of its data observation and management system, and increasing the multiple use of observation platforms and availability of real-time data. By the end of 2003, NOAA will develop an agency-wide strategic plan responding to its multiple user requirements. That plan will integrate atmospheric, oceanic, terrestrial, and freshwater observations and data management. See www.osp.noaa.gov.

Under the auspices of the Forum of Arctic Research Operators (FARO), an effort to combine several planned or existing terrestrial arctic data networks under an international umbrella termed **Circumarctic Environmental Observatories Network** (CEON) has now been endorsed by FARO and IASC to begin implementation. While NSF is not necessarily expected to lead the effort, it should play an active role, both in contributing to and extending the network where possible and in encouraging partnership by U.S. investigators. See www.cevl.msu.edu/ael/ceon.html.

Funded by the European Union Fifth Framework Program, **ENVINET** is a network of seventeen research infrastructures in Northern Europe focused on multidisciplinary environmental research, emphasizing biology and atmospheric physics and chemistry. See http://envinet.npolar.no.

The **Scandinavian/North European Network of Terrestrial Field Bases** (SCANNET) is a network in northern Scandinavia and Europe collaborating to improve comparative observations and access to information on environmental change in the North. SCANNET is funded by the European Commission, Research DG. See www.envicat.com/scannet.

We envision that the observing network will start initially as a linkage and interface between existing arctic research assets and grow gradually, in response to research needs and availability of funds. The network will include attributes of true measurement networks like the linked set of weather stations maintained by the National Weather Service (NWS), as well as more complex attributes like those of environmental observatories, Long Term Ecological Research (LTER) sites, and logistical bases. It will consist of both equipment and people, and an effective data management system will be crucial to optimal use of the observing network. Through the development of standardized protocols, memoranda of agreement, and convincing argument, the network will grow and expand, encompassing and partnering with current systems, adding new systems and locations, and developing innovative ways of collecting critical data.

It is vital that existing locations with in situ long-term observation programs be maintained while new locations are identified, occupied, tested, and eventually brought on line. For example, the International Arctic Buoy Program (IABP), which has maintained a network of drifting buoys on the sea ice of the Arctic Basin since 1979, has contributed crucial data to the understanding of the arctic climate. Linking existing arctic research assets and adding new sites as needed to form an observing network would enable investigators to address regional and continental scale environmental questions by providing:

- strategic siting of observing and monitoring facilities in locations where observations have maximum value;
- high-resolution data that truly integrate space and time and facilitate synthesis across scales;
- a foundation for research addressing scaling issues; and
- improved information access and management, including communication with arctic residents and methods for data archiving, sharing, use, and visualization.

Some observations can be obtained with existing technologies (e.g., aircraft-based surveys of the upper water column, deployment of current meter arrays, gauging of arctic rivers)—in several cases with relatively inexpensive off-the-shelf instrumentation. Many useful measurements can be made in or near existing arctic communities by local residents. Other observations will require the design and deployment of new technology (e.g., profiling floats that work under sea ice cover, autonomous soil moisture sensors, etc.). The most critical element is support to install and maintain a sufficient number of sites to characterize a region or process temporally and spatially. Elements of several components that could form the backbone of an arctic observing network are already in operation, including the Arctic Long-term Observatories (LTOs), the Circumarctic Environmental Observatories Network (CEON), the arctic Long Term Ecological Research (LTER) site at Toolik Lake, and the facilities associated with the Barrow Environmental Observatory (BEO).

It will be challenging to assemble current and future arctic research support components, operated by many different organizations, into a coherent and coordinated whole that can be improved as knowledge increases, technology advances, and needs evolve. We recommend that a blue-ribbon panel be appointed to develop a plan for the creation of an arctic observing network, including:

- reviewing the scientific objectives on which the observing system is based;
- taking an inventory of existing components and observations;
- identifying critical spatial and observational gaps;
- outlining an appropriate data processing, distribution, and archiving system; and
- developing a phased implementation schedule and budget.

The implementation of the network should begin as soon as possible, in close coordination with NSF and other agencies, in order to start capturing the data needed to detect and explain arctic environmental change. Several national and international entities are planning or proposing observing networks to improve regional and continental scale understanding of the environment that would complement the arctic network (box page 31). While coordination and communication among these initiatives, relevant agencies, and international programs will be key in the effective development of the arctic network, the blue-ribbon panel should move forward with the planning process without waiting for the implementation of these larger initiatives.

Major new scientific initiatives that rely on large-scale, long-term observations in the Arctic include:

- the Study of Environmental Arctic Change (SEARCH; SEARCH SSC, 2001),
- the Arctic/Subarctic Ocean Fluxes Program (ASOF; Dickson et al., 2002),
- the Community-wide Hydrological Analysis and Monitoring Program (CHAMP; Vörösmarty et al., 2001), and
- emerging efforts in the Arctic System Science Program (ARCSS), including Pan-Arctic Cycles, Transitions, and Sustainability (PACTS; Sturm et al., 2003), and Land-Shelf Interactions (LSI; Cooper, 2003).

These programs examine arctic physical, biological, and human systems over time scales covering years to decades. Meeting the scientific community's need for long-term observations may require a shift in thinking about what types of studies are appropriate for NSF to fund and renewed commitments from other agencies to continue their monitoring activities. Typically, NSF has not funded long-term observations. While some of the objectives of the new arctic initiatives can be addressed under the limitations of the NSF research mandate, funding for long-term observations of key

Tasks for the Blue-Ribbon Panel

A blue-ribbon panel should be established and provided with staffing and support to develop a plan for the creation of an arctic observing network, including:

- taking an inventory of existing components and observations;
- adjusting the design of the observing system to changing scientific needs;
- coordinating with international programs to identify essential observations;
- identifying critical spatial and observational gaps;
- supporting scale analysis studies to determine appropriate temporal and spatial scales for observation parameters;
- recommending the most effective strategies to obtain necessary observations;
- outlining an appropriate data processing, distribution, and archiving system;
- developing common measurement protocols and data format and archival standards across the international community;
- holding national and international working group meetings and working with residents of the Arctic to develop and coordinate implementation of the network; and
- developing a phased implementation schedule and budget.

variables at adequate spatial and time scales must be provided and will require increased involvement of all relevant agencies. Agency reviewing and funding mechanisms may need to be modified to support long-term, sustained monitoring and collection of time-series data as well as integrative multidisciplinary science.

Recommendations

- Establish, staff, and support a blue ribbon panel to develop a plan for an integrated terrestrial, marine, and atmospheric arctic observing network (box previous page).
- Restore essential long-term observation stations that are about to be or that have been phased out.
- Encourage international support for reestablishment of critical Russian arctic meteorology and hydrology stations.
- Support and expand the International Arctic Buoy Program.
- Support deployment of current systems for manned and autonomous measurements for terrestrial, atmospheric, and marine environments, as recommended by the blue ribbon panel.
- Support development of new technologies for instrumentation and measurement systems.
- Promote means to share responsibility for increased arctic monitoring among government agencies supporting arctic research, including NSF, National Oceanic and Atmospheric Administration (NOAA), Department of Energy (DOE), Department of Defense (DOD), National Aeronautics and Space Administration (NASA), U.S. Geological Survey (USGS), Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), Minerals Management Service (MMS), and Environmental Protection Agency (EPA).
- Establish a mechanism by which observing technologies developed by a basic science agency such as NSF can readily be transferred for operations to mission-oriented agencies such as NOAA.
- Encourage NSF support of long-term observations (three to twenty years) in cases where no other support is available.
- Use aircraft for remote sensing surveys of marine and terrestrial environments and for atmospheric measurements.
- Establish a clearinghouse for integration of specific types of data from disparate sources (e.g., weather data).
- Recapture and make easily accessible existing data and scientific "gray literature" that are relevant to large segments of the research community.

Facilitate Access to Distributed Systems of Hardware, Software, Information Bases, and Automated Aids for Data Management, Synthesis, Interpretation, and Modeling

Enabled by information technology, a qualitatively new and different scientific infrastructure has developed in recent years. This infrastructure delivers unprecedented computational power to access, distribute, and share data and synthesized products such as climatologies. It provides investigators with new research tools, including data analysis and interpretation aids, web-accessible databases, archives, and collaboratories (box). It allows modeling efforts, which are crucial to understanding the context of observations, to be more closely integrated with observations. Some research problems can be answered only through the use of new generations of these powerful tools.

As new observing systems come on line, researchers need increased capacity to distribute, archive, and assimilate their large data streams. Such data will be used for observing-system design and refinement, design of process studies, and investigations of a variety of processes that occur from local and regional to system-wide scales. A broad community of researchers also requires access to modeling results. Modelers traditionally do not archive results from model runs because the models are being improved constantly. With access to simulation results becoming critical for field support purposes and interpretation of observations (box page 15), the modeling community should develop an effective means for archiving and accessing the results of control model runs of a research project for use by the larger research community.

Establishing adequate capacity for such efforts requires access to sufficient central and distributed computing power, as well as the technologies of effective data transfer, curation, synthesis, and assimilation. While new efforts are likely to focus on assuring access to computer centers for the arctic research community, it may become necessary for the RSL Program to contribute to the expansion of these centers, if this is required to deal with the large data streams expected from the arctic observing network. Dedicated research centers that provide support such as high-speed computers and connectivity to establish physical or virtual teams can be used effectively for some parts of the tasks outlined above.

Collaboratories

A collaboratory is a networked instrument and computer simulation system, which assembles data and models and permits on-line "chat room" discussions between scientists. The collaboratory concept has significant potential for arctic research. By creating groups of investigators focused on common questions, collaboratories build synergies among investigators using different models, technologies, and approaches. Because of the existing concentration of research already taking place there, the North Slope of Alaska is an excellent candidate for a collaboratory.

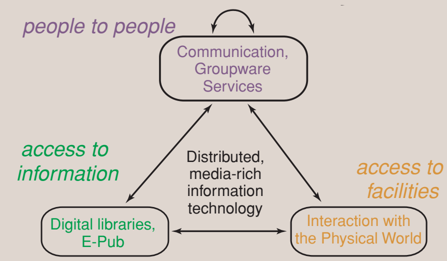


Figure from the Science of Collaboratories, an NSF-sponsored project at the University of Michigan. See www.scienceofcollaboratories.org.

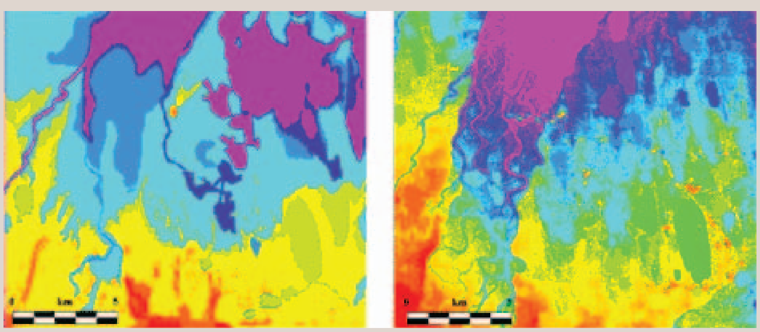
Geographic Information Systems. Another activity that contributes to synthesis is the development of web-based geographic information systems (GIS), which help science teams to visualize information, perform intensive analyses of variation, processes, and feedbacks, and distribute data widely.

Enhancements to Internet-based GIS would benefit nearly all arctic scientific disciplines and problems by improving spatial analysis and data sharing. Sharing datasets among various research groups can be difficult due to differences in map projection, data, data format, extent, and distribution channels. The arctic science community can take advantage of international efforts to develop data standards, organizational practices, and technology, collectively known as spatial data infrastructure (SDI). SDI provides a basis to support integrated and multi-sector decision making, research, and discovery at local to global scales.

Examples of GIS Investments

Providing the research community with high-resolution data and images results in tangible scientific benefits across numerous disciplines and increases the efficiency and significance of current and future research. An example of this type of investment is the recent project to purchase, validate, and distribute a new, high-resolution digital elevation model (DEM) of the Kuparuk River watershed in northern Alaska (figure). The DEM will be available through the Joint Office of Science Support (JOSS). In addition to purchasing the DEM product, the project will validate the new DEMs for accuracy, produce vector layers of stream channels for use in many GIS applications, provide basic hydrological information on the watershed, and include a variety of shareware software, still images, animations, references, and technical specifications.

A similar project will create three suites of spatial data products of the area near Barrow, Alaska, including the Barrow Environmental Observatory (BEO). Currently, NSF supports more than thirty-five research projects in the Barrow area. The new high-quality spatial information will be made available to all NSF-funded researchers through the ARCSS Data Coordination Center and will permit state-of-the-art analysis, establish a temporal baseline for decades of change-detection studies, and promote interdisciplinary collaboration.



A portion of the Kuparuk River watershed shown with the standard USGS DEM data (left) compared with the new, high resolution data (right). Figures courtesy of Matt Nolan.

Participants in the 2001 Arctic GIS workshop developed specific recommendations for establishing an effective arctic SDI (Sorenson et al., 2001). An advisory group of arctic researchers and experts in GIS standards and administration could guide and coordinate the process, including archiving existing data, developing an arctic data catalog, designing a plan for the incorporation of new GIS data, and providing for the long-term maintenance of an SDI to support arctic research. Combining future efforts to improve arctic GIS with existing U.S. and international spatial data sharing programs would increase the usefulness of a spatial data infrastructure for the Arctic.

Recommendations

- Improve researchers' access to data and modeling results through central web-accessible archives.
- Ensure adequate computer capacity for data transfer, synthesis, assimilation and modeling.
- Improve the synthesis of field observations and model-based understanding.
- Organize workshops that bring together modelers and field scientists around a focused question of understanding and predicting basic characteristics of and changes in specific elements of the arctic system.
- Encourage expansion, coordination, and linking of GIS activities and data.
- Foster spatial data infrastructure (SDI) and standards to support the development of regional SDI nodes that would contribute to a pan-arctic SDI.
- Facilitate continued sharing of remotely sensed data and development of value-added products from data archives.

Improve Communication and Data Transmission Capabilities, Remote Field Power Options, and Access to Satellite Observations

Access to technical infrastructure such as adequate communication and data transmission systems, dependable portable power sources, and satellite observations continues to be a major concern for arctic researchers. While voice and electronic mail capabilities have improved greatly, they remain problematic at high latitudes where geostationary satellites are low on the horizon, requiring very careful antenna alignment and limiting their usefulness for autonomous or other small, mobile operations. Improvements to these systems will enhance the scientific value and improve the safety and efficiency of field operations and will be critical in the implementation of an arctic observing network.

Specific solutions to these challenges will vary depending on the project's needs, the location, and the technology available. Existing or future technology could significantly improve high-latitude, broadband communications for scientific work. The successful development of an arctic observing network will depend on reliable access to broadband across locations. Communications improvements also are critical to increasingly sophisticated autonomous instrumentation, including remote data buoys, moorings, autonomous weather stations, and field stations. These require higher outgoing digital data rates than are currently available, as well as the ability for two-way communications—needed for changing sampling strategies in real time when anomalous events occur. For example, during SHEBA, data file transfer by satellite telephone provided

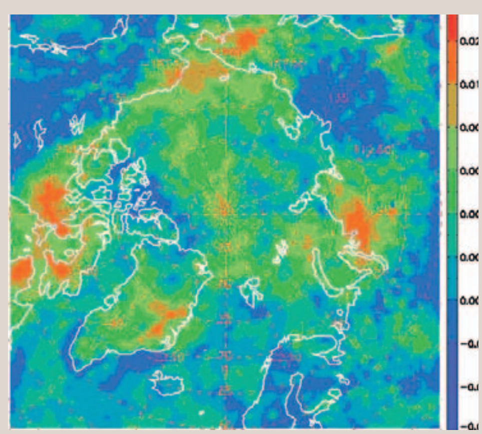
Satellite Observations

Satellite observations with the potential for determining arctic cloud properties, sea ice extent, surface temperatures, seasonal snow cover, and land characteristics extend back to 1978, but investigators have found it difficult to exploit fully the potential of these satellite records. Issues such as the long polar nights, which render visible channels unusable, and bright underlying snow and ice surfaces, which complicate surface and cloud identification, pose specific challenges to satellite observations at high latitudes (NRC, 2001).

Ongoing coordinated studies are required to maximize the value of the satellite datasets by gathering validation, reference, and calibration information from long-term, surface-based datasets to develop arctic-specific retrievals for atmospheric, surface, ice, and ocean properties. Important measurements include meteorological data, data from drifting ice/ocean buoys, and hydrographic data collected from ships. Once this is accomplished, the satellite datasets can fill in observational gaps in both space and time to provide a true pan-arctic perspective. Conversely, satellite observations can be used to check the consistency of field data.

As an example, long-term measurements from meteorological stations have shown that the surface temperature of arctic land areas has increased over the past few decades. These trends have been verified by satellite data for the past twenty years, and related trends in satellite-derived cloud amount (figure below) and the cloud radiative effect have recently been reported (Wang and Key, 2003). Data collected during the SHEBA experiment (page 49) provided critical in situ observations for validating the extended satellite products.

Trends in springtime arctic cloud amount 1982–1999, based on the extended Advanced Very High Resolution Radiometer (AVHRR) Polar Pathfinder satellite data product. Spring cloud amount has increased at a decadal rate of 0.031 (unitless on a scale of 0 to 1). The seasonal increase in cloud amount is generally consistent with increasing trends in cyclonic activity and in total precipitable water (courtesy X. Wang and J. Key).



principal investigators with daily data samples, which allowed them to spot and correct instrumentation problems and incorporate data into numerical models in near-real time.

In addition, ship and ice-station operations in the Arctic are enhanced greatly by up-to-date, detailed remote sensing imagery (visible, passive microwave, synthetic aperture radar, etc.), which also requires high data-transfer rates. Affordable options for high data-transfer rates, such as the NASA Ka-band Tracking and Data Relay Satellite System (TDRSS), should be explored.

The low-altitude, polar-orbiting Iridium satellite cellular telephone system will allow dependable two-way communication via standard modem protocols if appropriate multichannel bonded systems are constructed. The Iridium system is being used presently to provide long-range communication for NSF-funded remotely operated measurements in the Arctic. Currently proposed rates of slightly less than a megabyte per hour are useful for very low data-rate mobile applications but must be improved upon. VSAT technology communication systems are being marketed directly to residential and commercial users. These satellite dishes can provide direct high-speed Internet access in remote areas without a satellite or land-line phone and may be a cost-effective option in many situations.

Closely related to the requirement for improved broadband communications for remote locations is the need for clean, portable, dependable power sources with increased capacity. Past field operations have depended almost exclusively on diesel- or gasoline-engine generators for manned stations, or on lead-acid or lithium batteries for unmanned installations. These mature technologies are relatively dependable but have significant drawbacks for arctic work; alternative options for remote power generation, such as fuel cells, should be explored and used where feasible.

Satellite observations of the Arctic are increasingly important to planning and logistics as well as science (box previous page). For example, satellite products are used to support navigation in sea ice and weather forecasts for aviation. In some cases, scientists also need satellite products in the field to identify targets and anomalies to sample. Satellite measurements are especially important for ongoing observational programs, whether an active field program or an autonomous measurement. Satellite observations are frequently the only means of large-scale ocean, atmosphere, and terrestrial monitoring. The ice cover over much of the Arctic will make remote sensing techniques (perhaps deployed on submarines) critical for progress on several geophysical issues. It will also be necessary, however, to collect sediment and rock samples by drilling and dredging at select locations to "ground truth" the geophysical data.

Product generation from remote sensing will continue to progress toward merging of algorithms with models via data assimilation or other methods. This synthesis of modeling and remote sensing will provide a valuable route for taking advantage of separate advances in modeling and remote sensing and improved guidance for data collection targeted at specific types of uncertainties and errors (Maslanik, 2001). Too often, satellite information that could effectively support a field experiment is not obtained because of cost or bureaucratic administrative requirements. Often, information that is obtained is provided by happenstance or

Innovative Instrumentation and Technology

Operating scientific instruments in the Arctic can be challenging because of issues such as low temperatures, riming, difficulty in establishing Internet and satellite communication links, as well as transportation, housing, and power issues. Trained personnel can be the most expensive component of a project; thus a critical element of improving arctic observing science is the development of innovative, arctic-capable instruments that can operate in largely unattended modes.

Recognizing this, in 2000 the Office of Polar Programs (OPP) solicited proposals for a special competition in Polar Instrumentation and Technology. Eleven projects were funded for up to four years, totaling approximately $5.4 million, to develop state-of-the-art techniques and instruments for polar research and technologies to enhance or streamline support for remote facilities and operations. Funded projects include automatic weather stations, satellite-linked remote data collection systems, ocean flux buoys, unpiloted aerial vehicles (UAVs), and an atmospheric cloud and aerosol lidar.

In November 2002, OPP sponsored an Arctic Instrumentation Workshop (Reves-Sohn and Bellingham, in press) to examine the technology needs and opportunities for realizing year-round, synoptic, multiscale (spatial and temporal) observations in the Arctic Ocean. Three distinct formats for scientific research in the Arctic Ocean were evaluated: (1) expeditionary formats, (2) basin-scale networks of mobile platforms (e.g., gliders, AUVs), and (3) fixed sensor platforms (e.g., buoys) and cabled oceanographic observatories with real-time data and power connections to land. A combination of these formats will be required to achieve the goal of an arctic observing network.

The working group recommends that NSF and other agencies continue to support the development of instrumentation and technology to modernize measurement systems, minimize environmental impacts of research, and enhance research support capabilities. Continued work in such areas will strengthen the ability of the arctic science community to collect needed data; this effort must be combined with the development of either a long-term monitoring program at NSF or an interagency program by which NSF-developed technologies can be transferred for operations to agencies such as NOAA and EPA.

Top: In late 2001, Healy *supported testing of a new autonomous underwater vehicle (AUV) being developed at the Monterey Bay Aquarium Research Institute (MBARI) for the Atlantic Layer Tracking Experiment (ALTEX). While AUVs have been used for arctic science since the 1970s, their ranges have been limited to approximately 1 km and depths of a few hundred meters. The ALTEX AUV is designed to range 1,000 km and to depths of 4,500 meters, navigating and deploying ice-penetrating buoys to relay data via satellite. Photo by T. Walsh © MBARI 2001.*

Center: Advances in the design of autonomous ice/ocean buoys have enabled successful transmission of ocean measurements, including direct turbulent flux measurements, frequent high-resolution temperature and salinity profiles, and continuous upper ocean current profiling by acoustic Doppler techniques. A similar effort is needed to develop and deploy autonomous instrumentation to measure parameters such as weather, snowfall, and radiation in terrestrial locations. Photo by Timothy Stanton, Naval Postgraduate School.

Bottom: An Aerosonde unpiloted aerial vehicle (UAV) being collected after landing following an arctic mission over pack ice near Barrow, Alaska. Weighing less than 15 kg, this small robotic aircraft was designed to range up to several days and several thousand kilometers to provide environmental monitoring and surveillance over remote areas and in harsh conditions. The Aerosonde can be instrumented to characterize a variety of atmospheric and surface properties. Photo by James Maslanik, University of Colorado.

through individual investigators' knowledge and connections. Interagency agreements between NSF, NASA, NOAA, DOE, and DOD could substantially reduce costs and the time required to clear administrative hurdles (NRC, 2001). Where possible, the arctic research community should take advantage of satellite data access networks, such as the USGS AmericaView Program, to reduce costs and improve access. Also, NSF science steering committees should include a member (perhaps from NASA) who is cognizant of satellite data and can work to obtain coverage and access for the scientific needs of the program as well as for planning and safety.

Recommendations

- Voice: provide access to satellite communication systems that are reliable for the locations where research is being conducted.
- Data transfer: assure access to satellite systems with data-transfer rates compatible with the experiment.
- Provide access to two-way communication capability for remote autonomous sites.
- Foster development of dependable power for remote, harsh environments, including conventional generators, batteries, solar, wind generation, and fuel cell technology.
- Provide near-real-time access to remotely acquired imagery for planning, safety, and science support of field operations.
- Foster interagency cooperation, coordination of specific platforms, products, and imagery for arctic research.
- Improve access to archival collections of pertinent imagery.

Supporting the Infrastructure for Safe and Efficient Research

Continue to Improve Access by Supporting, Expanding, and Upgrading Marine and Terrestrial Facilities

Arctic researchers continue to increase their use of major research platforms such as field stations and research vessels (figure below). The facilities available through these platforms provide critical support to investigators performing intensive process studies, gathering basic geophysical data, and sustaining long-term observations. Important U.S. arctic research assets include the Toolik Field Station, the new U.S. Coast Guard Cutter *Healy,* the facilities in and near Barrow, Alaska, and the Summit site on the Greenland ice sheet. An Alaska Region Research Vessel (ARRV) is being planned to replace the aging *Alpha Helix.* The ARRV would provide berths for about twenty-four scientists and facilities for a variety of science missions.

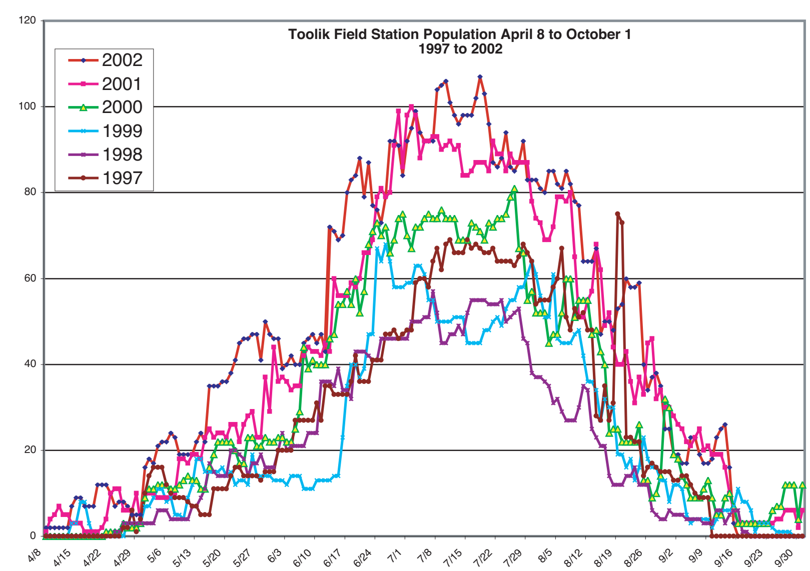
Each of these assets would be a major node in the proposed arctic observing network described in the previous section. The RSLWG recommends that NSF continue to expand and upgrade terrestrial and marine facilities in ways that allow more comprehensive spatial and temporal (year-round) observations and the access necessary to understand the geological evolution of the arctic region.

Significant expenditures to increase the capabilities at research platforms should be justified by scientific needs and guided by appropriate planning and oversight. When possible, logistics bases should be established or funded in areas where long time-series information already exists, and continuing to support such records should be a high priority. The working group recognizes that NSF faces some decisions in balancing its ongoing commitments to support these major platforms with researchers' needs for flexibility and spatial coverage.

The many process studies and long-term observations carried out at the permanent facilities such as Toolik, Summit, and Barrow are vital for developing generalizable models. They must be supplemented, however, by studies in many more regions before the modeling predictions will be representative of large regions of the Arctic. Additional surveys and paleoenvironmental and process studies are needed in far more arctic marine and terrestrial ecosystems, some throughout the year. To complement the functions of the major platforms, mobile field stations are needed to enable researchers to sample under-represented areas during all seasons. Submarine science missions can gather data from areas that are otherwise inaccessible. Logistical coordination and memoranda of understanding also should be maintained and updated for projects requiring access to arctic locations in other countries, for example, Resolute, Canada, Kangerlussuaq, Greenland, and Longyearbyen, Svalbard (page 46).

The higher resolution spatial and temporal observations needed to document and understand arctic environmental change also require year-round access to establish and maintain observation systems. Not all observation systems can be autonomous, and some sites will necessitate hands-on measurements and continuous maintenance. Year-round access to terrestrial and ocean locations is also necessary to develop a reasonable understanding of seasonal and year-to-year variability of specific variables and processes. Our current knowledge of these systems is largely confined to seasons when access is easiest from a logistical point of view; for many locations this is summer, but the data collected from U.S. sea ice camps in summer, for example, is very limited.

Planning must also take into account that the aging Coast Guard Polar Class icebreakers will soon be reaching the end of their design service life. In addition, recent Antarctic deployments have required two icebreakers, which may limit early spring arctic research cruises. A research vessel suitable for coastal arctic and subarctic research is needed as well; the ARRV is expected to meet this need.



Daily numbers of residents at Toolik Field Station from 8 April to 1 October, 1997–2002. Overall use of the station has grown from 4,202 userdays in 1997 to 7,128 in 2002, an increase of 69% in five years. Investigators are expanding their use of the station into the winter months as the facilities have improved to enable that use. Figure by Mike Abels.

Effective Guidance for Facilities Planning

The research community should continue to provide oversight and planning assistance for major arctic research platforms. For example, the implementation of science capability and operations of the *Healy* are guided by the Arctic Icebreaker Coordinating Committee, a UNOLS committee. This guidance has been the key to the vessel's effective scientific use. Similarly, a long-range plan developed by the user community guides the continuing development at Toolik Field Station (ARCUS, 1996). NSF should continue the planned upgrades to these research assets, where demand for use is very high.

The community of Barrow has a long and distinguished history of contributions to arctic research (Norton, 2001). Researchers supported by many state, federal, and private entities use Barrow as a research base. The logistics services of the Barrow Arctic Science Consortium (BASC) provide valuable support to NSF and other agencies' researchers, but much of the research infrastructure at Barrow predates World War II, is rapidly deteriorating, and is inadequate for current demand (ARCUS 1999b; BASC 2002). Congress provided $1 million in planning funds to the National Oceanic and Atmospheric Administration FY 2003 budget for a new science support facility in Barrow. The major infrastructure upgrades planned for the Barrow area should:

- correspond to science needs,
- continue to be guided by user planning and oversight,
- include resources specifically designated to cover operations and maintenance costs,
- be designed to help meet national and international training and educational needs (page 50), and
- consider including capabilities that will capitalize on Barrow's location, such as providing running seawater and a conduit for instrumentation running from the facility to the Arctic Ocean.

To maximize the scientific opportunities associated with major research platforms, sustained support will be needed for scientific oversight and analysis of standard observations from existing and future platforms, for example, from each cruise on the *Healy*. This support would ensure that a specific set of high-quality data is obtained consistent with a long-term observations strategy. Data collection and archiving according to agreed-upon protocols are essential to maximizing the utility of observations. Toward this end, the AICC recently formed a working group to oversee routine operation and data availability of SWATH mapping sonar on the *Healy*.

Recommendations

- Provide year-round access to terrestrial and marine locations.
- Provide remote transportable field camps for temporary or year-round occupation.
- Support remote autonomous or manned stations as necessary for year-round process studies.
- Support fixed science equipment calibration and maintenance on platforms by qualified experts.
- Support standard data collection, oversight, and analysis from existing instrument systems on current and future platforms (e.g., Seabeam data from USCGC *Healy*).
- Support the Arctic Icebreaker Coordinating Committee in working with the user community, federal sponsors, and the operators of other polar facilities to promote the best use of the U.S. Coast Guard icebreakers.
- Support deployment of autonomous vehicles to provide spatially distributed sampling throughout the year.
- Continue infrastructure and research support improvements to major research platforms when justified by science needs.
- Support the revival of U.S. Navy SCICEX cruises.

- Collaborate with industry to obtain geophysics and core data from the arctic shelves.
- Support geological and geophysical surveys, including bathymetry, seismology, drilling and coring, and acquisition of baseline remotely sensed datasets.

Support Safety Training and Planning

The hazards associated with arctic field research include outdoor activity, operation of mechanical and electrical equipment, diverse types of travel, extreme cold, darkness, poor communications, bears, dangerous ice conditions, and long distances to medical and emergency services. Specific and comprehensive attention is needed to ensure that arctic research remains a safe pursuit. This includes preventive measures in the form of training, equipment, and emergency response in the form of contingency planning to facilitate rapid and seamless action and cooperation between agencies and groups.

Differences in the nature of the arctic and Antarctic regions mean that the model used for promoting and facilitating safe research in the Arctic must be fundamentally different from that used in the Antarctic. In the Antarctic, limited access, screening of researchers, and the singular logistics support structure allows a centralized approach to safety and response to accidents and emergencies. In the Arctic, this approach is not possible, because the Arctic has multiple entryways, a resident human population, diverse local governments, and a wide array of agencies and groups associated with search, rescue, aviation, and medical services. Instead of a centralized system, arctic safety programs must be widely distributed and adapted to the local conditions and governments.

Institutional Responsibility. Currently, the institutional lines of responsibility for safety and emergency response in the Arctic are confused, as is liability in the face of a research accident or disaster. Institutions involved in arctic research include the researcher's home institution, contractors hired to provide logistical support, and the agency sponsors. Agencies involved in emergency response include federal (i.e., U.S. Coast Guard), state (i.e., Alaska State Troopers), and local groups with search and rescue responsibility and emergency management powers. Outside the U.S., similar multilayer lines of responsibility exist and are equally confusing. In most locations where arctic research is now conducted, local governmental control probably has jurisdiction under true emergency conditions. Because of this latter constraint, a hierarchical structure of responsibility and control for issues related to safety, like that employed in the Antarctic, is unlikely to be a useful model for the Arctic, though the proper model probably has not been defined yet. Defining that model may be the most essential task to be undertaken in reviewing institutional responsibility for safety. Two areas that need to be clarified through a formal assessment process in order to ensure seamless response in the face of accident or emergency are:

- who will do what?, and
- who is liable and responsible?

The answer to these questions will vary from one location to the next, and may change with time, but the basic system needs to be determined before a crisis occurs.

Toolik Field Station Emergency Medical Technician/safety officer Josh Pobrislo treats Heather Adams for an injury in June 2002. Photo by Richard Flanders.

Safety Assessment

To clarify the roles, responsibilities, and interactions of institutions involved in arctic research, the following formal activities should be undertaken:

Risk assessment: Determine what hazards and accidents are likely, and where. What disaster scenarios might need to be dealt with related to current and future arctic research?

Resource inventory: Determine what resources, local or otherwise, are available for medical or emergency response. How can they be put in motion? Who initiates action? Where are interagency frictions likely to hamper operations in an emergency? How should this inventory information be disseminated so that it is available to the person needing it at the time it is needed?

Contingency planning: What needs to be put in place (predeployment of equipment, memoranda of understanding, communications, translators, air ambulance) so that in the event of an accident, rescue and help can be mobilized rapidly? What interagency and institutional agreements should be put in place so that emergency response is seamless? How will efforts be coordinated? What political concerns should be anticipated that might complicate the response? Procedures and responsibility for medical evacuation from arctic locations need to be clarified among the relevant entities and disseminated to researchers.

Charter operator safety records: Appropriate standards for air and boat charter operator safety need to developed and disseminated. Safety records of charter companies need to be made available to contractors and individual researchers so informed decisions can be made concerning use and risk.

Protocols: Assure that researchers are aware of the proper procedures for summoning help in an emergency (who to radio, what frequencies are monitored, etc.)

Training. The skills needed to function safely in the Arctic take time and effort to develop. Both specialized training and field mentoring are essential to promote personal safety. Since 2001, VECO Polar Resources (VPR) has offered free courses in field safety for arctic researchers at several locations, including at Toolik Field Station and in association with arctic scientific meetings. This training program, which includes wilderness first aid, firearms safety, boating safety, aviation safety, and survival, should be continued and expanded. The arctic research community is not generally aware that funding is available to support safety training and for local hire related to safety issues. Local safety experts are available across Alaska's North Slope and in Chukotka, Russia, through the Barrow Arctic Science Consortium and the Chukotka Science Support Group. Similar cadres of local safety experts should be developed in other regions of the Arctic. Even experienced field personnel will be able to conduct themselves in a safer manner if they have access to local knowledge concerning travel, weather, and unusual conditions.

Field mentoring is even more important than classes for teaching and developing habits of safety in arctic research. More formal recognition of its value (as in the proposal review process) could help encourage such mentoring. Traditional knowledge is typically passed on through the mentoring process, and much of traditional knowledge has significant survival value in the Arctic. Interactions among students, scientists, and the bearers of traditional knowledge should be promoted at every opportunity. Training and mentoring programs similar to the NSF Research Experiences for Undergraduates (REU) should be put in place to produce the next generation of field researchers, specifically recognizing the importance of mentoring for field safety as well as mentoring for science.

Equipment. Dissemination of the proper equipment to persons and agencies can also promote safety and facilitate rapid and effective response when an emergency does occur. Currently, a variable range of equipment is available and used, depending on location. Some safety equipment can be provided in the Barrow area by BASC and in other areas by VPR. VPR also is able to issue medical kits and provide for remote medical advice. The entire equipment system needs to be assessed systematically, identifying how to improve both the content and distribution. Available equipment should be commensurate with the likely safety risks, so this exercise is linked to the risk and resource assessment described in the box on page 44.

Recommendations

- Continue and expand personal safety, survival, and medical training. Where possible, take the training to the field where researchers are located and where the training will be more relevant.
- Promote safety and field mentoring of young and inexperienced researchers and field support staff, through formal apprenticeship programs.
- Determine what safety equipment is needed and assess if these needs are being met. If not, ensure all researchers and research locations are properly equipped.
- Conduct a combined risk assessment and emergency response resource inventory for areas where arctic research is being done and use the results to establish protocols.
- Establish protocols for communication and emergency evacuation for U.S. researchers working in the U.S. and foreign territories.
- Continue to make equipment centrally available as is currently done in Barrow through BASC and in other locations through VPR. Equipment should include shelters, corers, melters, firearms, snowmobiles, field communications, and safety and survival gear.
- Streamline the process for getting the equipment to the right place at the right time so as to minimize investigators' logistics problems.
- Conduct contingency planning for possible accidents and emergencies. Through this planning process, help to anticipate political and bureaucratic obstacles to prompt response and identify sources of assistance.

Organizing Agreements and Relationships to Maximize Resources and Cooperation

Facilitate International Coordination and Cooperation

Cooperation with the international community is required to achieve better global coverage, gain access to shiptime on foreign vessels, and maximize the efficient use of limited arctic instrumentation and facilities. For example, international collaboration is essential for the effectiveness of hydrographic surveys and of large-scale comparative social science research. Currently, most international collaboration in arctic research is achieved through the efforts of individual PIs. Both individual investigators and U.S. agencies should be encouraged to increase their participation in appropriate international programs and projects. International exchanges of researchers should be supported to improve knowledge of relevant research programs, information networks, and logistical assets and to develop research methods that produce comparable data in different locations.

A formal mechanism, above the PI level, is needed for handling issues of international scientific access, especially to Russia. Impediments in access and permitting to study the vast Russian Arctic still prevent many investigators from working there. More than a decade after *Perestroika*, the number of collaborations between Russian and American arctic scientists is slowly growing, but intimidating obstacles persist. The success of any research project working in Russia is still highly dependent on the networking ability of the Russian research institutes. Logistics arrangements remain largely the responsibility of individual researchers, who depend on Russian contacts and their own experience.

In most cases, U.S. investigators must pay for nearly all expedition costs, including salaries for Russian collaborators when it can be justified. The widespread lack of trust in the Russian banking system makes it risky to pay for logistical costs via electronic transactions. The U.S. Civilian Research and Development Foundation (CRDF; box this page) has successfully facilitated many types of financial transactions; each must be planned carefully on an individual basis, however. In most remote parts of Russia, all transactions for food, lodging, or transportation require Russian rubles, forcing investigators to travel with large sums of cash. Customs arrangements and permitting to transport scientific equipment can be complex and protracted, often varying by port of entry, requiring Russian government approval, and involving unanticipated fees. The process can take months to years, out of sync with normal NSF funding cycles. While satellite phones are now tolerated in many areas due to

Civilian Research and Development Foundation

The U.S. Civilian Research and Development Foundation (CRDF) offers programs and services to assist NSF-sponsored activities in arctic sciences and geosciences in Russia, including:

- facilitating meetings, site visits, visa applications, etc., for NSF-sponsored visitors to Russia;
- assisting with financial transfers and equipment purchase and delivery to Russia, the arctic region, and elsewhere in the former Soviet Union; and
- offering two-year research grants to joint U.S.-former Soviet teams in all areas of sciences under the CRDF Cooperative Grants Program.

For more information, see www.crdf.org

the rapid popularity of cell phones, working in remote regions of Russia usually means no clear safety net for serious emergencies.

Several projects have made excellent progress in developing U.S.-Russian cooperation in arctic research. Funded by the Arctic System Science (ARCSS) Program, the Russian-American Initiative on Shelf-Land Environments in the Arctic (RAISE) is the only joint research program supported by both the Russian Foundation for Basic Research and the National Science Foundation (Forman and Johnson, 1998). RAISE coordinates a number of successful collaborative activities. The International Affairs Office of the U.S. Fish and Wildlife Service supports joint research with Russian and U.S. scientists, particularly on migratory species such as waterfowl and polar bears. The collaboration of the Barrow Arctic Science Consortium (BASC) with the government of Chukotka to form the Chukotka Science Support Group (CSSG; box) and the connections VECO Polar Resources (VPR) has established in the Russian north have helped make considerable progress in streamlining logistics issues for several field projects.

In one possible model for facilitating research in the Russian Arctic, many European countries have long-standing bilateral science agreements with the Russian government and its science agencies for arctic research efforts. Projects carried out under these annually renewed agreements follow a formalized permitting process and have recognition at high levels within the government science agencies. Russian scientists collaborating with scientists from these countries are then given access to special pools of funds from the Russian Foundation for Basic Research, funds that are not available to Russian scientists working with Americans without such agreements.

Recommendations

- Establish international cooperation for programs that cover large space scales and/or long time scales.
- Establish international cooperation for instrument development, deployment and recovery.
- Establish methods for shared use of major facilities, platforms, and equipment.
- Promote international collaboration, data sharing, information exchange, and reciprocity.
- Address issue of access to exclusive economic zones (EEZ).

Chukotka Science Support Group

A regional agreement connecting research support logistics on the North Slope of Alaska and in the state of Chukotka, Russia, is a promising model of international cooperation. Supported through the NSF/BASC cooperative agreement, two Native groups in Russia (the Yupik Eskimo Society and the Chukchi Naukan Production Cooperative) have created the nonprofit Chukotka Science Support Group (CSSG). CSSG also works with EPA, NOAA, NPS, and U.S. AID. The government of the Chukotka Autonomous Okrug recognizes CSSG as their liaison with foreign scientists.

CSSG maintains housing and field support equipment in Provideniya and Lavrentiya and has access to facilities in Anadyr. A laboratory on wheels is maintained in Lavrentiya. A full-time CSSG employee in Moscow performs liaison functions with the federal government. An advisor to CSSG represents Chukotka in the Russian parliament and serves on the parliament's Committee of the North. CSSG personnel travel with researchers to translate, undertake financial transactions on their behalf, arrange transportation, and facilitate safety issues. CSSG also helps foreign researchers with the permitting required on the national and regional levels in Russia. CSSG, the Pacific Oceanological Institute in Vladivostok, and BASC are negotiating a memorandum of understanding to expand logistical and permitting support.

- Streamline customs and permitting processes for movement of scientific gear, data, and personnel.
- Provide training workshops for researchers unfamiliar with local customs, ethics, and procedures.
- Use existing collaborations, such as RAISE and CSSG, as a model and build on their capabilities to provide safe access to Russia.
- Consider establishing formal collaborative agreements that would benefit collaborating Russian scientists and associated logistical arrangements for U.S.-funded projects, perhaps with the help of the U.S. Arctic Research Commission and the U.S. State Department.

Pursue Interagency Collaborations

Investigators supported by many federal, state, and local agencies perform research relevant to the arctic region. These research efforts address questions in a variety of topics, including using the Arctic as a natural laboratory, national defense issues, global and regional climate and weather, energy and minerals, transportation, communications, renewable resources, contaminants, environmental protection, health, and Native cultures. Thirteen federal agencies with significant arctic research interests are represented on the Interagency Arctic Research Policy Committee (IARPC; box this page). The 1984 legislation that created IARPC (Public Law 98-373, amended as Public Law 101-609, 1990) names the National Science Foundation (NSF) as the lead federal agency for arctic research, and the NSF director chairs the IARPC.

The special logistical demands of the arctic environment make it highly desirable that the various agencies coordinate their arctic research activities as much as possible. Although major interagency collaborations on arctic research projects have been relatively rare to date, those that have been attempted have been notably productive. Examples include:

- the collaboration between NSF and the U.S. Navy to develop the Scientific Ice Expeditions (SCICEX) cruises, a five-year program to explore the Arctic Basin with nuclear submarines;
- the collaboration between NSF and the Office of Naval Research to support the Western Arctic Shelf-Basin Interactions (SBI) project (Grebmeier et al., 1998); and
- the Surface Heat Budget of the Arctic Ocean (SHEBA) project (box next page).

Interagency Arctic Research Policy Committee

The Interagency Arctic Research Policy Committee (IARPC) includes representatives of the following federal agencies or offices:

- National Science Foundation
- Department of Commerce
- Department of Defense
- Department of State
- Department of Health and Human Services
- Office of Science and Technology Policy
- Department of Agriculture
- Department of Energy
- Department of the Interior
- Department of Transportation
- National Aeronautics and Space Administration
- Environmental Protection Agency
- Smithsonian Institution

and other agencies or offices deemed appropriate.

Examples of Interagency Coordination

Although all concerned agree that improved interagency cooperation would benefit arctic research, effective implementation has proved somewhat difficult. Three examples are discussed below.

Surface Heat Budget of the Arctic Ocean (SHEBA). The 1997–98 SHEBA program (Moritz and Perovich, 1996) provides an excellent example of agencies cooperating effectively on a major arctic research program. The NSF was the primary funding agency supporting the SHEBA ice camp and science. The Office of Naval Research (ONR) contributed significantly to the logistics and science funding. A number of NOAA and DOD investigators also participated in SHEBA, bringing critical expertise and equipment to the research teams. The DOE Atmospheric Radiation Measurement (ARM) program was another major SHEBA partner. In the spring and summer months, the NASA First ISCCP Regional Experiment (FIRE) Arctic Clouds Experiment (NASA, 1994) conducted an aircraft observing program over the SHEBA site. SHEBA also involved considerable international collaboration, including Canadian and Japanese investigations and, most notably, with the use of a Canadian ship for the year-long ice station. Through the coordination of these field activities and scheduling of joint science team meetings in following years, these agencies significantly furthered their mutual operational and science objectives for studying arctic ocean-atmosphere-ice processes and interchanges.

Study of Environmental Arctic Change (SEARCH). SEARCH exemplifies the planning needed from the outset of a major research effort when interagency cooperation is critical to its success. The Interagency Arctic Research Policy Committee (IARPC; box previous page) requested that its agencies coordinate activities for the SEARCH program through an Interagency Working Group. The Interagency Working Group for SEARCH (IWG-SEARCH) includes representatives from eight IARPC agencies as well as the U.S. Arctic Research Commission and the U.S. Coast Guard. The Department of Commerce National Oceanic and Atmospheric Administration (NOAA) chairs the IWG-SEARCH, which works closely with the SEARCH Science Steering Committee. The IWG-SEARCH is tasked with identifying agency activities that will contribute to the program goals of SEARCH, demonstrating how individual agency budget initiatives will collectively support SEARCH, and preparing multiagency coordinated budget initiatives to implement the SEARCH program.

Atmospheric Observatories in Barrow, Alaska. Both NOAA and DOE have an unusually strong set of atmospheric sensors in Barrow, Alaska. The NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) Baseline Observatory and the DOE Cloud Atmospheric Radiation Measurement (ARM) Program (ARM, 1996) gather some of the most technologically advanced and comprehensive measurements of the clouds, radiation, chemistry, and other aspects of the physical atmosphere. The NOAA/CMDL observatory monitors the atmospheric constituents that are capable of forcing climate change and those that may cause depletion of the global ozone layer. Measurements began in 1972–74 and are some of the longest continuous atmospheric records in the Arctic. Currently, over 200 different measurements are conducted at the Barrow Observatory through thirty-five cooperative programs. Adjacent to the NOAA site, the DOE/ARM North Slope of Alaska facility began collecting key radiation and cloud measurements in February 1998. Other agencies active in the immediate vicinity include the National Weather Service and the U.S. Geological Survey. NSF maintains a station of its ultraviolet (UV) Monitoring Network in cooperation with NOAA. The Barrow station, which includes a strong history of community support, serves as a prototype for atmospheric and terrestrial measurements that would be highly desirable at other key locations across the Arctic. Information technology upgrades at Barrow, initiated by NSF, are now being shared by DOE and NOAA. DOE is a long-term tenant of the NSF-supported BASC at both Barrow and Atqasuk, the village sixty miles south of Barrow where BASC maintains an inland support facility for researchers.

The Study of Environmental Arctic Change (SEARCH, box previous page), a new arctic research program, will begin implementation under the auspices of an interagency working group. Regional examples of interagency cooperation using nonprofit logistics support organizations are encouraging and should be emulated or expanded upon. For instance, both BASC in Alaska and CSSG in Russia were initiated to assist NSF researchers and now serve multiple federal agencies under NSF's guidance.

In the future, NSF and other key agencies must pursue effective interagency cooperation in support of arctic research. Federal, state, and local agencies must share in the responsibility of assisting in documenting and understanding the unprecedented change in the Arctic. Such cooperation will be particularly critical for the successful development of the arctic observing network, which will rely on existing agency assets, such as the 300-station seismic array in remote locations in Alaska. In many cases, other agencies have the most appropriate authority and capability to gather long-term observations of specific environmental variables, although some programs and measurement sites have been discontinued in recent years due to budget constraints. For example, NASA-sponsored research in the Barrow area is investigating the accuracy and stability of long-term satellite observations. Providing resources for BASC to support such non-NSF-funded work would lower overall costs and improve efficiency. Effective interagency coordination allows researchers to become aware of similar projects with common needs and tools, to make the most efficient use of logistical resources, and to maximize the scientific value and impact of their research efforts.

Recommendations

- Involve appropriate federal and state agencies in supporting long-term observations.
- Improve communication and coordination among agencies to facilitate effective use of logistical resources.
- Establish interagency working groups for all major arctic research initiatives.
- Make better use of marine, aircraft, and terrestrial assets, platforms, and satellites belonging to other agencies.
- Develop cost-sharing arrangements to provide interagency access to existing logistics and support services.

Enhance Communication and Partnerships with Arctic Communities

In recent years, Alaska Native tribes, arctic communities, and indigenous peoples throughout the North have become increasingly involved in arctic research. Arctic residents recognize that research addresses topics of importance to them, while researchers have found that arctic residents can contribute to research in a variety of ways, improving not only the research process, but also the relevance and usefulness of the end product.

The level of involvement and interaction varies by project, program, and discipline, ranging from informing arctic residents about research activities or local consultation during the preparation of proposals to establishing formal partnerships between researchers and Native groups and communities. Several documents provide guidance to investigators on these issues, including:

- the *Principles for Conduct of Research in the Arctic* (IARPC, 1990), which should be used by all investigators working in the Arctic;
- the draft *Guidelines for Improved Cooperation Between Arctic Researchers and Native Communities,* currently under development by NSF, which will help researchers work with local communities to avoid impacts to subsistence activities and to threatened or endangered species (expected early 2004); and
- NSF's Important Notice 127, which reemphasizes the importance of addressing the broader impacts of all NSF-sponsored investigations.

Such general guidance and encouragement is helpful, but leaves researchers seeking to work with communities to find their own solutions to many common challenges and vulnerable to miscommunications and misunderstandings. The process of establishing formal research partnerships, for example, is complex and time consuming. Many arctic researchers do not realize that support is available to form and maintain these partnerships, including seed funding to explore research ideas with local communities. Support also can be used to provide training for community researchers and report to communities about the results of the project. Disseminating useful resources, such as a network of local contacts, examples of collaborative agreements, and the ways in which ethical principles have been put into practice, will greatly benefit many researchers seeking to develop partnerships.

In addition, many indigenous arctic groups and communities are interested in developing their own research projects. Few, however, have the resources to develop proposals and carry out projects on their own. A key component of research support is to train local residents in the process of research and research management. In addition, tribes and communities will benefit from assistance in preparing proposals, getting access to existing data, and being able to contact active researchers for advice and assistance. It is important to note that many of the specific recommendations identified below rely on Internet access, which is not available to all arctic communities. Other means of providing these services should be explored, such as a support center where interested persons can get information over the telephone. In addition, the Alaska Native Science Commission can help to connect researchers with communities in the U.S. Arctic.

Arctic residents can be critical in maintaining observations. Above, Walter Brower, an employee of Ukpeaġvik Iñupiat Corporation, replaces a ZENO logger for the ARM Program (page 49) in Barrow. Photo by James Ivanoff Sr., courtesy of Ukpeaġvik Iñupiat Corporation.

Recommendations

- Organize community/researcher meetings to establish communication between local communities and scientists to better use traditional knowledge and local expertise.
- Provide for outreach activities describing research products and possible impacts.
- Encourage presentations by researchers to local schools.
- Encourage use of remote communities as sites for long-term observations and train local residents to make measurements.

Maintain and Disseminate Arctic Expertise and Train the Next Generation of Arctic Field Experts

The extreme environments of polar regions require expertise acquired from experience beyond that gained from brief visits. This is true for safety and survival issues, as well as for efficient and productive scientific activities and results. Success of field operations often devolves to a few key individuals who are able to keep crews flying, generators running, huts warm, snowmobile carburetors unfrozen, cooks happy, and other vital functions. These skills are sometimes difficult to quantify, but are readily recognized in the field. Such individual talent should be identified and fostered as much as possible.

Arctic residents represent an important pool of logistics providers with experience ranging from managing ice islands to conducting search and rescue operations and providing direct logistics support at remote sites. As new researchers and staff are introduced to the Arctic, the Research Support and Logistics program should tap into and use the existing pool of residents, U.S. scientists, and established logistics organizations at various institutions with extensive background in arctic operations. A registry of researchers and staff and their field of arctic expertise should be maintained to serve as a starting point for inquiries from researchers with less field experience. The program also should consider developing a training program in field operations, perhaps in collaboration with a third-party logistics provider. Participation of experienced individuals in training workshops and mentoring programs for new researchers and staff has significant benefits beyond obvious safety and survival issues. For example, proven techniques for efficient deployment and recovery of drifting buoys and under-ice moorings have evolved and should not have to be redeveloped by each new group. Using arctic residents as logistics providers to mentor novices has the added benefit of adding knowledge of the local culture to the process.

In addition, recruiting and training exceptional students is vital to science. There are few opportunities for formal training in arctic science in the U.S. except at the graduate level through participation in individual projects. University Courses on Svalbard (UNIS) is a program with extensive modern facilities in Longyearbyen, organized by a consortium of four Norwegian universities for students at the upper division undergraduate or beginning graduate level. Approximately one hundred students from all over the world undertake a one- or two-semester course from a range of science, technology, and policy offerings, with exposure to guest lecturers involved in state-of-the-art research in many disciplines (much of which is occurring nearby). Part of the experience is mandatory participation in several field expeditions on or near Svalbard, which provides excellent training for arctic field operations. UNIS warrants study by NSF, either as a model for student training, or in terms of encouraging U.S. student participation in its programs. Planning for a possible new science support facility in Barrow should include educational opportunities as a large part of the design process.

Barrow High School student Flora Ahsoak does laboratory work for the Nuvuk archeological project. Photo by Lollie Hopson.

Recommendations

- Provide long-term support for technicians and engineers with expertise in arctic research.
- Ensure access to this pool of technicians and engineers for the larger community.
- Ensure the mentoring and training of younger technicians and engineers.
- Provide for training of students in arctic field operations and encouragement of careers in arctic research.

Appendix A
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Appendix B
Progress through the NSF Arctic Research Support and Logistics Program, 1999–2003

Below is a summary of progress made since the first logistics report in 1997. It is not intended to be a comprehensive description of all activities, but we attempt to show where progress has been made and where it has not. We specifically address the five main recommendations of the original report.

In general, the U.S. Congress' appropriation of $22 million for the NSF to establish an Arctic Research Support and Logistics (RSL) Program in 1999 was the most tangible consequence of the first report. Since then the budget has risen to $29 million in fiscal year 2003. The first priority of the RSL program is to provide research support and logistics to the science projects that have been reviewed and recommended for funding by the Arctic Sciences Section, other programs in NSF that support arctic research, and those of other agencies. This has been done by allocating a significant portion of the RSL budget to fund the logistical component of research grants and by providing support through third-party logistics providers. Other priorities are to build the infrastructure, improve safety, and continue to invest in community-wide coordination and communication.

The prime route to access RSL support is through the regular proposal process, and field support should be justified in the context of the proposed science. The science team can propose to do all the supporting logistics themselves or have a third party logistics provider supply some or all of the support. Third party providers are organizations with which the NSF has an agreement that enables them to negotiate the appropriate level of support and directly transfer funds. Examples of third-party support include:

- using research vessels operated by University-National Oceanographic Laboratory System (UNOLS) or the U.S. Coast Guard Cutter *Healy* or Polar Class icebreakers;
- support at the Toolik Field Station by the Institute of Arctic Biology of the University of Alaska Fairbanks;
- support in the Barrow region by Barrow Arctic Science Consortium (BASC);
- work in other regions of Alaska, Greenland, or Russia, and provision of logistics or communications equipment through NSF's arctic support contractor, VECO Polar Resources (VPR).

The NSF management team (the science program managers and the Arctic Research Support and Logistics Program manager) determines the level of support that can be provided from the logistics program in the context of the reviewed proposal. In some cases, OPP may determine that several proposals can benefit from a centrally managed resource. If so, the resources would be coordinated with the principal investigators, consistent with the agreements between the investigators and their program managers.

Logistics Recommendations for an Improved U.S. Arctic Research Capability (1997) outlined five general recommendations that have guided the overall development of the RSL Program. These five recommendations are:

- Ensure access to the Arctic over the entire year.
- Increase availability and use of remote and autonomous instruments.
- Protect the health and safety of people conducting research in the Arctic.
- Improve communication and collaboration between arctic peoples and the research community.
- Seek interagency, international, and bilateral logistics arrangements to efficiently use all available resources and to reduce costs by avoiding duplication of efforts.

In the following pages, we summarize in general terms the progress the RSL Program has made in implementing these five recommendations.

Allowable Costs

RSL Program funds can cover:

- Movement of people and materiel to, from, and within the Arctic (but not travel to scientific meetings);
- Development, upgrade, management, maintenance, and operations of infrastructure such as Environmental Observatories, Long Term Ecological Research (LTER) sites, and other field/ocean stations;
- Development, purchase, and deployment of instruments, samplers, monitors, and similar equipment;
- Food and shelter (or equivalent user charges), health and safety equipment, and appropriate training (e.g., survival, medical, small arms);
- User fees for facilities including field camps, aircraft charter, submarine use, and Coast Guard, UNOLS or other ship time;
- Communication, navigation, and safety aids, including telemetry and distance-learning equipment;
- Salaries of science technicians hired specifically for field work in the Arctic (e.g., Summit winter-over team);
- Arranging permits and cooperation (e.g., meetings with village elders before, during, and after science projects; field guides);
- Acquisition of supporting datasets such as elevation data, ground surveys, and remotely sensed baseline maps;
- Data management support, particularly for larger teams of investigators who need specific resources to collect and compile interdisciplinary datasets efficiently;
- Workshops on logistics issues (e.g., use of Geographic Information Systems); and
- Indirect costs of the above.

Lunch in the dining hall at Toolik Field Station. Photo by James H. Barker, © 2002, courtesy of University of Alaska Fairbanks Institute of Arctic Biology.

Ensure Access to the Arctic Over the Entire Year

1997 Recommendation

Make platforms available that can deploy personnel and instrumentation to land-based sites and the Arctic Ocean and adjacent seas year-round. Platforms that will extend research capability include capable icebreakers, aircraft support, winter housing at Toolik Field Station, and winter-over capability at the GISP2 Summit site.

Progress to Date

Perhaps the single greatest step forward has been in providing access to the Arctic Ocean with the start of operations of the U.S. Coast Guard research icebreaker *Healy* in 2001. The *Healy* is available approximately 200 days each year and in three years has already worked in the eastern and western Arctic Ocean, the waters of the Canadian archipelago, and along the west Greenland coast. A University-National Oceanographic Laboratory System (UNOLS) committee, the Arctic Icebreaker Coordinating Committee (AICC) works with the U.S. Coast Guard on the planning and operations for the *Healy* as well as those of the Polar Class icebreakers (*Polar Sea* and *Polar Star*). The *Healy*'s initial research missions went well, and the AICC and Coast Guard have worked closely to continually improve the operation of the ship in a manner that is supportive of science missions.

The preliminary design for a research vessel to replace the thirty-seven-year-old R/V *Alpha Helix* has been completed, and funds to procure the vessel may be requested in 2005. This vessel, the Alaska Region Research Vessel (ARRV), is the first University-National Oceanographic Laboratory System (UNOLS) ice-capable vessel designed and equipped for oceanographic and fisheries research (trawling and acoustic) and geology and geophysics. The Alaska Region includes the Gulf of Alaska and the Bering, Chukchi, and Beaufort Seas. The ship's ice strengthening will allow year-round operation in the Bering Sea and summer access to the Beaufort and Chukchi Seas. The ARRV is expected to be used for a variety of science missions, with an emphasis on general oceanographic and fisheries investigations in high-latitude open seas, near-shore regions, and seasonal sea ice. The 236-foot vessel will provide science berths for twenty-four or more scientists. Construction costs are estimated at $60 million, with a total project cost of $82.2 million.

In October 1998, researchers completed a full year of successful field work in residence on the arctic pack ice during the Surface Heat Budget of the Arctic Ocean (SHEBA) project. This project was made possible by freezing a Canadian icebreaker (the *Des Groseilliers*) into the pack ice to serve as the hub for the research village that spread across the surrounding ice (page 49). In another example, the High Latitude Dynamics Program of the Office of Naval Research offered time at a preexisting Navy ice camp for approximately two weeks in April 2003 at a location 100 to 150 nautical miles north of Prudhoe Bay, Alaska, supported by twice-daily Twin Otter flights between the camp and Prudhoe Bay.

NSF supported the establishment of a North Pole Environmental Observatory in 2000, led by the University of Washington with support by VPR. Logistics sup-

Information Technology Improvements

The NSF RSL Program has supported improvements to meet the increasing information technology needs of the arctic research community, including collecting and accessing high-precision spatial data (GPS, GIS, and remotely sensed imagery), high-speed data transmission, and networking capability.

For example, the Barrow Arctic Science Consortium (BASC) has partnered with the University NAVSTAR Consortium (UNAVCO) to implement and maintain a differential GPS system. A high speed Internet link (T1) is being extended on a wireless radius of nearly twenty-five miles. BASC is developing a web-based Internet mapping interface to view locations of over 2,100 research sites present in the Barrow Area Information Database (BAID).

The Toolik Field Station completed a major communications upgrade in 2001. Connecting the station to the fiber optic cable that parallels the Trans-Alaska Pipeline provides phone and both wireless and hard-wired Internet access. Since 2001, a full-time GIS manager has been assembling spatial data and products for the area.

The Summit, Greenland, site now has a fully functional Internet connection and phone service. A recent upgrade distributes a 64 kbs VSAT satellite link throughout the camp with a wireless local-area network. A researcher can now deploy an instrument anywhere within the camp area and access it remotely.

port combines the use of aircraft and camps specifically provided for the project with use of aircraft supporting tourism near the Pole, when feasible. There is news that Russia is planning to reestablish a series of ice camps for science use on a fee-for-use basis.

Winter housing: Toolik Field Station added winter accommodation in 1998 and now staffs the camp during winter visits to improve safety and reliability of operations. The Summit field camp in Greenland supported winter operations in 2000–01 and 2001–02, and will operate year-round for at least the next three years. A small group of five to six researchers and camp staff will operate instruments and collect data for several U.S. and international projects. NSF is in discussions with the U.S. NOAA Climate Monitoring and Diagnostics Laboratory, Denmark, Greenland, and the European Union about developing Summit as a long-term international site.

1997 Recommendation

Provide additional mobile base camps for short- and long-term studies on land, some of which would be available for winter use, including temporary but coordinated logistics support and laboratory space in Barrow, Alaska, and logistics depots elsewhere in the Arctic for the supply and mobilization of field camps.

Progress to Date

NSF has tasked VECO Polar Resources (VPR) to develop an inventory of camp equipment that is available to projects and to establish and operate field camps when the proposed work requires it. Seasonal camps have been established in Alaska, Russia, and Greenland.

In Barrow, the Barrow Arctic Science Consortium (BASC) now provides laboratory space, an information technology infrastructure, logistics support and excellent connections to the local community to NSF researchers working in the region on a year-round basis through a cooperative agreement with NSF. The success of this model has encouraged BASC to develop additional agreements with other agencies. BASC and the local Barrow community are also seeking new funding to replace and expand existing locally owned facilities.

In Russia, the Northeast Science Station, under contract to VPR, has developed into a modest but successful base for U.S. research teams working near the mouth of the Kolyma River. This effort is based on scientific links between the U.S. research community and the scientific staff at Northeast Science Station. Other U.S. groups are following this model. Kangerlussuaq, Greenland, continues to be a base of operations for NSF and NASA projects in Greenland, with VPR operating a support group while leasing resources from the Kangerlussuaq Airport Authority. In addition, NSF and other agencies are developing agreements with international counterparts to provide access to non-U.S. stations and facilities. For example, NSF has a recent agreement with the Norwegian Polar Institute (NPI) for access to research facilities on Svalbard.

For the Arctic Ocean, the strategically positioned Canadian Forces base at Alert on Ellesmere Island has supported an increasing number of U.S. projects. Support has to be arranged well in advance and on a not-to-interfere basis with the work of the station, but relations with Canadian Forces continue to improve.

Other than *Healy*, most expansion of access has occurred in response to proposals. NSF has been able to respond to requests for an increased level of support, and a positive response has led to increased demand. For example, helicopters are now routinely used on the North Slope of Alaska to support groups based out of Barrow, Toolik, and more remote sites.

Increase Availability and Use of Remote and Autonomous Instruments

1997 Recommendation

Employ and encourage the development of a variety of remote and autonomous instrumentation systems, including Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs), telemetry systems, moored water collection systems, deep floats, monitoring buoys, automatic weather stations, atmospheric samplers, borehole loggers, and remotely piloted aircraft.

Progress to Date

Two special OPP competitions, Long-term Observatories (1999) and Polar Instrumentation (2001), specifically addressed the development of instrumentation and technology. In addition, regular awards may include a sizable component of instrumentation when justified in the context of the science being proposed. Research support dollars are available to support the instrumentation component.

In ocean technology, NSF has funded two AUVs with specific arctic applications, one for Ocean Bottom Seismometer (OBS) deployment and retrieval and one for long-range physical oceanography and sub-ice profiling. In the recent Fresh Water Cycle competition, NSF also funded a project that uses ocean gliders to make repeated measurements in Davis Strait. A variety of funded projects are deploying moorings (ice and bottom anchored).

To facilitate meteorology and unmanned aerial vehicles (UAVs), NSF has supported the development of an autonomous cloud observing lidar, new autonomous meteorological stations, and assistance to Roshydromet of Russia for the reestablishment of a metrological station in arctic Russia (Belyi Island) to continue a long-term record.

1997 Recommendation

Promote adaptation of existing technologies to extreme operating conditions. Increase the spatial and temporal resolution of long-term remote observations.

Progress to Date

NSF has recognized the importance of long-term observations and has modified the Research Support and Logistics Program to accept proposals to make long-term observations as, primarily, service measurements.

Through a grant to the University of Georgia, NSF continues to fund the development of a small, light-payload UAV termed the Aerosonde for polar use. Additional awards to support the development and/or adapt technology resulted from OPP's Polar Instrumentation and Technology Development competition. This was in addition to support provided through the normal programs.

Protect the Health and Safety of People Conducting Research in the Arctic

1997 Recommendation

Sponsor arctic travel skills and survival courses in cooperation with northern communities.

Progress to Date

VPR offers free courses in field safety, facilitated by Learn to Return (LTR) Training Systems, at a variety of locations. Travel support is available to participants. VPR has offered:

- four-to-five-day courses in field safety in Fairbanks, Alaska; Amherst, Massachusetts; Monterey, California; and Boulder, Colorado;
- one-day courses in helicopter and bear safety at Toolik; and
- a two-day course in aviation land and water survival in Anchorage.

BASC and the ANSC are specifically tasked to assist researchers with establishing connections with local communities. BASC provides contact with Native people and other arctic residents primarily in northern Alaska and Chukotka, Russia, including high school and college interns on projects. ANSC concentrates on developing connections between researchers and local communities in the remainder of Alaska. VPR, NSF, and others are currently investigating ways in which future field safety training courses could offer a training component in cultural skills.

1997 Recommendation

Supply, as needed, portable telephone satellite communications.

Progress to Date

By 2002, VPR made portable satellite telephones available for all field teams working in remote areas. SRI International provides field communications services to VPR-supported researchers, including:

- Provision of VHF and HF radios
- Development of data collection and transmission systems for autonomous instruments
- Provision of satellite telephones and mobile ISDN units
- Installation of VSAT systems for large field camps

1997 Recommendation

Identify a provider for cost-effective travel and health insurance to address health emergencies in the Arctic that can involve extraordinary expenses to investigators and federal agencies.

Progress to Date

NSF has not addressed this recommendation. Given the many factors that determine health or travel insurance, and the fact that so few of the people in the field have a direct relationship with the NSF, it is unlikely the NSF or any other federal entity can provide broad coverage. However, NSF does recommend that investigators planning projects with field work review their risks and provide the team with appropriate training and insurance. Both the training and the insurance are allowable costs under the grant.

1997 Recommendation

Establish U.S. bank accounts in local Russian cities to help researchers avoid problems with cash and other means of payment in Russia.

Progress to Date

The RSL program and the NSF Directorate for Geosciences (GEO), in partnership with the U.S. Civilian Research and Development Foundation (CRDF), have established a Cooperative Programs/Science Liaison Office in Moscow. This office provides on-site support of NSF-sponsored cooperative activities in Russia in the geosciences and in arctic research. In addition, the CRDF, through its Grant Assistance Program (GAP), is able to assist NSF-sponsored scientists and institutions involved in cooperative projects in Russia in transferring research funds and equipment to Russian researchers and in tracking their use. In addition, as noted above, U.S. researchers can obtain support through formal negotiated contracts arranged by VPR or, in Chukotka, the Chukotka Science Support Group through BASC so that science teams don't need to carry as much cash.

VPR contracts with Medical Advisory Systems, Inc. (MAS) to provide NSF-funded researchers with remote medical services. While in the field, participating researchers have round-the-clock access to MAS physicians via telephone, satellite phone, telex, HF radio, computer, or fax. VPR provides participating researchers with a MAS-assembled field first aid kit, including medications. Medications can be used on the advice of MAS after a medical consultation. Additional services can be arranged if necessary.

Improve Communication and Collaboration Between Arctic Peoples and the Research Community

1997 Recommendation

Make researchers working in the Arctic aware of the U.S. Interagency Arctic Research Policy Committee (IARPC)* Principles for the Conduct of Research in the Arctic *to enhance community/researcher relationships and access of investigators to research sites.

Progress to Date

The Interagency Arctic Research Policy Committee (IARPC) endorses thirteen principles for all arctic researchers to follow in the document *Principles for the Conduct of Research in the Arctic* (www.nsf.gov/od/opp/arctic/conduct.htm). These principles establish standards of communication and collaboration for arctic researchers. The principles document is available on the Arctic Sciences Section web site with links through the main part of the solicitation for proposals to the Arctic Sciences Section. Investigators are encouraged to consider these principles in developing their research plans, and funds can be provided for specific visits to discuss the planned research with local communities. The logistics contractors, BASC and VPR, and the Alaska Native Science Commission, working under a cooperative agreement with OPP, can inform researchers seeking more information for collaboration and communication with local communities (section below).

1997 Recommendation

Help researchers establish communication with communities. Identify points of contact in each major arctic region for coordination with communities.

Progress to Date

Many arctic researchers lack the community connections to implement fully appropriate communication and collaboration during research planning, conduct, and dissemination. To help researchers make these connections with local communities, NSF has tasked the Barrow Arctic Science Consortium and the Alaska Native Science Commission to help researchers make contacts and carry out the principles. BASC is well connected in Barrow, northern Alaska, and through the Chukotka Science Support Group in Chukotka, Russia. The Alaska Native Science Commission, which is managed through the Arctic Social Sciences program, is a resource for connecting researchers with local communities throughout the rest of Alaska. The ANSC holds two regional meetings in Alaska each year to discuss research needs and questions of local people and invites the attendance of researchers working in the area.

In addition, NSF is developing a document intended to inform the process of communicating and collaborating with local communities. These draft *Guidelines for Improved Cooperation Between Arctic Researchers and Northern Communities* are anticipated to be completed in early 2004 and will help researchers plan their research in the spirit of the *Principles for Conduct of Research in the Arctic* and avoid impacts to Native subsistence activities and threatened or endangered species.

1997 Recommendation

Formalize what has been ad hoc and gratis logistical assistance from local and regional authorities.

Progress to Date

In addition to its agreements with BASC and ANSC, NSF has developed agreements with other arctic nations for shared access to research facilities and coordination of research efforts. These include agreements with the Norwegian Polar Institute (NPI), Norwegian Research Council, Iceland, and the European community. Work is in progress on new agreements with Denmark, Greenland, and Russia.

1997 Recommendation

Extend the infrastructure that supports communication among scientists to support communication between scientists and communities. Most important is assistance with the establishment of telecommunications links and on-site equipment that will enable communities to send and receive electronic mail, data files, and documents, and to access the Internet.

Progress to Date

There has been little progress to date. The focus thus far has been to provide basic telecommunications capability to the research community.

1997 Recommendation

Seek guidance to accomplish these goals from trans-national Native organizations, such as the Alaska Native Science Commission, the Inuit Circumpolar Conference and the Nordic Saami Council, by direct consultation and inviting them to participate in national and international meetings that address arctic science and logistical issues.

Progress to Date

Transnational Native organizations are represented on the Arctic Council, a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by the arctic governments and the people of the Arctic. ANSC provides information for researchers on collaboration with arctic people through its website, newsletter, presentations, and at scientific meetings. ANSC is funded through a cooperative agreement with the NSF Office of Polar Programs. Its mission is to endorse and support scientific research that enhances and perpetuates Alaska Native cultures and ensures the protection of indigenous cultures and intellectual property.

Seek Interagency, International, and Bilateral Logistics Arrangements to Efficiently Use All Available Resources and to Reduce Costs by Avoiding Duplication of Effort

1997 Recommendation

Make the IARPC logistical coordinating mechanism effective.

Progress to Date

IARPC has not had a major role in coordinating logistics although the focus on developing the Study of Environmental Arctic Change (SEARCH) has improved the level of coordination in research planning. However, there are numerous examples of bilateral or multiparty agreements. The most critical is the interagency planning process for scheduling *Healy* among the USCG, NSF, NOAA, and other agencies. NSF and NASA share logistics resources in Greenland, including use of the 109th New York Air National Guard flight support.

The recommendation remains valid, but it will take effective means to communicate ongoing opportunities, which, in the large agencies, are often too numerous for IARPC agency representatives to keep track of. One emerging approach is to track projects in a database and present the information geographically using output from a GIS. VPR, under tasking by NSF, has begun to do this (see www.vecopolar.com)

1997 Recommendation

Fully implement the Arctic Logistics and Information Access and Services (ALIAS) Program.

Progress to Date

The Arctic Logistics Information and Support (ALIAS) project, developed by ARCUS, provides an online source of logistics information for research in the circumpolar Arctic and a portal for additional information resources. ALIAS (www.arcus.org/alias) serves as a primary access point to help the research community acquire support and logistics information for the Arctic. ALIAS provides a comprehensive information source for:

- assessing the feasibility of working in a particular area,
- planning the conduct of research,

- viewing current research in a given area, including maps and publications, and
- making support and collaboration contacts for both science and logistics.

When fully implemented, ALIAS will be interactive and database-driven, allowing users to conduct complex criteria-based searches to gather information on research sites and logistics resources. Users, including researchers, research site managers, and logistics providers, will be able to submit updated site and resource information to ALIAS through an online survey. ALIAS will also include links with other arctic data resources.

1997 Recommendation

Convene an international arctic logistics conference to improve communications and identify areas of common interest and plan for potential collaboration.

Progress to Date

The International Arctic Science Committee (IASC) has supported the development of a Forum of Arctic Research Operators (FARO; www.faro-arctic.org) The forum aims to encourage, facilitate, and optimize logistics and operational support for scientific research in the Arctic through international collaboration. Early objectives are to assist in the development of a Circumpolar Environmental Observation Network (CEON) and a mechanism to use the limited number of research vessels with icebreaking capability more effectively.

Appendix C
Procedures for Gathering Community Input and Survey Results

As a first step in updating the 1997 report, the working group conducted an online survey of the research community's recommendations for arctic research and logistics needs. We received 102 responses to this survey, which began in March 2000 and ended in August 2000. The responses to the online survey are summarized below. The working group also held a town meeting at the ARCUS annual meeting in May 2000 and presented information on the working group's efforts at scientific meetings, including the 2000 American Geophysical Union meeting and the 2002 American Association for the Advancement of Science, Arctic Section meeting. A previous draft of this report was available for open community review in May 2003 on the ARCUS web site; we received comments on the draft from 29 individuals (Appendix D). The arctic research community's contributions through the survey, discussions, meetings, and review process were essential in the development of this report.

Arctic Research Support and Logistics Survey Results

This summary identifies the major areas of consensus as well as the diversity of the research community's experience and opinions on arctic research support and logistics. The categories are not intended to be exclusive, but clearly overlap; for example, funding and access issues are interrelated. Because the respondents commonly gave multiple answers to each question, the numbers of responses do not reconcile, but do indicate the frequency with which similar answers were mentioned. A more detailed analysis of these results is available on the ARCUS web site (www.arcus.org/rslwg/fr_response.html) or in hard copy from ARCUS.

Reflecting a broad range of the arctic research community, respondents identified their primary interests as biological sciences (27), climate change (21), geological sciences (16), sea ice (14), oceanographic sciences (13), paleosciences (11), social sciences (10), hydrology (6), research support and logistics (5), upper atmosphere and space weather (4), and land management (1). Their sources of funding and logistical support were similarly varied. The majority of respondents received funding for their work from NSF (58) and the Office of Naval Research (15), but they had also had funding from nine other federal agencies, 18 other U.S. organizations (including foundations, corporations, and local governments), and 13 international entities. Respondents had received logistical support from 14 different federal agencies, 28 other U.S. organizations (including private contractors, local governments, and universities), and 25 international institutions.

Although the survey respondents had varied research interests and experiences, a remarkable majority (75) identified environmental change, including long-term observations, as the most important arctic science priority for the next decade;

they also noted that meeting this scientific need was currently constrained by a lack of funding and logistical support for long-term observations in every scientific discipline. They also felt that scientific progress in the Arctic is inhibited by difficulties in safely accessing remote sites for adequate periods of time, particularly in the Russian Arctic, and by the limited capabilities of some research platforms, notably the Polar Class icebreakers and the *Alpha Helix*. Respondents agreed, however, that the new NSF Arctic Research Support and Logistics Program had significantly improved the logistical system supporting their work.

When asked about their current research support and logistics needs, 97 respondents mentioned issues related to safe access to remote sites, 87 reported using major research platforms such as icebreakers and field stations, 57 cited communications issues, 27 mentioned computer resources and access to data and models, and 24 identified issues related to equipment, including mechanisms for sharing equipment and handling hazardous materials.

The RSLWG used the results of the survey to define the major scientific and research support issues outlined in this report. The survey also provided valuable guidance in formulating recommendations to address those issues.

Appendix D
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Appendix E
Acronyms and Web Addresses

Below is a list of acronyms used in this report and, where applicable, the web address of the program or organization.

AEWC	Alaska Eskimo Whaling Commission
AICC	Arctic Icebreaker Coordinating Committee. www.unols.org/aicc
ALIAS	Arctic Logistics Information and Support. www.arcus.org/ALIAS
ALTEX	Atlantic Layer Tracking Experiment. www.mbari.org/expeditions/Altex
AMAP	Arctic Monitoring and Assessment Programme. www.amap.no
ANSC	Alaska Native Science Commission. www.nativescience.org
ANSP	Arctic Natural Sciences Program, Office of Polar Programs, NSF. www.nsf.gov/od/opp/arctic/natural.htm
AO	Arctic Oscillation or Arctic Annular Mode
AOOS	Alaska Ocean Observing System
ARCSS	Arctic System Science Program, Office of Polar Programs, NSF. www.nsf.gov/od/opp/arctic/system.htm
ARCUS	Arctic Research Consortium of the United States. www.arcus.org
ARM	Cloud Atmospheric Radiation Measurement program, DOE. www.arm.gov
ARRV	Alaska Region Research Vessel
ASOF	Arctic/Subarctic Ocean Fluxes. http://asof.npolar.no
ASSP	Arctic Social Sciences Program, Office of Polar Programs, NSF. www.nsf.gov/od/opp/arctic/social.htm
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BAID	Barrow Area Information Database
BASC	Barrow Arctic Science Consortium. www.arcticscience.org
BEO	Barrow Environmental Observatory. www.arcticscience.org
BLM	Bureau of Land Management, Department of the Interior. www.blm.gov
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions. www.nsf.gov/geo/egch/gc_solar.html#cedar
CEON	Circumarctic Environmental Observatories Network. www.cevl.msu.edu/ael/projects/ceon.html
CHAMP	Community-wide Hydrological Analysis and Monitoring Program. http://arcticchamp.sr.unh.edu
CLIVAR	Climate Variability and Predictability. www.clivar.org
CMDL	Climate Monitoring and Diagnostics Lab, NOAA. www.cmdl.noaa.gov
CRDF	Civilian Research and Development Foundation. www.crdf.org
CSSG	Chukotka Science Support Group. www.arcticscience.org
DEM	Digital Elevation Model
DOD	Department of Defense. www.dod.gov
DOE	Department of Energy. www.doe.gov

ENVINET European Network for Arctic-Alpine Environmental Research. http://envinet.npolar.no
EPA Environmental Protection Agency. www.epa.gov
FARO Forum of Arctic Research Operators. www.faro-arctic.org
GIS Geographic Information System
GPS Global Positioning System
HARC Human Dimensions of the Arctic System. www.arcus.org/HARC
IARPC Interagency Arctic Research Policy Committee. www.nsf.gov/od/opp/arctic/iarpc
IABP International Arctic Buoy Program. http://iabp.apl.washington.edu
IASC International Arctic Science Committee. www.iasc.no
IOOS National Integrated Ocean Observing System. www.ocean.us
JOI Joint Oceanographic Institutions. www.joiscience.org/
JOSS Joint Office of Science Support. www.joss.ucar.edu
LSI Land-Shelf Interactions. http://arctic.bio.utk.edu/RAISE
LTER Long Term Ecological Research network. http://lternet.edu
LTO Long-term Observatories
MBARI Monterey Bay Aquarium Research Institute. www.mbari.org
MMS Minerals Management Service. www.mms.gov
NAO North Atlantic Oscillation
NASA National Aeronautics and Space Administration. www.nasa.gov
NEON National Ecological Observatory Network. www.nsf.gov/bio/neon
NOAA National Oceanic and Atmospheric Administration. www.noaa.gov
NPI Norwegian Polar Institute. http://npiweb.npolar.no
NRC National Research Council. www.nationalacademies.org/nrc
NSF National Science Foundation. www.nsf.gov
ONR Office of Naval Research. www.onr.navy.mil
OPP Office of Polar Programs, NSF. www.nsf.gov/od/opp
PACTS Pan-Arctic Cycles, Transitions, and Sustainability. www.laii.uaf.edu/pubs/PACTS.cfm
PARCS Paleoenvironmental Arctic Sciences. www.ngdc.noaa.gov/paleo/parcs/index.html
PCSP Polar Continental Shelf Project. http://polar.nrcan.gc.ca/
RAISE Russian American Institute for Shelf-Environments in the Arctic. http://arctic.bio.utk.edu/RAISE
REU Research Experiences for Undergraduates, NSF. www.nsf.gov/home/crssprgm/reu/start.htm
ROV Remotely Operated Vehicle.
RSL Arctic Research Support and Logistics Program, Office of Polar Programs, NSF. www.nsf.gov/od/opp/arctic/suplog.htm
RSLWG Arctic Research Support and Logistics Working Group. www.arcus.org/Logistics/RSLWG/working_group.html
SBI Western Arctic Shelf-Basin Interactions Project. http://sbi.utk.edu
SCANNET Scandinavian/North European Network of Terrestrial Field Bases. www.envicat.com/scannet/Scannet
SCICEX Scientific Ice Expeditions. www.ldeo.columbia.edu/SCICEX
SDI Spatial Data Infrastructure
SEARCH Study of Environmental Arctic Change. http://psc.apl.washington.edu/search
SHEBA Surface Heat Budget of the Arctic Ocean. http://sheba.apl.washington.edu
TDRSS Tracking and Data Relay Satellite System (NASA). http://nmsp.gsfc.nasa.gov/tdrss/oview.html
USAID United States Agency for International Development. www.usaid.gov

UAV Unpiloted Aerial Vehicle

UNIS University Studies at Svalbard. www.unis.no

UNOLS University-National Oceanographic Laboratory System. www.unols.org

USARC United States Arctic Research Commission. www.uaa.alaska.edu/enri/arc_web/archome.htm

USCG United States Coast Guard. www.uscg.mil

USFWS United States Fish and Wildlife Service. www.fws.gov

USGS United States Geological Survey. www.usgs.gov

VPR VECO Polar Resources. www.vecopolar.com

VSAT Very Small Aperture Terminal