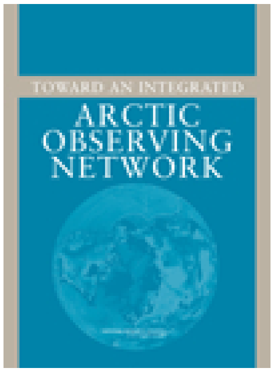

Toward an Integrated Arctic Observing Network

Committee on Designing an Arctic Observing Network,
National Research Council

ISBN: 0-309-65484-X, 128 pages, 8 1/2 x 11, (2006)

TOWARD AN INTEGRATED ARCTIC OBSERVING NETWORK

Committee on Designing an Arctic Observing Network
Polar Research Board
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This material is based upon work supported by the National Science Foundation under Grant No. OPP 0408590. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

International Standard Book Number 0-309-10052-6

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Wm. A. Wulf are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON DESIGNING AN ARCTIC OBSERVING NETWORK

W. Berry Lyons *(Chair)*, Ohio State University, Columbus
Keith Alverson, Global Ocean Observing System Project Office at the Intergovernmental Oceanographic Commission of UNESCO, Paris
David Barber, University of Manitoba, Winnipeg, Canada
James G. Bellingham, Monterey Bay Aquarium Research Institute, Moss Landing, California
Terry V. Callaghan, University of Sheffield, UK; Abisko Scientific Research Station, Sweden
Lee W. Cooper, University of Tennessee, Knoxville
Margo Edwards, University of Hawaii, Honolulu
Shari Gearheard, University of Western Ontario, Canada
Molly McCammon, Alaska Ocean Observing System, Anchorage
Jamie Morison, Polar Science Center, Seattle, Washington
Scott E. Palo, University of Colorado, Boulder
Andrey Proshutinsky, Woods Hole Oceanographic Institution, Massachusetts
Lars-Otto Reiersen, Arctic Monitoring and Assessment Programme, Oslo, Norway
Vladimir E. Romanovsky, University of Alaska, Fairbanks
Peter Schlosser, Lamont-Doherty Earth Observatory, Palisades, New York
Julienne C. Stroeve, National Snow and Ice Data Center, Boulder, Colorado
Craig Tweedie, University of Texas, El Paso
John Walsh, University of Alaska, Fairbanks

NRC Staff

Paul Cutler, Study Director, Polar Research Board
Matthew L. Druckenmiller, Science and Technology Policy Graduate Fellow (From September to December 2005)
Claudia Mengelt, Science and Technology Policy Graduate Fellow (From January to March 2005)
Rachael Shiflett, Senior Program Assistant, Polar Research Board

POLAR RESEARCH BOARD

Robin Bell (*Chair*), Lamont-Doherty Earth Observatory, Palisades, New York
James E. Berner, Alaska Native Tribal Health Consortium, Anchorage
David Bromwich, Ohio State University, Columbus
Calvin Robert Clauer, University of Michigan, Ann Arbor
Jody W. Deming, University of Washington, Seattle
Andrew G. Fountain, Portland State University, Oregon
Richard Glenn, Arctic Slope Regional Corporation, Barrow, Alaska
Jacqueline Grebmeier, University of Tennessee, Knoxville
Sven D. Haakanson, Alutiiq Museum, Kodiak, Alaska
Lawrence Hamilton, University of New Hampshire, Durham
Larry Hinzman, University of Alaska, Fairbanks
David Karl, University of Hawaii, Honolulu
Stephanie Pfirman, Barnard College, New York, New York
Diana Harrison Wall, Colorado State University, Fort Collins
John Walsh, University of Alaska, Fairbanks
James White, University of Colorado, Boulder
Warren M. Zapol, Massachusetts General Hospital, Harvard Medical School, Boston

Ex-Officio

Mahlon C. Kennicutt II (*U.S. Delegate to SCAR*), Texas A&M University, College Station
Patrick Webber (*U.S. Delegate to IASC*), Michigan State University, East Lansing
Terry Wilson (*Alternate U.S. Delegate to SCAR*), The Ohio State University, Columbus

NRC Staff

Chris Elfring, Board Director
Paul Cutler, Senior Program Officer
Maria Uhle, Program Officer
Matthew L. Druckenmiller, Science and Technology Policy Fellow (From September to December 2005)
Claudia Mengelt, Science and Technology Policy Graduate Fellow (From January to March 2005)
Rachael Shiflett, Senior Program Assistant
Andreas Sohre, Financial Associate

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

F. Stuart Chapin, III, University of Alaska, Fairbanks
Robert Corell, American Meteorological Society, Washington, D.C.
Joan Eamer, United Nations Environment Programme GRID, Arendal, Norway
Joan Fitzpatrick, Group on Earth Observations, Geneva, Switzerland
Jean-Claude Gascard, Université Pierre et Marie Curie, Paris, France
Mark Parsons, National Snow and Ice Data Center, Colorado
Vladimir Ryabinin, World Meteorological Organization, Geneva, Switzerland
Charles J. Vörösmarty, University of New Hampshire, Durham

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Kenneth H. Brink, Woods Hole Oceanographic Institution. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Figures, Tables, and Boxes

LIST OF TABLES

LIST OF FIGURES

LIST OF BOXES

Summary

Observable changes, many of which have regional and global implications, are underway across the Arctic. Although the Arctic is not the only region on Earth affected by environmental change, it poses special problems and concerns. It is a region with a limited record of observations—low density, and with limited duration and coordination—and yet, despite these constraints, rapid and systemic changes have clearly been identified.[1] The interconnectedness of physical, biological, chemical, and human components, together with the high amplitude of projected changes, make a compelling argument for an improved observation infrastructure that delivers a coherent set of pan-arctic, long-term, multidisciplinary observations. Without such observations, it is very difficult to describe current conditions in the Arctic, let alone understand the changes that are underway or their connections to the rest of the Earth system. Without such observations, society's responses to these ongoing changes and its capability to anticipate, predict, and respond to future changes that affect physical processes, ecosystems, and arctic and global residents are limited.

This report outlines the potential scope, composition, and implementation strategy for an Arctic Observing Network (AON). Such a network would build on and enhance existing national and international efforts and deliver easily accessible, complete, reliable, timely, long-term, pan-arctic observations. The goal is a system that can detect conditions and fundamental variations in the arctic system, provide data that are easily compared and analyzed, and help improve understanding of how the arctic system functions and changes. The network would serve both scientific and operational needs.

A comprehensive AON, by definition, transcends national boundaries and the timeframes of individual science investigations. Thus, a key contribution of the AON will be to provide a framework within which existing programs can be linked and supplemented. As the overarching network, the AON would provide continuity across national boundaries into the foreseeable future. By building on and supporting existing networks and observing capabilities, the AON would be enhancing their ability to report on status and trends in the Arctic. For example, the AON could provide a more comprehensive picture, rather than the current piecemeal view; it could achieve efficiencies by making better use of operational monitoring and through rationalizing logistics (i.e., getting more value for the same investment); and it could drive greater consistency in measurements so that comparisons can be made across areas and themes.

What would the AON look like? It would be a system of observational infrastructure—including satellites, terrestrial observatories, ocean buoys and moorings, weather stations, hydrologic monitoring stations, ecological sampling networks, arctic residents, and other data sources—that will collect, check, organize, and distribute arctic observations while taking the necessary measures to continuously adapt and improve the network.

BUILDING BLOCKS OF THE ARCTIC OBSERVING NETWORK

Humans have been observing change in the Arctic and using these observations to understand their surroundings and make decisions for thousands of years. Localized bodies of knowledge, passed down through generations of northern residents and arctic travelers and scientists, increasingly have been supplemented by an array of semi-permanent monitoring sites and automated sensors linked to digital databases. Society's many

[1] A major incentive for the Committee's work came from Schlosser et al.'s (2003) report, which states that improvements in research access, communications, sampling, and observational capabilities within the Arctic over the past decade are at least "partially responsible for the scientific evidence documenting the rapid environmental changes occurring in the Arctic."

contemporary observing systems, methodologies, and networks,[2] in addition to the body of local and traditional environmental knowledge, are all potential components of a pan-arctic network, which, in turn, can fit into a global-scale observing network.

Despite the long history of arctic observations, long-term records are incomplete, and there are measurement gaps in all domains. It is also difficult to compare data across disciplines. Many voids exist because measurement programs are inadequate or because of technological limitations created by the harsh conditions and remoteness. In addition, some areas have lost measurement capabilities as gauges and observatories have been decommissioned due to lack of resources. Declines in surface-based observations erode the capability to validate satellite imagery, thus also undermining the usefulness of that data source. Finally, many of the observational data that do exist come from specific research projects that collected data in limited areas for short periods of time. As such, continuity in time and space is rarely the result of a larger plan. Most existing science planning efforts address specific questions, processes, time scales, or regions, and they gather just the data needed for the specific project. The overlay of a comprehensive AON could supply the wide-area, long-term observations needed to track the state of the Arctic and understand how the system functions as part of the global environmental system.

THE COMMITTEE'S TASK

The U.S. National Science Foundation, through its Office of Polar Programs, requested guidance from the U.S. National Academies[3] to help design a pan-arctic observing network. Given the nature of this task, the study committee appointed to conduct the work was international in membership, and many efforts were made to include international input during the study and report review. The Committee was asked to develop an overarching philosophy and conceptual foundation for an AON and, where possible, provide advice to move the concept toward implementation. Because the network would necessarily build on existing efforts rather than duplicate them, the Committee was asked to review the purposes and extent of existing and planned global observing systems and platforms and to highlight critical spatial, temporal, or disciplinary gaps. In addition, the Committee was asked to identify key variables of importance to the Arctic, describe the infrastructure and approach needed to create a comprehensive network, comment on how to ensure sound data and information management and access, and recommend a strategy to ensure efficient, coordinated implementation and operation of the network.

To conduct its work, the Committee met five times over 15 months to gather information, deliberate, and write this report. The Committee held two workshops. The first was in Anchorage, Alaska, and focused on North American perspectives. The second was in Copenhagen, Denmark, and sought more international perspectives.

The Committee's report has seven chapters and begins with a summary of the motivations for an AON and the vision and context for the network. Chapter 2 then describes a process for identifying key variables to measure in the network and presents a list of 31 variables spanning physical, biogeochemical, and human domains. Chapter 3 contains an overview of existing observational activities and gaps, and is supported by an extensive annex that illustrates the range of programs, observatories, networks, satellites, data centers, and coordination activities upon which the AON could build. Chapter 4 presents a data management strategy for the AON and a series of implementation recommendations for data management. Chapter 5 covers options and strategies for network design, including philosophical considerations, network components, measurement approaches, principles and strategies for deciding where to make observations, and the role of technology. Chapter 6 presents detailed ideas and recommendations for implementing the AON, organized under four functional themes that work in parallel to enhance the network. These detailed ideas are summarized in the Committee's overarching recommendations in Chapter 7.

KEY RECOMMENDATIONS

An integrated, complete, dynamic, and multidisciplinary environmental observing network will improve society's understanding of and ability to respond to ongoing systemic changes in the Arctic and its capability to anticipate, predict, and respond to future change both in the Arctic and around the globe. The data flowing from this network could contribute to a wide range of programs and activities, including research studies, decision-support tools, and integrated environmental assessments that help decision makers understand what is happening and, as appropriate, adopt adaptation and mitigation measures.

Recommendation 1: An Arctic Observing Network should be initiated using existing activities and with the flexibility and resources to expand and improve to satisfy current and future scientific and operational needs. In its initial phase, the network should monitor selected key variables consistently across the arctic system.

A number of important internationally coordinated efforts with relevance to observing the arctic system are being

[2] For example, Arctic Monitoring and Assessment Programme (AMAP), European Monitoring and Evaluation Programme (EMEP), International Arctic Buoy Programme (IABP), International Tundra Experiment (ITEX), Study of Environmental Arctic Change (SEARCH), etc.

[3] The National Academies is the comprehensive term used to encompass the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council.

planned for the International Polar Year (IPY) 2007-2008. During the IPY, there will be a burst of new and intensive monitoring for a two-year period that will help jump-start the AON. Experience, knowledge, and infrastructure (in particular, new observations, data measurement and management approaches, and logistical support) gained through the IPY could provide new resources to advance the AON beyond its existing core components (e.g., AMAP, EMEP, IABP, ITEX, etc.). In addition, there are emerging activities including the Global Earth Observation System of Systems, SEARCH, the International Study of Arctic Change, the Arctic Council's Consortium for coordination of Observation and Monitoring of the Arctic for Assessment and Research (COMAAR) that provide timely opportunities to enhance and better coordinate the AON because they offer access to international partners and capabilities.

Recommendation 2: Work to design and implement an internationally coordinated Arctic Observing Network should begin immediately to take advantage of a unique window of opportunity created by a convergence of international activities during the International Polar Year that focus on observations.

The AON will build on existing efforts and will require new resources (including dedicated personnel) to fuel its development. The details of who should take responsibility for such efforts are outside the Committee's purview. Instead, the Committee presents fundamental activities that must be organized at the heart of the network and will need constant and focused activity to maintain and enhance observations and data flow. It is not necessary that one international body coordinate all of these activities, but these activities must be developed under a common framework. The AON would have four essential functions:

1. observing system development (which includes assessing complete coverage, system design and optimization, technology development, and sensor and observer deployment);
2. data acquisition (which includes maintaining existing observational capabilities and filling critical gaps);
3. data management, integration, access, and dissemination; and
4. network maintenance and sustainability (which includes network and observation sustainability, personnel development, coordination and integration regionally and globally, and communication).

Progress on all four of these functions is needed in parallel—in part because different communities and disciplines are at different stages of development, but also because each function is critical to development of a comprehensive network. Flexibility to accommodate technological improvements and changing sensor density is needed from the outset. The Committee presents detailed implementation ideas for these essential functions in Chapter 4 (data management) and Chapter 6 as well as related summary recommendations on each function in Chapter 7 (Box S.1 contains examples of these recommendations specific to network implementation and operation).

CLOSING REMARKS

Building the AON will require international cooperation and support. Because some areas of the Arctic have more developed monitoring and information systems than others, it will be critical to engage all arctic nations from the outset. This report provides a broad vision for such a network and the next step is for the international community of scientists, operational and research government agencies, other governmental and nongovernmental groups, arctic residents, and industry to take what they find useful from this vision, refine it, and implement the ideas. Because many potential components of the network already exist or are being planned, and because of the surge of activity during the IPY, there is an immediate opportunity for major progress.

Box S.1
General Recommendations that Relate to Network Implementation and Operation

Recommendation 3.1a: A system design assessment should be conducted within the first two years of AON development—that is, as a component of IPY—to ensure a pan-arctic, multidisciplinary, integrated network. This effort should be undertaken by a diverse team, with participation and input from multiple disciplines, stakeholder groups, and those involved in related international observing activities. The assessment should use existing design studies, models, statistical approaches, and other tools.

Recommendation 3.1b: The AON should be continuously improved and enhanced by taking advantage of the findings and recommendations in the system design assessment and performance metrics and data provider and user feedback that will become an enduring feature of the network.

Recommendation 3.2a: The first phase of AON development will require sustaining existing observational capabilities (including those under threat of closure) and filling critical gaps.

Recommendation 3.2b: The AON should support development, testing, and deployment of new sensors and other network-related technology. In parallel with recognizing the importance of systems engineering and instrument validation and calibration, this will require supporting (i) expert groups to track advances in technology that satisfy overarching network needs and (ii) centers of excellence and a technology incubator program to adapt and develop needed technology.

Recommendation 3.3: A data management system initially built on existing data centers and resources must be designed and implemented immediately by an AON data management committee to support major functions of the network. This system should be accessible through a single portal that connects data across disciplines and themes and should seamlessly link information from arctic sensors, historical datasets, and researchers and other users across space and time.

Recommendation 3.4a: For the AON to realize its potential, long-term, coordinated, international resources and efforts should be dedicated to sustaining observing platforms, providing incentives for contributions to the network, network coordination and integration, communication, and human resource development.

Recommendation 3.4b: Arctic residents must be meaningfully involved in the design and development of all stages of the AON. From the outset, the system design assessment should cultivate, incorporate, and build on the perspectives of human dimensions research and arctic residents. The AON must learn what is needed to facilitate the involvement of local communities and create an observing network that is useful to them as well as to scientists and other users.

1

Introduction

Observable changes, many of which have regional and global implications, are under way in the arctic atmosphere, hydrosphere, biosphere, cryosphere, and human sphere. Although the Arctic is not the only region on Earth affected by environmental change, it poses special problems and concerns. It is a region with a limited record of observations—low density, and with limited duration and coordination—and yet, despite these constraints, rapid and systemic changes have clearly been identified. The interconnectedness of physical, biological, chemical, and human components, together with the high amplitude of projected changes, make a compelling argument for an improved observation infrastructure that delivers a coherent set of pan-arctic, long-term, multidisciplinary observations. Without such observations, it is very difficult to describe current conditions in the Arctic, let alone understand the changes that are under way or their connections to the rest of the Earth system. The Arctic Climate Impact Assessment (ACIA, 2004) notes that "[r]econstructions of the past have been limited by available information, both proxy and instruments. The Arctic is a region of large natural variability and regional differences and it is important more uniform coverage be obtained to clarify past changes. In order for the quantitative detection of change to be more specific in the future, it is essential that steps be taken now to fill in observational gaps across the Arctic, including the oceans, land, ice and atmosphere."

This report presents the potential scope, composition, and strategies for implementing an Arctic Observing Network (AON). Such a network would build on existing capabilities, span disciplines, nationalities, and cultures, and provide near real-time reporting of the state of the arctic environment and long time-series of observations. These observations will improve the capacity to detect and predict changes, especially given increased knowledge about how environmental changes interact with social, political, cultural, and economic drivers within and outside the arctic system. Data from this network will enable scientists, policy makers, resource users, and other stakeholders to make more informed decisions about how to prepare for, mitigate, take advantage of, and otherwise respond to the challenges created by changing arctic conditions.

This introductory chapter has three parts. The first part summarizes the need for arctic observations. The second part provides details about the focus, organization, and scope of the report. The third part presents context and the Committee's vision for the AON, including its main functions and characteristics.

THE NEED FOR ARCTIC OBSERVATIONS

Rapid Arctic Change with Global Implications

Changes in the Arctic come in many forms—for example, those relating to climate, to pollution, and to social drivers (AMAP, 1998; ACIA, 2004; AHDR, 2004). Recent climate-related changes in the Arctic have attracted international attention (e.g., ACIA, 2004; Box 1.1). Drying soils and warming temperatures are increasing the prevalence of shrubs over tundra (Sturm et al., 2001) and creating a positive feedback for climate warming through changes in albedo (Chapin et al., 2005). In addition, increases in invasive plants, animals, and fish in the Arctic create new threats to endemic species and natural ecosystem interactions (Vitousek et al., 1997). Further, while reduced sea ice extent is likely to expand shipping, fishing, and oil extraction opportunities, the disappearance of seasonal sea ice could be devastating for polar bears (Derocher et al., 2004), ice-dependent seals (Kelly, 2001), and subsistence hunters who depend on these animals.

Many of the rapid changes being experienced in the Arctic have impacts on society and especially on people who live there (Krupnik and Jolly, 2002; Huntington and Fox, 2005). Arctic residents are economically, ethnically, and culturally diverse, and while the impacts of environmental change depend on local circumstances, the costs often have geographic and societal effects. For example, in communities

Box 1.1
Evidence of Climate Change in the Arctic

Temperature Across the Arctic

- Last decade (1990s) in the Northern Hemisphere is likely to have been the warmest in the last 1000 years, with the greatest changes observed at high latitudes (IPCC, 2000).
- Increases in positive departures from mean surface temperature have been observed in most areas of the Arctic over the past decade (Comiso, 2003).

Biosphere

- Widespread ecological changes are being observed in arctic lakes that are related to climate warming (Smol et al., 2005).
- Growing season length has increased by 4 to 12 days since 1900 in Scandinavia (Carter, 1998) and appears to be increasing throughout the Arctic (Keeling et al., 1996).
- The average acreage burned annually by wildfires in northern Canada and Alaska has more than doubled since 1970, and there has been a greater than doubling of burned acreage in the Russian boreal forest since the 1990s (ACIA, 2004). Alaska and the Yukon experienced the single largest recorded spruce bark beetle infestation in the 1990s, resulting in partial or total spruce mortality in more than 1 million hectares in the Kenai Peninsula and Copper River Valley alone (Ross et al., 2001; Burnside, 2005).

Cryosphere

- Sea ice extent and thickness have been at historic minima for the satellite record in the last 5 years (Serreze et al., 2003; Stroeve et al., 2005).
- Annual snowcover extent in the Northern Hemisphere has decreased 10 percent since the advent of satellite observations in 1966 (IPCC, 2001).
- Decreases in snowcover in the Arctic and other groundcover changes, both due to warming temperatures, are having a positive feedback that leads to additional warming (Chapin et al., 2005).
- Widespread permafrost warming, including thaw and degradation, is under way (Osterkamp and Romanovsky, 1999; Isaksen et al., 2001; Jorgenson et al., 2001; Camill, 2005; Smith et al., 2005).
- Coastal outlets of the Greenland Ice Sheet have begun to thin rapidly (Krabill et al., 2000; Rignot and Thomas, 2002; Thomas et al., 2003).
- Rates of glacial thinning in 67 Alaskan glaciers accelerated in the 1990s (Arendt et al., 2002).

located along receding shorelines, increased coastal erosion is commonplace because of more frequent and severe storms and decreased protection by sea ice, with subsequent ecological and economic costs. Communities and industries (e.g., oil and natural gas extractors) that depend on winter ice roads are losing transportation flexibility as the length of the winter season shrinks (NRC, 2003). Thawing permafrost will damage roads and buildings over wide areas (Nelson et al., 2001, 2002).

Climate-related changes by no means provide the sole justification for an AON. Existing observation networks such as the Arctic Monitoring and Assessment Programme (AMAP) have documented other needs, such as those created by unexpected and potentially dangerous long-distance dispersal and biomagnification of contaminants to high latitudes, including their effects on indigenous food resources (AMAP, 1998). In some cases, the highest human exposures on Earth for specific contaminants occur in the Arctic (AMAP, 2004).

Recent change has also come to human social systems including self-government in Greenland, economic collapse in much of the Russian Arctic, industrial development in the Alaskan Arctic, and establishment of Nunavut, Canada, a territory with a majority indigenous population. Thus, the climate-related changes in the Arctic that are arguably attracting the most attention are occurring in the context of changes to government and economic structures, concerns about pollutant transport and the long-term health of arctic peoples, and viability of subsistence food resources.

Arctic environmental changes are likely to have global influence, primarily through coupling in the atmosphere and oceans. An example is the connection between runoff into the Arctic Ocean and the North Atlantic thermohaline circulation (Peterson et al., 2002). Increases in freshwater runoff are expected to affect ocean stratification, circulation, and global climate processes because of the potential of freshwater to reduce vertical thermohaline circulation (Schiller et al., 1997; Weaver et al., 1999; Otterå et al., 2003). Melting glaciers, ice caps, and the Greenland Ice Sheet also contribute to global sea level rise. Accelerated wastage observed in the 1990s in Alaska alone accounts for as much as half of the current 1 mm per year rise in global sea level that is due to glacial retreat worldwide[1] (Arendt et al., 2002). This slow rise could increase if the mass balance of the Greenland Ice Sheet is affected by additional warming (Krabill et al., 2000). Changes in land, lake, and sea ice cover, in addition to changes in seasonal snow cover, also impart a strong albedo feedback that is quickly transmitted to the global atmosphere. Finally, there is the potential impact of reduced arctic sea-ice extent on trans-arctic shipping routes, with far-reaching effects that will influence decisions to expand the Panama Canal and international investments in ship building and ports.

Models Inadequate to Represent the Arctic

Observations and models show the Arctic to be one of Earth's most sensitive regions to climate change. Nonetheless, most general ocean and atmospheric circulation models are not as effective as they could be in representing northern regions. There are two reasons. First, the models do not have sufficient observational data to adequately reproduce the state of the Arctic Ocean, sea ice, and atmosphere. Second, the models do not adequately incorporate critical system-level feedbacks or reflect the chaotic physics of arctic climate. These deficiencies highlight the need for (i) observational data for model calibration and validation, and (ii) model improvement by inclusion of new processes, feedback mechanisms, and assimilation of observational data by reanalysis. In addition, models could be improved by incorporating underused sources of observations, such as the local and traditional knowledge of arctic residents.

Low Density and Limited Duration of Observations

The insufficient duration and density of measurements mentioned earlier in the quote from ACIA (2004) stems in part from logistical challenges presented by sea ice, winter darkness, and harsh climatic conditions. The basic infrastructure for supporting scientific observations in the Arctic is also weak. For infrastructure components such as river gauges, for example, funding support has waned and there has been a widespread loss of hydrological monitoring networks over the past 15 years in the United States, Canada, and Russia (Shiklomanov et al., 2002). There is also a paucity of coastal marine laboratories and only a small number of land-based stations that operate on a year-round basis. In addition, there is no running seawater system[2] designed for marine biological experiments anywhere on the coasts of the Bering, Chukchi, and Beaufort Seas—a capability taken for granted at most Pacific, Gulf, and Atlantic coastal marine laboratories belonging to the National Association of Marine Laboratories.[3] The marine station at Ny-Ålesund (on Svalbard) is possibly the only arctic scientific facility with running seawater at in situ temperatures. On a broader scale, the World Ocean Circulation Experiment—the most recent and ambitious internationally coordinated ocean measurement program—did not occupy stations in any of the deep basins of the Arctic Ocean beyond Fram Strait or north of Nunivat Island in the Bering Sea.[4] From a biological perspective, observations in the Arctic have been so limited that the wintering area for the entire world population of the spectacled eider was unknown until the mid-1990s (Petersen et al., 1999).

Observations have, nonetheless, been made for many millennia (Box 1.2). A major incentive for the Committee's work came from Schlosser et al.'s (2003) report, which states that improvements in research access, communications, sampling, and observational capabilities within the Arctic over the past decade are at least "partially responsible for the scientific evidence documenting the rapid environmental changes occurring in the Arctic." Some excellent observational data are now being collected from various platforms across the Arctic. To advance the observing network toward a state of seamless data integration, it is critical that current observational systems be continued, critical gaps are filled, and observations from established and maintained instrumented platforms such as satellites, ocean buoys and moorings, weather stations, and other observational methodologies become integrated across disciplines, nations, and cultures, including linkages to local and traditional knowledge.

Box 1.2
History of Arctic Observations

Humans have been observing and responding to changing conditions in the Arctic for thousands of years, beginning with localized bodies of knowledge (Figure 1.1). Arctic observations began to be linked into a network with knowledge transfer through the oral traditions of indigenous cultures, written records of the Viking era, and accounts of whalers and trappers. Such local observations and knowledge are now increasingly complemented by an expanding array of semi-permanent monitoring sites and automated sensors linked to sophisticated computer systems and digital databases.

[1]An additional ~1 mm per year rise in global sea level is due to the thermal expansion of seawater.

[2]A running seawater system supplies holding tanks and aquaria with seawater for marine biological and other studies.

[3]See http://www.naml.org.

[4]See http://www.woce.org/atlas_webpage/links.html.

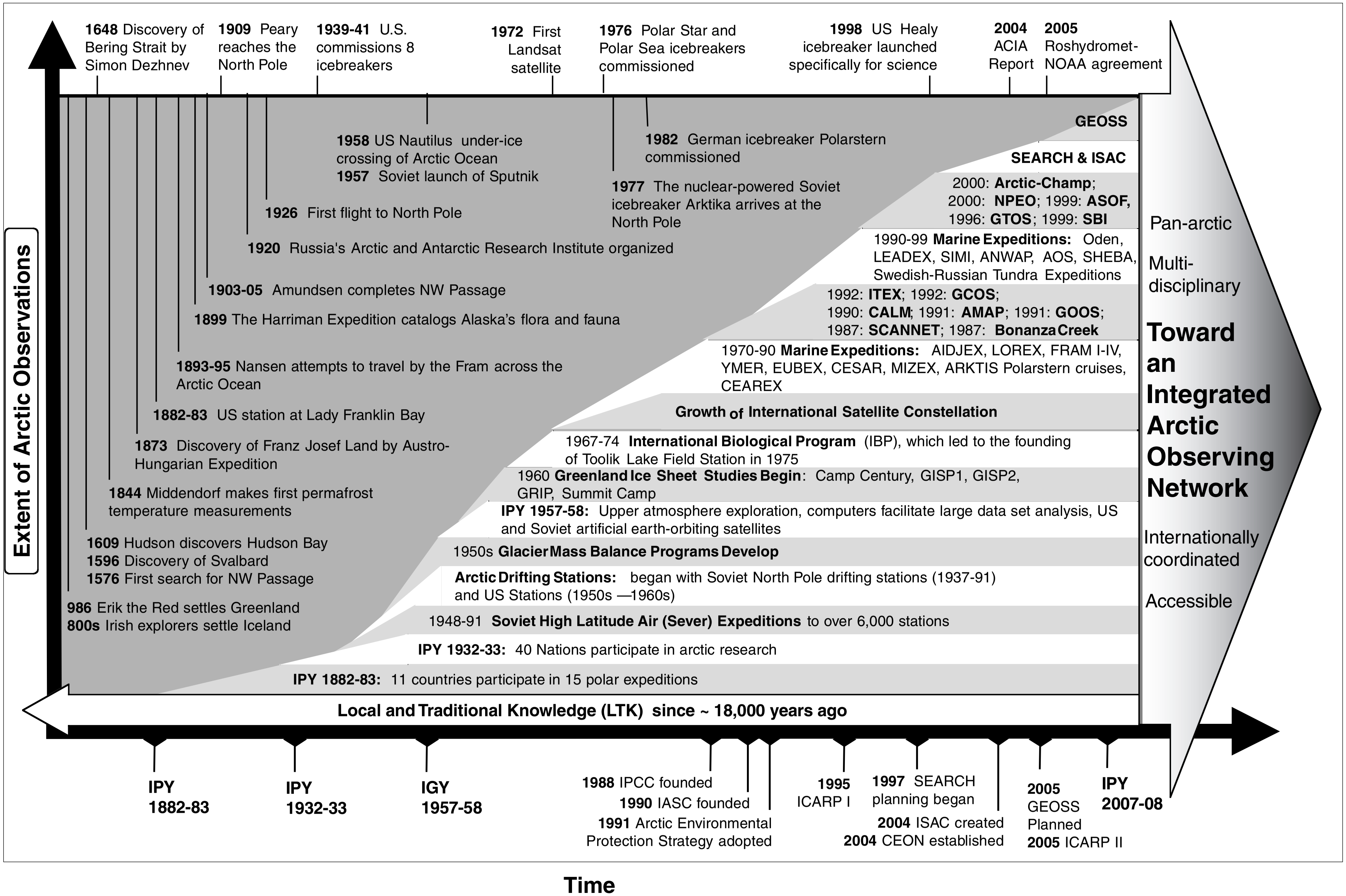

FIGURE 1.1 Evolution of the Arctic Observing Network. The figure gives examples of historical and ongoing activities of exploration, science, and planning that have built the AON to its current state. The growth in arctic observations (y-axis) is represented qualitatively. Historical time (x-axis) is displayed nonlinearly, with time (and activity) advancing from left to right. The items in the top portion of the figure are examples of historical events that had or continue to have an impact on arctic science and observation. Items in the bottom portion are examples of key programs, expeditions, meetings, or other efforts that have contributed to the network. Items in the interior portion of the figure represent examples of building blocks of arctic observations that collectively form the AON. Acronyms are defined in Appendix C. SOURCE: study committee.

REPORT PURPOSE AND STRUCTURE

The National Science Foundation, through its Office of Polar Programs, asked the National Academies to appoint an independent committee to provide guidance to help design an arctic land, atmosphere, and ocean observing network. The Committee was asked to provide thoughts on the overarching philosophy and conceptual foundation for such an international network and, where possible, provide concrete advice to move the concept toward implementation. Specifically, the Committee was asked to:

1. Provide an overarching philosophy of design for a comprehensive AON and identify key variables that must be monitored.
2. Briefly review the purposes and extent of existing and planned global observing systems and platforms, highlighting critical spatial, temporal, or disciplinary gaps of importance to the Arctic.
3. Describe the infrastructure and approach needed to create a comprehensive AON, including advice on types, number, and the distribution of network components; where observations might be effectively made; and the role that remote sensing and novel technologies might play. This discussion should explore two levels: an "ideal" network and a "minimal" network to help illustrate choices that may need to be made during implementation.
4. Comment on how to ensure sound data and information management and access in this type of network, using perspectives from data managers, those generating data, and those who use or might use the data.
5. Recommend a strategy to ensure efficient, coordinated implementation and operation of an AON, including methods to ensure that data products from different sensors are spatially and temporally consistent, processes that could be used to design the optimal mix of observations and test for data redundancies, and approaches that could be used to keep the network current and cost effective.

The structure of this report tracks closely to the order of the Committee's tasks. The Committee lays out a design philosophy (part of Task 1) in the remainder of this chapter. Because this responsibility for system design is complex, the Committee found it useful also to include functions and characteristics of the AON within the umbrella of system design. These examples and outcomes are used to understand how the observing system should be philosophically designed (i.e., operationally the "look and feel" of the completed AON). The second part of this task, identifying key variables, is discussed in Chapter 2. Chapter 3 summarizes global and other major networks and identifies critical observation gaps (Task 2). Chapter 4 discusses data management and access (Task 4, with aspects of Task 5)—the "backbone" of the network. Chapter 5 covers network design (Task 3 with aspects of Task 5) and Chapter 6 provides detailed implementation steps that could make the network function efficiently (Task 5). Chapter 7 collects the Committee's overarching recommendations. Each of these recommendations is supported by the specific implementation steps in the preceding chapter.

COMPLEXITIES FOR OBSERVING NETWORK DEVELOPMENT

Inclusiveness of the AON Concept

Because of the way the Committee views the AON—that observations in the Arctic have been made for thousands of years and existing networks have gradually matured with occasional accelerated growth or improved interconnectedness—the AON concept is inclusive of all arctic observations and related supporting activities and people.

Accepting the Complexity of the Arctic

Although the Arctic is often mistakenly viewed as a simple ecosystem with fewer species and less dense human populations than other regions of the globe, in fact, it represents a sophisticated complex of physical, biological, chemical, and human elements connected to other regions as well as global processes. For that reason, a subset of observation activities cannot be simply categorized as the AON. As a result, the Committee undertook its study with the assumption that the complexity of the Arctic can only be truly understood with an investment in new, sustained efforts with an emphasis on interdisciplinary and broad synergistic strategies.

Human Dimensions Observations

The vision of the AON, through its inclusiveness, encompasses monitoring of not only environmental variables, but ultimately also human dimension variables including basic demographic information and information relating to health, education, the economy, governance, adaptation, and resiliency. This inclusive vision of the AON is desired by many arctic residents who view their environment in a holistic way. This Committee respects that desire and acknowledges the importance and value in developing a comprehensive observing network. However, the Committee, as it is constituted, did not have sufficient expertise to develop recommendations on the socio-economic aspects and human dimension elements of a monitoring network within the AON. This report therefore provides more of a starting point for outlining the work needed to incorporate such observations.

Depth of Treatment

The Committee is tasked to "where possible, provide concrete advice to move the concept [of the AON] toward implementation." This statement reflects the fact that the many aspects of implementation (e.g., developing new sensors, developing relationships with arctic residents and indigenous organizations, siting new platforms and observatories, coordinating activities on an international level, and managing and distributing data) are not uniformly mature. Consequently, the Committee has dealt with each of these aspects of implementation to different depths in this report. The Committee avoided describing these implementation aspects in a prescriptive manner. Rather, it presents ideas to stimulate community discussion and action.

Value Added by the Report

Myriad networks, programs, measurement sites, and observational platforms already exist or are proposed for the Arctic. Some of these focus on specific thematic measurements; others are broad or focus on coordination rather than data acquisition. Many of these networks and their related communities have gone through extensive planning and implementation steps,[5] such as identifying key variables. It is not the intent of this Committee to duplicate or pass judgment on these efforts but rather to build from these documents. The challenge for this Committee is to add value to the enormous efforts that have already occurred, are ongoing, and are proposed for the future.

A key objective of this report is to convey the rationale and vision for a pan-arctic, international, interdisciplinary, and long-term perspective of the AON. In addition, this is an opportunity to provide a resource for diverse users by gathering the experiences of many who have been observing in the Arctic and elsewhere. Finally, the Committee is particularly focused on efficiencies and impacts—what efforts will make the biggest difference to the user communities in terms of efficient data collection, quality control, discovery, sharing, and network coordination. These efforts are characterized as "essential functions" of the AON, and the Committee provides recommendations on the necessary implementation steps to fulfill this vision on an international basis.

VISION FOR THE ARCTIC OBSERVING NETWORK

The Committee initiated its work with the assumption and rationale that society needs an integrated AON that provides easily accessible, complete, reliable, timely, long-term, pan-arctic observations that detect conditions and fundamental variations in the arctic system, can easily be compared and analyzed, and help improve understanding of how the arctic system functions and changes. What will the AON look like? The Committee envisions that the AON will be a system of observational infrastructure, including human observers, that will collect, check, organize, and distribute arctic data and observations while taking the necessary measures to continuously adapt and improve the network.

This vision includes observational systems to document ecological events such as oceanographic and climatic regime shifts, including changes in coastal storm activity, variability, and patterns in time (e.g., animal population cycles) and space (e.g., localized versus regional differences). Of particular interest are observations to document increased pollution of the Arctic, largely due to contaminant transport from non-arctic regions, and its effects on the health and lifestyles of arctic residents. For that reason and others, a comprehensive AON also considers human dimensions and documents changes in such variables as health, education, demographics, and resource use, as well as changes in local, regional, national, and international policies that interact with environmental changes. With efficient information flow from the AON, local residents, scientists, industry, managers and policy makers, regulators, and other stakeholders will be better informed and equipped to assess, respond, and adapt to change.

The AON will be integrated and bolstered in stages (most imminently during the upcoming 2007-2008 International Polar Year [IPY]), and, taking into consideration technological feasibility, operational efficiency, and cost-effectiveness, this pan-arctic network of observing systems will ultimately provide information at all appropriate spatial and temporal scales. A comprehensive network with a multitude of observing platforms, measurement variables, and analytical capabilities is optimal, but may not be realistic in the near future given funding limitations. For that reason, it is crucial that a core set of variables and sites be identified to provide pan-arctic coverage. It is also important that a core set of "essential functions" be identified and acted upon that are mostly discipline-neutral and could benefit all AON participants.

This vision will evolve over time and should adapt with society's concerns in response to arctic and global environmental change, taking advantage of technology advances and methodological improvements as these arise. The network's impact and benefits will derive from a synergistic sum that is greater than its parts.

Essential Functions and Characteristics of the Network

The AON will necessarily build on existing efforts and yet will require new resources (including dedicated personnel) to fuel its incremental development. The details of who should take responsibility for such efforts are outside the Committee's purview. Instead, the Committee presents four fundamental activities—essential functions—that must

[5] See, for example, the extensive list of planning documents in Appendix A of SEARCH, 2005 (http://www.arcus.org/search/resources/reportsandscienceplans.php).

be organized at the heart of the network, will need constant and focused activity, and operate in parallel.

The first essential function is observing system development. This includes assessing complete coverage by identifying geographic, thematic, and temporal gaps and prioritizing which gaps to fill first; system design and optimization; technology development; and sensor and observer deployment. The second essential function is data acquisition, which includes maintaining existing observational capabilities, and filling critical gaps. The third function covers data management, integration, access, and dissemination, including use of a single portal that has the capacity to search and access all arctic data and monitoring activities. The final function is network maintenance and sustainability, which includes improving network and observation sustainability by building support among users, personnel development within and on behalf of the network, coordination and integration among network participants regionally and globally, and promoting improved communication among all network participants—and especially data providers and data users.

In addition to the essential functions, it is critical that the AON be established with these characteristics:

- is pan-arctic and inclusive, reflecting an international partnership with a broad mix of participants (government, academia, arctic residents, nongovernmental organizations, industry);
- builds on participation from existing networks and long-term observation sites and platforms, while adding value to these existing networks through better linkages, including linkages from arctic to global observations;
- involves arctic communities in true partnership from the outset and recognizes that the inclusion of local and traditional knowledge and community-based monitoring will require a significant new investment and appreciation of local language, multiple literacies, and intellectual property rights;
- can incorporate new variables over time, especially variables identified and prioritized by arctic communities, and can be adapted to incorporate new networks, observation sites, and technologies;
- includes terrestrial, ocean, atmosphere, and human dimension observations;
- includes a variety of observations: past as well as present and future, real-time and less immediate, and current as well as contextual data (e.g., historic, archaeological, paleoclimatic, local and traditional knowledge); and
- provides an end-to-end system from observations to data management to communication services that interfaces effectively with the separate data analysis function. (Data analysis is not just in the purview of scientific research, but also among those who use it for policy development, economic decisions, etc.)

Although the AON will not by itself provide analysis and synthesis of the observational database, reasonable downstream outcomes that can be expected from an integrated observational system include the following significant improvements over current capabilities:

- more comprehensive information than currently available for the public, resource managers, industry, residents, and others to use to respond and/or adapt to changes;
- an enhanced synoptic view spanning local to regional to global scales that will help users determine if change is isolated or being observed elsewhere in the Arctic, and learn from the experiences of others who may be seeing change earlier in their region;
- improved capabilities to predict future changes and potential need for responses;
- insights into developing observation networks with arctic communities and linking local and traditional knowledge with more traditional scientific observations;
- improvements to models, concepts, and theories; and
- development of methods for ensuring arctic data can be easily found, accessed, and seamlessly exchanged and integrated, as well as preserved for future use.

IMPLEMENTATION CONTEXT

In addition to building from existing networks and programs, the AON will need to be developed in conjunction with emerging global observation efforts. Increasingly, a global consensus is developing that most of Earth's environmental observational networks need to be improved and better coordinated to serve scientific and societal needs. Those charged to establish the AON will also need to take advantage of opportunities presented by the IPY (Box 1.3), the International Conference on Arctic Research Planning II, and other such periodic catalysts. For example, the arctic observation components being developed for IPY in 2007-2008, once solidified, could be incorporated into the AON.

The AON must assist and use focused international and national networks and programs (e.g., AMAP, ArcticNet, CAFF, CEON, CliC, COMAAR, EMEP, GCOS, GOOS, GTOS, IABP, IASC, IEOS, ISAC, ITEX, NEON, SCANNET, SEARCH—see Appendix C for a list of acronyms). Many of these are well established and provide an opportunity to build upon existing assets and augment their utility. Others are emerging and present new opportunities for coordination and cooperation.

A key to successful linkage among these and other programs will be to share common goals or projected benefits. For example, planners of the Global Earth Observation System of Systems (GEOSS; see Box 1.4) have identified nine such benefit categories. A globally linked AON not only has scientific value, but also would contribute societal benefits in each of these areas. There may be observational

Box 1.3
International Polar Year (2007-2008)

There have been a number of major international science initiatives in polar regions since the first International Polar Year (IPY) in 1882-83 (see Figure 1.1) and all have had a major influence on the understanding of global processes. Many of these initiatives involved intense periods of multidisciplinary research, collected a broad range of measurements, and provided snapshots of the state of the polar regions.

The last such initiative—the International Geophysical Year in 1957-58—involved 80,000 scientists from 67 countries. It produced unprecedented exploration and discoveries and fundamentally changed how science was conducted in the polar regions. Fifty years on, technological developments such as Earth observation satellites, autonomous vehicles, and molecular biology techniques offer opportunities for a further major step upwards in observing and understanding polar systems. The next IPY, in 2007-2008, affords an opportunity to engage the upcoming generation of young Earth system scientists, educate the public on the global influence and current state of the polar regions, and inject momentum into (and supplement) ongoing observing activities.

SOURCE: http://www.ipy.org/about/what-is-ipy.htm.

Box 1.4
Global Earth Observation System of Systems

In response to the need for improved access to environmental information, over 60 countries have endorsed a 10-year plan to develop and implement the Global Earth Observation System of Systems (GEOSS). Nearly 40 international organizations also support the plans. GEOSS has identified nine societal benefit categories where an integrated and coordinated system of earth observing networks would provide help. These are disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity.

Commenting in 2005 on the 10-year Strategic Plan for the U.S. component of the GEOSS, John Marburger, director of the White House Office of Science and Technology Policy and presidential science advisor, stated:

"GEOSS will allow scientists and policy makers in many different countries to design, implement and operate integrated Earth observing systems in a compatible, value-enhancing way. It will link existing satellites, buoys, weather stations and other observing instruments that are already demonstrating value around the globe and support the development of new observational capabilities where required."

SOURCE: http://usgeo.gov/docs/EOCStrategic_Plan.pdf.

data that would be primarily of local interest—for example, the distributions of animals used as subsistence food resources in the Arctic by local populations, or changes in the distributions of shrubs and trees in local landscapes—but the AON must be developed as an organic, integrated component of both national and international emerging Earth observation efforts that typically have weak arctic representation.

As GEOSS gains traction, it may provide a unique opportunity for the AON to assert itself as the arctic contribution to GEOSS. However, to do so, the AON will need to ensure its connections to other global networks that will be key contributors to GEOSS such as the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), and the Global Climate Observing System (GCOS).

2

Key Variables to Monitor in the Long Term

In identifying key variables, the Committee was guided by its vision, expressed in Chapter 1, that an integrated Arctic Observing Network (AON) should provide easily accessible, timely, long-term, pan-arctic observations that detect the fundamental variations in the arctic system, can easily be compared and analyzed, and help improve understanding of how the arctic system functions and changes.

The task of identifying key variables[1] to monitor in such a broad, multidisciplinary network is challenging. Recognizing that a single discipline might take many years to settle on its own "key" variables, and that in some disciplines or communities these key variables have yet to be agreed upon, the Committee developed a purposely broad list of 31 key variables. Clearly, not all variables listed will be key to all disciplines or stakeholders. The list is expected to evolve and grow over time as the value of particular variables is demonstrated, as new questions arise, and as resources allow. The Committee's intent with this list is to stimulate discussion.

The Committee's deliberations on key variables revealed that this approach is readily applied to physical variables but becomes harder in the biological and human dimensions realms. Similar difficulties have led some groups (e.g., Study of Environmental Arctic Change planners) to follow different paths toward setting measurement priorities. These alternate approaches focus on determining inter-relationships among variables, elucidating the workings of processes, or addressing key questions driving the science. A pertinent example of a scientific driver is the attribution of recent change. The AON will accommodate both question-driven observations and the key variables approach by integrating the data streams resulting from a variety of programs in a unified form. The AON is envisioned as a backbone of the observing activities that will outlive most of the theme-driven projects that contribute observations. On the other hand, the results from theme-driven programs will clarify which variables deserve inclusion in the AON.

Many of the key variables identified here are already being measured at many sites. However, formulating the list of key variables can lead to observing system enhancements by identifying variables that are needed in many disciplines and by highlighting the need for available and accessible data on these variables. In particular, cross-disciplinary assessments of the need for pan-arctic datasets of these variables can help prioritize the network expansions that will serve the greatest needs in integrated monitoring.

As illustration, assume that an observing station measures 500 variables including 10 that are "AON key variables." The data related to these variables could be reported in a standardized way, undergo a quality control step, and then contribute to a pan-arctic dataset that is served through a single entry point—a central portal.[2] An incentive for observatories to contribute their data to a pan-arctic network could be the knowledge that some of the variables they are measuring are important in an international context and that participation in the network could result in additional funding. In addition, they would be able to use the pan-arctic datasets for comparative studies.

DEFINITIONS

As the Committee worked to identify key variables, it recognized that the term caused some confusion and that, in fact, there were two terms of importance: key variable and

[1]What is a "variable?" Zackenberg Station in northeast Greenland measures over 2,500 "variables." If temperature is measured in the air and down a soil profile, this is considered several variables by those at Zackenberg. At Abisko, Sweden, temperature is considered to be one variable even if measured at 10 sites. For the purposes of this report, temperature is a single variable—whether measured in ocean, atmosphere, or at depth in the ground. In other words, the Committee's usage of the term does not separate measurements of the same variable whether measured in the atmosphere, within permafrost, or in a human, for example.

[2]Standardized observations and quality control for local and traditional knowledge components of the AON will take special consideration (see Chapter 5).

key indicator variable. A **key variable** is a variable that is fundamental and related to questions that are important throughout the Arctic, is essential to an overall understanding of the arctic system, and is also relevant at the local scale. A key variable is a necessary component of integrated monitoring because changes in associated variables cannot be understood without knowledge of changes in the key variable. The key variable is a disaggregated driver of lower-level changes.[3] An example is temperature.[4]

A **key indicator variable** is a response variable or index that can be conveniently measured to denote changes in one or more key variables. Examples are phenology (the timing of events) and indices of human activity. For example, the proportion of whales harvested in open water by an arctic community during autumn rather than spring can be an indicator of climate-driven changes in sea ice cover. Key indicator variables may manifest themselves differently at different locations.

In the framework to be used here, a key variable is a key variable whether its variations are obtained from direct measurements or by proxy methods. A proxy measurement of a key variable is an indirect estimation of the key variable, usually consisting of a measurement preserved in some physical manifestation. An example is tree ring width or density in fossil and modern wood samples: from the patterns of ring widths, one can infer variability in environmental variables such as, for example, temperature. The value of proxies to monitoring networks is that they provide historical context for the contemporary measurements and instrument records. They also improve data products that arise from reanalysis efforts. Beyond tree rings, other examples of proxies include ice and lake sediment cores and local and traditional knowledge of environmental history. Proxy records often share a common threat of being lost (perhaps through melting of an ice cap in which a climate record is preserved or through death of a village elder). Data in old formats are similarly at risk of being lost.

WAYS OF GROUPING KEY VARIABLES

Variables can be grouped in many ways. One approach is to organize variables according to underlying concepts. These concepts define the basic state of the physical, biological, chemical, and human environment, and identify and characterize natural variability and anthropogenic change. These concepts represent the most basic approach to system understanding and to the identification of the causes of change (e.g., physical-chemical drivers, human and biological drivers, environmental impacts, human and biological responses). Integrated monitoring is a particularly effective approach for recording these variables, and field manipulation experiments can be performed to obtain relationships among them. Such an approach is particularly useful for testing process formulations in models.

This conceptual approach is the most consistent with the AON vision statement because this way of thinking provides an umbrella for the individual questions, hypotheses, and themes, and it facilitates a pan-arctic focus and long-term perspective. In addition, this approach is inclusive in its philosophy, cross-disciplinary, and represents a stable base that can evolve as key questions, access to the Arctic, technology, and human needs change. Although there are other ways of categorizing variables, such as organizing by problems or research theme, organizing by concept has the distinct advantage that the concepts are less likely to change over time than questions or themes. Thus, the Committee prefers an organization that is founded on state variables but presents other options to encourage discussion. These other options entail grouping by practicality and approach, grouping by synergies (i.e., creating benefits that only arise from a suite of measurements or combination of measurements and existing data), and grouping by timescale.

Grouping by What Is Practical

Groupings can be based on discipline, theme, and measurement approach. For example, variables can be classified by major disciplines: atmosphere, ocean, cryosphere, terrestrial. Themes that can provide the basis for classifications include biodiversity, land cover, and sustainable resource use. In terms of measurement approach, variables can be organized by platform (satellite, observatory, human observers, buoys, etc.), thereby maximizing the use of existing expertise and the cost-effectiveness of infrastructure. In addition, classifications can be responsive to initiatives that define their own information needs. Examples are the International Polar Year and the Arctic Climate Impact Assessment. These initiatives can provide structure and permanence to data. Finally, variables can be classified by stakeholder priorities such as the priorities of arctic communities.

Grouping by Synergies

A classification scheme can be based on one of a number of types of synergy. For example, synergies among existing and new monitoring activities can lead logically to groupings of variables. Synergies can also arise from better use of existing data (e.g., satellite images, photographs, biological samples that have untapped potential). For example, precipitation data collected by weather stations and then thrown

[3] To be clear, this definition does not preclude a key variable from changing.

[4] Consider the changing migration pattern of a caribou herd. The fundamental driver (key variable) could be temperature, which might be linked to changes in migration pattern because of its effect on vegetation phenology and composition, snow cover, and consequently the availability of food. These changes are lower-level responses that are driven by changes in the key variable temperature. Lower-level changes such as migration pattern are then *indicators* of changes in the key variable temperature.

away can instead be analyzed for pollutant chemistry, biological propagules, and isotopic composition. Improved interactions among existing networks can lead to synergies by revealing common needs or shared interests, for example, as can bridging of disciplines or domains such as physical science and local and traditional knowledge.

Grouping by Timescale

Classifications of variables can be based on the different timescales of measurements such as real-time (e.g., weather observations), seasonal (e.g., caribou locations, snowpack water equivalent), annual (e.g., permafrost temperature and active layer depth), decadal (e.g., land cover change), or longer timescales related to paleo studies. Another time-related differentiation is between "surprises" (i.e., unexpected occurrences) and steady change. Local observations can be a very cost-effective source of change detection and early warning (e.g., Chapin, 2005). Local observations can capture changes that are not easily tracked by measurements made at constant intervals or at low resolution.

When grouping by timescale, it is essential to begin with a clear understanding of how the collected data will be organized because the observation strategy influences the sampling frequency (i.e., an intense decadal survey would perhaps rely on many mobile platforms whereas a permanent station network might be needed for the higher frequency monitoring).

IDENTIFYING KEY VARIABLES

Because the selection of key variables often depends on a particular context or application, many such variables have been identified for particular programs or for particular purposes by the planners for those activities (e.g., the Essential Climate Variables of the Global Climate Observing System). The Committee drew from these identified sets of variables the ones that, in the context of the preceding discussion, can be regarded as describing the basic state of and trends in the arctic environment. These variables support the AON vision. That is, they enable detection of fundamental variations in the arctic system, help improve understanding of how the arctic system functions and changes, and can easily be compared and analyzed. In further prioritizing the list, the Committee sought variables that, when they change, have major consequences for the arctic and/or global system and humanity.

An important question that arises is "what is the appropriate number of key variables for this first phase of the AON?" Is it reasonable to consider the AON focusing on a small number of clearly important phenomena or must it include a wide range of variables? The Committee is charged to consider the "ideal" network and the "minimal" network, so is it reasonable to strive for a small total number of key variables? In the Committee's view, it is unrealistic to include only a small number of variables when considering the arctic system as an integrated system, spanning an extremely broad spectrum of needed information, and for that reason Table 2.1 lists 31 variables.

From a practical perspective, however, it is unlikely that pan-arctic datasets of all these variables can be produced with sufficient measurement density from the outset. There is a need to start with a reasonably limited subset and build incrementally from that point as resources allow and priorities evolve. Beginning with a subset of key variables could also show proof of concept and stimulate the necessary interest and resources to improve measurement density for these variables and gradually build up the number of key variables receiving focused attention.

Given the preceding discussion, the question then becomes how to prioritize effort among the key variables for the first phase of the AON. The immediacy of an initial phase of the AON suggests three considerations in the assignment of priority:

1. Key variables (or their proxies) that are at risk of being lost. This might include information in ice cores from diminishing ice caps or ice sheets, knowledge of elders, biological materials—for example, DNA of threatened species or long-term measurement records that are being terminated such as data from arctic river gauging stations or glacier mass balance networks. Reanalysis, where applicable, would guide where to focus effort.
2. Key variables for which there are critical data gaps. Undoubtedly, some key variables have poorer coverage than others. Perhaps having particulary weak coverage among the key variables should move a variable higher up the priority list. Feasibility is also a factor in prioritizing which critical gap to fill. That is, could the available technology and logistics enable the gap-filling for certain key variables more readily than others?
3. Key variables that have broad public appeal or are easily conveyed to the public. Examples include numbers of polar bears or extent of glacier retreat. These kinds of variables might help with broad buy-in to the value of the AON.

SUMMARY TABLE

Table 2.1 summarizes variables that have been identified by the Committee as an initial set of essential measurements for the AON. Because of the AON's broad geographic and disciplinary scope, the list has 31 variables. The preceding discussion offers ideas for prioritizing effort among them. All of these key variables fulfill the criteria laid out in this chapter—they define the basic state of the environment and many of them can be used to improve understanding of the arctic system and identify and characterize change. The list

TABLE 2.1 The Arctic Observing Network's 31 Key Variables and Key Indicator Variables

Variable[a]	Examples of Why the Variable Is Important	Critical and Major Gaps in Observations (spatial, temporal, or thematic)
PHYSICAL VARIABLES		
Albedo (K)	• Influences global change (through changes in cloud, land, and ocean cover—including ice and snow cover)	• Time sequences of fields of albedo, particularly in vegetated areas where there is masking, and also over ice
Elevation/bathymetry (including shoreline) (K)	• A fundamental measure of shape of Earth's surface • Influences ocean and atmosphere circulation (including microclimate) • Reveals coastal erosion • Controls how materials are transported • Important for glacier motion • Potential hazards for transportation	• Whole Arctic Ocean (patchy coverage) • Coverage at high resolution (elevation in coastal regions)
Ice characteristics (including thickness, extent, and concentration) (K)	• Influences arctic energy balance • Reservoir of stored fresh water • Affects coastal erosion • Influences marine and lacustrine transportation • Affects biological habitat • Affects hunting success	• Sea ice thickness everywhere • Sea ice concentration in summer • Sea ice extent in coastal areas • Glacier thickness • Permafrost thickness and ground ice concentration
Precipitation (K)	• Controls biological community distribution • Influences human water supply and causes droughts and flooding	• Arctic Ocean • Topographically complex areas • River systems smaller than the Arctic's 10 largest systems • Southeast Alaska to Prince William Sound
Pressure (K)	• Driver of winds and ocean circulation, glacier motion (i.e., basal pressure)	• Marginal seas • Central Arctic Ocean (below surface)
Radiation (K) (spectral composition and fluxes from thermosphere to shallow ocean)	• Ultimate driver of weather and climate, biological activity, human health (e.g., UV damage)	• Spectrally resolved radiation • Surface across entire arctic
Salinity (K)	• Affects ocean density distribution and circulation • Affects biological community distribution and populations	• Arctic Ocean
Snow depth/ water equivalent (K)	• Affects arctic energy balance • Insulates underlying soils/sea ice • Affects biological activity (e.g., caribou distributions, ringed seal reproduction) • Affects winter transportation for humans	• Perennial sea ice • Entire Arctic Ocean • Distribution on land
Soil moisture (K)	• Affects runoff, vegetation, biological productivity, terrestrial transportation	• Everywhere in subsurface areas
Temperature (K)	• Direct measure of global warming • Moderates all chemical and biochemical reactions • Controls biological community boundaries • Causes changes in permafrost that affect infrastructure	• Entire Arctic Ocean plus subarctic seas • Atmosphere (especially above the first few meters) • Terrestrial subsurface (particularly in the Central Siberia, Russian North East, and areas in Canada and China) • Lack of year-round temperature in ocean
Velocity (K)	• Feature of weather (storms, winds), ocean circulation, glacier motion, river runoff	• Arctic Ocean and marginal seas; height-resolved circulation above troposphere and over oceans

TABLE 2.1 Continued

Variable[a]	Examples of Why the Variable Is Important	Critical and Major Gaps in Observations (spatial, temporal, or thematic)
Water vapor concentration (including cloud properties) (K)	• Influences radiation budget (both up- and down-welling) through attenuation of UV-B • Cloud and precipitation formation if aerosols are present • Strongest radiatively active gas (i.e., more than carbon dioxide) • Accelerates stratospheric ozone depletion if ice crystal deposition occurs	• Greenland • Arctic Ocean • Subarctic seas
Freshwater flux (I)	• Influences ocean salinity and circulation • Has impacts on fisheries, landscape change and human habitation and travel, wetland distribution	• Declining number of gauging stations plus not always at river mouth • Glacier runoff • Small rivers • Contributions to Bering Strait
Lake level (I)	• Affects human and other biological habitation and activity, water resources and fisheries, land use, lacustrine transportation • A key land-water boundary and indicator of water balance	• Entire arctic
Sea level (I)	• Influences coastal dynamics, human and other biological habitation and activity, oil and gas exploration, marine transportation • A key land-water boundary and indicator of water balance	• Alaskan and Canadian coastline • Russian Arctic: many sites are not operational • Greenland—more than half of the Danish gauges in Greenland have been abandoned
Aerosol concentration (K) (physical or biogeochemical variable)	• Influences air quality and human health, atmospheric energy balance, global climate, cloud formation	• Aerosol chemistry • Limited beyond ARM sites (over time or space)
Land cover (I) (Physical or biogeochemical variable)	• Influences habitat fragmentation, water balance, coastal erosion, transportation, animal migration, biological community boundary change, land use and management	• High resolution surface characteristics
BIOGEOCHEMICAL VARIABLES		
Atmospheric chemistry and the contribution of trace gases (ozone, nitrous oxide, methane) (K)	• Influences human health (ozone) • Most are radiatively active gasses • Relevant to carbon sequestration • Reveals nitrous oxide releases • Reveals effects of land use/cover change	• Quantitative understanding of sources, sinks, and chemical processes in lower atmosphere
Biodiversity (including species distributions) (I)	• Reveals natural and anthropogenic impacts on species richness and ecosystems, invasive species impacts, endangered species impacts • Indicator of ecosystem structure	• Basic species list for the Arctic • Genetic libraries • Basic nomenclature
Biomass (K)	• Relevant to food supply; ecosystem health, structure, and function; carbon sequestration and allocation; ocean color (i.e., by influencing albedo and thus transmission of light); • Affects albedo by masking of snow	• Frequency and methods for assessing biomass on land, ocean, sea ice
Carbon concentration (K)	• Impact on global warming (radiatively active gas—carbon dioxide, methane) • Influences biological productivity, carbon sequestration, food web dynamics, ecosystem structure	• Terrestrial (including surface) observations and in biosphere (particularly in Russia and Canada) • Winter coverage
Nutrient concentration (K)	• Affects primary production, ecosystem structure and function, food webs/trophic interactions, energy fluxes • Fundamental element of life	• Localized measurements (soils, vegetation, water) • Understanding of function in biocomplex systems

continued

TABLE 2.1 Continued

Variable[a]	Examples of Why the Variable Is Important	Critical and Major Gaps in Observations (spatial, temporal, or thematic)
Contaminant concentration (I)	• Affects human and animal health, water quality, atmospheric composition • Indicator of anthropogenic activity and impacts	• U.S. arctic • Critical chemical species • Gaps in human levels
Dissolved oxygen concentration (I)	• Indicator of biological production and exchange with the atmosphere	• Frequency of temporal coverage and density of spatial coverage
Phenology, organismal behavior, and performance (I)	• Reveals changes in bud break, growing season, migratory timing, food availability for migrant birds, reproductive success, albedo, and carbon sequestration • Indicator of timing and success of biological events	• Allometric data • Biomass • Reproductive success • Hibernation ecology
Tracer chemistry (natural tracers rather than localized tracer additions) (biogeochemical or physical variable) (I)	• Indicator of biogeochemical and physical processes, changes in pathways, climate-water interactions • Reveals fundamental properties of aquatic systems	• Spatial and temporal patchiness throughout the arctic system • Frequently, lack of multitracer approaches
HUMAN-DIMENSION VARIABLES		
Human demographics (population size and structure (K), births, deaths, migration (I))	• Impacted by and impacting climate change, resources, globalization, infrastructure, governance, resource availability and utilization, land use, capacity of ecosystems to support subsistence economy, patterns and variability in social change, population sizes/habitat fragmentation	• Disaggregated data by gender, indigenous/nonindigenous • Regional gaps
Health (e.g., birth weight, breast milk quality, cause of death, cultural health) (I)	• Help reveal quality of life, standard of living, human potential • Indicator of human condition	• Mental health and diet • Access to health care • Quality of health care • Regional gaps
Cultural diversity (I)	• Help reveal quality of life, standard of living, human potential • Indicator of human condition	• Cultural diversity (indigenous participation in government and research, languages in use, religious membership)
Education (e.g., graduates, enrollment) (I)	• Human potential • Indicator of human condition	• Access to education • Understanding needs for education
Economic indicators (e.g., employment, subsistence, government structure) (I)	• Help reveal quality of life, human-environment relations, social change • Show effects of globalization and devolution of control to local people • Indicator of human activity	• Assessment of new institutions in the Arctic • Tracking employment opportunities • Disaggregation of economic indicators (e.g., gender differences)

NOTE: Column 1 lists the variable plus whether it is a key variable (K) or a key indicator variable (I). Column 2 gives examples of why the variable is important. Column 3 gives examples of major and critical gaps in observations. Variables are arranged alphabetically followed by assignment to one of three clusters—physical, biogeochemical, or human. There are intimate relationships among variables in the three clusters, so these assignments are not necessarily perfect or unchangeable. Furthermore, a continued discussion of the human variables in particular will require input from fields not included in this Committee, and more work will be needed to incorporate this dimension into the AON. The list is, as stated earlier, intended as a starting point for discussion.

[a]K = key variable, I = key indicator variable.

is based on the Committee's collective experience and expertise and information gathered during this study. Although the Committee's composition introduces an inevitable subjective component to the compilation process, the list represents the Committee's consensus and is intended to serve as a starting point for establishing AON measurement priorities.

The table is divided into three clusters—physical, biogeochemical, and human dimensions. It became clear to the Committee that the "key variables" approach, although required by the charge given to the Committee, does not fit all aspects of the observing system equally. This approach is better suited to physical variables than to biogeochemical and human ones. The concept is loosened up for these later two categories, and in the future these components in particular will need further attention. The table also highlights critical gaps in observations. Because the table is a compilation of variables for which present observing networks are in widely different stages of evolution, the critical gaps vary from spatial or temporal details to thematic considerations. The latter are more common among the biogeochemical and human-dimension variables.

3

Arctic Observations: Existing Activities and Gaps

This chapter reviews ongoing and planned arctic and related global observing activities and highlights critical gaps that exist in these activities. The chapter is comprised of an overview of these activities and gaps and an extensive supporting annex. The annex has three parts. The first is a large but not exhaustive list of ongoing and planned networks, observatories, satellites, data centers, coordinating bodies, and programs that could be the foundation of the Arctic Observing Network (AON). The second annex provides additional details of some of the major global and regional observing networks that include the Arctic. The third annex examines current measurement approaches and gaps among temperature measurements in particular and cryospheric measurements in general.

EXISTING ACTIVITIES

The AON will connect local observations with those from regional and global networks to provide the coverage needed to monitor and document current state and change throughout the Arctic. This network will be founded on and support existing observing stations, networks, and programs (Annex 3A, B) that cover a broad spectrum of domains, including the atmosphere, hydrosphere, cryosphere, biosphere, and human dimension. The AON is being conceived at a time when significant new observation systems, platforms, networks, and integrating functions are being planned (e.g., Annex 3A, B) in connection with the International Polar Year (IPY). A rare opportunity exists to advance arctic observations on a unified track.

A challenge for AON participants will be to define the appropriate level of connection among its component activities. For example, the large networks described in Annex 3B have a wide range of foci, variables being measured, data management approaches, and funding mechanisms. Possible solutions to this challenge are presented in subsequent chapters, but it is worth highlighting examples of existing and planned arctic or global networks that already have an interdisciplinary outlook, are well coordinated, and therefore share goals with the AON.

An international-scale example is AMAP (Arctic Monitoring and Assessment Programme, Annex 3B), which was established in 1991 to implement components of the Arctic Environmental Protection Strategy. AMAP measures the concentrations and assesses the effects of contaminants, climate, and ultraviolet radiation in the arctic environment. It has produced a series of assessments of pollution trends in the Arctic.[1]

A national-scale example that is just starting is ArcticNet (Annex 3B)—a network of Canadian centers of excellence that brings together numerous individuals to study the impacts of climate change in the coastal Canadian Arctic. The central objective of ArcticNet is to contribute to the development and dissemination of knowledge needed to formulate adaptation strategies and national policies related to climate change and globalization in the Arctic.[2]

An example of a planned international network that closely relates to AON goals is the Global Earth Observation System of Systems (GEOSS) (see Box 1.4 and Annex 3B), which seeks to obtain high-quality information on the state of the entire Earth system for policy and decision making. The Integrated Earth Observation System (IEOS) is the U.S. contribution to GEOSS, and is intended to be an interagency effort that builds on current observing systems. The AON would also be integral to the Study of Environmental Arctic Change (SEARCH) (Annex 3B)—a U.S.-driven activity—and its fledgling international umbrella, ISAC (International Study of Arctic Change). SEARCH, currently in the planning and early implementation phase, is conceived as a broad, interdisciplinary activity geared toward understanding the future of the Arctic.

[1] See http://www.amap.no.
[2] See http://arcticnet-ulaval.ca.

CRITICAL GAPS

Long-term records over large geographical areas are required to understand the arctic system and project possible changes and their consequences. Understanding the rate and scale of arctic change is also inherently a multidisciplinary problem, and records of many interconnected variables are needed (Schlosser et al., 2003). Unfortunately, long-term records for key arctic variables are incomplete and there are measurement gaps in all domains. In some cases, there are huge voids. These include the Arctic Ocean as a whole (Figure 3.1). Because there is uneven coverage across the Arctic in many variables (e.g., Figure 3.2), it is critical to engage all arctic nations in addressing gaps from the outset.

Many voids exist because measurement programs are simply inadequate for the task. Other gaps are created by technological limitations, which are pervasive in the Arctic due to the unique challenges created by extreme cold and remoteness. Some areas have actually lost capabilities as important networks and observatories have been decommissioned due to lack of resources (Shiklomanov et al., 2002; Annex 3C). Declines in ground-based observations also erode the capability to validate satellite imagery, thus undermining the usefulness of that source. Work is being done to fill some gaps, but resources are insufficient to address all critical needs.

Various planning and research groups have identified data gaps (e.g., AMAP, 1998; SEARCH, 2001; AHDR, 2004; ACIA, 2005; GEOSS, 2005). There is considerable overlap between the Committee's list of key variables and gaps (Table 2.1) and the list of global observational requirements from the GEOSS planning process (GEOSS, 2005), for example. Space prohibits a complete discussion of all the

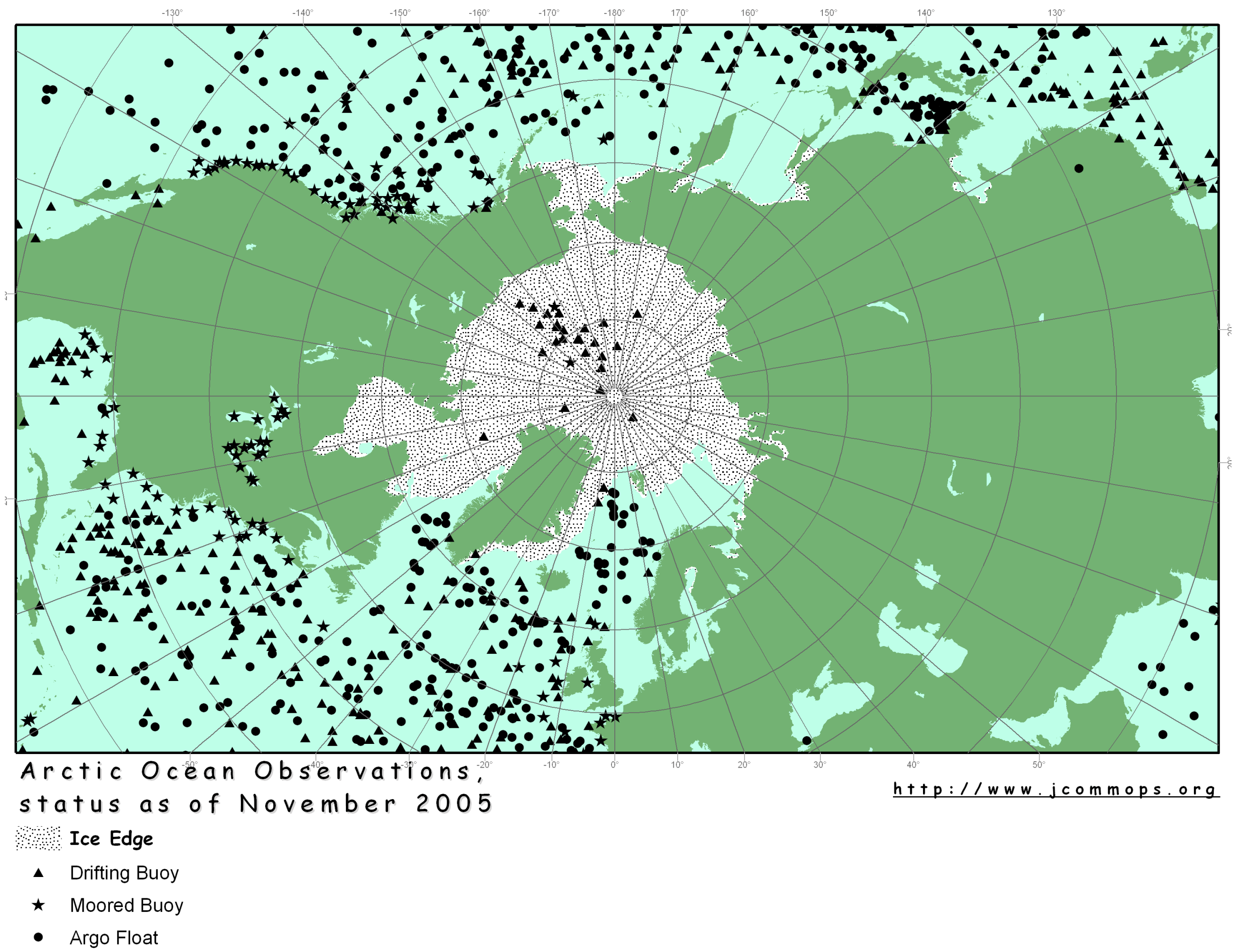

FIGURE 3.1 Distribution of Argo floats (measuring temperature and salinity), drifting buoys (measuring sea-surface velocity and temperature, air pressure [in some cases], and subsurface temperature profiles [in a small number of cases]), and moored buoys (measuring sea-surface temperature, air pressure and temperature, wind, and mean significant wave heights) in the world's northern oceans on September 13, 2005. SOURCE: Argo Information Centre, http://argo.jcommops.org.

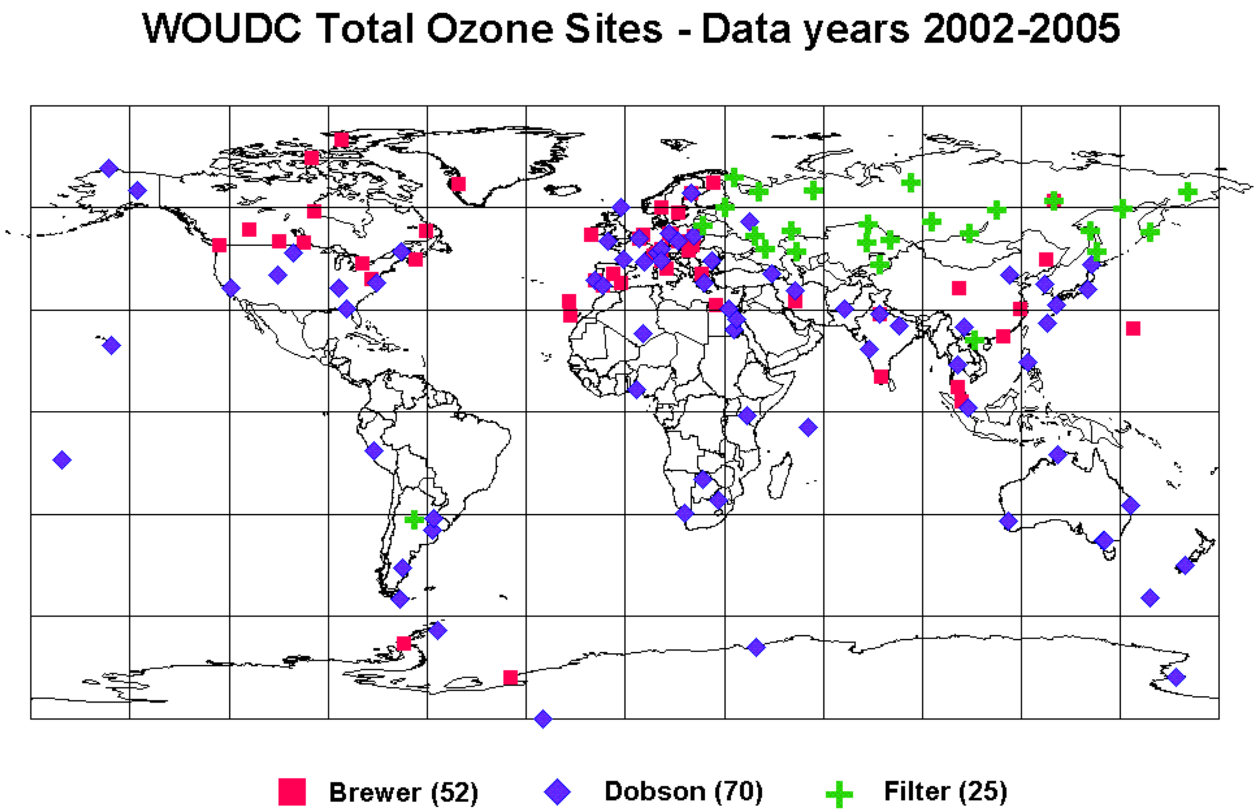

FIGURE 3.2 Global distribution of stations in a network that measures ozone concentration in the atmosphere (data years 2002-2005). The different types of data points represent different types of instruments. Squares, diamonds, and crosses represent Brewer, Dobson, and filter instruments, respectively. Gaps are apparent especially over northern Canada, Siberia, and northern Greenland—areas where indigenous communities live and could be affected by changes in ultraviolet radiation tied to fluctuations in ozone concentration. There are also gaps in the subpolar North Atlantic. SOURCE: This image was produced by the WOUDC (World Ozone and Ultraviolet Radiation Data Centre), which is operated by Environment Canada under the auspices of the World Meteorological Organization.

gaps. Instead, the Committee presents examples of what it considers critical gaps. These gaps are in spatial and temporal coverage, thematic and disciplinary coverage, and data access and management. The entries in Annex 3B include supporting details on gaps in existing and planned large global and regional networks. In addition, Chapter 5 includes an expanded discussion of spatial gaps and Table 2.1 lists examples of critical spatial, temporal, and thematic gaps in key variables.

System-wide Gaps

In the Arctic as a whole, the needs are acute for monitoring of surface radiation balances, precipitation, ocean salinity and temperature, sea ice distribution and thickness, and land cover characteristics to advance the understanding of global climate and produce more accurate weather prediction and reanalysis models. There is little ongoing collection of radiative data for the entire arctic region and no precipitation data are collected regularly over the Arctic Ocean. Compared to other regions of the Earth, and especially given its vast area, the Arctic in general has very few precipitation gauging stations. Furthermore, there is a lack of salinity and temperature data for the Arctic Ocean, especially in the areas covered by sea ice (e.g., Figure 3.1). Sea ice thickness data are lacking, as is high-quality information on ice in coastal regions (e.g., Holloway and Sou, 2002). Finally, high-resolution land cover data are lacking in most of the Arctic, as are time series of albedo, especially in vegetated areas and on ice (Box 3.1).

Temporal Gaps

Making measurements in the Arctic is inherently challenging, particularly during the winter. There are only a few sites where measurements are made year-round, and the number has been declining. This lack of continuous measurements makes it difficult to fully understand the system, identify trends, or study the intensity and frequency of extreme events. For some variables, arctic residents might be able to provide year-round measurements. And satellite-

Box 3.1
Example of System-wide Gap: Albedo

Surface albedo datasets must capture the progression of melt-freeze at sufficient resolution for surface energy budget evaluations and model validation (NRC, 2001). Although optical measurements are continually made in polar regions, the only surface albedo product that covers land, sea ice, and ice sheets available on a daily basis is the Advanced Very High Resolution Radiometer Polar Pathfinder Product which contains twice-daily, gridded observations. These data run from 1981 to 2000, and thus there is a gap after 2000 even though the instruments are still flying. A prototype snow albedo algorithm for MODIS (Moderate Resolution Imaging Spectroradiometer) was developed and could have been used to fill the temporal gap after 2000, but the algorithm was not incorporated into the routine processing of Terra and Aqua snow data products until September 2003. Because of the lack of calibration and verification, the MODIS daily snow albedo product is considered a beta-test product and therefore may still contain significant errors. Additionally, the dataset does not provide surface albedo over sea ice—only snow-covered land surfaces. There is a 16-day MODIS albedo product that can fill the data gap between 2000 and 2003, but its coarse spatial resolution misses important daily or weekly events and it too does not provide albedo over sea ice.

derived information can supplement ground-based measurements for a number of key variables unless the long polar night affects the satellite measurements.

A comprehensive AON must satisfy the needs for long-term measurements of many variables over differing time scales. For example, temperature needs to be measured frequently, whereas the movement of the tree line does not. Extreme events may be short-lived, rare, localized, and observed only if there happen to be measurements at that time and place, whereas documenting the arctic-wide interactions of longer term climatic variability such as the Arctic Oscillation and the North Atlantic Oscillation[3] is also part of the AON. The current array of arctic observing activities does not satisfy these demands.

Thematic Gaps

Observations within the AON should characterize chemical, biological, physical, and human systems and their interconnections. However, there are limited pan-arctic records of long-term changes in these systems (e.g., Holmes et al., 2000) and many disciplines and domains are not represented within existing observational networks. Examples of measurement gaps in chemical systems (carbon dioxide fluxes), biological systems (landscape-related parameters such as leaf area index and net primary production, species lists, biological sampling from drifting and moored marine platforms), physical systems (glacier contributions to freshwater fluxes, bathymetry and elevation), and human systems (human-environment relations and demographic data) are discussed in this section. In addition to these straight thematic gaps, there is also a lack of integration across themes—for example, among ecological and physical data.

It is not currently possible to measure carbon fluxes and variations through time. Although it is generally thought that warming temperatures will increase the role of the Arctic as a carbon dioxide (CO_2) source (Billings et al., 1982), it is not known whether the Arctic as a whole is a source or a sink for CO_2 and methane. Presently, fluxes are only resolved for small experimental measurement sites (e.g., Weller et al., 1995).

Within the biological domain, there is a dearth of landscape-related parameters such as net primary production and leaf area indices that could be monitored routinely by satellite. No follow-on Landsat mission is planned, and the most similar mission—ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)—will not replace the types of observations made by Landsat. Even a basic species list for many taxa is lacking,[4] and, in the marine domain, biological sampling from drifting and moored platforms is just beginning and requires substantial sensor development before biological observations from these platforms will have broad-based use.

In the physical domain, quantifying the contribution of glacier melt to the overall freshwater flux in the Arctic is a critical gap. Although the mass balance of the Greenland Ice Sheet has been monitored through NASA's Program for Regional Climate Assessment, there has been little systematic observation of the mass balance of other, smaller ice masses (Arendt et al., 2002). Dyurgerov and Carter (2004) concluded that glacier runoff was a larger source than river runoff for increased freshwater fluxes to the Arctic Ocean between 1961 and 1998, but also stated "[w]e cannot accurately calculate the meltwater discharge from all pan-arctic glaciers due to the lack of data."

In addition to physical parameters that are changing over human time frames, baseline information that is taken for

[3]The Arctic Oscillation (AO) is a mode of atmospheric variability that currently has a positive trending index that may be indicative of greenhouse warming (SEARCH, 2001). Climate indices supported by many physical and biological time series show coherent changes across the Arctic that are decadal in scale (Overland et al., 2004). Variations in the AO and the North Atlantic Oscillation may have direct links to interannual to decadal variations in precipitation and river discharge in the Arctic (Peterson et al., 2002; Déry and Wood, 2005).

[4]See, for example, http://www.sfos.uaf.edu/research/arcdiv/index.html.

granted outside the Arctic such as oceanic bathymetric information and digital elevation models (DEMs) is broadly lacking in the Arctic. Bathymetry and DEMs are needed to help develop future models and monitoring strategies. Tide gauges in the Arctic Ocean are also sparse (Plag, 2000).

In the human domain, there are many questions about human-environment relationships for which substantial information gaps exist. For example, human demographic data (e.g., population size, composition, birth rates, death rates, and migration) often are collected through national and state agencies and it can be difficult to locate or access the data. The AON could help fill a key gap by making existing demographic data (and other human dimension data such as those on health and education) more easily available and helping organize these data into a common structure so that information is comparable across the Arctic. In addition, there is an absence of and need for disaggregated data (e.g., broken down by indigenous/non-indigenous, male/female, by community, size) (AHDR, 2004) that would show community-level trends rather than only national trends.

Data Management and Access Gaps

Many attendees of the Committee's two workshops expressed concern over data management and access limitations for arctic data and a strong need for a unified approach to data management and data sharing by those collecting arctic observations.[5] There is a gap in the synthesis and integration of data being collected throughout the Arctic that is partly caused by difficulties "stitching together" time series from sensors and platforms that span different time frames, sampling frequencies, and levels of accuracy. In addition, different measurements of a particular variable are often difficult to reconcile. For example, there are substantial qualitative differences among precipitation amounts obtained from gauges and their various correction procedures, from different interpolation methods, and from in situ and remote sensing information.

Data accessibility is a related problem (see Annex 3C). Access to data is impeded by a number of barriers that include national regulations that limit access because of national security and exclusive economic zone restrictions, age and geographic constraints (e.g., research embargos) that influence when or where data are shared, and concerns over privacy and intellectual property rights.[6] Different nations and different government agencies often have their own rules for data distribution and access, and data collected by the private sector are often not accessible. Finally, individual scientists often only store their data in personal archives with the likelihood that these data will be lost if there is no concerted effort to share them with data centers that can manage and share them more effectively in the long term.

SUMMARY AND CHAPTER RECOMMMENDATIONS

There are many ongoing and planned international activities that, if coordinated and integrated, could be the core of the AON. However, there are also many geographic, temporal, thematic, and other gaps even given these available resources. This lack of adequate and coordinated observations limits the capability to identify the geographic extent of ongoing changes, as well as the attribution of these changes. It limits society's responses to these ongoing changes and its capability to anticipate, predict, and respond to future changes that affect physical processes, ecosystems, and arctic and global residents. An initial focus of effort on consistently measuring a subset of important variables (e.g., the key variables discussed in the previous chapter) could provide a practical starting point.

Recommendation: An Arctic Observing Network should be initiated using existing resources and with the flexibility to expand and improve to satisfy current and future scientific and operational needs. In its initial phase, the network should monitor selected key variables consistently across the arctic system.

The upcoming IPY is an opportunity to "design and implement multidisciplinary observing networks" (NRC, 2004). The IPY will include an international, coordinated set of activities that will provide a burst of new and intensive monitoring for a two-year period that will help jump-start the AON. Experience, knowledge, and infrastructure (in particular, new data, new data measurement and management approaches, and new logistical support) gained through IPY could provide additional resources to advance the AON beyond its existing core components.

Recommendation: Work to design and implement an internationally coordinated Arctic Observing Network should begin immediately to take advantage of a unique window of opportunity created by a convergence of international activities during the International Polar Year that focus on observations.

[5]The next chapter is dedicated to data management and access issues and explores in greater depth the issues introduced briefly in this subsection.

[6]In particular in human dimensions and life sciences.

ANNEX 3A

EXAMPLES OF EXISTING NETWORKS, OBSERVATORIES, DATA CENTERS, SATELLITES, COORDINATING BODIES, AND PROGRAMS

A fundamental message of this report is that the AON should not start from scratch. Myriad networks and programs, existing and planned, are its building blocks. This annex provides an overview of the range of observatories, networks, programs, and other resources that could be these building blocks. It is difficult to separately group networks, observatories, instruments, and programs, for different elements of an observatory may be parts of separate networks—perhaps because of differences in the historical development of the variety of observing programs and also in how different countries and disciplines operate. These are critical factors that the AON will need to embrace as it develops. The Committee has tried to identify as many resources as possible, but the list is not exhaustive. If the reader becomes acquainted with more new entities than they find missing, then the Committee has achieved its goal for this table. Nonetheless, readers should contact the Polar Research Board with information on missing observatories, networks, or other entries to help expand the master list of potential partners and observation platforms that could contribute to the AON. This annex contains six tables that provide examples of networks, observatories, satellites, data centers, coordinating bodies, and programs, respectively. The following abbreviations are used in all tables:

Abbreviation	Domain
A	Atmosphere
Co	Coastal
Cr	Cryosphere
F	Freshwater
HD	Human Dimensions
M	Marine
SP	Space Physics
T	Terrestrial

ANNEX TABLE 3A.1 Examples of Currently Operating and Planned Arctic Networks[a]

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information/URL
ABEKC	HD, T	Arctic Borderlands Ecological Knowledge Co-op	Community-based monitoring of weather, ice, rivers, fish, caribou, other animals, and land activities	1995	Alaska		This network identifies key variables. http://www.taiga.net/coop/index.html
ALIS	SP	Auroral Large Imaging System	Aurora	1993	Sweden	SM	http://www.alis.irf.se/ALIS
ALISON	Cr, T	Alaska Lake Ice and Snow Observatory Network	Ice thickness, snow depth, temperature and mean density	1999	Alaska	MED	http://www.gi.alaska.edu/alison/
AMAP/ Marine	M	Arctic Monitoring and Assessment Programme	Contaminants, climate, UV, and physical, chemical, and biological variables	1991	Pan-arctic		This network identifies key variables. http://www.amap.no/
AMAP/ Atmosphere	A	See previous	Contaminants, climate, UV, and physical and chemical variables	1991	Pan-arctic		See previous URL
AMAP/ Freshwater	F	See previous	Contaminants, climate, UV, and physical, chemical, and biological variables	1991	Pan-arctic		See previous URL

continued

ANNEX TABLE 3A.1 Continued

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information/URL
AMAP/ Human Health	HD	See previous	Contaminants, climate, UV, and physical, chemical, and biological variables	1991	Pan-arctic		See previous URL
AmeriFlux	T		Ecosystem-level exchanges of CO_2, water, energy, and momentum spanning diurnal, synoptic, seasonal, and interannual time scales	1996	Alaska, U.S. National Network	SM	http://public.ornl.gov/ameriflux/
ANKN	MD	Alaska Native Knowledge Network	Information related to Alaska Native Knowledge systems		Alaska		http://www.ankn.uaf.edu
AOOS	M	Alaska Ocean Observing System	Oceanographic, sea ice, and biological observing	2005	Arctic Alaska and Bering Sea		http://www.aoos.org
ARCN I&M	T	Arctic Network Inventory and Monitoring Program	Climate, water quality, plant biodiversity, plant productivity (NDVI), mammal diversity, lemming populations, visitor impact, plant phenology, cultural integrity, and snow melt patterns	1994	Alaska	SM	Operated by the National Park Service http://www1.nature.nps.gov/im/units/arcn/index.cfm
ARGO	M	—	Floats that measure temperature and salinity of the upper 2000 m of the ocean	2000	Global	LG	http://www.argo.ucsd.edu/
ASIAQ	T	"Asiaq" is a weather goddess in Inuit mythology	Climate, glacier maps, and hydrological gauging stations	1975	Greenland		http://www.asiaq.gl
Canopus	SP	Canadian Auroral Network for the Open Program Unified Study	Aurora	1989	Canada	MED	http://www.space.gc.ca/asc/eng/sciences/canopus.asp
Digisonde network	SP	University of Massachusetts Digisonde Network	Ionospheric density	1981	Global	LG	http://ulcar.uml.edu/index.html
DMI Geomagnetic, Ionosonde, and Riometer Observatories	A, SP	Danish Meteorological Institute	Absolute and relative geomagnetic vector data, ionization of gases in the atmosphere, and ionospheric absorption of cosmic radio noise	1950s	Greenland	MED	http://dmiweb.dmi.dk/fsweb/projects/chain/greenland.html

ANNEX TABLE 3A.1 Continued

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information / URL
DMI Meteoro-logical Observing Stations	A	See previous	Climate, precipitation, temperature, relative humidity, wind, and air pressure	1960s	Denmark, Faroe Islands and Greenland	SM	http://www.dmi.dk/dmi/tr04-20.pdf
Eiscat	SP	European Incoherent Scatter Radar	Ionospheric and thermospheric parameters	1996	Scandinavia	SM	http://www.eiscat.uit.no/eiscat.html
EMAN-North	Co, Cr, F, T	Ecological Monitoring and Assessment Network-North	Impacts of industrial development and climate change in northern ecosystems	1991	Northern Canada	MED	http://www.emannorth.ca/main.cfm
EMEP	A	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe	Collection of emission data, measurements of air and precipitation quality, and modeling of atmospheric transport and deposition of air pollution	2000	Europe	LG+	http://www.emep.int/index.html
EuroFlux	T		Long-term carbon dioxide and water vapour fluxes of European forests and interactions with the climate system	1996	Iceland, Denmark, Finland	MED	http://www.unitus.it/dipartimenti/disafri/progetti/eflux/euro.html
GCOS	A, Cr, F, M, T	Global Climate Observing System	Detects climate trends and climate change due to human activities, predicts seasonal-to-interannual climate, reduces uncertainties in long-term climate prediction, and improves data for impact analysis	1992	Global	LG+++	This network identifies key variables. http://www.wmo.ch/web/gcos/Second_Adequacy_Report.pdf (section 6.2) and http://www.wmo.ch/web/gcos/Implementation_Plan_(GCOS).pdf (Chapter 5)
GEMS	F	Global Environment Monitoring System	Maintains a global freshwater quality information system and provides this information to support global and regional environmental assessments	1977	Global	LG+++	http://www.gemswater.org/index.html
GLOBE	MD	Global Learning and Observations to Benefit the Environment	Atmosphere, hydrology, soils, and land cover/phenology	1995	Global		GLOBE is a worldwide hands-on, primary and secondary school-based education and science program in which students take scientifically valid measurements. http://www.globe.gov

continued

ANNEX TABLE 3A.1 Continued

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information/URL
GOOS	Co, M	Global Ocean Observing System	Physical, chemical, and biological oceanography	1991	Arctic Ocean	LG+++	http://ioc.unesco.org/goos/
GSN	A	GCOS-Surface Network	Surface temperature, precipitation, and pressure	1997	Global	LG+++	This network identifies key variables. http://www.wmo.ch/web/gcos/gcoshome.html
GTOS/ GTN-P	T	Global Terrestrial Observing System/ GTOS Terrestrial Network for Permafrost	Bore hole temperature	1999	Europe	LG+	This network identifies key variables. http://www.gtnp.org/index.html
GTOS/ GTN-P/ CALM	T	GTOS/GTN-P/ Circumpolar Active Layer Monitoring	Active layer, permafrost monitoring network	1994	Pan-arctic	LG	This network identifies key variables. http://www.fao.org/gtos
GTOS/ GTN-P/ INPO	T	GTOS/GTN-P/ International Network of Permafrost Observatories	Bore hole temperature	2000	Pan-arctic	LG	This network identifies key variables. http://www.fao.org/gtos
GUAN	A	GCOS-Upper Air Network	Vertical profiles of temperature, humidity, and wind speed and direction through the troposphere	1992	Global	LG+	This network identifies key variables. http://www.wmo.ch/web/gcos/gcoshome.html
IABP	M	International Arctic Buoy Program	Maintains drifting buoy network measuring meteorological and oceanographic data, including sea ice	1970s	Arctic Ocean	LG	http://iabp.apl.washington.edu/
ICS	HD	International Circumpolar Surveillance	Infectious disease	1999	Pan-arctic		http://www.cdc.gov/ncidod/aip/research/ics.html
ITEX/ NATEX and CANTEX	T	International Tundra Experiment/North American Tundra Exp. and Canadian Tundra Exp.	Climate, biodiversity, and ecosystem function	1992	Pan-arctic	MED	Plot level passive warming manipulation. This network identifies key variables. http://www.itex-science.net/
LTER	T	Long Term Ecological Research	Terrestrial and aquatic ecosystem monitoring	1987	Toolik Lake & Bonanza Creek, Alaska, U.S. National Network	SM	http://ecosystems.mbl.edu/arc/
MACCS	SP	Magnetometer Array for Cusp and Cleft Studies	Magnetic field	1995	Canada	SM	http://space.augsburg.edu/space/MaccsHome.html

ANNEX TABLE 3A.1 Continued

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information/URL
Miracle	SP	Magnetometers-Ionospheric Radars-Allsky Cameras Large Experiment	Magnetic field and aurora	1997	Scandinavia	MED	http://www.ava.fmi.fi/MIRACLE
MLTR	A, SP	Mesosphere Lower Thermosphere Radar Network	Mesospheric winds	2000	Global	MED	http://sisko.colorado.edu/TIMED
NDBC/ Atmosphere	A	National Data Buoy Center/Atmosphere	Wind direction, speed, and gust, barometric pressure, air temperature, and relative humidity	1991	Global	SM	http://www.ndbc.noaa.gov
NDBC/ Marine	M	National Data Buoy Center/Marine	SST, significant wave height, and average and dominant wave period	1991	Global	MED	http://www.ndbc.noaa.gov
NOP	M	National Observer Program	Biological data and fisheries	1973	North Pacific & Bering Sea	SM	http://www.st.nmfs.gov/st4/nop/ index.html
Norwegian Atmospheric Terrestrial and Freshwater Monitoring	A, F, T		Acidification of fresh water, precipitation, ground ozone, and forest observations	Early 1970s	Norway	LG+	This is a Norwegian national effort.
NWS Radiosonde Network	A	National Weather Service Radiosonde Network	Tropospheric winds and state variables	1940s	Global	LG	http://www.srh.noaa.gov/bmx/ upperair/radiosnd.html
NWS VOS	A	National Weather Service Voluntary Observing Ship Program	Weather		Global	LG+++	http://www.vos.noaa.gov/index.shtml
R-ArcticNet/ National	F	Regional-ArcticNet	River runoff and chemistry	1960s	Pan-arctic	LG+++	http://www.r-arcticnet.sr.unh.edu
SCANNET	T	Scandinavian/North European Network of Terrestrial Field bases	Climate variability, key human drivers of change, indicators of social and environmental change, trends of biodiversity, and species performance and phenology	1987	Scandinavia	MED	http://www.sannet.nu
SliCA	HD	Survey of Living Conditions in the Arctic	Living conditions	2000	Pan-arctic		This network identifies key variables. http://www.iser.uaa.alaska.edu/ projects/Living_conditions/ index.html
SuperDarn	SP	Super Dual Auroral Radar Network	Ionospheric convection patters and mesospheric winds	1993	Arctic and Antarctic	MED	http://superdarn.jhuapl.edu

continued

ANNEX TABLE 3A.1 Continued

Currently Operational Networks

Acronym	Domain[b]	Acronym Definition	What Is Measured/ Products/Key Variables	Inception	Region	Extent in the Arctic[c]	More Information/URL
WHYCOS (WMO)	F	World Hydrological Cycle Observing System (World Meteorological Organization)	Range of hydrological parameters	1993	Global		http://www.wmo.ch/web/homs/projects/whycos.html
WMO-GOS/WWW	A	WMO-Global Observing System of World Weather Watch	Physical parameters of atmosphere	1963	Europe, North America	LG+++	Made up of 10,000 stations, 7,000 ships, and 3,000 aircraft
WMO-GAW	A	WMO-Global Atmosphere Watch	Chemical parameters of atmosphere	1989	Global	LG++	GAW is considered the atmospheric chemistry component of the Global Climate Observing System (GCOS). http://www.wmo.ch/web/arep/gaw/gaw_home.html

Planned Networks

Acronym	Domain[b]	Acronym Definition	What Will Be Measured/ Products/Key Variables	Region	Comments
ACCO-Net	Co, M	Arctic Circum polar Coastal Observatory Network	Approximately 20 sites including deltas and estuaries of major Siberian and North American rivers are proposed. The sites will be loci for multidisciplinary studies and will include sensitive areas with varying degrees of human impact. Site selection will be coordinated with local communities and build upon existing monitoring programs and data availability.	Pan-arctic	http://www.awi-potsdam.de/acd/acconet/
AICEMI	HD	International Network of Arctic Indigenous Community-Based Environmental Monitoring and Information Stations	Community based monitoring of environmental, social, economic variables	Pan-arctic	Proposed IPY 2007-2008 project
ARN	HD	Arctic Residents' Network	Integration of local/traditional knowledge and science to assess vulnerability	Pan-arctic	Proposed IPY 2007-2008 project
BTF	T	Back to the Future	Vegetation change in polar regions	Pan-arctic	Proposed IPY 2007-2008 project
CAFF-CBMP	T	Conservation of Arctic Flora and Fauna/Circumpolar Biodiversity Monitoring Program	Biodiversity of arctic flora and fauna	Pan-arctic	This network identifies key variables. http://www.caff.is/
CARMA	T	Circumarctic Rangifer Monitoring & Assessment Network	Wild rangifer subspecies, focusing on the large migratory herds from North America and Russia	Pan-arctic	Proposed IPY 2007-2008 project http://www.rangifer.net/carma/
CAT-B	T	Circum-Arctic Terrestrial Biodiversity	Terrestrial biodiversity	Pan-arctic	Proposed IPY 2007-2008 project

ANNEX TABLE 3A.1 Continued

Planned Networks

Acronym	Domain[b]	Acronym Definition	What Will Be Measured/ Products/Key Variables	Region	Comments
ELOKA	HD	Exchange for Local Observations and Knowledge of the Arctic	Community-based monitoring and data management and networking service for local and traditional knowledge and observations	Pan-arctic	Proposed IPY 2007-2008 project
EMSO	M	European Multidisciplinary Seafloor Observatory	Continuous monitoring of geophysical, biogeochemical, oceanographic, and biological active phenomena	Europe	Project proposed by the the European Strategy Forum on Research Infrastructure (ESFRI) to establish 10 regional monitoring networks
MAOOS	M	Mooring-Based Arctic Ocean Observational System	Ocean circulation, water mass transformations, biogeochemical fluxes, key mechanisms of variability, and links to the lower-latitude processes	Arctic Ocean	Proposed IPY 2007-2008 project
NEON/ HLEO	T	National Ecological Observatory Network/ High Latitude Ecological Observatory	Interdisciplinary measurements and experiments on ecological systems	Alaska	http://mercury.bio.uaf.edu/iab/hleo/
RENNET	HD	Reindeer Network	Coping mechanisms and the adaptive capacity of reindeer herding in a changing climate	Norway	Proposed IPY 2007-2008 project; an arctic vulnerability network study driven by ACIA

NOTE: A network is a collection of spatially distributed instruments managed by different lead investigators or researchers using the same or similar methodologies to measure common or similar parameters that can be integrated with the goal of addressing a specific scientific question or uncertainty. Networks typically consist of a few (5 to 10) to hundreds of standardized measurement units distributed across a geographic region. These measurement units can be automated instrument packages or may involve a human component.

[a]A dash (—) indicates undetermined information or not applicable.

[b]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.

[c]Extent in the Arctic refers to the number of sites (N) in the Arctic, even though some networks may extend beyond the Arctic. SM ($N < 10$); MED ($10 \leq N \leq 25$); LG ($25 \leq N \leq 100$), LG+ ($100 \leq N \leq 250$), LG++ ($250 \leq N \leq 500$), and LG+++ ($N \geq 500$).

ANNEX TABLE 3A.2 Examples of Currently Operational Arctic Observatories[a]

Name	Domain[b]	What Is Measured/Products/Key Variables?	Inception	Location	More Information/URL
Abisko	T	Dynamics of plant populations, recent climate changes in the region, and local variations of the microclimate in subalpine and alpine ecosystems	1903	Sweden	http://www.ans.kiruna.se/
Alert	A, M, T	Chemistry of the atmosphere - greenhouse gases, organic pesticides and fine particles, stratospheric ozone, etc.	1956	Ellesmere Island, Canada	
Alexandra Fjord	T	Nitrogen and other nutrients in tundra ecosystems	1992	Ellesmere Island, Canada	Sites operated under by the International Tundra Experiment (ITEX)
Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR)	A, SP	Atmospheric wind, temperature, chemistry, aurora, and ionosphere	1994	Norway	http://alomar.rocketrange.no/rmr.html
Arctic Station	Cr	Air temperature, humidity, incoming and outgoing radiation, wind speed and direction, rainfall, and ground temperature		Disko Island, Greenland	http://www.nat.ku.dk/as/indexuk.htm
Atmospheric Radiation Measurement (ARM)	A	Radiation, climate, and other atmospheric parameters		Barrow, Atqasuk	http://www.arm.gov
Barentsberg	Co	Sea level		Svalbard	
Barrow Environmental Observatory (BEO)	A, M, T	Long-term baseline and monitoring studies for contaminants, permafrost, soils, vegetation, wildlife, etc.	1992	Alaska	http://www.sfos.uaf.edu/basc/beo/
Bering Strait Environmental Observatory (BSEO)	M	Physical, chemical, and biological variables in the marine environment	2000	Bering Strait	http://arctic.bio.utk.edu/AEO/index.html
Bonanza Creek	T	Forest dynamics and biogeochemistry	1987	Alaska	http://www.lter.uaf.edu/
Cherski (Northeast Science Station)	A, Co, M	Geological and marine investigations along the coast of the Arctic Ocean, global carbon and methane fluxes, seasonal cycle of atmospheric CO_2, and the discharge of carbon and nitrogen into the Arctic Ocean	1989	Russia	http://www.faculty.uaf.edu/fffsc/station.html
Eureka (Arctic Stratospheric Ozone Observatory)	A	Stratospheric ozone	1993	Ellesmere Island, Canada	http://woudc.ec.gc.ca/e/eureka/eureka.htm
Hornsund (Polish Polar Station)	M	Marine biodiversity	1957	Svalbard	http://hornsund.igf.edu.pl/index.php
Kilpisjarvi	A	Ionospheric studies	1994	Finland	http://www.dcs.lancs.ac.uk/iono/iris
Kiruna (Swedish Institute of Space Physics)	A, SP	Atmosphere, ionosphere, and aurora	1957	Sweden	http://www.irf.se/
Lena Delta (The International Biological Station)	T	Biodiversity	1995	Siberia, Russia	http://www.yakutiatravel.com/eng/travdir/lenanord.htm
Longyearbyn	A, SP	Atmosphere and aurora		Svalbard	Operated by the University of Spitzbergen

ANNEX TABLE 3A.2 Continued

Name	Domain[b]	What Is Measured/Products/Key Variables?	Inception	Location	More Information/URL
Mars Arctic Research Station (MARS)	M	The Earth's geologic past, cosmic phenomena (e.g., impact cratering), and robotic testing and human exploration technologies and strategies	1999	Nunavut, Canada	http://resources.yesican-science.ca/trek/mars/
Nansen and Amundsen Basin Observational System/Canadian Basin Observational System (NABOS/CABOS)	M	Structure, strength, water-mass transformation mechanisms, heat transport, and variability of ocean circulation		Arctic Ocean	http://nabos.iarc.uaf.edu/ http://www.frontier.iarc.uaf.edu/NABOS/index.php http://www.frontier.iarc.uaf.edu/CABOS/index.php
North Pole Environmental Observatory (NPEO)	Cr, M	Physical variables for sea ice, surface meteorological observations, ocean conditions over a wide area and to the bottom of the Arctic Ocean	2000	Arctic Ocean	http://psc.apl.washington.edu/northpole/
Ny Ålesund	A, Cr, M, T	Atmosphere, ionosphere, cryosphere, biosphere, and marine systems		Svalbard	Multinational research done by Norway, Germany, Japan, France, Italy, China, etc.
Oulu Cosmic Ray Station	A, SP	Cosmic ray measurements	1964	Finland	http://spaceweb.oulu.fi/projects/crs/
Point Barrow Observatory	A, M, SP, T	Aerosol quality control plots, Barrow isentropic plots, carbon cycle sampling network, chromatograph of trace gases, station meteorology, total ozone data, and the Geomagnetism Program of the USGS	1973	Alaska	http://www.cmdl.noaa.gov/obop/brw/
Poker Flat	A, SP	Atmosphere, ionosphere, and aurora	1968	Alaska	http://www.pfrr.alaska.edu/pfrr/index.html
Resolute Bay	A, SP	Atmosphere, ionosphere, and aurora	1966	Canada	http://www.astronautix.com/sites/restebay.htm
Sermilik Station	Cr	Glaciological monitoring of the Mittvakkat-glacier	1970	Greenland	Owned by the University of Copenhagen http://www.geogr.ku.dk/facilit/fieldst/sermiklik.html
Sondrestrom Fjord	A, SP	Atmosphere, ionosphere, and aurora	1983	Greenland	http://isr.sri.com/
Summit	A, Cr	Atmospheric chemistry, meteorological data, and snow-atmosphere interactions	1989	Greenland	http://www.geosummit.org/
Tiksi Bay Observatory	A, SP	Weather and geophysical station		Russia	Operated by the Institute of Cosmophysical Research and Aeronomy (IKFIA)
Toolik Field Station	F, T	Biology, physiology, climatology, hydrology, and ecology	1975	Alaska	http://www.uaf.edu/toolik/
Zackenberg Ecological Research Operations (ZERO)	M, T	Biological variables, climate, and snow cover	1996	Denmark	http://www.zackenberg.dk/
Zhigansk Ionospheric Station	Sp	Ionospheric studies		Russia	http://ds.iszf.irk.ru/welcomeZ.html

NOTE: An observatory is a site or locality that supports the operation of multiple measurement units all managed by a single lead investigator or a collaboration of investigators drawn to the same site/locality of interest. Observatories range in size from large, multidisciplinary sites to smaller, more focused observatories that support single disciplines or focus on a specific scientific topic.
[a]A dash (—) indicates undetermined information.
[b]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.

ANNEX TABLE 3A.3 Examples of Arctic-related Satellite Missions and Instruments Past, Present, and Planned

Key Variable	Domain[a]	Satellite(Instrument)
Physical Variables		
Albedo	Cr, M	*Landsat 3-5(TM),* AQUA(MODIS,CERES), Envisat(MERES), EO-1 Hyperion, Landsat 7(ETM), TERRA(MODIS, CERES, MISR, ASTER), NOAA*1*-**17**(AVHRR), POLDER, SPOT-5, **METOP(AVHRR), NPOESS(VIIRS),**
Elevation/Bathymetry	Cr, M, T	ERS-1and 2(radar altimeter), Envisat(RA-2), GRACE, ICESAT(GLAS), JASON-1, TERRA(ASTER), TOPEX(POSEIDON), **CRYOSAT-2, OMST(CNES)**
Ice Thickness (sea ice and land ice)	Cr, M	AQUA(AMSR-E), DMSP *F8*-**F17** (SSM/I, **SSMI/S**), Envisat(RA-2), ERS-1and 2(radar altimeter), ICESAT(GLAS), Seawinds-II(QuikSCAT), TERRA(ASTER), **CRYOSAT-2**
Ice Extent and Concentration (including snow)	Co, Cr, M, T	*Landsat 3-5(TM), Nimbus-5(ESMR)***,** *Nimbus-7(SMMR)***,** ADEOS(NSCAT), AQUA(MODIS, AMSR-E), DMSP *F8***-F17**(SSM/I, **SSMI/S**), Envisat(MWR), ERS-1 and 2(ESCAT), Landsat 7(ETM), NOAA 7-**17**(AVHRR), Seasat-A(SASS), Seawinds-II(QuikSCAT), TERRA(MODIS, MISR), **NPOESS (VIIRS)**
Precipitation	F, M, T	**CLOUDSAT, GPM** (to 65 degrees N)
Clouds	A	AQUA(MODIS, CERES, AIRS), EARTHPROBE(TOMS), Envisat(GOME, MERES), Envison(MIPAS), ERS-2(GOME), NOAA *6-12*,14(TOVS), TERRA(MODIS, CERES), **CALIPSO, CLOUDSAT(CPR)**
Pressure (atmospheric)	A	NOAA-*6, 7, 9-12(TOVS)*, TIMED(SABER), UARS(HALOE), **NPOESS(CrIS)**
Radiation	A, Cr, M, T	AQUA(MODIS, CERES), IMAGE(FUV), Landsat *3-5*, 7, NOAA*1*-**17**(AVHRR), SDO(SOLSTICE), SOHO, TERRA(MODIS, CERES, MISR), TIMED(SEE), UARS(ACRIM), **METOP(AVHRR), NPOESS(VIIRS)**
Salinity	M	**Aquarius**
Snow Depth	Cr	*Nimbus-7(SMMR)*, AQUA(AMSR-E), DMSP *F8*-**F17**(SSM/I, **SSMI/S**)
Soil Moisture	T	AQUA(AMSR-E), Envisat(MWR)
Temperature (atmosphere)	A, Cr, SP, T	AIM, AQUA(MSU, AMSU, AIRS), AURA(HIDRLS), DMSP(SSMT-1 and SSMT-2), Envisat(MWR, GOMOS), Envison(MIPAS), ERS-2(GOME), NOAA11-**17**(TOVS), ODIN, SAGE, TIMED(SABER, TIDI, GUVI), TOMS, UARS(MLS, HRDI), **DMSP(SSMI/S)**, **METOP(HIRS, AMSU-A, IASI, GRAS)**, **NPOESS(CrIS)**
Temperature (skin)	Cr, M, T	AQUA(MODIS, CERES), Envisat(AATSR), ERS-1 and 2 (ATSR), Landsat *5*-7, NOAA*1*-**17**(THIR, AVHRR), TERRA(MODIS, CERES), **METOP(AVHRR), NPOESS(VIIRS)**
Velocity (wind, ocean circulation, ice)	A, Cr, M	*Geosat, GOES 3, Seasat,* Envisat(ASAR, RA-2), ERS-1 and 2, JASON-1, POLARMETRICSAR, RADARSAT1-2(SAR), Seawinds(QuikSCAT), TIMED(TIDI), TOPEX(POSEIDON), UARS(HRDI, WINDII), **METOP(ASCAT)**, **OSTM (CNES, Jason-2)**
Water Vapor	A	AQUA(AIRS/VTPR), Envisat(MWR, MERES, GOMOS), Envison(MIPAS), ERS1-2(GOME), NOAA-*6-7, 10, 12*-**17**(TOVS), ODIN, SAGE I-III, TOMS, UARS, **CLOUDSAT(CPR)**, **METOP(HIRS, MHS, IASI)**, **NPOESS(CrIS), OMST(AMR)**
Freshwater Flux	Cr, F, M, T	None
Lake Level	T	None
Sea Level	Co, F, M	Envisat(RA-2), JASON-1, TOPEX(POSEIDON), **OMST(CNES)**
Aerosol Concentration (stratospheric)	A	*Nimbus-7(SAM II),* AEM-B(SAGE I), AURA, ERBS(SAGE II), METEOR-M(SAGE III), **NPOESS(APS)**
Land Cover	T	ALOS, AQUA(MODIS), EO-1 Hyperion, IRS-P5/P6(CARTOSAT-1 and 2), JERS-1, NOAA *1*-**17**(AVHRR), TERRA(MODIS, ASTER), TOPSAT, **EROS B/C**, **METOP(AVHRR), TerraSAR-X**

ANNEX TABLE 3A.3 Continued

Key Variable	Domain[a]	Satellite(Instrument)
Biogeochemical Variables		
Trace Gasses (e.g., CH4, O3, ClO)	A	*Nimbus-7(LIMS, TOMS)*, AEM-B(SAGE I), AQUA(AIRS/VTPR), AURA, EARTHPROBE(TOMS), Envisat(GOMOS, MIPAS), Envison(MIPAS), ERBS(SAGE II), ERS-2(GOME), Meteor-3M(SAGE III), NOAA *6-12*, 14(TOVS), OSIRIS(ODIN), TIMED(SABER), UARS(HALOE), **CALIPSO, METOP(GOME-2), NPOESS(OMPS)**
Biodiversity	T	None
Biomass		None
Carbon Concentration (CH4, C02, VOCs)	A	*Nimbus-7(SAMS)*, AURA(HIDRLS, TES), TERRA(MOPITT), UARS(HALOE, ISAMS)
Nutrient Concentration		None
Contaminant Concentration		TERRA(MOPITT)
Dissolved Oxygen Concentration	A, M	None
Phenology	A, Co, Cr, HD, M, T	*Nimbus 7(CZCS),* AQUA(MODIS), Envisat(MERIS), IKONOS, Landsat *5*-7, NOAA *1*-**17**(AVHRR), QUICKBIRD, SeaWifs(CZCS), SPOT-5, TERRA(MODIS, ASTER), **METOP(AVHRR)**, **NPOESS(VIIRS)**
Upper Atmosphere	A	AURA(HIDRLS), UARS(WINDII, PEM, ISAMS)
Human Dimensions Variables		
Economic Indicators	HD	CORONAS, IKONOS, Landsat, QUICKBIRD

NOTE: Italics denote expired missions and bold denotes planned missions. The list is linked to the key variables listed in Table 2.1. It is evident that satellite data are more prevalent for physical variables than biogeochemical and human. Each satellite platform is listed with any relevant sensor, if known, in parentheses. Acronyms are defined in Appendix C.
[a]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.

ANNEX TABLE 3A.4 Examples of Arctic Data Centers, Archives, and Portals

Acronym	Domain[a]	Acronym Definition[b]	Data Products	Country	More Information/URL
Operational Data Centers					
ADIS	A, Cr, F, M, T	ACSYS Data and Information Service	Over 1,400 datasets relating to the atmosphere, hydrosphere, ocean, sea ice, cryosphere, modelling, biosphere, ecology, and land	Norway	http://acsys.npolar.no/adis/adis.php
AMAP	A, F, HD, M, T	Arctic Monitoring and Assessment Programme	Contaminants (atmospheric, hydrosphere, terrestrial), radioactivity, and human health	Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden, USA	http://www.amap.no/
APDA	F, M, T	Arctic Precipitation Data Archive	Global precipitation data	Germany	http://www.dwd.de/en/FundE/Klima/KLIS/int/GPCC/Projects/APDA/
ARDB	F, M, T	Arctic Runoff Data Base	Global river discharge data	Germany	http://ardb.bafg.de
CO-OPS	M	Center for Operational Oceanographic Products and Services	Physical variables: tides, currents, and sea level	USA	http://www.co-ops.nos.noaa.gov
DISC	Cr	Data and Information Service for CliC	Metadata for cryospheric datasets	Norway	http://clic.npolar.no/disc/
EOS	A, Cr, F, M, T	Earth Observing System	Satellite data from polar-orbiting and low inclination satellites	USA	http://eospso.gsfc.nasa.gov/
GINA	A, Cr, F, M, T	Geographic Information Network of Alaska	Distributed data system for geospatial information (e.g., GIS)	USA	http://www.gina.alaska.edu/
UNEP/GRID-Arendal	HD	United Nations Environmental Program	Environmental cartographic products	United Nations countries (Norway)	http://www.grida.no/
ICES	M	International Council for Exploration of the Sea	Marine ecosystems covering environment, oceanography, and fisheries	19 nations	http://www.ices.dk/
NCDC	A, Cr	National Climatic Data Center	Climatic data	USA	http://www.ncdc.noaa.gov
NGDC	M, SP, T	National Geophysical Data Center	Sea floor, solid Earth, and solar geophysical data	USA	http://www.ngdc.noaa.gov/
NILU	A	Norwegian Institute for Air Research	Measurements from atmospheric research and monitoring programs	Norway	http://www.nilu.no/
NODC	Co, M	National Oceanographic Data Center	Global oceanographic and coastal data	USA	http://www.nodc.noaa.gov/
NSIDC	A, Cr	National Snow and Ice Data Center	Snow and ice data from land, sea, air, space; holdings of NSF Arctic System Science (ARCSS) projects	USA	http://nsidc.org/

ANNEX TABLE 3A.4 Continued

Acronym	Domain[a]	Acronym Definition[b]	Data Products	Country	More Information/URL
NSSDC	SP	National Science Space Data Center	Atmosphere, ionosphere, and magnetosphere parameters	USA	http://nssdc.gsfc.nasa.gov/
NWS	A	National Weather Service	Radiosonde	USA	http://www.nws.noaa.gov/
WDC	MD	World Data Center System	List of and links to World Data Centers by subject (including Climate, Glaciology, Land Cover, Marine Environmental Sciences, Marine Geology and Geophysics, Oceanography, Paleoclimatology, Remotely Sensed Data, etc.)	Russia, USA, UK	http://www.ngdc.noaa.gov/wdc/wdcmain.html
Operational Data Archives					
AOOS	M, Co	Alaska Ocean Observing System	Real-time and historic datasets on ocean and coastal variables	USA	http://www.aoos.org
AAGRUUK	Co, M	Arctic Archive for Geophysical Research: Unlocking Undersea Knowledge	Bathymetry and geophysical data and maps for the Arctic Ocean basin	USA	http://www.soest.hawaii.edu/HMRG/Aagruuk/index.htm
CEDAR	A, SP	Coupling Energetics and Dynamics of Atmospheric Regions	Atmosphere, ionosphere, and magnetosphere parameters	USA	http://cedarweb.hao.ucar.edu
CEON	F, T	Circumarctic Environmental Observatories Network	Terrestrial and freshwater observations, data, and maps	USA	http://www.ceoninfo.org/
ENVINET	A, M, T	European Network for Arctic-Alpine Environmental Research	Environmental data, primarily within atmospheric physics and chemistry and marine and terrestrial biology	EU	http://envinet.npolar.no
JOSS/UCAR	M	Joint Office for Science Support/University Corporation for Atmospheric Research	Geophysical data for programs that JOSS has supported	USA	http://www.joss.ucar.edu/
LTER	A, F, M, T	Long Term Ecological Research Network	Ecological datasets	USA	http://www.lternet.edu/
TIMED	A, SP	Thermospheric, Ionospheric, Mesospheric Energetics and Dynamics	Atmosphere and ionosphere parameters	USA	http://www.timed.jhuapl.edu
UNAVCO	A	University NAVSTAR Consortium	GPS geodetic data for the measurement of crustal deformation	USA	http://www.unavco.org/
Current and Planned Data Portals					
BAID-IMS	A, F, HD, M, T	Barrow Area Information Database and Internet Mapping Server	Spatially relevent data for historical research and research infrastructure on the western north slope of Alaska	USA	http://www.baidims.org
CEON-IMS	A, F, HD, T	The Circumarctic Environmental Observatories Network Internet Map Server	Distribution of network and partnered observation platforms north of 45 degrees	USA/Internatonal	http://www.ceonims.org

continued

ANNEX TABLE 3A.4 Continued

Acronym	Domain[a]	Acronym Definition[b]	Data Products	Country	More Information/URL
IPY DIS	MD	International Polar Year Data and Information Service	Metadata catalog for all IPY projects and a provision of Web-based portals to global IPY data archives	USA/ Internatonal	Proposed IPY 2007-2008 project
Polar View	C, M, T	—	Monitoring for oil spills, icebergs, sea ice floe edges, river ice, and glaciers, high-resolution ice charts, sea ice thickness charts, and met-ice-ocean regional forecasting	Canada	http://www.northernview.org/index.htm
VGMO	SP	Virtual Global Magnetic Observatory	Interfaces geomagnetic data repositories and performs online data acquisition and processing	USA	http://maggy.engin.umich.edu/mist/vgmo.html
VSO	SP	Virtual Solar Observatory	Database of solar data searchable by data source, instrument, or observed physical variable	USA	http://umbra.nascom.nasa.gov/vso

NOTE: Data centers and portals are mechanisms for archiving and sharing data, respectively. A data center is a central location where data are archived. The data can come from large programs or single investigators and are typically quality controlled to ensure a basic level of integrity. Data centers provide a mechanism for the long-term archiving of datasets. A data portal is different from a data center and provides a mechanism, typically through the Web, to support a distributed repository of data. Data holdings at data centers may be large, terabyte-sized datasets from a satellite program, observations from a single investigator in the field, historical or paleoclimate records from ice cores, or recorded history from an indigenous person.
[a]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.
[b]A dash (—) means not applicable.

ANNEX TABLE 3A.5 Examples of Coordinating Bodies[a]

Acronym	Domain[b]	Acronym Definition	What Is Measured/Products/Key Variables?	Inception	More Information/URL
ArcticNet	Co		Climate change impacts in the coastal Canadian Arctic	2004	http://www.arcticnet-ulaval.ca
CBMP	Co, Cr, F, M, T	Circumpolar Biodiversity Monitoring Program	Biodiversity and identification of indicators of trends in habitat and biodiversity	2005	An endorsed IPY project that includes the development of a data portal through the World Conservation Monitoring Centre; http://www.caff.is/sidur/uploads/Circumpolar%20Biodiversity.pdf
CEON	F, T	Circumarctic Environmental Observatories Network	Provides access to data and information, access to facilities, adequate coverage of standardized observations and regional observatories, up-scaling of site specific observations, parameterization and validation of models and remote sensing, proxies and reoccupation of abandoned sites, development and testing of methodologies and sensors, and development of ecological theory	2004	http://www.ceoninfo.org/
CEOS	MD	Committee on Earth Observation Satellites	Coordinates international civil spaceborne missions	1984	http://www.ceos.org/
CIFAR	A, Cr, M, T	Cooperative Institute For Arctic Research	Atmospheric and climate research, climate modeling, UV and arctic haze, hydrographic and sea ice studies, marine ecosystems, tsunami research, contaminant effects, fisheries, oceanography, and data archiving and support	1994	http://www.cifar.uaf.edu
CliC	Cr	Climate and Cryosphere	Monitoring of the entire cryosphere (i.e., snow cover, sea, lake, and river ice, glaciers, ice sheets, ice caps and ice shelves, and permafrost), climate-related processes involving the cryosphere, and the assessment of changes in the cryosphere as indicators of global climate change	2000	CliC was originally established by WCRP; however, in 2004 SCAR became a co-sponsor of the project. http://clic.npolar.no
CLIVAR	A, M	Climate Variability and Predictability	Climate variability and predictability on seasonal, interannual, decadal, and centennial time scales and the response of the climate system to increases of radiatively active gases and aerosols		http://www.clivar.org/
COMAAR	MD	Consortium for Coordination of Observation and Monitoring of the Arctic for Assessment and Research	Intended to provide a forum for observation and monitoring networks in the Arctic, to consider new observation and monitoring platforms, and to improve coordination	Planned	http://www.ans.kiruna.se/meetings/comaar/info.htm
DAMOCLES	Cr, M, T	Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies	Sea ice cover and the regional and global impacts on the environment of human activities	Planned for 2006	European marine parallel to SEARCH; http://www.seaice.dk/damocles/
ENVINET	A, M, T	European Network for Arctic-Alpine Multidisciplinary Research	Coordination of research and monitoring infrastructures to focus on atmospheric physics and chemistry and the marine and terrestrial domains	2000-2003 (not currently active)	Involved 17 environmental research infrastructures in Europe and 3 international organizations; biologywww.envinet.npolar.no/

continued

ANNEX TABLE 3A.5 Continued

Acronym	Domain[b]	Acronym Definition	What Is Measured/Products/Key Variables?	Inception	More Information/URL
GCOS	MD	Global Climate Observing System	Monitors of the climate system, detects and attributes climate change, assesses the impacts of climate variability and change, and supports research for modeling and prediction of the climate system	1992	http://www.wmo.ch/web/gcos/gcoshome.html
GEOSS	MD	Global Earth Observation System of Systems	Will collect data, enhance data distribution, and provide models to obtain integrated water resource management, ocean and marine resource monitoring and management, weather and air quality monitoring, forecasting and advisories, biodiversity conservation, sustainable land use and management, public understanding of environmental factors affecting human health and well-being, better development of energy resources, and adaptation to climate variability and change	Planned	GEOSS will be a large national and international cooperative effort to bring together existing and new hardware and software, making it all compatible to supply data and information at no cost. This activity will identify key variables. http://earthobservations.org/docs/10-Year%20Plan%20Reference%20Document%20(GEO%201000R).pdf
GOOS	M	Global Ocean Observing System	Physical, chemical, and biological oceanography	1991	This activity identifies key variables. http://www.wmo.ch/web/gcos/Second_Adequacy_Report.pdf (section 6.2) and http://www.wmo.ch/web/gcos/Implementation_Plan_(GCOS).pdf (Chapter 5)
GTOS	Co, T	Global Terrestrial Observing System	Terrestrial carbon observations, climate observations, land dynamics, and terrestrial coastal environments studies	1996	http://www.fao.org/gtos/
IASC-WAG	Cr	International Arctic Science Committee-Working group on Arctic Glaciology	Dynamics and mass balance of arctic glaciers and ice sheets in relation to sea level and climate change	1992	Currently includes a proposed project, GLACIODYN, that will address glacier dynamics. http://www.phys.uu.nl/%7Ewwwimau/research/ice_climate/iasc_wag/
ICES	M	International Council for the Exploration of the Sea	Coordinates and promotes marine research (e.g., climate, fisheries, and marine ecosystems) in the North Atlantic, including the Baltic Sea and North Sea	1901	http://www.ices.dk
IGOS	MD	Integrated Global Observing Strategy	Links research, long-term monitoring and operational programs, and data producers and users to determine observation gaps and to identify needed resources	1998	http://www.fao.org/gtos/igos/index.asp
INCHR	HD	International Network for Circumpolar Health Research	Conducts, sponsors, and promotes research programs and projects investigating the patterns, determinants, and impact of health conditions among circumpolar peoples and the strategies for improving their health		http://www.inchr.org/

ANNEX TABLE 3A.5 Continued

Acronym	Domain[b]	Acronym Definition	What Is Measured/Products/Key Variables?	Inception	More Information/URL
IOC	M	Intergovernmental Oceanographic Commission	Coordinates GOOS by developing, promoting, and facilitating international oceanographic research programmes, by providing technical assistance relating to the systematic observations of the global ocean and its coastal zone, and by ensuring efficient handling and availability of ocean data	1960	http://www.ioccg.org/about/ioc.html
IPY IPO	MD	IPY International Program Office	Provides support to the ICSU-WMO joint IPY committee for IPY's central planning, coordination, and oversight	2004	http://www.ipy.org/international/programme-office/
ISAC	MD	International Study of Arctic Change	Aims to internationalize SEARCH for arctic climate change studies	Planned	The Science overview document (SOD) was completed in 2005. http://www.aosb.org/ISAC_SOD_Jan05.pdf
MOSJ	MD	Miljøovervåking Svalbard og Jan Mayen	Collects information from thematic monitoring programs, provides online quality assured data with metadata and interpretations, assess the state of the environment, gives recommendations for environmental management, and coordinates local environment monitoring		http://miljo.npolar.no/mosj/start.htm
SEARCH	MD	Study of Environmental Arctic Change	Aims to understand the nature, extent, and future development of the system-scale change presently seen in the Arctic	Planned	This activity will identify key variables. http://www.arcus.org/search/resources/reportsandscienceplans.php
WMO	A, F, M	World Meteorological Organization	Facilitates free and unrestricted exchange of data and information, products, and services that are related to safety and security, economic welfare and environmental protection	1950	WMO is a Specialized Agency of the United Nations. http://www.wmo.ch/index-en.html

NOTE: These bodies coordinate and manage communication and cooperation among various mixes of regional or disciplinary networks or observatories to maintain consistency in observational methods, data management, report preparation, or asset sharing. Branches of a coordinating body share either a common research interest or specific resources and may not necessarily have a center for operations.
[a]A dash (—) means not applicable.
[b]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.

ANNEX TABLE 3A.6 Examples of Programs

Acronym	Domain[a]	Acronym Definition	What Is Measured/Products/Key Variables?	Inception	More Information/URL
Arctic-CHAMP	F, T	Arctic Community-wide Hydrological Analysis and Monitoring Program	Natural variability, changes, stocks, and fluxes within the arctic hydrologic cycle and the direct impacts of variability and its feedbacks on biological and biogeochemical systems, the Earth system, and human society	2000	http://arcticchamp.sr.unh.edu/index.shtml
ASOF	M	Arctic/Subarctic Ocean Fluxes	Fluxes of heat, salt, and mass through subarctic seas and their variability, forcing, and effects	1999	ASOF is a subprogram of International SEARCH. http://asof.npolar.no/
CASES	Cr, M	Canadian Arctic Shelf Exchange Study	Ice growth, decay and transport, photosynthetic production, impacts of increased UV radiation on biological productivity, particulate matter and carbon fluxes, contaminant distribution, impacts of ice habitat reduction, and variations in ice cover	2001	http://www.cases.quebec-ocean.ulaval.ca/
F-MAP	M	Future of Marine Animal Populations	Census of marine life	2002	http://as01.ucis.dal.ca/fmap/
GEOSS	MD	Global Earth Observation System of Systems	Will seek advances in nine societal benefit areas: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity	2003	http://www.epa.gov/geoss/
GCTE	T	Global Change and Terrestrial Ecosystems	Effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agriculture, forestry, soils, and biodiversity, and how these effects lead to feedbacks to the atmosphere and the physical climate system	1986	Core Project of the International Geosphere-Biosphere Programme (IGBP); http://www.gcte.org/
H-MAP	M	History of Marine Animal Populations	Census of marine life	2004	http://www.hmapcoml.org/
iAOOS	A, Cr, M	integrated Arctic Ocean Observing System	Will predict the loss of perennial sea ice and the associated effects and controlling forces	Planned for 2007-2008	IPY proposed programs can be explored at http://www.ipy.org/development/eoi/
IGBP	M	International Geosphere Biosphere Programme	Develops international frameworks for collaborative research, forms research networks, promotes standardized methodologies, guides construction of global databases, undertakes model intercomparisons and comparisons with data, and facilitates patterns of resource allocation	1986	http://www.igbp.kva.se
IPY	MD	International Polar Year	Large-scale environmental change assessments, observational network design, and human environmental dynamics research	Planned for 2007-2008	Accepts Expressions of Intent (EoI) proposals from an international audience of scientists with the goal of fostering international collaboration. http://www.ipy.org/

ANNEX TABLE 3A.6 Continued

Acronym	Domain[a]	Acronym Definition	What Is Measured/Products/Key Variables?	Inception	More Information/URL
JWACS	M	Joint Western Arctic Climate Study	Physical, biochemical, and paleoceanography studies at the shelf-slope area from the Northwind Ridge to Banks Island	2002	http://www.martechpolar.com/JWACS%202004/JWACS%202004%20Index.htm
LAII	A, Cr, T	Land-Atmosphere-Ice Interactions	Interactions between land, atmosphere, and ice in the Arctic	1993	http://nsidc.org/arcss/projects/laii.html
PARCA	T	Program for Regional Climate Assessment	Climate (AWS), ice thickness, ice motion, and mass balance	1991	Metadata available at NSIDC; http://cires.colorado.edu/science/pro/parca/
SBI	M	Western Arctic Shelf-Basin Interactions Project	Physical and biological shelf and slope processes that influence the structure and functioning of the Arctic Ocean	1999	http://sbi.utk.edu/
SHEBA	A, Cr, M	Surface Heat Budget of the Arctic Ocean	Surface heat budget of the Arctic Ocean	1995-2002 (completed)	http://sheba.apl.washington.edu/
SOOP	M	Ship of Opportunity Programme	Fulfills upper ocean data requirements which have been established by GOOS and GCOS (e.g., TSG, XCTD, CTD, ADCP, pCO2, phytoplankton concentration)	1999	http://www.ifremer.fr/ird/soopip/
WCRP-COPES	MD	World Climate Research Programme-Coordinated Observation and Prediction of the Earth System	Will facilitate the prediction of climate system variability and change by building on existing and future WCRP projects	Planned for 2005–2015	http://www.wmo.ch/web/wcrp/copes.html

NOTE: This table includes goal-oriented programs that aim to advance arctic observations. The focus of these programs ranges from discipline-specific to multidisciplinary. A program is a cluster of projects or operations intended to meet clearly identified goals. Programs typically have criteria for participation and a defined course of action. Programs may either be narrowly focused or widely interdisciplinary, and either continuous or discontinuous in duration (e.g., operational programs or science programs, respectively). Projects within most programs are generally supported by the same funding agency. Only major programs active within the last 10 years and planned in the near future have been listed. Although certain satellite platforms, such as EOS Terra and Aqua, may fall under this definition of programs, satellite-based resources are included in a separate table (Annex Table 3A.3).

[a]A = atmosphere, Co = coastal, Cr = cryosphere, F = freshwater, HD = human dimensions, M = marine, SP = space physics, T = terrestrial.

ANNEX 3B

EXAMPLES OF MAJOR GLOBAL AND REGIONAL NETWORKS OF SIGNIFICANCE TO THE ARCTIC

ANNEX TABLE 3B.1 GCOS NETWORK

Network Name/URL	Global Climate Observing System (GCOS) (http://www.wmo.ch/web/gcos/gcoshome.html).
Existing or planned?	Existing, with proposed enhancements. It does not gather data itself. Instead, it relies on other global networks for data. Existing atmospheric networks include GCOS Surface Network (GSN), atmospheric component of the composite surface observation system, including sea level pressure, GCOS Upper-Air Network (GUAN), Global Atmospheric Watch (GAW), global CO_2 network, MSU-like radiance satellite observations, total solar irradiance and Earth radiation budget satellite observations.
Foci	Climate-related observations and information. The proposed system will "characterize the state of the climate system and its variability; monitor the forcing of climate; support the prediction and attribution of climate change; enable the characterization of extreme events."
Customers	United Nations Framework Convention on Climate Change (UNFCCC) and intergovernmental organizations.
Realm	All realms: relies on surface and upper air networks for atmosphere; Global Ocean Observing System (GOOS) for ocean observations; and Global Terrestrial Observing System (GTOS) for terrestrial observations.
Coverage	Global.
Spatial Density	Depends strongly on variable; satellite measurements can have resolutions of ~10 km, while rawinsonde measurements are much more widely spaced (plans call for establishment of a high-quality reference network of about 30 precision rawinsonde stations distributed globally).
Variables	Atmospheric, oceanic, terrestrial. Atmospheric variables that are considered "essential climate variables" include surface variables (air temperature, precipitation, pressure, surface radiation budget, wind, and water vapor), upper-air variables (temperature, including MSU radiances, wind, water vapor, cloud properties, and Earth radiation budget, including solar irradiance), and composition variables (CO_2, CH_4, ozone, long-lived greenhouse gases, and aerosol properties).
Duration of Record	Started in 1992. However, measurements of some variables at some locations extend back farther in time.
Frequency of sampling observations (in time)	Varies by variable: essentially continuous for surface measurements at automated stations; 12-hourly for upper air (rawinsondes); less frequent for composition measurements.
Time Scale of the phenomenon the network means to observe	Seasonal to interannual and decadal variability.
Accessibility of data	GCOS Implementation Plan states: "International standards and procedures for the storage and exchange of meta-data need to be developed and implemented for many climate observing system components, including those of the operational satellite community." GCOS Implementation Plan calls for the establishment of International Data Centers because "The flow of data to the user community and to International Data Centers is not adequate for many essential climate variables."
Data Management & Archiving Approach	Global Observing Systems Information Center (GOSIC) is to provide portals for data from all participating networks and programs; not yet implemented (see preceding entry). Data management varies widely by system component and variable. A network for the archival of standard atmospheric measurements is in place, but generally not for oceanic and terrestrial variables.
Compatibility & Integratability with sources of similar data outside network	Intended, but has not yet been implemented/achieved.
Staff	The permanent staff dedicated to GCOS, based at their project office at World Meteorological Organization (WMO) Secretariat in Geneva, Switzerland, consists of a director and a secretary. The chair of the scientific committee donates a substantial portion of time to GCOS matters.

Funding Sources	The budget of the GCOS secretariat is about $100,000 per year. Co-sponsored by the WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU).
Comments	Participant in IGOS: Integrated Global Observing Strategy.

ANNEX TABLE 3B.2 GOOS NETWORK

Network Name/URL	Global Ocean Observing System (GOOS) (http://ioc.unesco.org/goos/).
Existing or Planned?	Component measurement systems exist to varying extents, but need augmentation. The Implementation Plan states: "Parties need to provide global coverage of the surface network by implementing and sustaining (a) the Global Sea Level Observing System (GLOSS) baseline network of tide gauges, (b) an enhanced drifting buoy array, (c) an enhanced (tropical) moored buoy array, (d) an enhanced Voluntary Observing Ships Climatology (VOSClim) network, and (e) a globally-distributed reference mooring network." "Parties need to provide global coverage of the sub-surface network by implementing and sustaining (a) the Argo profiling float array, (b) the systematic sampling of the global ocean full-depth water column, (c) the Ship-of-Opportunity Expendable Bathythermograph (XBT) trans-oceanic sections, and (d) reference mooring networks." Essential ocean satellite system activities include (a) sustained support for vector-wind (scatterometer), sea ice, sea surface temperature, and ocean-color measurements, and (b) continuous coverage from altimeters to provide high-precision and high-resolution sea-level measurements. The Implementation Plan states "The surface ocean network depends critically on the continuity of satellite observations, most of which are in research rather than operational status..."
Foci	Monitor ocean conditions including physics, chemistry, and living resources; operational monitoring and prediction of ocean conditions and ocean hazard warnings. Main foci include the Open Ocean Panel for Climate (OOPC), the Coastal Ocean Observations Panel (COOP), and a number of GOOS regional alliances. An arctic regional alliance has been proposed and may be implemented during the IPY.
Customers	IPCC (through GCOS), intergovernmental agencies, national agencies, a wide spectrum of individual users including the offshore and marine transport industry, coastal development insurance and management, and the ocean and climate research community.
Realm	Ocean and sea ice component of cryosphere.
Coverage	Global, but large gaps (see "existing/planned" entries above).
Spatial Density	Varies widely. Satellite measurements have resolutions of 10-100 km, while moorings are widely spaced and XBTs are highly irregular in time.
Variables	"Essential Climate Variables" for the ocean. The OOPC classifies these as surface variables (sea surface temperature, surface salinity, sea level, sea state, sea ice, current, ocean color for biological activity, and CO_2 partial pressure) and subsurface variables (temperature, salinity, current, nutrients, carbon, ocean tracers, and phytoplankton). Coastal variables, from the COOP, are less well sampled and more regionally heterogeneous.
Duration of Record	Since 1991/1992; enhancements of system are ongoing.
Frequency of sampling observations (in time)	Highly variable—several times daily for some satellite-measured quantities and every several years for ship-based measurements.
Time Scale of the phenomenon the network means to observe	Seasonal to interannual and decadal for most variables; moorings and satellite observations can provide information on higher-frequency (e.g., eddy) variations, including sea state (waves).
Accessibility of data	Components of the GOOS that report in real time have data available via Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology in situ Observing Platform Support Centre JCOMMops (http://www.jcommops.org). Increased data availability and transparency is an issue of increasing importance as more satellite products enter the operational phase.
Data Management & Archiving Approach	Distributed.

Compatibility & Integratability with sources of similar data outside network	Addressed on a platform-specific basis.
Staff	Project office at UNESCO-IOC headquarters in Paris has a dedicated staff of approximately 10 people.
Funding Sources	Project office in Paris has an annual budget on the order of $300,000 per year, provided by IOC, WMO, UNEP, ICSU, Food and Agricultural Organization (FAO) (UN), National Oceanic and Atmospheric Administration (NOAA) (USA), Natural Environment Research Council (NERC) (UK).
Gaps	Major gaps exist in the Southern Ocean and Arctic, where most products (except sea ice) are in the development phase.
Comments	Participant in IGOS: Integrated Global Observing Strategy; Provides the ocean observations component for GCOS and the marine coastal component of GTOS; part of IGOS, which is the U.S. contribution to GOOS; and the Alaska Ocean Observing System (AOOS) is the U.S. arctic contribution to Integrated Ocean Observing System (IOOS). The regional coastal ocean observing systems that are part of IOOS (such as AOOS) are also supposed to be part of Coastal GOOS (C-GOOS.

ANNEX TABLE 3B.3 GTOS NETWORK

Network Name/URL	Global Terrestrial Observing System (GTOS) (http://www.fao.org/gtos/).
Existing or Planned?	Existing in rudimentary form; "The climate observing system in the Terrestrial Domain remains the least well-developed component of the global system" (GCOS Implementation Plan).
Foci	Detect environmental change; provide for sustainable development.
Customers	Researchers, policy makers.
Realm	Terrestrial.
Coverage	Global.
Spatial Density	Varies widely. Satellite products are global at potentially 1-10 km resolution, while in-situ measurements are much more widely spaced, especially in areas of permafrost, ice sheets, and glaciers.
Variables	"Essential Climate Variables" listed in the GCOS Implementation Plan include: river discharge, ground water, ground water extraction rates and usage, lake levels, snow extent and duration, snow depth, glacier/ice cap inventory and mass balance, glacier length, ice sheet mass balance and extent, permafrost extent, soil temperature profiles and active layer thickness, albedo, land cover, above-ground biomass, photosyntheticly active radiation (PAR), leaf area index (LAI), and fire disturbance (burnt area, date and location of active fire, burn efficiency). Priority terrestrial satellite products include: daily global albedo, LAI and fraction of absorbed photosynthetically active radiation (FAPAR) products, snow cover (both hemispheres), digital elevation maps of ice sheet surfaces, full glacier inventory from current spaceborne cryosphere missions, and land-cover characterization datasets.
Duration of Record	Began nominally in 1996, but the system is still in the early phases of development.
Frequency of sampling observations (in time)	Varies widely. Satellite products are global at potentially 1-10 km resolution, while in-situ measurements are much more widely spaced, especially in areas of permafrost, ice sheets, and glaciers.
Time Scale of the phenomenon the network means to observe	Varies widely. Satellite measurements can be several times daily, in situ measurements can be essentially continuous for some measurements (e.g., recording thermistors, stream flow rates), but infrequent for observations requiring human intervention.
Accessibility of data	Free access, but some data holders may charge for access.
Data Management & Archiving Approach	The Terrestrial Ecosystems Monitoring Sites database is an international directory of sites (called T.Sites) and networks that carry out long-term terrestrial monitoring and research activities. The database is maintained and facilitated by GTOS; however GTOS is not the owner of the data. There is a GTOS Data and Information Management Plan.

Compatibility & Integratability with sources of similar data outside network	GTOS Implementation Plan: "Parties are urged to develop a global network of at least 30 reference sites (collocated with atmospheric sites if possible) to monitor key biomes."
Staff	The main office with a staff of five is hosted by FAO in Rome.
Funding Sources	Project office budget on the order of $300,000 per year, provided by FAO, WMO, UNEP, UNESCO, and ICSU.
Gaps	Present coverage of the permafrost measurement network is highly irregular spatially; many satellite products are still in an algorithm-development phase.
Comments	Participant in IGOS: Integrated Global Observing Strategy.

ANNEX TABLE 3B.4 SEARCH DMO

Network Name	Study of Environmental Arctic Change (SEARCH) Distributed Marine Observatories (DMO).
Existing or Planned?	Planned but with 30 percent in place.
Foci	Track, understand, and respond to decadal-scale (3-100 yrs), pan-arctic change.
Customers	Science community and society.
Realm	Ocean.
Coverage	Pan-arctic.
Spatial Density	On the order of 200 km except where denser sampling is required to resolve major features, e.g., boundary currents.
Variables	In-situ standard physical and biological measurements plus remote sensing.
Duration of Record	Since 2002 in some cases.
Frequency of sampling observations (in time)	Approximately hourly (e.g., time series) to annual (e.g., repeat surveys).
Time Scale of the phenomenon the network means to observe	Decadal.
Accessibility of data	Freely accessible.
Data Management & Archiving Approach	Compatible as possible.
Compatibility & Integratability with sources of similar data outside network	Distributed at present but more central data management is planned.
Staff	No significant dedicated staff at present.
Funding Sources	National Science Foundation (NSF), NOAA, National Aeronautics and Space Administration (NASA).
Gaps	About 70 percent of the moorings and automated drifting stations are not established. A similar percentage of the repeat sections are not being repeated on a regular basis. Biological sampling from the automated drifting and moored platforms is just beginning as new sensors become available.

ANNEX TABLE 3B.5 SEARCH DQU

Network Name	SEARCH Detecting and Quantifying Unaami (DQU).
Existing or Planned?	Planned but with many elements in place.
Foci	Track, understand, and respond to decadal-scale (3-100 yrs), pan-Arctic change.
Customers	Science community and society.
Realm	Paleo: terrestrial, marine, and atmospheric.
Coverage	Pan-arctic.
Spatial Density	100s of proxy paleo sites and sites with historical records.
Variables	Historical physical records plus paleo (e.g., lake and marine sediments, ice cores, tree rings).
Duration of Record	—
Frequency of sampling observations (in time)	N/A.
Time Scale of the phenomenon the network means to observe	Decadal.
Accessibility of data	Freely accessible.
Data Management & Archiving Approach	As compatible as possible. Proxy issues are critical.
Compatibility & Integratability with sources of similar data outside network	Distributed at present but more central data management is planned.
Staff	No dedicated staff at present.
Funding Sources	NSF, NOAA, NASA.
Gaps	—

ANNEX TABLE 3B.6 SEARCH DTO

Network Name	SEARCH Distributed Terrestrial Observatories (DTO).
Existing or Planned?	Planned but with many elements in place.
Foci	Track, understand, and respond to decadal-scale (3-100 yrs), pan-arctic change.
Customers	Science community and society.
Realm	Terrestrial.
Coverage	Pan-arctic.
Spatial Density	On the order of 6 Intensive Sites in representative regions (tundra, taiga forest, etc.) around the Arctic plus larger numbers of Intermediate Sites, and Extensive Sites.
Variables	Intensive Sites: complete set of physical and ecological measurements. Intermediate Sites: range of physical and ecological measurements. Extensive Sites: sites with specialized measurements (e.g., borehole temperatures, river gauging stations). Remote Sensing: for surface properties (e.g., snow cover, NDVI).

Duration of Record	Since 2002 in some cases.
Frequency of sampling observations (in time)	Approximately hourly (e.g., time series) to annual (e.g., repeat surveys).
Time Scale of the phenomenon the network means to observe	Decadal.
Accessibility of data	Freely accessible.
Data Management & Archiving Approach	As compatible as possible.
Compatibility & Integratability with sources of similar data outside network	Distributed at present but more central data management is planned.
Staff	No significant dedicated staff at present.
Funding Sources	NSF, NOAA, NASA.
Gaps	Of the Intensive Sites, the Abisko site is likely the closest to the right combination of colocated intensive physical and ecological observations. The Bonanza Creek-Toolik Lake-Barrow triumvirate is ripe to form an Intensive Site or Sites. Svalbard is also close to this status. Resolute and Cherski probably need considerable work. Thus, with respect to the Intensive Sites, coverage is approximately half complete. Also, some Intermediate Sites such as Eureka and Zackenberg might easily be upgraded to Intensive. A key element remaining is standardization of key measurements. Intermediate and Extensive Sites need further development in size, and a better job needs done to bring their information together, as the Circumarctic Environmental Observatories Network (CEON) is doing. A disciplinary gap in the SEARCH Implementation Strategy is glacier mass balance. There is evidence that glacier mass balance is undergoing significant decadal change, and station, such as Summit will need to be included in the DTO observation set.

-

ANNEX TABLE 3B.7 SEARCH LAO

Network Name	SEARCH Large-scale Atmospheric Observatories (LAO).
Existing or Planned?	Planned but with many elements in place.
Foci	Track, understand, and respond to decadal-scale (3-100 yrs), pan-arctic change.
Customers	Science community and society.
Realm	Atmospheric.
Coverage	Pan-arctic.
Spatial Density	On the order of 6 shore-based major observatories around the Arctic, observations at DMO and DTO sites, and remote sensing.
Variables	Complete set of atmospheric measurements extending from the surface to the top of the atmosphere.
Duration of Record	Since 2002 in some cases.
Frequency of sampling observations (in time)	Approximately hourly (e.g., time series) to annual (e.g., repeat surveys).
Time Scale of the phenomenon the network means to observe	Decadal.
Accessibility of data	Freely accessible.
Data Management & Archiving Approach	As compatible as possible.

Compatibility & Integratability with sources of similar data outside network	Distributed at present but more central data management is planned.
Staff	No significant dedicated staff at present.
Funding Sources	NSF, NOAA, NASA.
Gaps	One of the major atmospheric observatories is in place at Barrow and arguably Abisko and Svalbard have the required capability. Efforts are under way to upgrade to such a station at Eureka, Nunavut, Canada (rather than at Alert as suggested in the Implementation Strategy). There is also work at an early stage to develop the station at Tiksi in Russia. The less intensive sites shared with DMO and DTO have corresponding gaps in coverage (i.e., probably about 70 percent).

ANNEX TABLE 3B.8 SEARCH SEI

Network Name	SEARCH Social and Economic Interactions (SEI).
Existing or Planned?	Planned but with some in place.
Foci	Track, understand, and respond to decadal-scale (3-100 yrs), pan-arctic change.
Customers	Science community and society.
Realm	Social/human dimension.
Coverage	Pan-arctic.
Spatial Density, Duration of Record, Sampling Frequency	N/A.
Variables	Records of harvests, erosion and flooding, resource use, transportation, commercial fishing, livelihood strategies, and quality of life.
Time Scale of the phenomenon the network means to observe	Decadal.
Accessibility of data	Freely accessible. A goal is to establish Community/Industry Data Networks.
Data Management & Archiving Approach	As compatible as possible.
Compatibility & Integratability with sources of similar data outside network	Distributed at present but more central data management is planned.
Staff	No significant dedicated staff at present.
Funding Sources	NSF, NOAA, NASA.
Gaps	Uncertain at this time.

ANNEX TABLE 3B.9 SCANNET

Network Name	Scandinavian/North European Network of Terrestrial Field Bases (SCANNET).
Existing or Planned?	Existing.

Foci	Understanding many aspects of the natural environment.
Customers	Researchers, local authorities, national weather canters, etc.
Realm	Terrestrial, atmosphere, hydrosphere, cryosphere.
Coverage	Western north Atlantic, including Greenland (west, southeast, and northeast), Svalbard, Finland (subarctic sites), Sweden (subarctic site), Norway (alpine), Scotland (alpine), Faroe Islands, and Iceland.
Spatial Density	Differs according to location and variable. Often there is a major site and sample plots within the vicinity (10s of meters to kilometers).
Variables	Several thousand across the network including meteorological, ecological, atmospheric, contaminants.
Duration of Record	The network started in 2000 and persists. The earliest monitoring started in 1904.
Frequency of sampling observations (in time)	Differs according to variable from continuous to annual.
Time Scale of the phenomenon the network means to observe	Continuous to decadal according to variable.
Accessibility of data	A meta-database is on the SCANNET Web site with links to data owners. Some data are freely available on the Web site or from the owners. Other data have restrictions.
Data Management & Archiving Approach	Distributed. Few standardized formats exist because of different sites' histories.
Compatibility & Integratability with sources of similar data outside network	Differs according to variable but there is usually compatibility with similar data outside the network.
Staff	The network has a part-time secretary and coordinator. Some network partners have dedicated staff to contribute to making data accessible. All monitoring is handled by staff at the sites that participate in the network but do not get their salaries from the network.
Funding Sources	The European Union funded the network with a small but important contribution from NSF to link SCANNET to CEON. The monitoring activities are funded from various sources at each site.
Gaps	There are many gaps, although the geographical coverage is good within its area. Freshwater ecology is missing at many sites. Carbon emissions are not measured routinely at the sites. Parameters of the landscape (e.g., vegetation, albedo, LAI, insect damage, thermokarst) that could be monitored routinely from satellites are poorly represented. Only a small fraction of the biota is monitored at most sites.
Comments	The success of SCANNET is due to the network's working nature, in which most of the participating sites had a discrete work package and funding sources. The sites therefore gained resources in addition to providing information. A lesson learned is that it takes resources to participate in networks, even if the input is brief. This need for resources, even if small and token in nature, needs to be considered.

ANNEX TABLE 3B.10 ArcticNet

Network Name	ArcticNet.
Existing or Planned?	Existing. Funded for 2003 to 2010.
Foci	Measurement and monitoring of environmental change in the Canadian Coastal Arctic.
Customers	Governments at the federal, provincial, and territorial level, northern peoples, science and policy makers, international policy and science.
Realm	Marine, sea ice, atmospheric, ecological, terrestrial, human dimensions, and most importantly the interconnections of the coastal marine system.

Coverage	Canadian Coastal Arctic and marine waters.
Spatial Density	Variable. Sampling typically in the km range and upwards.
Variables	All aspects of the physical and biological systems operating within the study region from the bottom of the ocean to the top of the atmosphere; many social-related issues which pertain to environmental change in the Arctic.
Duration of Record	With North Water Polynya (NOW) and Canadian Arctic Shelf Exchange Study (CASES) projects, the record for many observations goes back to the early 1990s. The Integrated Regional Impact Studies (IRISs) of ArcticNet will operate for a maximum of 14 years (2003-2017).
Frequency of sampling observations (in time)	15-minute averages through to annual and interdecadal.
Time Scale of the phenomenon the network means to observe	Contemporary observations coupled to traditional knowledge studies of Inuit to paleoclimate investigations spanning the last millennium.
Accessibility of data	All data will be inventoried in the Canadian Cryospheric Information Network (CCIN) housed at the University of Waterloo. Data will be proprietary for use by student and network investigators for a period of two years after which they become public domain. This is negotiable in terms of the AON under mutually agreeable terms.
Data Management & Archiving Approach	ArcticNet will archive data within the CCIN using standardized metadata forms and is fully compatible with other database clearing houses such as National Snow and Ice Data Center (NSIDC).
Compatibility & Integratability with sources of similar data outside network	ArcticNet produces a wide range of data types. Automated 'observatories' are now located in various places within the ArcticNet sampling domain. These numerical data are typical of automated observatories. The ship cruises aboard the Amundsen collect similar types of data including standardized physical variables spanning a wide range of ocean-sea ice-atmosphere process relationships. Traditional knowledge data are also being collected as are social, economic, and health survey information; these variables are more diverse in form and interoperability.
Staff	ArcticNet has over 100 network investigators and several hundred students, technicians, community volunteers, and associates.
Funding Sources	ArcticNet has core funding of $45 million over the first cycle of operations (7 years). This funding levers another $150 million in contributed funding from various partners for things such as equipment, instrumentation, access to the Amundsen, staff, field program, etc.
Gaps	ArcticNet does not deal with northern terrestrial ecosystem issues unless they can be considered coastal. All of theme 2 deals with coastal terrestrial processes with a particular bias on freshwater in these terrestrial areas. There is only limited paleo-environmental work within the Network. Gaps in data management exist for traditional knowledge information.
Comments	Details are available in the full ArcticNet proposal, in annual reports to ArcticNet, and from the ArcticNet Web site (http://www.arcticnet.ulaval.ca).

ANNEX TABLE 3B.11 GEOSS (Global Earth Observation System of Systems)

Network Name	GEOSS (Global Earth Observation System of Systems).
Existing or Planned?	Planned.
	The Earth Observation Summit on July 31, 2003 was the official launch date for the GEOSS concept. The original group was co-chaired by the U.S., the European Commission, Japan, and South Africa. The final plan was presented at the Earth Observation Summit III in February 2005. In the U.S. over the past few decades, federal agencies have been working with local, state, national, and international partners to strengthen cooperation in Earth observations. Building on this previous work, the U.S. Interagency Working Group on Earth Observations considered the management, planning, and resource allocation strategy for a U.S. Integrated Earth Observing System—the U.S. contribution to GEOSS. The outcome of this is the U.S. framework for participating in GEOSS. The U.S. framework will be built on new and existing Earth observation systems and capabilities, and will be developed to meet both national and international societal, scientific, and economic imperatives.

Foci	GEOSS is a planned observational system of systems that is to be implemented over a 10-year period by developed and developing nations. The focus of GEOSS is to unify data collection networks on a global basis to develop a comprehensive, coordinated, and sustained Earth observation network that will produce and better manage information about the environment. Emphases are on enhancing data collection capacity, improved data dissemination, coordination of existing data sources, greater interoperability and connectivity among individual component observing systems, and filling gaps. The 10-year implementation plan was approved by representatives of 61 nations at a meeting in Brussels in February 2005. Ultimately, GEOSS will help countries to identify and address global environmental and economic challenges—such as climate change and natural disasters - by creating a single, comprehensive, and sustained Earth observation system.
Customers	Stakeholders are defined on a broad basis to include nearly everyone using or benefiting from Earth observation data systems. For decision makers, there is a specific focus on transferring data to developing countries.
Realm	All earth science data, including in situ data, such as data collected from gauges, sensors, buoys, weather stations, airborne and satellite systems monitoring.
Coverage	Global. Earth surface, atmosphere, and ocean processes on a global basis.
Spatial Density	Varied.
Variables	The goals set for this system were developed during the First Earth Observation Summit (Washington, DC, July, 2003) and the subsequent activities of the ad-hoc Group on Earth Observations, which originated from needs identified for better coordination of earth observational activities discussed at the World Summit on Sustainable Development (Johannesburg, September, 2002) and the G8 Evian meeting (June, 2003). Building on efforts from existing international programs, GEOSS will seek advances initially in nine societal benefit areas: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. Specifically, these advances will (1) improve weather forecasting, (2) reduce loss of life and property from disasters, (3) protect and monitor our ocean resource, (4) understand, assess, predict, mitigate and adapt to climate variability and change, (5) support sustainable agriculture and forestry and combat land degradation, (6) understand the effect of environmental factors on human health and well-being, (7) develop the capacity to make ecological forecasts, (8) protect and monitor water resources, and (9) monitor and manage energy resources.
Duration of Record, Sampling Frequency, Time Scale, Staff	—
Compatibility & Integratability/ Accessibility/ Data Management Approach	GEOSS will consist of existing and future Earth observation systems across the processing cycle from primary observation to information production. The Earth observation systems that participate in GEOSS will retain their existing mandates and governance arrangements. Through GEOSS, they will share observations and products with the system as a whole and take steps to ensure that shared observations and products are accessible, comparable, and understandable, by supporting common standards and adaptation to user needs. GEOSS will abide by interface standards for the data systems that are shared so that the products are more compatible with those from other systems and of use to a wide community. In meeting its needs, it will work towards maintenance of data requirements, data description, and exchange standards. Data will be interfaced through interoperability specifications established by open and international standards and adhered to by all contributing systems. Clearly defined formats will be set for both data and metadata, and quality indications to enable search and retrieval. GEOSS will not attempt to incorporate all Earth observing systems into a single, centrally controlled system. Instead, its intent is to improve the data supply to users. It will not try to annex existing observation and data distribution systems into a new international organization. Access to data and information will be accomplished through various service interfaces to be designed. The actual mechanisms may include many varieties of communication modes, with a primary emphasis on the Internet, but ranging from very low technology approaches to highly specialized technologies. Side note: The U.S. Integrated Earth Observation System will provide full and open access to all data in accordance with the Office of Management and Budget (OMB) Circular A-130 (and at little cost).
Funding Sources	An ad hoc working group led by the U.S., European Commission, Japan, and South Africa spearheaded this system. In the United States, the Environmental Protection Agency (EPA) is playing a lead role with NOAA and other agencies participating in the United States Interagency Working Group on Earth Observations (http://iwgeo.ssc.nasa.gov/). A secretariat for GEOSS has been established at the WMO in Geneva. As a contribution to GEOSS, NOAA announced in January, 2005 that it will spend $37.5 million over the next two years deploying 32 advanced sensor buoys in the Pacific and Indian oceans for early warming of potentially catastrophic ocean events. The United Nations also plans to spend about 10 percent of its tsunami aid donations on warning systems.

Gaps	—
Comments	Membership in Group on Earth Observations (GEO) is open to all member states of the United Nations. GEO also welcomes as Participating Organizations intergovernmental, international, and regional organizations with a mandate in Earth observation or related activities, subject to approval by Members. A list of the current participating members can be found at (http://earthobservations.org).

ANNEX TABLE 3B.12 AMAP

Network Name/URL	Arctic Monitoring and Assessment Programme (AMAP) (http://www.amap.no/).
Existing or Planned?	Existing.
Foci	Monitoring and assessment activities: temporal and spatial trend studies focusing on priority contaminant issues and climate/ultraviolet (UV)/ozone issues, monitoring of human health and biological effects, the collection of information on contaminant types and sources, and the assessment of the combined effects of climate and contaminants.
Customers	Science community and society. AMAP reports to and is directed by the Arctic Council, an intergovernmental, Ministerial forum with membership that includes the eight Arctic rim countries, indigenous peoples organizations, observing countries, and observing organizations. It is founded in the programs and organizations that were established as part of the Arctic Environmental Protection Strategy (AEPS).
Realm	Atmosphere, marine, terrestrial/freshwater, biological, social/human dimension.
Coverage	Pan-arctic.
Spatial Density	Within the AMAP-defined Arctic, 10 "key areas" have been identified: (1) Northern Alaska/North Slope, (2) lower Mackenzie River and Delta, (3) Canadian Arctic Islands and Arctic Archipelago, (4) Baffin Island and West Greenland, (5) Svalbard and East Greenland, (6) Kola Peninsula and Northern Fennoscandia, (7) Novaya Zemlya, Kara, and Pechora Seas, and Mouth of Pechora River, (8) Taymir Peninsula/Norilsk, (9) Mouth of Lena River, and (10) Chukotsky Peninsula. These are the target areas for integrated, multicompartmental monitoring efforts. Other areas are covered, but normally with less intense activity.
Variables	Persistent organic pollutants (POPs), heavy metals (e.g., mercury, cadmium, and lead), radioactivity, acidification and arctic haze, petroleum-based hydrocarbons, environmental consequences and biological effects resulting from climate change, stratospheric ozone depletion and biological and human health effects due to increased UV, human health effects due to pollution and climate change, and combined effects of pollutants and other stressors on ecosystems.
Duration of Record	Since AMAP's establishment in 1991, a series of assessments has been produced that draws on (1) data already published in scientific literature, (2) data obtained from AMAP's monitoring program, and (3) traditional knowledge. Although most observations are recent (i.e., within the last 30 years), some parts of the assessments (e.g., assessment of long-term trends) use observations dating back to the early 1900s, and environmental archives that extend back even further.
Frequency of sampling observations (in time)	Differs according to variable and assessment project.
Time Scale of the phenomenon the network means to observe	Decadal (but with many observations based on daily to annual sampling, therefore, it also covers seasonal phenomena, etc.).
Accessibility of data	As much as possible, data are compiled within AMAP Thematic Data Centers (TDCs) from which they are made available to scientists engaged in AMAP assessments under strict conditions that protect the rights of data originators.
Data Management & Archiving Approach	Most data are either archived or planned to be archived at one of the AMAP TDCs (atmospheric contaminants data at the Norwegian Institute for Air Research (NILU), marine contaminants data at the International Council for the Exploration of the Sea (ICES), freshwater and terrestrial contaminants data at the University of Alaska, Fairbanks (UAF) - UAF Syncon Database, radioactivity data at the Norwegian Radiation Protection Authority (NRPA), and human health data at the AMAP Secretariat). One of the main objectives of this data handling strategy is to ensure long-term access to data that contribute to the AMAP assessments.
Compatibility & Integratability with sources of similar data outside network	AMAP TDCs provide a means to ensure that data are treated in a consistent manner and undergo uniform statistical analysis, etc., including application of objective quality assurance procedures.

Staff	The AMAP Secretariat (comprising the Executive Secretary and Administrative Assistant) is located in Oslo, Norway; two Deputy Executive Secretaries work remotely from Rotterdam, Netherlands and Moscow, Russia.
Funding Sources	The AMAP Secretariat is funded by Norway, with additional support from several of the Arctic countries and organizations such as the Nordic Council of Ministers. These sources also provide most of the funding for core AMAP activities such as production of assessments and operation of TDCs, etc. AMAP monitoring work is based largely on ongoing national and international monitoring and research programs; a part of the Arctic countries national programs are identified as their AMAP 'national implementation plan.'
Gaps	Other Arctic Council groups (see below) address a number of work areas that are therefore not covered by AMAP (sustainable development, biodiversity, etc.); however, there is a degree of overlap with most groups (in particular concerning assessment of issues such as climate change, etc.) and mechanisms are in place to coordinate activities within the respective groups. Geographical gaps in monitoring coverage exist, in particular in parts of the territories of the Russian Federation and the central Arctic Ocean where financial and logistical problems impose obvious constraints, however AMAP is continually working to try to overcome these limitations.
Comments	AMAP is one of five Working Groups of the Arctic Council. The four others include The Sustainable Development Working Group (SDWG), Protection of the Arctic Marine Environment (PAME), Conservation of Arctic Flora and Fauna (CAFF), and Emergency, Prevention, Preparedness and Response (EPPR).

ANNEX TABLE 3B.13 Earth Observing System (EOS) Terra and Aqua

Network Name/URL	Earth Observing System (EOS) Terra (EOS AM) and Aqua (EOS PM) (http://eospso.gsfc.nasa.gov/ http://terra.nasa.gov/index.php, http://aqua.nasa.gov/index.php).
Existing or Planned?	Existing. The Terra platform was launched December 18, 1999 and Aqua was launched May 4, 2002.
Foci	Terra's mission is to improve understanding of the movements of carbon and energy throughout the Earth's climate system. Aqua's mission is to collect observations related to the Earth's water cycle and other elements of the Earth's climate system. Aqua was the first member launched of a group of satellites termed the Afternoon Constellation, or sometimes the A-Train. The second member to be launched was Aura, in July 2004, and the third member was PARASOL, in December 2004. Upcoming are CloudSat and CALIPSO in 2006 and OCO in the more distant future. Once completed, the A-Train will be led by OCO, followed by Aqua, then CloudSat, CALIPSO, PARASOL, and, in the rear, Aura.
Customers	Scientists, educators, general public, and policy makers.
Realm	Atmosphere, ocean, terrestrial, and cryosphere.
Coverage	Global.
Spatial Density	Variable, spatial resolution varies from 15 m to 57 km. Except in the very near vicinity of the poles (a few degrees latitude), the spatial density of the data collection is greatest in the polar regions. Coverage from some instruments in the polar regions is limited however, such as observations of carbon monoxide and methane. Furthermore, accuracy of some of the derived data products, such as sea surface temperature measurements, which are complicated by the presence of sea ice, or surface albedo, remain inadequate for many climate studies.
Variables	Terra collects data on land, ocean and air temperature, land and ocean reflectivity (albedo), radiative fluxes, atmospheric water vapor, aerosols, CO and CH_4, precipitation, clouds, soil moisture, surface elevation, vegetation cover on land (including NDVI, LAI, FPAR [fraction of photosynthetically active radiation], net photosynthesis), phytoplankton and dissolved organic matters in the ocean, snow and ice extent. Aqua collects data related to the Earth's hydrological cycle, including evaporation from the oceans, water vapor in the atmosphere, clouds, precipitation, soil moisture, sea ice, land ice, and snow cover on the land and seasonal ice. Additional variables also being measured by Aqua include snow water equivalent, snow and ice extent, radiative energy fluxes, aerosols, vegetation cover on the land (including NDVI, LAI, FPAR, net photosynthesis), phytoplankton and dissolved organic matter in the oceans, and air, land, and water temperatures, and surface reflectance.
Duration of Record	Since December 18, 1999 for Terra and May 4, 2002 for Aqua.
Frequency of sampling observations (in time)	Dependent upon instrument. For example, the MODIS instrument sees the entire surface of the Earth every 1-2 days (the poles more frequently than the equator), MISR sees the entire Earth every 9 days, with repeat coverage between 2 and 9 days depending on latitude, whereas ASTER will take 5 years to see the entire surface.

Time Scale of the phenomenon the network means to observe	Seasonal to interannual and decadal for most variables.
Accessibility of data	Accessible through several NASA Distributive Active Archive Centers (DAAC), such as the National Snow and Ice Data Center (NSIDC) DAAC, Langley DAAC, Land Processes DAAC, Goddard Earth Sciences DAAC.
Data Management & Archiving Approach	Distributed. The EOS Data and Information System (EOSDIS) provides the total ground system for processing, archiving, and distributing science and engineering data from all the EOS spacecraft. However, the data are held at four different DAACs. Data are stored in standardized formats.
Compatibility & Integratability with sources of similar data outside network	Addressed on a platform specific basis.
Staff	Operated by staff at the DAACs.
Funding Sources	NASA.
Gaps	Carbon monoxide and methane measurements are only available from 65ºS to 65ºN. Aerosol measurements are not accurate over snow- and ice-covered surfaces. No rainfall or precipitation is measured in the polar regions. No daily snow and ice albedo products exist. No information is collected below the surface such as in the oceans, including temperature under sea ice. Accuracy of vegetation indices such as NDVI, LAI, and FPAR degrade when snow covers the vegetation. Gaps also exist in the near vicinity of the pole.
Comments	There is a lack of hemispheric-wide grids of variables. For example, if a user wants to look at surface temperature in the Arctic over oceans and land, they must order the SST product from the ocean group, the land surface temperature from the land group, and the sea ice surface temperature product from the cryosphere group. In addition, using data from multiple sensors for improved products still has not been done. Many improved data products as well as value-added products could be generated from the wealth of data acquired by the EOS platforms.

ANNEX 3C

EXAMPLES OF DATA CAPTURE AND ACCESSIBILITY WITHIN NETWORKS AND PLATFORMS: TEMPERATURE AND CRYOSPHERIC VARIABLES

The Committee selected two foci—temperature and the cryosphere—to illustrate the variety of measurement approaches and data accessibility for the Arctic. These two parameters are used here for illustrative purposes only and are not meant to be a comprehensive review of all the methods available in accessing these data. These parameters were chosen because they are critical variables for detecting change in the Arctic (Chapter 2).

Temperature

Temperature is a key variable that is monitored in its own right and also as a driving variable of processes that are the focal points of various networks and platforms. Temperature measurements are therefore either explicitly represented in environmental monitoring databases, or are less visible among data that underpin the primary target of the network, for example, active layer dynamics. Temperature is measured and derived in many ways, including by direct measurements, remotely located sensors, proxies, and local and traditional knowledge.

Direct measurements are made routinely (Earth surface, soil, cryosphere, ocean) and during campaigns (atmosphere, ocean, land surface, soil). A range of standardized (e.g., IABP, ITEX—see Annex Table 3C.1) and individualistic measurements are made throughout the Arctic, although weather stations that measure temperature are being discontinued—particularly in the Russian Arctic. Accessibility of data is varied: data from campaigns or short-term projects are numerous but generally difficult to access, even in summarized, published form, as they are often "hidden" in publications and reports where they provide background to or support the primary aims of the study. Networks that monitor temperatures of lakes, ponds, and rivers were not found. Soil temperatures from the ground surface down to 3.6 m have been routinely measured at the Russian meteorological stations and available from the local and centralized data archives. However, the Committee did not assess the quality of these and this could be different for different stations. Also, the number of such stations in the Arctic declined substantially in recent years and access to these data has become more difficult. The technology for direct measurements of temperature is advanced and cheap (for example, battery operated, self-networking electronic equipment), and it is generally lack of organization, networking, or funding that are the main constraints on more comprehensive data capture and archiving.

Data derived from remotely located sensors are becoming increasingly important as weather stations decrease in numbers and geographical coverage. For example, the Advanced Very High Resolution Radiometer Polar Pathfinder Product provides twice daily 5-km gridded skin temperature observations from July 1981 through December 2000. Spatial coverage extends from 48.4 degrees to 90 degrees north latitude. There are also some gridded observations available at 1.25 km from August 1993 through December 1998. Users can also get observations for other years at whatever grid resolution they want through a National Snow and Ice Data Center Web interface tool. Surface temperature is also available from the Moderate Resolution Imaging Spectroradiometer (MODIS). The data collection began with the Terra satellite platform in December 1999 and continues today with both Terra and Aqua. There are a number of MODIS temperature products that must be accessed through different MODIS teams. These products include temperature over sea ice, land surface, and sea surface.

Proxy temperature records can be obtained from several sources. These records are usually used to provide descriptions of past environments but could be used more extensively to provide better geographical coverage of recent past environments. Ice and lake core records provide proxy temperatures for many thousands of years with varied resolution, but can be annual. Tree-ring data provide proxies for temperatures for the last 7,500 years with annual resolution for the subarctic of Finland and Sweden. Diatoms, chironomids, pollen, and macrofossils provide temperature proxies for at least the last 10,000 years. The resolution of these proxies varies, but can be annual. Each proxy, particularly the biological proxies, has individual biases in the relationship between a measured variable (e.g., growth) and derived temperature. For example, tree rings correlate better with temperature in areas with greater soil moisture than in drier, continental areas.

The Arctic possesses a particularly rich archive of temperature proxies. However, much of this archive is threatened by climatic warming and drainage of peatlands, and a concerted effort is needed to preserve cores from disappearing archives.

Local and traditional knowledge on weather exists throughout the Arctic, presumably because of its importance in determining the abundance and behavior of natural biological resources and the possibilities and timing for travel. Although uncertainties are difficult to assess, important knowledge about the climate and environment exists. In terms of temperature, local and traditional knowledge provide important observations in time and space. For example, elders have knowledge about past temperature trends based on direct observations or changes in activities. An example is elder Barnabus Peryouar from Baker Lake, Nunavut, who has said that kerosene used to freeze during the winter in the early 1940s (Fox, 2002). This kind of knowledge can provide a proxy for past temperatures.

Cryosphere

The cryosphere is represented by many variables that respond to changes in drivers such as temperature. The major domains are sea ice, lake and river ice, glaciers and ice caps, and terrestrial and marine permafrost.[7]

Sea ice. Measurements include thickness, extent, concentration, velocity, duration, timing of formation and thaw, and albedo. Apart from thickness, most of these variables are derived from satellite images. Thickness is derived from both upward (submarine-based) and downward (satellite-based) radar. Historical records for some areas such as harbors and sounds are often available from local sources and local traditional knowledge.

Lake and river ice. Major measurements include thickness, extent, duration, timing of formation and thaw, and date of ice-dam collapse. Geographical coverage is variable and often extremely localized to individual lakes and rivers: the Committee could not find specific networks of monitoring activities. Records sometimes extend back over 100 years although much older data exist for some rivers and lakes. For example Magnuson et al. (2000) demonstrated that the freeze date of the Mackenzie River, Canada has moved forwards 6 days per 100 years, while lakes in Finland show earlier breakup from 8-9 days per 100 years over the past 160 years.

Glaciers and ice caps. The main variables measured are extent, thickness, velocity, and mass balance. In some areas, systematic scientific monitoring (e.g., for mass balance) has been in progress for about 50 years (e.g., at Storglaciären in northern Sweden). However, data from old photographs, paintings, and drawings that have been available locally for at least 200 years, and the dating of moraines by various techniques, extend information on glacier dynamics even further back in time. Recently, remote sensing has provided a plethora of relevant data, such as ice extent, velocity, and elevation. International coordinating efforts exist or are planned to monitor and assess mass balance and glacier dynamics, such as MAGICS (Mass balance of Arctic Glaciers and Ice sheets in relation to Climate and Sea level changes) (see Table 3C.2) and the proposed GLACIODYN program.

Terrestrial and marine permafrost. The monitoring of permafrost distribution and dynamics, mostly on land, is well-coordinated within the International Permafrost Association (IPA). Measurements and observations include mapping various categories of permafrost (continuous, discontinuous, sporadic), measuring temperatures of permafrost in bore holes (Thermal State of Permafrost [TSP] network), and measuring the depth of the active layer above the permafrost (the Circumpolar Active Layer Monitoring [CALM] network). No systematic monitoring of permafrost under continental shelves has been identified, although this would be important in connection with the possible future destabilization of methane hydrates. Relevant data are probably possessed by oil companies, but are not readily accessible. Data for terrestrial permafrost are available on the IPA Web site and they are periodically assessed. The main limitation in such an assessment for the Russian Arctic stems from the lack of regularity in temperature measurements in most of the Russian permafrost boreholes.

[7]Snow and other solid precipitation are also cryospheric parameters that are measured at meteorological stations, although they are not covered in this Annex.

ANNEX TABLE 3C.1 Examples of Temperature Networks and Platforms

Network/ Platform	Acronym Definition[a]	Geographical Coverage	Temporal Coverage		Sensor Type	Sensor Location	Data Availability	Web Site
			Period	Frequency				
Abisko (Platform)		Torneträsk catchment (100 km^2); main meteorological station + periodic measurements at satellite locations throughout the catchment	1913 - present	10 minutes - 12 hours	Automatic station, standard manual station, and thermohygrograph	2 m above surface	Available on request, some available on the Web site	www.ans.kiruna.se
				5 days	Mercury thermometers	5-150 cm below ground surface		
CEON (Network)	Circumarctic Environmental Observatories Network	Pan-arctic, comprised of partnered networks and observatory platforms	Real time	Mostly real time	WMO climate stations	Mostly 2 m above ground surface	Link to real time weather on Web site, no database	www.ceoninfo.org, www.ceonims.org
GSN (Network); Operated by WMO[b] members	GCOS (Global Climate Observing System) Surface Network	Pan-arctic	1997 - present	Real time	Meteorological surface reporting stations	2 m above surface	Available through the US National Climatic Data Center	http://www.wmo.int/web/www/Earthwatch/wmo-gcos-fsn-guan.html
GUAN (Network); through US NCDC's CARDS;[c] part of WMO's 800 radiosonde stations	GCOS Upper Air Network	About 10 platforms in the Arctic (terrestrial) that have long records and are good representatives for radiosonde measurements	Various (starting 1950-1990)	12 hours	Thermometers on radiosondes	In troposphere up to 5 hPa	Available on the CARDS Web site	www.guanweb.com
IABP (Network); part of the WMO World Weather Watch Programme	International Arctic Buoy Programme	Arctic Ocean; 25 buoys	1979 - present	12 minutes	Thermometers on drifting buoys	Surface air and ocean water	Available on IABP Web site and through National Snow and Ice Data Center (NSIDC)	iabp.apl.washington.edu
IPA/CALM (Network)	International Permafrost Association/ Circumpolar Active Layer Monitoring	Pan-arctic; more than 100 platforms	Various (starting 1990 and forward)	Hourly	Thermistors on dataloggers	Permanently installed devices in bore holes and frost and thaw tubes	Summaries for many of the CALM sites are available through the NSIDC	www.udel.edu/Geography/calm/index.html

continued

ANNEX TABLE 3C.1 Continued

Network/ Platform	Acronym Definition[a]	Geographical Coverage	Temporal Coverage		Sensor Type	Sensor Location	Data Availability	Web Site
			Period	Frequency				
ITEX (Network)	The International Tundra Experiment	Pan-arctic; 28 platforms	Various (starting 1991 and forward)	Hourly-daily	Automatic station, standard manual station, and thermohygrograph	2 m above surface and down to 0.5 m below ground surface	Summaries in published papers	www.itex-science.net
SCANNET (Network)	Scandinavian/ North European network of terrestrial field bases	North Atlantic region (Finland to Iceland; Scotland to Svalbard)	Various (starting 1913 to 2000)	Hourly-daily	Standard automatic and manual stations	2 m above ground and 0-11.3 m below ground surface	Available on request; some available on the Web site	www.scannet.nu

[a] A dash (—) means not applicable.
[b] World Meteorological Organization (WMO).
[c] Comprehensive Aerological Reference Data Set (CARDS).

ANNEX TABLE 3C.2 Examples of Networks and Programs for Cryospheric Parameters

Network/ Program	Acronym Definition	Geographical Coverage	Temporal Coverage		Main Variables	Sensor Type	Sensor Location	Data Availability	Web Site
			Period	Frequency[a]					
GLIMS	Global Land Ice Measurements from Space	Global	1999-present	Annually	Ice margins and surface feature velocities	Radiometers measuring visible, near infrared, and shortwave radiation	Radarsat, Landsat 7, and EOS Terra	Satellite images and processed maps can be found at the Web site	www.glims.org
IABP (Network); part of the World Weather Watch Programme (WMO)	International Arctic Buoy Programme	Arctic Ocean; 25 buoys	1979-present	—	Sea ice growth/melt, ice temperature, and ice motion	Anemometers, pressure sensors, pressure transducers, and thermistors	Surface air and ocean water	Available on IABP Web site and through the NSIDC	iabp.apl.washington.edu
IASC WAG; includes the MAGICS project[b]	International Arctic Science Committee Working Group on Arctic Glaciology	Pan-arctic; 28 glaciers and ice caps	Various (starting in 1950)	Biannually	Glacier mass balance	Ablation stakes, snow pits, photography, optical and microwave satellite sensors, and gauging stations	Glacier surface, glacial runoff waters, aircrafts, and satellites	Summaries available on Web site	www.phys.uu.nl/~wwwimau/research/ice_climate/iasc_wag/home.html
IPA/CALM (Network)	International Permafrost Association/ Circumpolar Active Layer Monitoring	Pan-arctic; more than 100 platforms	Various (starting in 1990)	Annually	Active layer, and permafrost temperature	Frost or thaw tubes, small diameter metal rods, and dataloggers	Permanently installed devices in bore holes and frost and thaw tubes	Summaries for many of the CALM sites are available through the National Snow and Ice Data Center	www.udel.edu/geography/calm/index.html
WGMS	World Glacier Monitoring Service	Global	Various (starting in 1894)	—	Glacier mass balance, extent, and perennial surface ice distribution	Ablation stakes, snow pits, photography, optical and microwave satellite sensors	Glacier surface, aircraft, satellites	Available through the World Glacier Inventory (WGI) at the NSIDC	http://www.geo.unizh.ch/wgms/index.html

[a] A dash (—) means undetermined.
[b] Mass balance of Arctic Glaciers and Ice sheets in relation to Climate and Sea level changes (MAGICS).

4

Data Management

A successful, international Arctic Observing Network (AON) must link sensors, observers, data, and users across space and time. The key to accomplishing this goal is data management, and data management—from data collection through distribution to users—will surely be the central challenge for integrating the AON. Previous chapters summarized the abundance and diversity of arctic observing systems and programs, but the infrastructure to integrate results from these resources is lacking. Accommodating a wide variety of users and uses will require building a data management system that is independent of nation, language, background, expertise, and subject matter.

The goal of this chapter is to provide a roadmap for building the AON data management system by discussing strategies for developing the overall system and parts thereof and then making specific recommendations for implementation. Recognizing that the meaning of "data management" varies depending on whether one is a data user, instrument developer, or employee at a national or international data archive, this discussion strives to assess aspects of AON data management from diverse perspectives.

DESIRED CHARACTERISTICS OF THE AON DATA MANAGEMENT SYSTEM

The fundamental purposes of the AON are to characterize the current state of the arctic environment and its variability and to support studies of attribution and prediction of arctic change. To accomplish these tasks, the AON data management system will need the following characteristics. Data from multiple disciplines will need to be made available to all users quickly, easily, and reliably with standardized metadata and supporting documentation. The AON will encourage full and open exchange of data, metadata, value-added products, and even instruments and platforms within the network. Data and networks must therefore be interoperable so that international scientists, engineers, arctic communities, residents, and policy makers can generate and access data in formats and languages that are understandable and useful to them. Data and supporting metadata must also conform to national and international standards for their discipline and, where feasible, be monitored to ensure high quality. The AON should provide access to both raw data and derived products to ensure that the information helps the broadest range of users. Data products derived by users would be incorporated back into the data management system and made available to help guide decisions ranging from international policy choices to what instrument to deploy to where to hunt on a given day.

Time-series analyses are crucial to recognizing and monitoring arctic environmental change; therefore, a fundamental goal of the AON data management is that, from the time the system is initiated, all observations and samples are preserved. Where cost-effective, the AON could also try to rescue data. AON data will need to be managed with both short- and long-term needs in mind. In the short term, users need to be able to obtain, interpret, disseminate, and store data. In the long term, data will need to preserve the integrity of scientific disciplines and the knowledge of local people, ensuring that research and assumptions can be verified into the future and provide new insights into previous investigations. Because the spectrum of AON data is broader than the expertise presently available at any one national or world data center, AON data will need to be warehoused in a handful of existing data centers organized by discipline, with discipline-specific standards, protocols, maintenance, and management, then tied together in such a way that users can access all data through one portal (e.g., Box 4.1).

DATA MANAGEMENT STRATEGY

To meet AON scientific objectives, the AON data management strategy needs to address acquisition, quality control and data standards, metadata and documentation, access, interoperability, dissemination, archiving, and processing for both extant and pending data. In developing

Box 4.1
An Imaginary Journey Through the Arctic Observing Network Portal

Suppose one day you read an interesting article speculating on the contribution of processes in submarine canyons to the global carbon cycle and decide to explore arctic datasets. Entering the AON data portal, you first encounter icons for terrestrial, atmospheric, oceanic, and human dimensions that contain a summary of data holdings under each discipline. You then have the option to browse datasets by discipline or by theme. Using data exploration tools, you search for canyon processes and determine what relevant meteorological, geophysical, and oceanic datasets are archived, and their availability in space and time.

Although you do not realize it, the information accessed comes from four different data centers in two different countries. For observations that are interesting but unfamiliar, you find links to descriptions of the instrumentation, the methods, and the data processing steps. You also find links to browse images of the datasets and, after inspection of these, you decide flow levels of the X River bear closer investigation, as the X River appears to be associated with the Y Canyon, and both the oceanic and terrestrial environments are well instrumented.

Plotting the time series using the online data display tools, you observe that three years ago, in June, the gauges reported an abrupt drop in water level after a gradual rise through late spring. The screen also shows an icon that looks like the silhouette of a parka. Curious, you click on the icon, and a text box pops up describing a large ice dam that gave way about the time of the abrupt water level drop, with a notation from the Inuit hunter who reported the event. Now you open the relational database interface in the AON portal and frame a query requesting turbidity measurements within 100 km of the mouth of the X River during the timeframe of the ice dam collapse. Within seconds, you have links to data streams and generate another series of plots. These show an increase in turbidity within the Y Canyon two days after the ice dam collapsed. You suspect that you have identified a flow event carrying sediment into the deep Arctic Ocean. Wondering how general these events are, you search for abrupt drops in tide gauge measurements coupled to local increases turbidity measurements for other arctic river systems and find three more candidate events.

It is almost the end of the day and you download your time-series plots and email them to your colleagues twelve time zones away for their review tomorrow. You save your AON session using the password protection you have installed so that you can access the data again tomorrow without having to redo the data searches. Before wrapping up, you post a request to the event detection service, providing the combined tide gauge turbidity criteria as the trigger. Finally, you post a request to the observation scheduling list, starting the process to request time on the docked autonomous underwater vehicle near the mouth of the X River to be triggered on detection of an event. It has been a productive day.

the data management strategy of the AON, it is imperative not to reinvent the wheel. Much has been written about scientific data management (e.g., NRC, 1995; CCSDS, 2002; NSF/LOC, 2003; ICSU, 2004; Hankin and the DMAC Steering Committee, 2005; IPY, 2005; NSB, 2005), and many nations are establishing standards to promote integration and accessibility (e.g., FGDC, 1998; ISO, 2003). A successful AON data management strategy will follow nationally (or internationally) accepted guidelines and tailor data to meet the needs of the arctic user community while remaining flexible enough to allow for unanticipated use of the instruments and data.

Many different countries and organizations make observations in the Arctic. Increasingly, the integration of consistent and high-quality international observations requires a mechanism to prepare regulatory and guidance material relating to data collection, data management, and development of data products.

Recommendation: As a first step toward implementing the AON data management strategy, a permanent AON data management committee should be established to provide (i) oversight and coordination of long-term planning for data acquisition, access, distribution, and preservation; (ii) consistency and development of data policies; (iii) oversight of data management system design and engineering; (iv) collaboration with network designers; (v) distribution of integrative and interpretative products to inform national and international policy; (vi) user outreach, and (vii) oversight for the evolution of AON standards.[1]

Ideally, this group would include advisory members who establish strategies for various components of the data management system as well as members who can implement the strategic recommendations: for example, selecting and disseminating value-added products to inform policy decisions or arctic communities of observed environmental change. The AON data management committee would promote shared infrastructures for AON observations and provide a central portal in a distributive environment for contribution of and access to all the observations that are a part of the AON.

[1]In Chapter 6 the Committee collects its ideas about implementation steps for the AON and breaks these ideas into near-term (minimum) actions and longer-term actions for an "ideal" system. Because the topic of the present chapter (4) is one of the Committee's four Essential Functions, and because it is this "essential function" framework on which implementation recommendations are hung, it is more convenient and effective to place the implementation ideas on data management throughout this chapter than to wait until Chapter 6, where the other essential functions are discussed in detail. Most of the ideas in Chapter 4 are considered necessary near-term actions, but two are mostly for the "ideal" system and are marked accordingly.

The data management committee would initially assess and build upon the success of similar common-purpose data portals (e.g., the Antarctic Master Directory [Leicester et al., 2001]). Organizations that already adhere to regulatory guidelines, such as World Data Centers and other regional and national data centers, could be represented on the AON data management committee. Furthermore, groups working on data management for the International Polar Year could be engaged, or their policies adopted or modified as needed. Creating this committee would have the additional benefits of involving instrument developers, scientists, and indigenous and local people in data management, and data managers in project planning and data collection.

Another critical step toward implementing the AON data management strategy is to decide whether the AON data management system will exist in a distributed or centralized data holding environment. Data holdings for the Arctic are currently highly fragmented in the sense that they are managed by a wide variety of organizations and individuals. Presently, an instrument developer hoping to widely distribute long-term monitoring data acquired by a new sensor must determine appropriate data and metadata standards and assess the ability and expertise of existing data centers to assemble, maintain, disseminate, and preserve the data. A user searching for a particular parameter must first know which organizations are making those measurements, then become familiar with each organization's data system to search and access data. Searches that encompass multiple data sources are conducted manually and typically involve downloading archives or subsets of archives to conduct additional searches on a local machine. This process is cumbersome and does not always yield the data in a format that is easy to use.

Two approaches have been championed to improve the data contribution and discovery processes. The first approach is to develop standards and tools that support distributed searches. The second approach is to centralize data holdings for single-point searches. Given the merits of each (Box 4.2), a combination of these two approaches is best.

Recommendation: The AON data holdings should be stored and maintained at a few discipline- or theme-specific data centers so that diverse arctic datasets can be managed by groups having the appropriate expertise (including arctic communities that desire to maintain their local and traditional knowledge). The AON, through its data management committee, should exercise the necessary authority and common sense of purpose to link these data centers and identify and remove gaps in the integrated data management system.

The data management strategy will need to consider the users of the data and the level of service the AON is to provide to its stakeholders. The AON will need to provide data in a format that is friendly to all types of users, not just those who acquired the data. This includes determining what level of accessibility is needed, what tools are needed, and what data synthesis and value-added support is required. Significant new efforts are likely to be needed to incorporate human dimensions and local and traditional knowledge (LTK), which are poorly represented in scientific data archives (Krupnik et al., 2005). One of the primary challenges facing the AON will be developing an approach in which researchers and communities learn to use and manage LTK and link it to other diverse sources of information. The successful AON data management system will need to evolve as new observing capabilities, new understandings of arctic variability and change, and better awareness of the needs of local and global communities develop.

There are several additional key elements to consider when developing a data management strategy for the AON. To optimize cost-effectiveness, the AON will need to make use of existing metadata centers such as the Global Change Master Directory (GCMD), which contains a large number of arctic dataset descriptions and data repositories (see, e.g., Annex Table 3A.4). Previous scientific data management activities should also guide AON efforts. There will always be unanticipated uses of instruments and the data they collect, and the AON data management system will need to be sufficiently flexible to accommodate new approaches.

Data Acquisition

Linking and invigorating data acquisition is a significant potential benefit from the AON. There are many observing networks and sites in the Arctic, but with no coherent organization to produce pan-arctic datasets. In developing a strategy to support AON data acquisition, historic and current data, as well as data that will be collected in the future, must be considered. The challenge of acquiring data is compounded by data ownership, the proprietary nature of some data, and the costs and efforts required to rescue observations that have been discontinued. Incentive strategies for contributing data to a network may be necessary to facilitate data submission. These could include paying arctic residents to maintain an instrument developer's sensor over extended periods or encouraging funding agencies not to support researchers who do not contribute their data to the AON.

Implementation of the data acquisition strategy will focus on two components: assembly of data that are already in repositories and acquiring data from sensors not presently supported by existing data centers. Data assembly is actually a significant component of data acquisition; the multidisciplinary, pan-arctic database managed by the AON can be assembled by linking information and samples at existing or developing archives.

The AON will need to review the interoperability of hardware, software, and data management technologies of contributing data centers to demonstrate the ability to locate, retrieve, and work with data across disciplines, countries,

Box 4.2
Comparison of Centralized and Distributed Data Holding Approaches

When should data holdings be distributed, and when should they be centralized? Any vision for the future of data management must grapple with rapidly changing foundation technologies such as computation, storage, bandwidth, and algorithmic complexity. These changes are, to first order, predictable and provide a framework that shapes data management solutions. For example, Moore's Law (Moore, 1965), which observed that the rate of technological capability (gauged by the complexity of an integrated circuit with respect to minimum component cost) doubles in about 24 months, has held true over four decades. Critical trends for data management are increasing storage capacity (a 100-fold increase in the last decade), growth in data bandwidth (a 10-fold growth in the last decade), and increasing complexity of algorithms. The combination of these trends supports a push toward more centralized facilities (Gray et al., 2005).

The distributed model offers a number of advantages for holding scientific data. For example,

- a wide number of funding agencies support data collection, and data archiving and management tends to stay with the funding agency;
- many funding sources lack natural mechanisms for supporting central data management;
- any one organization is unlikely to have all the appropriate scientific expertise to manage the extremely diverse datasets for the Arctic;
- quality control of many datasets is an ongoing process and is best done by the experts who acquired the data;
- many datasets are large and centralization is impractical;
- issues of ownership or confidentiality may be involved and are best handled locally;
- distributed datasets are demonstrated to be readily searchable—the National Virtual Observatory developed by the astronomical community (NVO, 2005) is one example;
- having many organizations involved in data management increases the talent pool developing data solutions; and
- for arctic peoples, the distributed model may be desirable since there is interest in having local knowledge held in arctic countries and communities, as well as an interest in training and jobs for local people in data management.

There are, however, problems with the distributed data model. For example, effective data management requires dedicated staffing and a range of skill sets that many small organizations simply cannot muster. The rapid rate of technological change creates a continuing need to improve technical expertise, reinforcing the need for such expertise. Furthermore, a distributed search relies on the existence of common standards for metadata and data formats and compliance of the many participating organizations with those standards. The costs of distributed data management can be high, not only because there will necessarily be duplication of skill sets at different organizations, but because the development and maintenance of the standards and tools to support distributed data search appear to require substantial investment. Distributed data holdings can also be fragile in that data management is often an ancillary activity of a scientific investigation, and thus may only be maintained through the period of funding. Thus, arguments for more centralized data management can be made on administrative as well as technical grounds.

languages, etc. This approach would incorporate those institutions that have mature data management practices and minimize the work to resolve incompatibilities among data types. For those networks and institutions without mature data infrastructure, the AON will need to provide support including guidelines for data and metadata production, dataset documentation, and enforce the established standards.

Recommendation: Where data acquisition involves the collection of information from a sensor or network with limited infrastructure and no established ties to national or world data centers, the AON data management system should facilitate data handoff to the most relevant archive.

The AON data management committee's role of providing the common sense of purpose will encourage diverse data centers to work together. The Committee will also need to identify gaps between networks and data centers and recommend approaches to ensure that AON data are managed and preserved. Additional roles for the AON data management committee include tracking treaties and guidelines for handling and preserving national and international data and metadata and encouraging funding agencies to ensure that Principal Investigators (PIs) meet their obligation to archive data and metadata.

Data Quality Control

From a strategic point of view, the first measure of whether data should be managed by the AON should be based on their quality. Data of poor quality can hinder scientific analyses and thus should not be included in data archives. Timely quality control of the present-day observations by monitoring centers and subsequent notification to data collectors regarding errors will stimulate corrective action. If data errors are not identified and corrected quickly, errors and biases accumulate.

Recommendation: The AON should implement an operational system to track, identify, and notify data collectors of observational irregularities, especially time-dependent biases, as close to real time as possible. This system could also be used to evaluate extant data that are submitted for inclusion in the data archives.[2]

The AON data management system would be the appropriate mechanism for reporting errors to monitoring centers and following up on these reports. This functionality would be especially useful for data quality problems that do not emerge until different datasets are merged (although internal consistency does not mean that data are necessarily correct; similarly, inconsistency does not mean that data are wrong—for example, discrepancies between LTK and sensor readings do not render either dataset useless).

Besides setting up a means for tracking and identifying errors, the AON will need to promote data quality at every step in the data pipeline, starting with instrument development, to the observations, and finally to the derived products. For example, many satellite products have error characteristics of derived geospatial variables that could be fully characterized and reported in the dataset documentation. In general, tracking data uncertainties and managing against inappropriate use (see, e.g., Couclelis, 2003; Parsons and Duerr, 2005) will be necessary components of quality control.

Data quality among LTK contributions is an issue that would benefit significantly from early attention. Some quality issues can be addressed if local people are using scientific instruments to make AON-related measurements. However, LTK itself cannot be judged or quality-controlled by scientific standards. An effort to link LTK into the AON data management system with input from local and indigenous partners would address these issues.

Data and Metadata Protocols and Standards and Dataset Documentation

The strategy addressing standardization of data formats and transfer protocols, metadata formats, and supporting dataset documentation is central to the AON data management system. Without metadata standards, it is not possible to make queries across disparate data centers. Standardized data transfer protocols are essential to support data access, dissemination, and analysis. Dataset documentation is an important legacy, allowing information to be correctly understood and processed long after it was acquired. In contrast, data format standards present a moving target. Data formats vary from discipline to discipline. Even within a discipline, different measurement protocols may be in use, possibly for the same variable. As new instrumentation and approaches are developed, data formats evolve (SEEDS [Strategic Evolution of Earth Science Enterprise Data System] Formulation Team, 2003). However, inconsistency limits the capacity to observe both short- and long-term changes in the Arctic. For the AON data management strategy to succeed then, the ability to merge and integrate different datasets across disciplines as well as across diverse user communities must exist. Data standards will need to focus on a key subset of common parameters whose standardization would most facilitate data interfacing. SEEDS has shown that discipline-specific data format standards are more closely followed than standards imposed by outside forces (SEEDS Formulation Team, 2003). Candidate AON standards would be those set by existing data centers for the various domains (i.e., terrestrial, ocean, atmosphere, etc.) that are tasked with developing data standards for their community and existing international protocols (e.g., World Meteorological Organization resolutions for hydrometerological data). The AON will also need to look to experienced data managers to provide advice on archival standards and to the Open Geospatial Consortium (OGC)—a common venue for interoperability technical specification development (Box 4.3).

Recommendation: System implementers should adopt standard specifications agreed upon by consensus, with preference to formal international standards such as those of the International Organization for Standardizations.[3]

Box 4.3
Open Geospatial Consortium

Open Geospatial Consortium Inc. (OGC), is a nonprofit international industry/user/technical consortium of 298 companies, government agencies, and universities participating in a voluntary consensus process to develop publicly available standards for geospatial and location-based services. OGC members create open and extensible software interfaces for geographic information systems and other mainstream technologies that make complex spatial information and services accessible and useful with all kinds of applications.

[2] See previous footnote. This recommendation is for the longer-term "ideal" data management system.

[3] See IWGEO (2005) for a parallel recommendation.

Standardization can be as critical for data as it is for data formats. Consider, for example, common references such as time and location. Detailed measurements of ice canopy thickness can be derived by combining satellite altimetry data with upward-looking sonar measurements from an autonomous underwater vehicle. But if the two instruments were not synchronized or the clock on underwater sensor drifted after it was initially synchronized, integrating the two datasets to produce measurements of sea ice thickness can become difficult or even impossible. Similarly, although the Global Position Satellites now provide standardized positional information on land and at the sea surface, they are unavailable for observations made beneath the surface of the Arctic Ocean.

Recommendation: The AON should establish standardized temporal and spatial reference frames to facilitate arctic research, particularly considering difficulties associated with operating under-ice and underwater sensors.

Implementation of standard formats for date, time, latitude, and longitude has already been useful for comparing and collecting data from international, multidisciplinary projects such as Surface Heat Budget of the Arctic Ocean (Uttal et al., 2002).

Second only to the quality of the data themselves is the quality of the supporting metadata. Metadata should explicitly describe all preliminary processing associated with each dataset, its underlying scientific purpose, as well as describe and quantify uncertainties resulting from each processing step. At a minimum, a metadata file needs information about parameter, keywords, source, sensor, location, project, temporal coverage, spatial coverage, uncertainties, processing steps, personnel, data center, distribution and media, Directory Interchange Format information, lineage, and versioning information.

Recommendation: The AON should serve as the central resource linking all arctic metadata regardless of nation, program, institution, or individual contributor.

In this capacity, the AON would enforce established metadata standards (e.g., ISO 19115; Geographic Information Metadata, and the Content Standard for Digital Geospatial Metadata established by the Federal Geographic Data Committee), contribute to the development and acceptance of new standards as necessary, and coordinate and set the requirements for the metadata database. A centralized metadata repository could link metadata from existing sources for the initial metadata base population (e.g., GCMD), identify and gather missing metadata, and provide a mechanism for incorporating future metadata. Having a centralized metadata center for the Arctic would also address some of the concerns that arise when metadata are broadly distributed (Box 4.4).

Box 4.4
Metadata Concerns and How the AON Data Management System Could Help Address Them

Loss of Metadata: Often an ASCII or binary format is used for the data and the documentation is kept separately (e.g., readme files). This is a potential problem since the metadata may become separated from the data as the data spread through the user community, and might result in unintentional use of the data. By relying on one repository that hosts all versions of the metadata and tracks data and metadata heritage, users should always be able to find information describing various iterations of data processing and products.

Ownership of Metadata: A recurring problem with widely disseminated datasets is determining who owns the metadata, who can edit what parts of the metadata, and how communications between multiple groups maintaining the same metadata will be handled. The policies of a centralized metadata repository can address these issues for all users.

Development of Metadata for LTK Observations: These observations may not easily conform to metadata standards set for standard scientific datasets. The AON will need to consider the best ways to provide metadata for LTK allowing for flexibility in the various metadata requirement categories or even the creation of new categories since many LTK studies are not replicable. As stated in OCEAN.US (2005): "Although the goal of [the International Ocean Observing System] may be to provide automatic access to data, it may be necessary to implement this in a staged approach, particularly for historic data." This may be an approach to consider for LTK.

The metadata database will need to be designed to handle new requirements as they are defined and to promote and facilitate standardization.

Recommendation: The AON should be responsible for dissemination of procedures and tools to (i) ensure the collection of adequate and appropriate metadata, (ii) ensure the quality of the metadata collected, and (iii) ease the burden in helping data providers and network and instrument developers meet metadata obligations.[4]

[4]See footnote on second page of this chapter. Items (ii) and (iii) in this recommendation are for the longer-term "ideal" data management system.

Given that data collectors sometimes have difficulty providing metadata with their datasets, the ability to develop and disseminate software for creating metadata through a centralized repository is advantageous. Because different communities will undoubtedly have different requirements (such as the LTK observations), distributing tools to produce metadata in a standard framework will help accommodate the different needs of disparate arctic researchers.

In addition to effectively managing metadata, the AON can advocate that all datasets be accompanied by guide documents. Without well-documented data, sensors, and infrastructure, it is not possible for users of the data to understand any limitations or special characteristics of data, instruments, or networks they are using. Supplemental guide documentation may contain descriptions of a dataset; details of study design and data collection protocols (including instrument or network description, where and how the data were collected, etc.); quality control procedures; any preliminary processing derivation, extrapolation, or estimation procedures; the use of professional judgment; quirks or peculiarities in the data or a sensor; an assessment of features of the data that would constrain their use for certain purposes; and references and project Web site. By recommending that all data be accompanied by complete documentation and providing approaches for creating well-organized documentation (e.g., CCSDS, 2002), the AON data management system would further facilitate arctic research.

Data Access

To develop a strategy for data access, the AON needs to consider who the users of the data are and their particular needs. User needs vary depending on whether they are scientists, instrument developers, educators, policy makers, indigenous people, or others. For example, scientists need to know where the data are, how to access the data, the level of quality control of the data, and data uncertainties. Instrument developers need to know the requirements and processes for making their datasets available. Educators need tools and products to use data for teaching and to have access to data and analysis tools at little or no cost. Policy makers need derived products to help them interpret what is happening in the Arctic and make informed decisions. Indigenous peoples need data available in accessible formats (e.g., visual data products) and in their own languages. Some indigenous languages like Inuktitut or Gwich'in require special fonts that will need to be available online in standardized forms.

Large gaps exist between the definition of the word "data" for all of these users. The term "data" reflects the experiences of the users, the context in which they work, and the questions they are trying to answer. Raw measurements may be data to scientists but not to educators or students. Similarly, policy makers may be more interested in model results and prediction rather than in raw observations.

Recommendation: The AON data management system should provide interactive, direct access to data through a single portal.

The Committee supports a Web services approach[5] to portal design because it has a minimal impact on data management choices made by data contributors and is broadly adaptable to existing and new (client) applications. However, when choosing a Web service, it is important to consider that, in general, the more sophisticated the data system, the more it will require from data contributors (e.g., special formats, documentation). The AON will need to consider these issues in weighing how to manage arctic data and work to ensure the necessary (ever-changing) technologies are adopted. In the initial development of data delivery, access would be provided to those data available online and associated with high quality. Eventually, the AON will develop a catalog system that provides access to all data including those datasets that are only available offline, such as physical samples and historic transcripts.

For arctic communities to access the AON, those communities will need the appropriate resources and capabilities. The AON will need to consider the state of computer access in arctic communities as well as what is needed in terms of capacity building, training, and systems for troubleshooting. A useful function for the AON would be to help provide infrastructure for improved data access to encourage locations where Internet connections remain slow to input their observations into the AON framework, as well as to use AON data and products.

Long-term Archival of Data

Long term archival (LTA) is the central pillar of systems designed to monitor environmental change in the Arctic. According to the Consultative Committee for Space Data Systems (CCSDS, 2002) "long-term" is defined as a period of time long enough for there to be concern about the impacts of changing technologies, including support for new media and data formats, of a changing user community, and on the information being held in a repository. From a strategic point of view, this definition implies that LTA needs to be a continuing program for preservation and integrity of comprehensive data, products, and information. Not only is simple access to the original data needed, but any LTA must allow for future development of new and improved products and for use of data in ways that were not originally anticipated. For example, algorithms to derive variables evolve,

[5] In this approach, data reside in their parent data center or other archive, but, through interactions among two or more Web applications, can be seamlessly merged with data from other locations on the Web to create new graphics or to support an analysis, for example.

and it is necessary to archive raw measurements for future processing and reprocessing.

Within the AON data management system, a mechanism would be needed for reprocessing from the start of a specific data record or even the archival of a specific data type. This necessitates extensive documentation that goes well beyond typical metadata needs. Metadata for archival purposes must at a minimum contain versioning, lineage, and reference information. These are required to support modifications and corrections to data in archives as well as to maintain reference information for the archived data.

The Arctic System Science (ARCSS) Program at the National Science Foundation has shown that the data submission rate from PIs to the ARCSS Data Coordination Center has been much lower than optimal. Lessons learned from ARCSS demonstrate that plans for submitting data in the archive need to be addressed by the PIs at the proposal and field collection stage. Among a number of desirable traits (Box 4.5), the LTA system within the AON will need to be proactive in encouraging PIs to plan for submission of their data and to encourage timely acquisition of data and metadata for LTA.

Derived Data Products

Making the data usable is typically the responsibility of the researcher or engineer who initially collected the data. Users of the data—whether the original collector, those conducting assessments or educational outreach with the data, or researchers who merge and manipulate data with data from other sources—add value to the original data, creating more polished products that potentially are of broader interest and utility than the original elements of the product.

Recommendation: The AON should expand the usefulness of derived data products by being responsible for disseminating value-added data.

Box 4.5
Desirable Traits for a Long-term Archiving System

- Ready data discovery and use:
  - — Datasets need to be searchable across the entire time horizon;
  - — Increased attention is needed to recover and access past records (e.g., instrumental and paleoclimate reconstructions, traditional knowledge records such as transcripts or tapes of deceased elders) to better establish the variability and long-term trends in the arctic environment.
- Consistency Upheld:
  - — The operations of the component networks need to be monitored on a continuous basis to ensure that standards are being maintained and that observations are being received by the designated AON data management center;
  - — Data need to be preserved and citable;
  - — Data assimilation and reanalysis products need to be archived—for example, reanalysis products might be a primary product for many users and might be needed in 'real time;'
  - — Rescued/recovered data need to be transferred into "preservable" formats (e.g., audio tapes to CD-ROMs or digital audio (for LTK), paper ice charts to digital; floppy disks to digital), and proper storage of paper (maps, charts) and films is needed;
  - — Products need to be considered that will be useful to local community audiences.
- IPR (Intellectual Property Rights) system in place:
  - — This system will address who 'owns' data contributed to AON data management system. For LTK, communities might want to own their intellectual property and have potential researchers contact them for permission to use this data. Can they still be linked into the AON? The IPR system must be flexible, but once data are deposited, are they public? Proper handing of IPR and "sensitive" data is an open question.
- Ability to migrate to new systems:
  - — Electronically stored data need to be continually migrated to newer storage devices and access software;
  - — Qualitative data (e.g., non-numeric and context-specific data) need to be accommodated (this is especially key for archiving LTK such as audio and video interviews, text interview transcripts, artwork, maps, drawings).
- Processing and reprocessing capabilities are available.
- Data flow to modeling and analysis is possible through translator software.
- Education of data users and providers is ongoing.
- Skilled, experienced, and technologically advanced data management staff present.
- A philosophy to embrace proven new technologies.
- A philosophy to embrace feedback from users and incorporate this into an evolving system.

There are many instances when users have difficulty accessing large datasets or do not have the knowledge to work with such observations. Access to and understanding of these data can be made more effective through derived and/or value-added products. Additionally, many products are generated by blending data from different sources, such as blending in situ and satellite observations or combining observations from several sensors. For many applications, maximum benefit is extracted from all the various observations through real-time data assimilation and reanalysis systems in which different data are integrated into comprehensive and internally consistent descriptions of the state of the Arctic. Rather than requiring all users to repeat these efforts to integrate data, the AON can provide derived products, particularly those useful for educational and policy-making purposes, through its data portal.

SUMMARY

An abundance and diversity of arctic observing systems and programs already exists, but the infrastructure to integrate results from these resources is lacking. Because this infrastructure will need to accommodate a broad spectrum of users, the AON will need a data management system that is independent of nation, language, background, expertise, and scientific interest—no small feat. But the successful completion of this task is the most significant contribution to creating a truly integrated network.

Recommendation: A data management system initially built on existing data centers and resources must be designed and implemented immediately by an AON data management committee to support major functions of the network. This system should be accessible through a single portal that connects data across disciplines and themes and should seamlessly link information from arctic sensors, historical datasets, and researchers and other users across space and time.

5

Designing the Network

This chapter describes the infrastructure and approach needed to create an Arctic Observing Network (AON), including ideas on types, number, and distribution of network components; where observations might be effectively made; and the role that remote sensing and novel technologies might play. It also describes processes that could be used to design the optimal mix of observations and test for data redundancies. The Committee adopts a philosophical approach in this chapter and reserves specific implementation ideas for the next chapter. There are many ongoing and planned observation programs and their design plans have details that relate to this chapter. The value added by this chapter is to raise considerations that are specific to building a network that can generate multipurpose, pan-arctic datasets.

PHILOSOPHICAL CONSIDERATIONS FOR NETWORK DESIGN

In recent decades it has become clear that much environmental change in the Arctic is systemic. The change of state at any one place is likely to be strongly dependent on the state at locations far removed in space and time. For example, it is thought that seasonal sea-ice retreat that has been observed in the Chukchi Sea in recent years is at least in part dependent upon long-term, Northern Hemisphere atmospheric forcing (i.e., Arctic Oscillation shifts) that has brought younger and thinner ice that is more readily melted into the North American Arctic (Rigor et al., 2002; Rigor and Wallace, 2004). Connections to the rest of the globe also depend on pan-arctic systemic behavior. Two factors that are arguably among the most important in strongly coupling the Arctic with the rest of the Earth are ice-albedo feedback and control of global thermohaline circulation through export of freshwater to the subarctic seas. The Arctic is a key control point for these processes through changes in snow cover; glacier, lake, and sea-ice cover; and freshwater provided by arctic runoff and melted sea ice.

The AON will provide the critical data necessary to expand understanding of the ways the arctic system is connected and functions. Many existing observational mechanisms are research projects that have limited spatial and temporal scope. Continuity in time and space is rarely the result of a larger plan. Most existing science planning efforts cover specific realms, processes, time scales, or regions. The observing system needs for these can often be met with the traditional organizational and operational approaches. However, the overlay of the AON could supply the wide-area, long-term observations needed to track the state of the Arctic and understand how the system functions as part of the global environmental system.

Such an AON will not be unprecedented. Over the past several decades, there has been progress in recognizing the importance of time series from sustained observational efforts. For example, the beginnings of the Keeling record of continuous atmospheric carbon dioxide measurements at Mauna Loa was connected with the 1957 International Geophysical Year activities, but it was only maintained through the persistence of Keeling and colleagues (Keeling, 1998).[1] This record is now critical for evaluating human use of fossil fuels and subsequent carbon cycling and sequestration, and the Mauna Loa collections have become an institutionalized resource that is the longest continuous record in the global carbon dioxide monitoring network. Requests for transfers of data from the Carbon Dioxide Information Analysis Center in Oak Ridge, Tennessee, which is the designated depository for this network, including the Mauna Loa record, typically exceed 10,000 per day.[2] These requests come from almost every country on Earth. Yet, despite the demonstrated

[1] See also http://www.mlo.noaa.gov/HISTORY/PUBLISH/20th%20anniv/co2.htm.

[2] See http://cdiac.esd.ornl.gov/wwwstat.html.

value, sustaining these and other long-term measurements remains problematic and undervalued.

Network and observational systems require different funding strategies than shorter-term research projects. For the network to serve its purpose, a long-term commitment to network components is needed. The U.S. Long Term Ecological Research (LTER) and the National Oceanic and Atmospheric Administration (NOAA) trace gas monitoring programs are examples of a longer-term commitment to addressing science questions that are not posed as hypotheses that can be resolved in a field season or two. There have been many examples of long-time-series datasets from the LTER program that have helped guide research questions and set hypotheses, as well as evaluate regulatory and policy effectiveness. For example, in research conducted as part of the Bonanza Creek LTER project in Alaska, Grünzweig et al. (2004) showed that as agriculture expands at high latitudes, soil carbon losses are likely to be greater than those in other biomes. In another review, LTER data collected in the mid-1980s from Bonanza Creek were used to generalize about the long-term impacts upon nitrogen cycling of severe forest fires (Smithwick et al., 2005).

To be important and worthy of long-term support, networks should not need to be driven by hypotheses that can be tested over two-to-five-year funding cycles. It is clear that longer-term observations can directly help experimental research by providing the tools needed to address specific hypotheses. However, incentives and rewards for building long-term datasets are not always apparent, given the prevalence of two-to-five-year funding cycles. Protection of intellectual property rights to use data collected by individual observers, while still making them accessible to a larger community of users, will also remain a complex challenge for networks. And one of the key challenges for sustaining the AON beyond an initial effort like the International Polar year (IPY) is how to make the transition from pilot-type efforts like Keeling's in the late 1950s to an institutionalized observing system that fulfills broad societal and scientific needs.

In addition to being founded upon a philosophy that values systematic, long-term, extensive measurements, the AON will also benefit if participants adhere to several other philosophical approaches. These include recognizing the value of measuring variables that are not currently changing in addition to variables that are changing dramatically; valuing open source, nonproprietary software and tools that allow data sharing across platforms and disciplines; valuing the ability to evolve with and embrace new technologies, opportunities, and demands; valuing the human dimension of the arctic system (see Box 5.1) and participation of local observers who make the AON more cost-effective and help make year-round observations; and valuing data management because of the efficiencies and overall cost-effectiveness that it can bring to the AON.

Box 5.1
The Human Dimension of the Arctic Observing Network: Perspectives from Human Dimension of the Arctic System

The following text is adapted from a brochure produced by HARC (Human Dimensions of the Arctic System) called "Designing the Human Dimensions into an Arctic Observing Network" (HARC, 2005).

Arctic environmental change is the set of biophysical transformations of land, ice, oceans and atmosphere, driven by an interwoven system of human activities and natural processes. Research on the human dimensions of arctic change addresses the coupled human-natural system and investigates how individuals and societal groups contribute to, are influenced by, and mitigate and respond to the changes that take place on a local, regional, and global level. Human dimensions science therefore encompasses may topics, approaches, methods, and disciplines.

Understanding how social systems interact with natural systems (both physical and biological) involves qualitative analyses and quantitative studies that rely on forms of hypothesis testing and analysis familiar to fields such as atmospheric science, terrestrial ecology, glaciology, or ocean biogeochemistry. When biophysical scientists study human-influenced phenomena such as ice roads, river flows, or fish catches, understanding human influences becomes critical. These are nontrivial challenges for biophysical-human dimensions research.

The human dimensions component of the AON could consist of a network of social scientists, citizens, and other observers who help make available and accessible arctic human dimensions data that are being collected in a common data structure with circumpolar scope. This part of the AON could also identify data gaps and fill them. Data might include the size, well-being, and livelihoods of arctic communities; demographic vital statistics, health and economic statistics; qualitative data such as historical accounts or life histories; and global economic and institutional trends (see also Table 2.1).

A key role for the human dimensions component of the observing network beyond collecting and organizing data could be to perform analyses needed to disseminate useful, useable, relevant, and timely data to researchers, policy makers, and the public through a single Web portal with multiple links.

CHARACTERISTICS OF THE NETWORK AS THEY RELATE TO THE MIX OF NETWORK COMPONENTS

A systems approach to understanding the Arctic defines needs that transcend national boundaries and the timeframes of individual science investigations. Thus, a key contribution of the AON will be to provide a framework within which existing programs can be linked and supplemented to achieve an interdisciplinary pan-arctic observation capability. As the overarching network, the AON will need to provide continuity across national boundaries into the foreseeable future. Challenges of achieving spatial coverage include identifying and filling observational voids and ensuring that observations made across AON's component networks are equivalent and comparable. In the temporal domain, the network needs to be flexible to adapt to improved understanding and new technology, while at the same time providing continuity of certain key measurements across decadal periods or more. Also in the temporal domain, the observations will be needed at frequencies ranging from almost continuous (and near-real-time) to years. Finally, the data content of AON will span physical and biogeochemical variables and also include human dimensions measurements and observations to help understand how humans affect and are affected by the arctic system (Table 2.1). In discussing the idea of developing a human dimensions observing network in the Arctic, HARC (2005) notes that such a network would be "essential to understanding common patterns and local variations in the flow of Arctic social change, testing hypotheses and developing models about their causes, and developing credible, evidence-based future scenarios and policies useful for supporting decision making under conditions of escalating environmental and social change."

NETWORK COMPONENTS

Building Blocks

A variety of tools and platforms is available for arctic observations (Table 5.1). The compilation in Table 5.1 classifies observation platforms in broad, general categories of varying costs, duration, and range of coverage and measurement and provides some brief description of advantages and disadvantages of each platform. This list is not exhaustive and categorizations are subject to change as technology improves. Nevertheless, these are examples of platforms that will likely provide the infrastructural foundation for data acquisition in the AON.

Measurement tools and platforms are either automated or rely on direct human involvement. On the automated side, satellites provide remote sensing of a variety of parameters like temperature, albedo, vegetation cover, clouds, winds, ice extent and concentration, and glacier altimetry. Fixed unattended observation systems can be stationed on land, attached to ice, and moored to the seafloor, and depending upon location, flexibly equipped with in-situ environmental sensors for such parameters as salinity, temperature, current speed, wind speed and direction, photosynthetic active radiation, ice thickness, chlorophyll, nutrients, atmospheric gases, and contaminants. Automated devices can also drift with the ocean currents or winds, and self-propelled unattended systems are becoming available in the form of unmanned air vehicles (UAVs), autonomous underwater vehicles (AUVs), and underwater gliders.

Many measurements are sufficiently complex that there is no alternative to having experts on site, whether in an arctic community, on a ship or aircraft, at a field camp, or at a more permanent field station. The local residents of the Arctic constitute an invaluable resource as expert and intimate observers as well as potential collaborators for professional researchers who cannot be present on a year-round basis in remote high-latitude locations. A special investment will be needed to cultivate relationships with arctic communities and organizations and to collaborate on researching ways of linking local and traditional knowledge (LTK) and scientific data. Some general guidelines for incorporating LTK in the AON and for working with arctic communities were developed by Joan Eamer in her input to the Committee, and these, in addition to guidance from other sources (Box 5.2) provide a starting point for the AON with respect to collaborating with arctic residents.

The AON must leverage all of these capabilities—automated and manual—to maximize the value of the resulting data for the available resources.

Measurement Approaches

Observational approaches that can be used for the AON are categorized in the SEARCH implementation plan documents (SEARCH SSC and IWG, 2003; SEARCH, 2005) as intensive measurement programs at a few carefully chosen sites, broadly distributed or "extensive" measurements of more easily measured parameters, repeated surveys or sections giving detailed snapshots of spatial variability, and remotely sensed (e.g., satellite-based) measurements for achieving continuity across spatial domains and in situ data in-filling.

Intensive Measurement Programs

Flagship observatories that make intensive measurements in the terrestrial realm (Shaver et al., 2004) are situated in representative areas with access to a wide variety of arctic terrain. They have well-developed suites of comprehensive measurements and of time series for key variables throughout the year. Examples of sites that could fill this role include Abisko, Alert, Barrow, Bonanza Creek, Cherski, Kluane Lake, Ny-Ålesund, Pallas, Summit, Tiksi, Toolik Lake, and Zackenberg. Some of these intensive sampling sites are oriented toward specific disciplines. For example, Summit

TABLE 5.1 Comparison of Examples of Existing Arctic Observation Platforms

Platform	Cost	Duration	Range	Coverage	Advantages	Disadvantages
Satellites	$$$$	Long-term	Surface, atmosphere	Time series on spatial grid	Comprehensive space-time coverage	Limited to surface and atmospheric information, continuity issues
Airplanes	$$$	Synoptic	Surface, atmosphere	Surveys	Mobility	Cost and weather limited
Manned Drifting Stations (ice camps)	$$$	Synoptic	Surface and subsurface	Lagrangian[a] time series, process studies	Provides access for many disciplines	Cost, ice, and weather limited
Icebreakers	$$$	Synoptic	Surface and subsurface	Sections, process studies	Provides access for many disciplines	Cost, time and ice limited
Submarines	$$$	Synoptic	Subsurface	Sections	Mobility	Infrequent, sensor, and personnel limited
Gliders and AUVs	$$	Synoptic	Subsurface	Sections	Mobility	Frequency and duration under development
Surface Drifters	$	Long-term	Surface	Lagrangian time series	Inexpensive, extensive temporal sampling	Limited to surface
Ice-Tethered Buoys	$$	Long-term	Surface and subsurface	Lagrangian time series	Extensive temporal and vertical sampling	Too few; Lagrangian time series
Bottom-Tethered Moorings	$$	Long-term	Subsurface	Eulerian time series	Extensive temporal and vertical sampling	Too few; surface and near-surface not sampled
Intensive Observatories	$$	Long-term	Surface, atmosphere	Eulerian time series	Temporal sampling	Limited geographical coverage
Extensive Measurement Sites	$	Short to Long-term	Surface, atmosphere	Eulerian and Lagrangian time series	Inexpensive, broad geographic coverage	Limited range of measurement parameters
Local Observers	$	Long-term	Surface, atmosphere, socioeconomic, health	Eulerian and Lagrangian time series, sections	Year-round presence, inexpensive	Geographically focused (e.g., coasts), intercomparison challenges

[a]The Lagrangian approach measures properties at a point whose geographic position changes with time. The Eulerian approach measures properties at a geographically fixed point.

specializes in atmospheric sampling including trace gases and atmospheric contaminants whereas hydrological and ecosystem-level variables are the focus at Toolik Lake. However, a broader goal of these sites is to provide co-located, multidisciplinary measurements that reveal the interdependence of physical, chemical, biological, and geological domains. For example, several sites (e.g., Alert, Barrow, and Tiksi) are co-located with rawinsonde stations, thereby contributing upper-atmosphere measurements to the comprehensive suite of surface and subsurface measurements.

In the Arctic Ocean and its marginal seas, marine observatories are already positioned in key areas to characterize variability and long-term changes of oceanic circulation and water properties year round. Examples of these sites include the North Pole Environmental Observatory, the Beaufort Gyre Observing System, and the Nansen and Amundsen Basin Observing System. Other internationally supported marine observational sites include the moored ASOF (Arctic-Subarctic Ocean Fluxes) transects in the straits and gateways of the Arctic Ocean. As is the case for the terrestrial observatories, these marine intensive sites also incorporate repeat surveys and suites of more widely distributed instruments.

Distributed Observations

Distributed observations are more limited in scope than those at intensive sites but nevertheless provide needed

Box 5.2
General Guidance on Incorporating Local and Traditional Knowledge into Observing Networks[a]

- The AON must work in partnership with local and indigenous organizations from the outset to determine the type of information that will be linked to the AON, how it will be collected and used, and who will make decisions regarding control of information. There must be open and ongoing communication with communities as well as local and regional capacity building so that local people can engage with the project (Eamer, 2005; Loring, 2005). This process will take significant investment of time and resources. Existing guidelines and procedures for working with local communities and LTK should be examined and adapted. These include ethical and methodological guidelines from relevant regional or national organizations or funding agencies (e.g., Center for Arctic Cultural Research, 1989; Grenier, 1998; NRI and ITC, 1998; ARCUS, 2004; NSF, 2005).
- When considering how LTK should be incorporated into the AON, there should be a distinction between
  i. incorporating LTK to improve science-based monitoring,
  ii. using LTK to help design and interpret monitoring, and
  iii. developing community-based monitoring systems that are linked to the AON.

  It is also important to distinguish between monitoring, repeated observations, and traditional knowledge studies that document local knowledge, beliefs, and observations of change over a past period. These are complementary, as are science-based research and monitoring (Eamer, 2005).
- Issues of ownership, program management, processes for informed consent, processes for obtaining any necessary permits (e.g., research licenses), demonstration of respect for local experts, intellectual property rights, and information sharing protocols must be addressed early on (NRI and ITC, 1998; Eamer, 2005; Loring, 2005).
- Methodological issues and best practices to forming research relationships with communities must be considered. These include appropriate methods for LTK collection, especially before implementing a standard approach, and methods in relation to the desired contribution and results (Eamer, 2005). LTK research should follow the “3 Rs”: respect, reciprocity, and relationship (Grenier, 1998).
- The LTK component of the AON should not act to support or confirm scientific monitoring—it should stand on its own and make a unique contribution (Eamer, 2005).
- The AON should take care to respect LTK as it is and keep the context and richness of LTK data (Eamer, 2005; Loring, 2005). Quantitative analyses are possible (e.g., creating indices, charting trends), but do not reduce LTK to a yes/no survey response (Eamer, 2005).
- Environmental responses should not be separated out from social and economic responses because of the important interactions between these and because it will not make sense to local people to separate them (Eamer, 2005).

[a]The guidelines are from input to the Committee (in particular, from recommendations submitted by Joan Eamer, UNEP-GRID, and Eric Loring, ITK) and other literature and online sources.

spatial and temporal context. They are essential for monitoring the evolution of the broader state of the Arctic. As a small-scale example, measurements in the Imnavait Creek microscale system (a 2.2 km^2 headwater catchment) and the Kuparuk River basin supplement more intensively studied variables at Toolik Lake. At the pan-arctic scale, the Global Terrestrial Network (GTN)-Permafrost program[3] measures active layer thickness and permafrost temperatures around the Arctic. In addition to fixed networks of distributed measurements, mobile platforms can also determine local synopticity or spatial context for intensive sites or larger-scale measurements.

In the marine setting, distributed observations will provide critical details on the temporal development of spatial gradients important to circulation and water mass transformations. Distributed marine observations will need to include mobile platforms such as drifting buoys, ice-tethered profilers, and AUVs, and also simple moored measurements and low-intensity manned observations such as for sea-level or sea-ice conditions. A combination of mobile platforms and fixed infrastructure (i.e., moored and cabled observatories), satellites, and underwater navigation and communication systems are key marine components of the AON (e.g., Proshutinsky et al., 2004; Coakley et al., 2005; SEARCH, 2005).

Repeat Transects, Sections, Surveys, and Hotspots

In the marine environment, repeat sections or transects by ship or aircraft are critical means of determining spatial gradients responsible for ocean circulation, biological

[3]See http://www.gtnp.org/.

community composition, species distributions, and ice conditions. In many cases, there are no practical alternatives to transects for collecting water samples for key chemical and biological analyses.

On land, transects provide periodic sampling of areas that are particularly remote and not represented in existing networks. By including several sites along the climate gradient (e.g., the five bioclimate subzones portrayed on the Circumpolar Arctic Vegetation Map [CAVM Team, 2003]), for example, it is possible to reduce logistics costs of visiting these areas. Furthermore, by focusing several different projects along the same transect, the climate, soil, active layer, permafrost, vegetation, and biodiversity data can be compared among projects.

The atmospheric rawinsonde network, by virtue of its fixed nature, can be considered a source of repeat surveys of the atmosphere, albeit at frequent (12-hourly) intervals. The assimilation of rawinsonde soundings into operational analyses and reanalyses adds a vertical atmospheric dimension to surface transects for which projects from various disciplines have converged. Preservation of the rawinsonde network will allow the provision of temporal context to repeat transects, sections, and surveys performed at the surface.

In some disciplines, particularly biology, improved understanding of the arctic system requires studying "hotspots" where biological activity is high and observations are dependent upon intermediate (decadal) efforts that fall between the observing needs of field programs (annual efforts) and multidecadal time series.

Remotely Sensed Observations

On the broadest spatial scales, satellites provide a powerful synoptic observation capability for a wide variety of parameters and a means of obtaining systematic, repetitive coverage for many arctic applications. Sun-synchronous polar orbiting satellites (e.g., ERS, Landsat, NOAA polar orbiting meteorological satellites, SPOT—see Annex Table 3A.3) pass over the Arctic on every orbital period, and complete coverage of the Arctic is acquired except directly at the pole. The advantage of satellite remote sensing in polar regions is that large and inaccessible areas can be studied easily and even under darkness and through fog, cloud, or rain in the case of non-optical sensor systems. This is particularly important in the Arctic, which is frequently cloud-covered and has months of darkness.

Satellite instrumentation platforms provide key observations for understanding the Arctic such as the extent of sea ice and snow. There are also technologies available for determining freshwater altimetry; bottom water pressure; sea surface heights; ice type, ice motion, and perhaps sea ice thickness; land cover; leaf phenology (e.g., date of leaf out); species changes; tundra-to-bush transition; treeline locations; and some aspects of photosynthetic activity. Satellite observations provide relevant data for almost all of the Committee's physical key variables, many of the biogeochemical key variables, and one of the human variables (Annex Table 3A.3). In addition to the growing range of measurement capabilities, there is also a growing archive of untapped remotely sensed data that presents excellent opportunities for innovative uses and synergistic studies.

In some cases, entire satellite missions are developed to support specific arctic science initiatives. These missions often include multiple instruments on a single satellite platform. These instruments provide different but complementary measurements to one another. In other cases, the mission may be collecting global measurements or have only a subset of the instruments collecting relevant measurements for arctic science. Because of the complexity and size of each satellite program, they are typically designed and operated under the direction of large government agencies such as Canadian Space Agency and ESA (European Space Agency), or NASA (National Aeronautics and Space Administration), Department of Defense, or NOAA in the United States.

Satellite systems are reliant on ground observations for calibration and validation. Ground stations are also critical because satellite missions have finite duration and may not be replaced immediately or at all, as is the case for Landsat. Consequently, when follow-on missions are scheduled, the sensing systems are unlikely to be identical. And although these differences are part of a healthy improvement in observational capability, they create problems in continuity of measurements. One unfortunate result of the advent of satellite remote sensing is that its promise has caused the closure of many ground-based observing systems that are still needed.

WHERE TO MAKE OBSERVATIONS

Basic Principles and Strategies

The proposed or planned global observing networks, in general, have poor coverage in the Arctic and typically do not treat the Arctic as a separate region with unique observational challenges. For example, the Global Ocean Observing System has no specific Arctic Ocean component, although there are internationally coordinated groups focused on regional seas such as the Black Sea, Baltic Sea, and Mediterranean.[4] Gap identification and prioritization of gap filling will therefore constitute an early phase of the AON.

In constructing the AON, it will be necessary to identify and incorporate existing observing systems because of the logistics and data that can be used as a base for future expan-

[4]Black Sea: http://www.ims.metu.edu.tr/Black_Sea_GOOS/, Baltic Sea: http://www.boos.org/, Mediterranean: http://ioc.unesco.org/goos/MedGOOS/medgoos.htm.

sion and development of an effective network. For this reason, terrestrial locations such as Abisko, Barrow, Cherski, Ny-Ålesund, Pasvik river basin, Summit, Tiksi, and Toolik Lake have obvious advantages as network nodes because scientific data collection has been under way for many decades in some cases. Although the scope of ongoing data acquisition, particularly in Russia, is uneven, the small set of existing long-term research stations identified as potential flagship observatories (Shaver et al., 2004) (that includes those listed above) provides a starting point for multi-disciplinary understanding of ecosystem processes. These 6 to 12 key arctic terrestrial observation nodes would be underpinned by data and observations from supporting networks of smaller field stations and individual research projects.

This model of centralized data collection at a small number of representative sites is not applicable to all fields of scientific observation that could be affiliated with the AON. This model may also prove challenging to link with LTK that is widely dispersed and often extends over large spatial scales during seasonal food gathering cycles. In addition, some scientific disciplines have used locations that do not coincide with flagship observatories for other research fields. For example, the space physics and aeronomy research community has used locations such as Alomar, Eureka, Heiss Island, Poker Flat, Resolute, Sondrestrom, and Svalbard for observing the aurora and other upper atmosphere processes, but there may be few data available from these sites for other fields of study. Many of these intensive sites were chosen because of their location relative to the auroral oval, geomagnetic pole, or proximity to rocket ranges that provide an opportunity for in situ rocket measurements. In recent years, there has been an increased thrust within the space physics and aeronomy community to install distributed autonomous instruments in the polar regions such as magnetometers, passive optical sensors, and small radars that support its intensive observatories.

It therefore should be recognized at the outset that it is difficult to designate geographical locations of the intensive site components of the AON that would be ideally shared by all disciplines. Reanalysis of existing datasets could identify discipline-by-discipline gaps, but in the end, a practical implementation of the AON will incorporate a suite of existing and expanded sampling sites that are not likely to be ideal or shared for all disciplines. There are regional precedents among arctic networks in which such a mix can work (Box 5.3).

Assessment and Design of Observing Networks

There will be an initial assessment and design phase of the AON that leads into an operational design and optimization phase. Several steps will be required in the initial assessment and design phase, namely forming partnerships across disciplines and arctic communities, agreeing on the objectives of the network, defining the type and scale of observa-

Box 5.3
European Network for Arctic-Alpine Environmental Research

The emerging AON strategy of linking and expanding existing research infrastructure to connect environmental observations over the Arctic has regional precedents. For example, the European Network for Arctic-Alpine Environmental Research (ENVINET; http://envinet.npolar.no/) was a European Union-supported "infrastructure co-operation network" that incorporated environmental observation activities at 17 research stations. The objectives of ENVINET were to

- exchange experience and information,
- prepare existing data for research across the stations,
- identify needs for new data collection,
- improve the methods for obtaining data through dissemination of "best practice" in the network and projects for scientific/technical development, and
- coordinate activities to foster common research projects on existing datasets, sampling of new data, data management, or improved methods.

The research stations participating in the network are diverse in orientation, including the Kiruna Observatory operated by the Swedish Institute of Space Physics, the Kristineberg Marine Research Station operated by Gøteborg University, and national research facilities operated by Italy, Germany, the United Kingdom, and Norway at Ny-Ålesund in Svalbard.

Because of the diversity of research programs within the station network, as would be the case in the broader AON, not all data collected at any single station are of universal interest. As a result, several criteria were selected for the datasets targeted for ENVINET research infrastructure and network improvement. These data

- are relevant for studying climate change, ozone depletion, long-range transport of pollutants and changes in biodiversity, and cover the needs of different sciences involved,
- have high quality and are intercomparable across the stations, and
- are large enough and have great enough geographic extent to study the changes of environmental phenomena in time and space, or their variation under changing environmental conditions.

European Union funds for ENVINET lasted three years and the network has not been fully functional for several years, despite its many good ideas.

tions, and using data assessment techniques to initially optimize the network. The assessment will need to determine the effectiveness of the AON for detecting the state of the Arctic, the speed of environmental change, the impacts of change, and net changes in fluxes.

Assessment of the adequacy of geographical density of sampling platforms will need to consider accuracy, sampling error, cost, coverage, overlap, and field reconstruction error. A key consideration is the optimal sampling distance for specific measurements, based upon cost/benefit analysis. For at least some system components, data assimilation into models will feed observing system sensitivity studies that assess key types of measurements and locations. The effectiveness of the measurement density can also be evaluated through process-oriented design, using variational methods to search for the most sensitive area for a given process. These processes will be assisted by end-users such as scientists and arctic residents. For other system components, the data fields are so undersampled that objective approaches to observing system design are not useful. In these cases, observations are a compromise between efficacy and technical, operational, and financial practicality.

One of the working assumptions in the AON design process is that 100 percent effective coverage is not likely to be necessary to establish the initial iteration of the network. For example, in the case of a sea-surface temperature network in the Baltic Sea, satellite coverage provides extensive information content and in situ data collection only improves accuracy by 20 to 30 percent (She and Høyer, 2004). Although these are probably unrealistically low limits for in situ sampling for many arctic variables, an iterative process can, in principle, reveal the sampling density needed to provide the required functionality for any particular variable. Cases where remotely sensed data can be validated directly will lead to synergistic benefits that can be applied in both synoptic understanding and modeling. In general terms, when the required sampling density is not initially clear, data can be collected and then sensitivity experiments performed to characterize the sufficiency of sampling density.

One of the strategies to optimize network development will be to employ the forementioned mix of intensive and distributed sites. This mix will vary for different themes, such as social sciences relative to physical oceanography, in part because of the varied representativeness of sites for different themes. Furthermore, improved understanding of the arctic system in some disciplines and themes requires creative combinations of transects, repeat surveys, hotspots, and integration of remotely sensed data and data from paleo studies. A flexible network geometry is therefore critical. Considering the likely variable funding situation for network elements, the network will have to be sufficiently flexible to accommodate the transient nature of some participants.

Recommendation: A system design assessment should be conducted within the first two years of AON development—that is, as a component of IPY—to ensure a pan-arctic, multidisciplinary, integrated network. This effort should be undertaken by a diverse team, with participation and input from multiple disciplines, stakeholder groups, and those involved in related international observing activities. The assessment should use existing design studies, models, statistical approaches, and other tools.[5]

The initial system design assessment, in conjunction with the pulse of new data from the IPY projects, will provide valuable guidance for enhancing the AON and maximizing its potential utility, as will information on specific performance metrics and user feedback.

Recommendation: The AON should be continuously improved and enhanced by taking advantage of the findings and recommendations in the system design assessment and performance metrics and data provider and user feedback that will become an enduring component of the network.

For any one discipline, many useful sampling locations can be specified (see, e.g., SEARCH [2005] or the distribution of Arctic Monitoring and Assessment Programme network sites). But, as stated at the outset, one set of locations cannot be expected to be ideal for all disciplines. Thus it is probably more useful to outline strategies for system design and incremental expansion. Individual networks that can be better networked are a starting point for such discussion, and this is probably a more practical approach than to specify "ideal" locations where sampling should be coordinated. While recognizing that specification of locations is ultimately affected by the variables to be measured, the Committee provides examples in the next section of locations that are crucial within specific disciplines and themes and could be early targets for preservation or gap filling.

Specific Geographic Considerations

Atmosphere

Routine atmospheric observations are made at many locations for use in operational weather forecasting. These observations would be potentially valuable elements of the AON, provided that continuity, homogeneity, and spatial distribution are used to filter them for use in monitoring. Assimilation of data into models can provide one such filter. Recent losses of weather stations in Russia and Canada are potential concerns with respect to coverage, however. In addition, upper troposphere and lower stratosphere measurements from in situ instruments (e.g., rawinsondes) over the

[5]See Chapter 6 for specifics relating to this recommendation.

Arctic Ocean are notably absent. Fortunately, in situ surface measurements from drifting buoys are valuable sources of information on sea-level pressures and near-surface temperatures over the central Arctic Ocean.

Fixed sites for comprehensive atmospheric sampling, including those monitoring pollution levels, are already well established at Alert (replacing Station Nord in Greenland that was operated until 2002), Amderma, Ny-Ålesund, Pallas, and Summit, although varied sampling regimes complicate intercomparison. Some sites provide an observational database for inorganic contaminants and trace metals, while others (e.g., Barrow) are part of trace gas (carbon dioxide) monitoring networks. In addition, there is a major observational gap from Alert (on Ellesmere Island, Canada) across arctic Canada, Alaska, and Siberia—or approximately 75 percent of the Arctic. Additional sampling locations might be needed at air mass boundaries or to detect specific sources such as Asian dust or air pollution (e.g., an Aleutian or Alaska Peninsula location such as Attu, Cold Bay, Dutch Harbor, or Shemya to sample the North Pacific boundary region) and a western Siberian site for industrial activities. Because of the need for sampling representative air masses and boundaries, a minimal atmospheric network would also include representative air mass sampling locations such as the central Arctic Ocean, the Canadian Arctic at Alert, and the Lena River delta at Tiksi. Sampling for trace gases like carbon dioxide and methane can be sustained with a lower sampling density than organic contaminants and heavy metals.

The upper atmosphere from the mesosphere through the thermosphere and into the magnetosphere plays a key role in the transfer of solar energy from the sun to the lower atmosphere and Earth's surface.[6] Measurements of upper atmosphere processes are therefore important for the AON. Many upper atmospheric process are global in extent and require a relatively uniform distribution of sensors in longitude (approximately 6 to 12) per latitude and with latitudinal gradients that require measurements at every 4 to 8 degrees. The ionospheric and magnetospheric processes, which are geomagnetically aligned, have different spatial distribution requirements and must consider the location of the auroral oval and geomagnetic polar cap. Examples of existing upper atmospheric networks are the SuperDARN (Super Dual Auroral Radar Network) and CANOPUS (Canadian Auroral Network for the Open Program Unified Study) magnetometer network. These networks include high-frequency radars for determining the auroral ionospheric convection pattern and a distributed array of autonomous magnetometers.

Major gaps in upper atmosphere measurements exist in Russia, where many sites were decommissioned, and over the Arctic Ocean, where the required infrastructure is not available. The lack of measurements in Russia inhibits study of the full extent of upper atmosphere processes that are inherently global.

Marine Systems

For the purposes of describing the AON, the arctic marine system includes the Arctic Ocean and subarctic seas, and the overlying sea ice cover and atmosphere. Key processes in arctic marine systems include ocean, ice, and atmospheric circulation, water mass distributions, chemical transport and fluxes, and biological variability.

The SEARCH Science Plan (SEARCH SSC, 2001), which is oriented toward understanding functional change in the Arctic on a system basis, called for a coordinated program of long-term, pan-arctic observations. This plan has guided development of implementation plans (e.g., SEARCH, 2005) and recommends locations for intensive and distributed marine observatories (DMOs). A number of these DMOs are already in place at some functional level (see Figure 4 in SEARCH SSC and IWG, 2003) although key observational gaps remain including the Makarov Basin and the northern part of the Canadian Basin, particularly along the Canadian Archipelago and the Siberian shelves.

DMOs may include many elements but these can be grouped into three categories: moorings, instrument systems tethered to the sea ice, and repeat sections. These activities can and should be done together if only to minimize costs and ensure optimum coverage. Moorings are targeted for ocean pathways along the continental slopes and mid-ocean ridges, cross-shelf exchange sites such as shelf canyons, basin sites that are good indications of large-scale circulation changes, gateways to the Arctic Ocean (e.g., Fram Strait, Bering Strait, and the Canadian Archipelago), and representative shelf sites. Ice-tethered instruments provide observational coverage of the upper ocean, ice, and atmosphere measurements, and are vital to measuring the conditions and fluxes at the air-ice-ocean interface that are critical to both the ice-albedo and global thermohaline circulation feedbacks on global climate. In contrast to moorings and fixed coastal observatories, ice-tethered ocean buoys provide a Lagrangian description of mixed layer changes and interactions with the ice and atmosphere, as well as hydrographic sections over drift paths. Repeat sections, which can be obtained by aircraft in addition to ships, will need to include sampling across the critical straits (e.g., ASOF sections),

[6]Nearly half of the incident solar radiation on Earth is absorbed by the atmosphere before reaching the surface. Energetic particles that are output from the sun during large solar storms, called coronal mass ejections, impact the Earth's magnetosphere and travel down the high-latitude magnetic field lines into the atmosphere and result in dramatic displays of the northern lights. These processes also cause a heating and thus an expansion of the atmosphere in addition to a redistribution of atmospheric constituents through transport processes and solar-related chemical processes. Although the variation in total solar irradiance is small, variations in specific wavelength bands such as the extreme ultraviolet can be dramatic over the course of the 11-year solar cycle or a short-term solar event such as a flare or coronal mass ejection.

sections radially across the major deep basins and key pathways, and on the arctic shelves. The Arctic Ocean Science Board has endorsed an integrated Arctic Ocean Observing System Shelf-Basin Exchange initiative as an IPY activity[7] that proposes standard sections from shelf to basin and across key gateways on a pan-arctic basis. Continuation of these observational transects beyond the IPY could provide the basis for long-term pan-arctic DMO sections, as can sections that are now being regularly occupied as part of existing prototype marine observatories.

Finally, observational programs should be further elaborated and continued for areas of high biological productivity. Hotspots of productivity have been identified and monitored with varying temporal resolution in the Bering and Chukchi Seas, Barrow Canyon, the Boulder Patch (kelp-based community) in the Beaufort Sea, and the Gakkel Ridge spreading plate boundary. Other localized areas of high productivity exist throughout the Arctic, including within recurring polynyas, at Hat Island in the Canadian Archipelago, in Baffin and James Bay, in the White Sea, and along the Kola Peninsula. Changes in these biological communities can have a direct bearing on food webs and human communities as well as illuminating impacts of environmental change, particularly upon subsistence food gathering communities that are located in areas they long ago identified as having high biological productivity.

Coastal Zones

Coastal locations are home to most of the largest cities and highest density human populations in the Arctic (State Committee of the USSR on Hydrometeorology and Controlled Natural Environments, 1985). It would therefore be beneficial to centrally locate most coastal observatories close to or within human communities, particularly where communities are co-located with sites that are independently identified in scientific planning as important for arctic time-series and observations. Because of the importance of coastal zones for human use, runoff, and terrestrial ecosystem exchanges, some observation systems will need to be situated to monitor coastal zone processes that are often missed in separate marine and terrestrial research efforts (Cooper, 2003).

Important details of coastal waters, including fast ice thickness and the separation of chlorophyll pigments relative to river plumes, are not well resolved by satellites, so development of observational systems in coastal and estuarine waters may be particularly challenging yet critically important for biological systems used by human communities. There are several examples of emerging observing coastal networks. One example is called Arctic Coastal Dynamics (Box 5.4).

[7] See http://www.aosb.org/ipy.html.

Box 5.4
Arctic Coastal Dynamics

Arctic Coastal Dynamics (ACD)[a] documents changes in coastline configuration and promotes research on causative factors for changes in coastal dynamics, including erosion. Sites that are currently incorporated in this network are documented on the ACD Web site and include Barrow, Kongsfjorden (Ny-Ålesund), and Zackenberg, where other marine and/or terrestrial observations and intensive research are ongoing.

[a] See http://www.awi-potsdam.de/www-pot/geo/acd.html.

Improving observation systems in Russian arctic coastal regions will be crucial because these zones are key areas for sea ice formation (e.g., Laptev and East Siberian Seas). The Russian Arctic also has the largest undersea permafrost deposits, which may be an important source of dissolved and particulate organic carbon, carbon dioxide, and methane in response to climate warming and increased coastal erosion as sea ice cover decreases. Because of these unique characteristics associated with the Russian Arctic, the AON without significant Russian participation will not meet the goal of providing an observational basis for monitoring the state of the Arctic or understanding arctic environmental change and connections with the global system.

Terrestrial Systems

The concept of focused intensive sites with multidisciplinary research activities is particularly appropriate in terrestrial systems. Vegetation maps can be used to identify areas that are underserved by existing observatories. Observational gaps will need to be identified and filled at major boundaries such as the current tree line, at plant community boundaries (e.g., tundra to shrub transitions), and at locations where soil moisture conditions are changing. LTK of plant communities can help in this effort.

Physiographic processes such as the lack of glaciation in eastern Siberia during the last glacial period have resulted in biological communities that are not present in other portions of the Arctic. Globally significant peat deposits are also located in Russia, particularly in the western Siberian lowlands, and these deposits are likely to be important in affecting global carbon cycling in many global warming scenarios (Frey and Smith, 2005). All of these factors illustrate the need for better observational coverage in the Russian Arctic.

The most remote and coldest areas of the Arctic are home to terrestrial life at the extreme. These areas may show some of the most dramatic physical and biological changes because their present-day summer temperatures are close to freezing and large temperature changes are likely in these areas if sea ice distribution changes dramatically. Repeat transects are useful for sampling these terrestrial environments that are not represented by existing research facilities. One such transect is the North American Arctic Transect that connects sites along the Dalton Highway in northern Alaska (Toolik Lake to Howe Island) and sites in the western Canadian High Arctic. The Canadian sites include Inuvik, Green Cabin, Mould Bay, and Isachsen. This transect was established as part of a National Science Foundation (NSF)-funded Biocomplexity in the Environment project (Walker et al., 2004). Another such transect is being considered for the Yamal Peninsula and Novaya Zemlya in Russia. This transect could attract a variety of research and link to several ongoing circumpolar and global research projects such as the International Tundra Experiment (ITEX), the Thermal State of Permafrost (TSP) project, the Circumpolar Active Layer Monitoring (CALM) project, the FLUXNET[8] project, and the Circumpolar Arctic Flora and Fauna Biodiversity Monitoring Program.

Rivers

Ten percent of world runoff enters the Arctic Ocean. Recent observations show increasing runoff (Peterson et al., 2002), and arctic runoff variations potentially influence freshwater balance and ocean stratification, including vertical mixing in the North Atlantic. Despite the importance of river observations, there has been a widespread loss of hydrological monitoring networks over the past 15 years in the United States, Canada, and Russia (Shiklomanov et al., 2002). This decrease in monitoring increases the uncertainty in the estimates of water, chemicals, and sediments from the pan-arctic drainages (Shiklomanov et al., 2002). At a minimum, these observation systems need to be restored and enhanced for major Arctic rivers, including the Yukon, Mackenzie, Yenisey, Ob, and Lena. But there is an important caveat. These five largest arctic rivers have drainages that extend well into temperate latitudes,[9] so these rivers are not necessarily representative of organic carbon, tracers, and other materials contributed to the Arctic Ocean from tundra systems drained by smaller rivers and from retreating shorelines. Furthermore, gauged discharge from the ten major arctic river basins captures only approximately one percent of pan-arctic glacier discharge to the Arctic Ocean (Pfeffer and Dyurgerov, 2005) and total pan-arctic glacier contributions to arctic runoff are 30 to 40 percent uncertain due to sparse and diminishing glacier mass balance observations (Pfeffer and Dyurgerov, 2005). In other words, basin-wide precipitation and glacier runoff not carried by major river systems is very poorly characterized by present-day programs. As a result, sampling only the largest rivers will not produce a representative view of all runoff contributions to the Arctic. Additionally, the freshwater inflow through Bering Strait also appears to have been underestimated (Woodgate and Aagaard, 2005), so an arctic river sampling program that is at least minimally coordinated with Bering Strait sampling is critical for observations of freshwater balance in the Arctic Ocean.

Renewing and improving hydrometeorological observation networks in Russia is crucial for the freshwater flux measurements within the AON. The recent memorandum of understanding between the Russian State Committee for Hydrometerology (Roshydromet) and the U.S. National Weather Service[10] is an example of the wider multigovernmental participation that will be needed to fully develop the AON. In the case of this memorandum, which may lead to World Bank funding, Roshydromet is seeking support to upgrade and modernize its basic hydrometeorological capabilities. This agreement will have benefits beyond Russia and the Arctic, and is seen as a vital link in building the Global Earth Observation System of Systems.

Permafrost

Permafrost has received much attention recently because surface temperatures are rising in most permafrost regions bringing permafrost to the edge of widespread thawing and degradation. Permafrost thawing that already occurs at the southern limits of the permafrost zone can generate dramatic changes in ecosystems and infrastructure functionality (Jorgenson et al., 2001; Nelson et al., 2002). However, there is no global database that defines the thermal state of permafrost within a specific time interval. Internationally, borehole temperature measurements have been obtained at various depths and periods over the past five or more decades indicating changing permafrost temperatures at different rates for different regions. Several cryospheric observation systems are already under way and can serve as a geographical focus for permafrost monitoring and other related observational activities. The International Permafrost Association[11] is responsible for developing and implementing the GTN–Permafrost[12] network of the Global Climate Observing System. The CALM network is a component of GTN-Permafrost and is providing data on active layer thickness measurements using approved protocols (Brown et al., 2000) (Box 5.5).

[8]This is not an acronym. See http://www.fluxnet.ornl.gov/fluxnet/index.cfm.

[9]See http://ecosystems.mbl.edu/partners/default.htm.

[10]http://www.publicaffairs.noaa.gov/releases2005/jun05/noaa05-083.html.

[11]http://www.geo.uio.no/IPA/.

[12]http://www.gtnp.org/.

Box 5.5
The Circumpolar Active Layer Monitoring Network: Lessons in Data Harmonization

The Circumpolar Active Layer Monitoring (CALM) network was initiated in the early 1990s. Its initial focus was on formalizing measurement programs at sites that were making active layer measurements or had done so in the past, creating new observatories, and creating coherent data archives. Data on active layer thickness are now available for 130 locations in the Arctic, the Antarctic, and at lower latitudes where permafrost occurs. Participants from 15 countries are involved with CALM, many of them on a voluntary basis.[a]

One of the initial concerns was that active layer measurements were collected using a wide variety of methods. Because there was a paucity of information about how observations collected by the different methods related to each other, the issue of sampling design (e.g., spatial sampling for probed data) was also a concern. Early efforts in CALM therefore focused on comparing methodologies and sampling designs (e.g., Fagan, 1995; Nelson et al., 1998, 1999; Brown et al., 2000; Gomersall and Hinkel, 2001).

Another component of CALM created a protocol for field measurements (Nelson et al., 1996; Nelson and Hinkel, 2003). CALM developed links with the International Tundra Experiment (ITEX) and its field measurement protocol was included in the 1996 ITEX field manual. Network representatives also made presentations on CALM and the need for standardized observations at a variety of meetings. Actions on these various fronts helped to create a system of standardized measurements as the network grew rapidly in the late 1990s.

One of CALM's most useful roles has been to provide reliable, relatively unambiguous data for model validation (F.E. Nelson, personal communication, December 2005). The data available from the network through the Frozen Ground Data Center (a component of the U.S. National Snow and Ice Data Center) are well documented, and shortcomings are noted. Working with data center staff (specialists in data organization, storage, and access) was a critical step in making the data useful to modelers and others.

Improvements in data and network design continue. CALM network members have started to analyze shortcomings in the geographic coverage of the network and further analysis of the accuracy of data collected using different techniques and sampling designs is under way.

[a]See http://www.udel.edu/Geography/calm/.

A number of candidate sites have also been identified for a global borehole network for monitoring the thermal state of permafrost (Romanovsky et al., 2002).[13] As part of the IPY, the International Permafrost Association plans to develop a network of permafrost boreholes for long-term observations. This network will include hundreds of sites in both hemispheres and initially involve participants from 20 countries. Some of these sites are located where CALM sites have also been implemented. In the United States, several of the borehole sites are located near or adjacent to areas of concentrated terrestrial ecological research. For example, Galbraith Lake and Imanavait Creek, both near Toolik Lake, are borehole and CALM sites.

Glaciers and Snowcover

Observations of glacier ice mass at high latitudes are important for understanding potential sea-level fluctuations and arctic runoff but are being discontinued. Glacier mass balance programs, such as in Alaska (e.g., the nearly defunct Alaska mass balance transect), Canada (e.g., Ellesmere, Axel Heiberg, Devon, and Penny Ice Cap), and Russia (e.g., Severnaya Zemlya), are in need of revitalization, maintenance, or expansion to extend valuable long-term time series. Furthermore, glaciers that are located in the subarctic will need to be monitored and linked into the AON, not least because of their rapid retreat (Arendt et al., 2002). In addition to contributing to river flow and sea-level rise, the loss of glacier ice is endangering potential proxy paleoclimate records that could provide information on Earth system history. The AON will need to provide for the contingencies of collecting and analyzing paleoclimate records stored in glacier ice that might otherwise be destroyed with continuing widespread glacier retreat.

Airborne and satellite-based laser altimetery, historical photographs, and remote sensing technology are among the resources available to supplement ground-based observations and to document changes in arctic glacier ice cover more broadly (e.g., Cogley and Adams, 2000; Zeeberg and Forman, 2001; Thomas et al., 2003). Because glacier observations have become highly dependent on remotely sensed images and data, the geographical co-location of terrestrial, cryospheric, and coastal observatories with glacial observatories is not critical. However, seasonal snow cover observations are closely related to vegetation patterns and albedo (Liston et al., 2002), so coordination of some snow cover observation programs with other environmental observations will be critical. Seasonal snow cover is an important hydrologic resource as well as an essential component of the physical system, and knowledge of snow water equivalent and albedo is particularly valuable. To facilitate calibration of remote sensing of these variables, in situ

[13]See also http://www.gtnp.org/english/location.htm.

measurements in areas of large interannual variability will need to be placed to enable upscaling to watersheds and satellite pixels (for validation of remote sensing), and for incorporation into system models.

Arctic Residents

Many arctic residents are widely dispersed in small communities throughout the Arctic that are distant from the few centralized flagship observatories that are likely to emerge, at least for the terrestrial components of the AON. A somewhat different situation is present in Russia, where the largest arctic population centers are located, but there are only minimal observations for a number of important parameters of environmental change and human health. Also, the Russian portion of the Arctic has limited documentation of LTK compared to North America and Fennoscandia (Huntington and Fox, 2005). Providing linkages from local communities to the wider network and collecting data of value to arctic residents are key components for successful AON implementation. An illustration of the types of data that could arise from widespread, distributed community observations is provided by Riedlinger (1999).

> Our first visit to Sachs Harbour substantiated and added to the initial observations that had provided the basis for the project. It was clear that environmental change had not gone unnoticed. In the first day of workshops, the community discussed the accumulating evidence of changes occurring in the landscape around them. They described freeze-ups that were three to four weeks late and severe storms with wind, thunder, lightning, and hail. They discussed intense, unpredictable weather and fluctuations in seasons. Hunters described not seeing ice floes in the summer anymore, umingmak (muskox) being born earlier, geese laying eggs earlier, and nanuq (polar bears) coming out from their dens earlier because of warming and thaw. They also described catching species of Pacific salmon (identified by the Department of Fisheries and Oceans as sockeye *Oncorhynchus nerka* and pink *Oncorhynchus gorbuscha*) in their nets, when traditionally such occurrences were unheard of. Too much open water in the winter was making harvesting animals difficult, as was the lack of snow in spring, the lack of sea ice in summer, increased freezing rain, and thinner ice.

Given this example of the plethora of climate-related observations that are available from one small community in the Canadian Arctic, a valid answer to the question as to where the AON should be geographically located is that it should be located everywhere that people live, hunt, fish, and work in the Arctic. Ultimately, a successfully implemented AON will link those widely distributed observations with intensive, intercomparable data collected at centralized, flagship sites.

Summary

There are many design considerations for positioning observations in the AON. Often these are discipline- or theme-specific. However, there are some generalizations that emerge for the initial phase of building the AON. For example, existing observatories and platforms will form the core of the AON if they are sustained. Additionally, even though observing systems are deteriorating in some parts of the Arctic—especially noticeable in Russia—there is still some possibility to reverse this process and recover some of the infrastructure that was available recently.

Recommendation: The first phase of AON development will require sustaining existing observational capabilities (including those under threat of closure) and filling critical gaps.

THE ROLE OF TECHNOLOGY IN THE AON

The arctic environment creates challenges to sensing in all realms. For example, the majority of the Arctic Ocean is covered by ice that makes measurements of key ocean variables (e.g., water temperature, salinity, currents) difficult without the use of ice breakers, submarines, or aircraft. Terrestrial and atmospheric instruments must contend with the extreme temperatures, high winds, ice accumulation, and damage from animals. Instruments that are remotely deployed must also contend with power generation issues during the polar night. And people working in the field need improved technology for such actions as downloading data and viewing computer screens under harsh conditions. These are only a few of the challenges that must be surmounted when developing sensing technology and supporting infrastructure for the Arctic.

Technology development and innovation must and will play a pivotal role in the continued development of the AON. There are two key areas where technological advancements can contribute: improving infrastructure that will benefit all realms of the AON and enhancing sensors that measure key variables in the Arctic.

Infrastructure

It is often assumed that because a technology already exists it should not be difficult to put the pieces together and make things work. This is a fundamental misconception. For example, consider a medium-sized scientific satellite that costs $300 million. The technology integrated into the satellite has "flight heritage" and has been used elsewhere so the fundamental engineering effort is on the interfaces between the system elements to ensure they all work together and will achieve the mission goals. Because the satellite will be placed in a harsh and remote environment, significant efforts are made to identify and manage potential risks and increase the probability of success. This so-called "systems engineering approach" is fundamental for complex technology development projects like those that will support the AON. The single investigator approach where small numbers of measurement systems are designed and deployed individually—while useful for development of new sensors—is not a sustainable model in AON infrastructure development. The AON will have an element of "big science" that will require significant coordination among scientists who are experts in application and engineers who are experts in technology.

Four areas of infrastructure technology are key to the development of the AON: communications, navigation, power storage and generation, and automation.

Communications

Communication to instrument platforms is needed for retrieving data and determining instrument status. Where bidirectional communications are available this link can also be used to remotely control the instrument. The requirements on a communications link vary depending on the measurement and observational cadence of the instrument. For some long-term monitoring applications, for example, it may be possible to retrieve data by physically visiting the site each year and collecting the data. However, without a near real-time communications link one cannot be sure the instrument is running until the annual visit and a system failure can result in significant data loss. In many cases, data are required either in real time for nowcast or forecast applications or within a few weeks of collection for scientific applications. Such requirements necessitate the use of real-time wireless communications, typically via satellite using the Iridium or a similar system.[14] Increased connectivity to remote instruments will improve reliability because data can be streamed directly back to data analysis centers where operators can monitor the instrument performance in near real-time. In the event of a problem, the system can be reconfigured remotely as soon as an error is reported. Furthermore, increased connectivity would reduce costs in situations where a device no longer needs to be physically recovered to download its data. One example is a data uplink from subsurface moorings by means of an automated underwater vehicle or glider serving as a data shuttle—thus removing the need to recover the mooring to obtain its data.

Communications are therefore an important focus for innovation and technology development. Standard interface and communication protocols will allow for ready integration of instrumentation into the AON. There is a fundamental need to ensure that the elements within the AON can exchange data among mobile platforms (e.g., undersea vehicles, gliders, and either floating or other ice-surface vehicles), vessels (both surface and submarine), and aircraft, using both acoustic and radio frequency, so that the data collected will be retrievable by multiple pathways. This capability needs to be managed to minimize power drain (e.g., through scheduling or when data volume reaches a specified level), while remaining reliable and robust so that the failure of a single antenna or transmitter does not cause data loss.

Navigation

All mobile observing systems need navigational capabilities. It is therefore of high priority to develop standards for navigation beacons. In the marine setting, by way of illustration, the highest priority for acoustic navigation is to determine the sound frequency and to ensure that deployed sound sources are compatible with all potential systems that are now under development. Some of these problems may be resolved under activities of the NSF PLUTO concept (Polar Links to Undersea Telecommunications and Observatories), which is particularly versatile and would link acoustic tomography, cabled observatories, moorings, gliders, and UAVs to provide coordinated synoptic arctic datasets. In cases where acoustic sensors are not available, low-cost inertial sensors must be used. These sensors could be used in UAVs and AUVs.

Power Storage and Generation

The power requirements of systems can range from very low power (a few watts) for underwater gliders to kilowatts for autonomous land-based observatories. Gliders can operate for extended periods of time using energy stored in batteries. However, the higher power land-based observatories either require a combination of renewable energy sources, such as solar and wind power, or large quantities of stored chemical energy, such as propane. Continued research and development on efficient sources of power generation (e.g., fuel cells) and power storage will undoubtedly benefit the AON. Although it is doubtful that the AON will have the resources to drive the technology in this area, its members would need to be active in the discussion of technology requirements to ensure that potential solutions can operate in the harsh arctic environment. The AON could benefit from collaboration with other technical entities that have power systems development programs (e.g., ESA in Europe or NASA and the Department of Energy [DOE] in the United States).

Increased Automation

Automation can enhance all network components through increased efficiency in data collection and improved data quality. An ability to automatically measure variables is particularly appealing in the harsh arctic environment where the cost and risk to humans is high and where human observers cover a small geographic area.

The variety of autonomous platforms includes anchored ocean moorings, autonomous underwater vehicles, ocean

[14]Over the continental United States, satellite television vendors offer real-time Internet access with data rates in excess of 1 megabit per second (compared with the 10 kilobits per second data rates for Iridium).

gliders, autonomous aerial vehicles, and autonomous observatories based on land, ice, and the ocean bottom. These instruments may operate unattended for extended periods of time and may need a self-contained power generation or storage system, a basic data logging capability, a mechanism for transferring data to a central processing location, and a sophisticated navigation system if they are mobile. Although simple systems can operate with little or no user input or control, more complicated systems such as autonomous unmanned vehicles require a robust supervisory control system. Automation is difficult to centralize because the requirements for each system can be vastly different. However, where there is overlap between instrument systems, coordinated development of resources will create efficiencies. Development of proprietary source code is detrimental to this approach. Instead, the distributed open source model or a more coordinated approach would benefit the AON.

Sensors

The development and integration of sensors within the AON will need to include three components: (1) adapting existing sensor technology to arctic requirements, (2) identifying observational platforms that can benefit from common technology and develop the hardware to meet these needs, and (3) determining where the AON has gaps caused by a lack of sensor availability and fill these gaps by investing in next-generation sensor research and development.

Adapting Existing Sensor Technology to Arctic Requirements

Not all new technology will be directly transferable to the arctic environment because of special challenges for developing instrumentation for polar regions. A case in point is the emerging micro- and nano-fabrication capability that has revolutionized sensory systems. Micro- and nano-electromechanical systems (MEMS and NEMS) have many advantages over their macro-scale counterparts: lower cost, smaller volume and weight, and lower power consumption. And MEMS/NEMS sensors can play a major role in the next generation of measurement systems. To reliably operate in harsh conditions, however, special sensors must be designed. To date, such developments have been limited due to the lack of commercial interest resulting from the very small potential market. Adapting MEMS/NEMS and other sensors and developing lower power versions of existing proven devices will need to be supported within a broad initiative for adapting new technologies that spans all disciplines and interests.

Common Technology

The cross-cutting nature of the AON lends itself to the development of sensors that can be deployed from a variety of arctic platforms. Shared sensors will increase the cost-effectiveness and maintainability of AON observing systems. For example, a set of sonar transducers and electronics can be mounted on an AUV to map the sea floor, or alternatively, attached to an ice-based platform, or a moored platform in an upward-looking direction to measure changes in sea ice draft over a broad swath. Ice mass-balance buoys being developed at the U.S. Cold Regions Research and Engineering Laboratory can also be co-located with other moored ice profile sonars, on helicopter or submarine surveys, or on other drifting buoys. There are a handful of other common marine-oriented sensors that are also useful in a broad spectrum of research disciplines[15] and the AON could benefit from their shared development. These sensors include sonars, current profilers, CTDs (conductivity, temperature, and depth sensors), fluorometers, transmissometers, in situ nutrient analyzers, and optical plankton counters.

Common atmospheric variables with broad applications include temperature, pressure, and relative humidity. A small and simple measurement package that senses these or other broadly applicable key variables could be deployed on UAVs, autonomous meteorological stations, or perhaps on snowmachines. These small packages could be deployed as sondes and dropped from manned or unmanned aircraft to measure the vertical structure of the atmosphere or distributed across the ice and land to create an integrated sensor network. By also equipping these packages with small, low-power global positioning system receivers, accurate time and position information can be obtained and, in cases where the sensor resides on a nonstationary surface such as sea or glacier ice, used to infer motion.

Filling Gaps Created by Lack of Appropriate Sensor Technology

Measurement requirements may not be satisfied by existing sensing technologies. The result is a measurement gap. In cases where measurement gaps are created, research and development will be required to create the sensor. The time and effort required to conduct sound engineering and development should not be underestimated, and the decision to invest in such efforts will be aided by the AON system design activity, which will be broad-based and have a strategic outlook. Because of the cost and time considerations, a prioritization effort is needed to identify sensor technologies that are applicable to multiple disciplines and are critical to the overarching goals of the AON. Where possible, such efforts would benefit from coordinating with entities that have overlapping interests (e.g., DARPA, DOE, ESA, NASA, NSF). For example, sensor technology that is being developed for sensing chemical and biological agents for

[15]For example, acoustics; physical, biological, and chemical oceanography; marine geology and geophysics; and cryogenics.

security applications could be leveraged for arctic observing—either by directly applying these technologies or with some modification for arctic operation.

Novel Technology and Arctic Communitites

Arctic residents can bring valuable insights to the design and deployment of new technologies and they provide a year-round presence to supervise testing, provide maintenance, and help with other aspects of novel technology development.

In addition, technology will facilitate the participation of arctic residents (particularly educators and students) in the AON. For example, advances in health technologies may offer better ways for locals to monitor disease or contaminants. Local people have ideas about technologies that will help them make observations and enhance community-based observation and knowledge documentation programs that link into the AON. The AON will need to strive to understand the technological needs of arctic communities to participate in the network.

Issues for Technology Development

A number of issues need to be addressed to maximize the contribution of technology development to the AON. Four of these issues are illustrated with U.S. examples because the sponsor of the study is a U.S. funding agency, but the issues are more broadly applicable.

First, the present research funding paradigm (e.g., in NSF) does not promote technology development for an AON-type endeavor. Under the present system, a single or small group of investigators is allocated resources to address a specific scientific problem. To receive funding, investigators are often overambitious in their technical objectives and do not have the time or resources to conduct proper engineering studies. Instruments are deployed without proper testing and may or may not operate as intended. Such an approach leads to unreliable equipment that cannot be propagated into future projects and provide a solid technological foundation. A coordinated engineering approach is needed where centers of excellence in polar engineering technology foster technology development. This is not without precedent. From the late 1940s until the early 1980s, the Naval Arctic Research Lab in Barrow promoted technology developments that supported polar research.

Second, support for technology development, for example by the Office of Naval Research and the Air Force Office of Scientific Research, has declined significantly in recent years. Without this or similar investment into developing, integrating, and deploying the technology, new arctic technology development will decline and adversely affect the ability of the AON to achieve its goals.

Third, validation and calibration of sensors is often neglected and little if any support is available for such efforts even though they can be complicated and time consuming. Validation and calibration are critical for long-term measurements and are as important as science goals. Without these measurements, it is impossible to conduct long-term monitoring and science since the measurement techniques and technology will inevitably change.

Fourth, the complexity and rapid evolution of technology makes it difficult for individuals or small teams to stay abreast of all advances, become experts in particular fields (e.g., communications, power storage, and power generation), or to tackle broad challenges that could address the overarching needs of networks such as the AON. Without a process for tracking and considering the benefits of all potentially useful technological advances (and identifying critical technology gaps), the AON will fall short of its goals.

SUMMARY

The potential for continued technological improvement to develop the AON is strong and will begin to be realized as these issues are addressed. Technology will continue to evolve and the state of technological advancement cannot be predicted. The AON will need to continuously evaluate the readiness levels of technology that could significantly enhance measurement of key variables in the Arctic. Technology that will improve current measurement quality and reliability will need to be continuously evaluated and strategically introduced. The AON will need engineering expert groups that track developments in sensor and infrastructure technology[16] and weigh actions (such as modifications of non-arctic technologies or development of new technology) that address overarching network needs expressed by the AON community and its users.

In conjunction with and downstream of these groups, the AON will need centers of excellence to develop and adapt existing sensor and infrastructure technology. These centers could coordinate with small businesses and with experts on specific technologies. The centers could also coordinate with a technology incubator program based on a competitive peer review process that provides resources to individual investigators or small teams to develop critical new technologies for the AON. Finally, the AON will need to foster cultural change on two fronts. The first change places infrastructure and sensor development, and validation and calibration of instruments, on the same level of importance as the resulting science and operational value. The second change replaces the culture of small independent research groups reinventing

[16]This tracking could be enhanced by creating linkages with other groups that have shared networking challenges but not necessarily an arctic focus. In the U.S., these three examples are the National Ecological Observatory Network, the Consortium of Universities for Advancement of Hydrologic Sciences, and the Alliance for Coastal Technologies.

the wheel to solve their arctic infrastructure problems with a coordinated pan-arctic approach. This latter approach could embrace the systems engineering paradigm that the private sector and NASA use to tackle complex multidisciplinary engineering problems.

Recommendation: The AON should support development, testing, and deployment of new sensors and other network-related technology. In parallel with recognizing the importance of systems engineering and instrument validation and calibration, this will require supporting (i) expert groups to track advances in technology that satisfy overarching network needs and (ii) centers of excellence and a technology incubator program to adapt and develop needed technology.[17]

[17]See Chapter 6 for detailed implementation ideas that relate to novel technology.

6

Detailed Implementation Ideas

This chapter provides ideas for implementation steps for the Arctic Observing Network (AON) and is organized around the essential functions that the Committee sees as foci of effort on the AON. The ideas presented in this chapter are drawn from many sources, including from participants at the Committee's workshops in Alaska and Denmark. These ideas are prioritized. Those in bold type provide details that support the Committee's broad recommendations that appear in the final chapter. The broad recommendations are, in fact, integrated summaries of these detailed points. The items in bold type are considered critical for the AON to reach a level of implementation in the near future that satisfies the basic characteristics of the Committee's vision of the AON (i.e., the "minimum" level mentioned in the Committee's task). Other ideas in this chapter reflect potential enhancements of the AON that could occur over a longer time period.

The Committee identifies and expands on four essential functions that support all observing activities in the AON, regardless of their mission or purpose. These functions are

1. observing system development (which includes four components: assessing complete coverage, system design and optimization, technology development, and sensor and observer deployment[1]);
2. data acquisition (which includes maintaining existing observation capabilities and filling critical gaps);
3. data management, integration, access, and dissemination; and
4. network maintenance and sustainability (which includes four components: network and observation sustainability, personnel development, coordination and integration regionally and globally, and communication).

The order of these functions follows, as best it can, the arrangement of functions in Figure 6.1. There is no significance attached to the starting point in the list of functions because (as shown in Figure 6.1) the functions are linked in a continuous loop that reflects an ever-improving network. All functions operate in parallel with respect to time. In what follows, the Committee recommends implementation steps to fulfill this vision on an international basis.

OBSERVING SYSTEM DEVELOPMENT (Essential Function 1)

The essential function of observing system development has four components: assessing complete coverage, system design and optimization, technology development, and sensor and observer deployment.

Component 1: Assessing Complete Coverage

This component identifies gaps in coverage and recommends activities to eliminate them. There are two kinds of gaps: (1) lack of coverage of specific observations, whether temporal, spatial, or thematic and (2) lack of knowledge on what determines specific subsystem dynamics. The latter is a research question that may inform future data needs within the AON and the former is more directly related to current needs within the AON. Potential collaborators to this component include the Arctic Council working groups (e.g., AMAP—Arctic Monitoring and Assessment Programme) and Permanent Participants, the IPY (International Polar Year) subcommittees on observations and data management, CEOS (Committee on Earth Observation Satellites), GEOSS (Global Earth Observation System of Systems), IGOS (Integrated Global Observation Strategy), ISAC (International Study of Arctic Change)/SEARCH (Study of Environmental Arctic Change), WMO (World Meteorological Organization), thematic groups (e.g., groups with in-depth knowledge of observation gaps for permafrost, or hydrology, or human

[1]Sensor and observer deployment is a necessary action in observing system development and therefore important to mention even though the Committee does not have specific input on the logistics of this action.

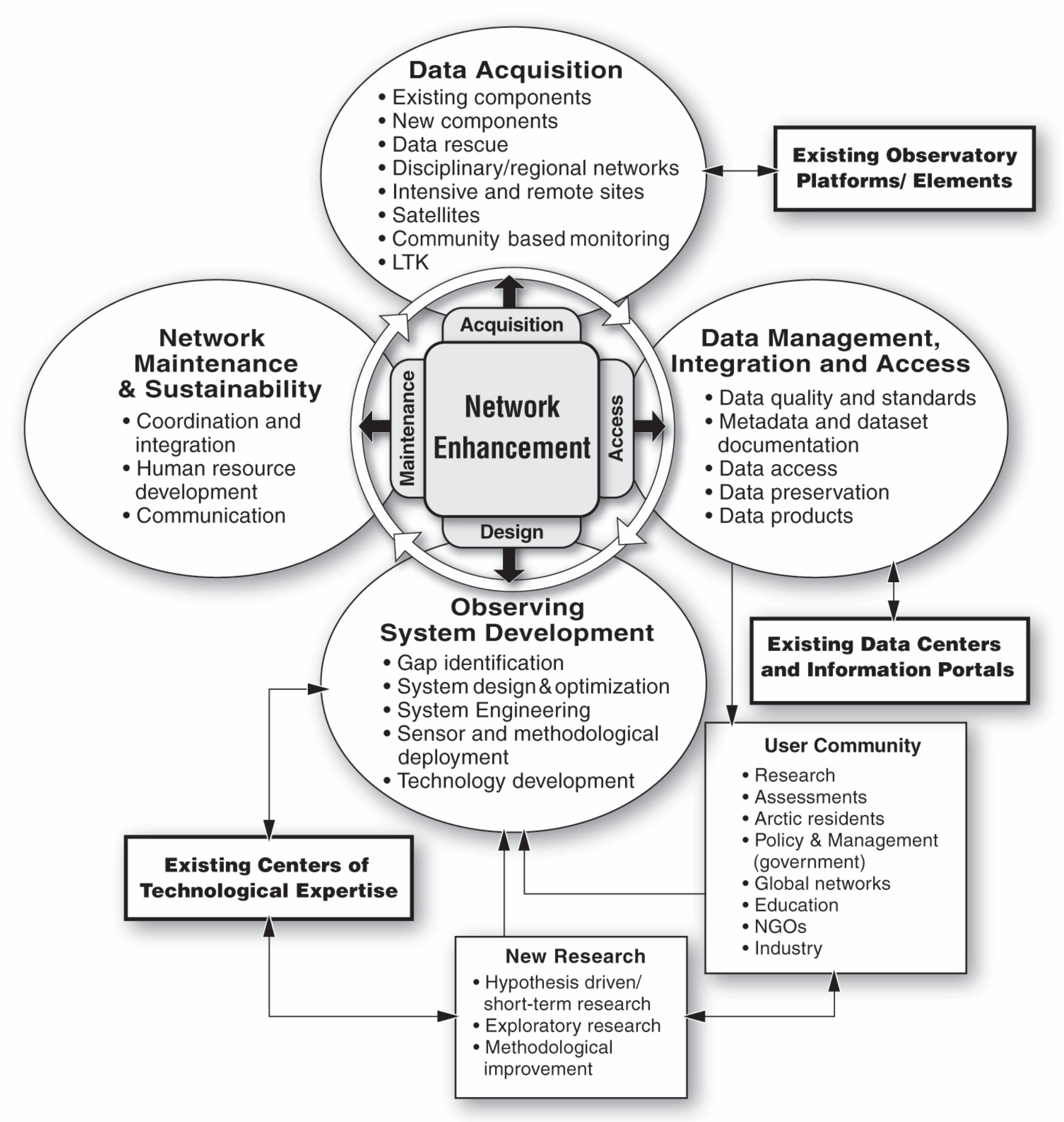

FIGURE 6.1 Flow diagram showing how the four essential functions of the AON (large ovals) relate to each other and the broader stakeholders. The direct connection of AON functions to the stakeholders indicates that the AON builds on and enhances existing capabilities. The placement of network enhancement at the center of the diagram and its connectivity to all elements of the network shows how the AON plays a central role in tying together many existing components, strengthening ties among observation platforms, data centers, and users, and generally supporting and enhancing observing activities of all participants. Graphics by N. Hulbirt and B.G. Bays, Jr., University of Hawaii.

dimensions), regional and national initiatives, and attendees of the State of the Arctic conference in 2006.

Progress in assessing complete coverage[2] could be made by

i. **Identifying key measurements that are currently under-represented, at risk, or without coverage. Where appropriate, this activity could use input from such techniques as statistical optimization approaches as well as Observing System Sensitivity Experiments (OSSEs) that would be developed and refined under the "system design and optimization" component (next section). Another facet of this process could involve feedback from assessments and syntheses that use the data from components of AON and can highlight weaknesses.**
ii. **Assessing the technological capacity and spatial and temporal adequateness of existing network components.**
iii. **Prioritizing and optimizing the mix, number, and locations for deployment of sensor and human-observer programs, especially those that will improve information flow, increase the AON's cost-effectiveness, and enhance the capacity for cross-disciplinary cooperation.**
iv. Identifying critical sites or systems that are at risk of being lost or are falling into disrepair. Demonstrate that jeopardized observations are key elements of a pan-arctic, long-term observing system.
v. Tracking emerging key science questions and assessing gaps in data to address them.
vi. Identifying what predictions of change would be most useful to stakeholder groups associated with fisheries, marine transportation and development, renewable resource use/subsistence harvests and highlight current information gaps to fill.
vii. Making better use of contextual information by developing methods to integrate paleoenvironmental data and local and traditional knowledge (LTK) with modern instrumental records.
viii. Communicating gaps to the arctic community, research programs, and agencies.

Component 2: System Design and Optimization

This component improves methods for network design and optimization. There is a positive feedback within the envisaged AON structure between observations and these design and optimization approaches. That is, observations will provide better inputs or constraints for network optimization tools that, in turn, will guide improvements in the observing strategy. Observation location, density, temporal frequency, and timeliness can also be tuned to aid reanalysis and real-time prediction efforts. In all of these efforts, an enhanced AON data management system will improve availability of observations for use in system design and optimization. Finding ways of implementing AON designs will likely require examination of how work is proposed and reviewed. Any changes would need to be addressed by the funding agencies and investigator community.

Potential collaborators on this component include institutions such as the Danish Meteorological Institute, Environment Canada, the European Centre for Medium Range Weather Forecasts, and U.S. entities such as DOE (Department of Energy), NASA (National Aeronautics and Space Administration), NCAR (National Center for Atmospheric Research), NGDC (National Geophysical Data Center), NSF (National Science Foundation), NOAA (National Oceanic and Atmospheric Administration), NSIDC (National Snow and Ice Data Center), and ONR (Office of Naval Research), among many. Collaborating projects could include ARCMIP (Arctic Regional Climate Model Intercomparison Project), AOMIP (Arctic Ocean Model Intercomparison Project), ASR (Arctic System Reanalysis), CARCMIP (Coupled Arctic Regional Climate Model Intercomparison Project), the Coordinated Enhanced Observing Period II (CEOP II), GLIMPSE (Global Implications of Arctic Climate Processes and Feedbacks), and THORpex (The Observing-system Research and predictability experiment). Broader networks such as GCOS, GOOS, GTOS, and GEOSS could also play a role.

Progress on system design and optimization[3] could be made by

i. **Designing the observing system using rigorous design tools such as OSSEs and statistical approaches. This will require**
   - **exploring the utility of coupled OSSEs (atmosphere-ice-ocean-land),**
   - **examining whether there is an observing system requirement to make the OSSEs more effective, and**
   - **validating OSSEs. Dense observations are needed over a limited (testbed) area. This does not have to be a continuous process. The observations can be obtained in a short-term, intensive field program such as IPY.**
ii. Designing integrated, multidisciplinary measurements at single sites. For example, ecosystem measurements require physical measurements (and vice versa) for context; coastal regions are best understood through integrated marine, terrestrial, and

[2]The items in bold are judged to be necessary to achieve the basic level of the Committee's vision for the AON. These ideas provide details that support general recommendation 3.1a and 3.4a.

[3]These ideas provides details that support recommendations 3.1a and 3.4a.

human dimensions observations; and interpreting proxy indicators of change commonly involves relating physical and biological variables.

iii. Testing the importance of unmodeled processes and improving model parameterizations by
- using intensive observing sites with measurements targeting processes coupling variables,
- using data from a mix of terrains (tundra, forested, glacial, sea ice, etc.),
- testing the role of subgrid-scale processes,
- including tides where applicable, and
- including internal waves (most models are currently hydrostatic).

iv. Relating observable quantities to modeled variables by
- testing whether observations match needs of models (for example, many satellite measurements such as radiance and normalized differential radiance index are not represented in models), and
- testing whether models provide output that can be tested against observations.

v. Improving data products through reanalysis.

vi. Developing real-time capabilities for
- error and failure checking on instruments, and
- quality control of data streams provided by models.

Component 3: Technology Development

This component improves the sensors, data telemetry, and operational infrastructure in the network. Potential collaborators to this function include European governments and the ESA, the governments of Japan and Australia, and the Canadian and U.S. funding agencies (civilian agencies such as NSF and NASA, and military agencies such as AFOSR [Air Force Office of Scientific Research], ONR [Office of Naval Research], and DARPA [Defense Advanced Research Projects Agency], for example), nongovernmental organizations, and private-sector entities.

Progress on technology development[4] could be made by

i. Adopting a "systems engineering" approach that examines how things work together (including sensor deployment, operations, and data acquisition—i.e., similar to the satellite design and development process) within a single, integrated AON.

ii. Developing and deploying new sensor technologies and observational methodologies based upon overarching network needs (both extant and projected). Such needs would be expressed through workshops or a working group that represents the diverse AON community.

iii. Developing expert groups to support improvements in sensors and infrastructure. These groups would provide engineering expertise to the AON on technology trends and usage, and on the systems engineering requirements for integrating technology into deployable systems. These groups would assess current technology, draft a requirements plan that covers extant and projected arctic infrastructure needs (e.g., communications bandwidth, power storage, and generation requirements), and provide a roadmap to achieve these goals.

iv. Creating centers of excellence and a technology incubator program to support sensor and infrastructure development. The centers of excellence would provide technological expertise in strategic areas (e.g., communications, power systems, sensors) for the AON. These centers would focus on developing or modifying existing technology for reliable and robust operation in the Arctic. The centers would drive improvements in technology readiness toward an operational level from the present average state that is closer to research level. The technology incubator program would complement the centers by supporting single and small groups of investigators to develop new technology for the AON. The incubator program would attract experts from technical areas where specific expertise is not readily available within the centers of excellence. Partnerships with small businesses could be initiated by employing funding mechanisms like the SBIR (Small Business Innovation Research) or STTR (Small Business Technology Transfer) programs in the United States. Such a technology incubator program would expand the financial resources focused on AON needs, using those resources to engage the talent of small companies.

v. Communicating realistic expectations of what a novel technology can achieve. Convey also its limitations and any cautions such as "this remote technology should not be seen as a replacement of ground-based monitoring." Ensure that descriptions of new technologies are written for a range of audiences, including a nonspecialist decision maker.

vi. Creating infrastructure to encourage development and migration of sensors from the research to operational realm.

vii. Investigating new ways of overcoming physical, budgetary, cultural, and other constraints on observing. For example,
- exploring the potential for a pan-arctic distribution of inexpensive sensors,

[4]These ideas provide details that support recommendation 3.2b.

- developing culturally appropriate language and technology through new technologies to bridge barriers between disciplines and cultures, and
- overcoming physical and logistical challenges (e.g., challenges due to long night, ice, freeze-thaw, distance from infrastructure, telecommunications linkages, bears).

viii. Developing replacement sensors/platforms for existing systems that are becoming obsolete but also investigating whether old sensors should be continued (for continuity of long-term data streams) versus deploying improved sensors.

ix. Learning from other disciplines—e.g., space studies—through workshops or conferences to bring researchers from disciplines together.

DATA ACQUISITION
(Essential Function 2)

This function acquires data using network assets. It includes devising strategies to maximize the value of existing measurement resources, maintain measurement sites or platforms, enhance the use of new systems, and is the function that fills the gaps identified by the "Assessing Complete Coverage" function of the AON. Examples of potential collaborators on this function—groups that are currently positioned to acquire data—are listed in Annex Table 3A.1.

Progress on existing systems[5] could be made by

i. **Maintaining ongoing critical observations.**

ii. **Revitalizing infrastructure that is judged a potential or actual critical gap and has fallen into disrepair or disuse (e.g., meteorological stations, river gauging stations, sea-level stations).**

iii. **Coordinating efforts to develop, deploy, and manage assets in the AON. The AON will not be successful with uncoordinated, single-investigator-type efforts.**

iv. **Encouraging ground-validation and cross-calibration activities to determine the equivalence of observations from different instrumentation, and to ensure the integrity and continuity of datasets.**

v. **Moving pilot research projects to operational observation status.**

vi. **Creating datasets for key variables to use as a baseline for measuring variability and change.**

vii. Incorporating LTK and observations, especially in topics of mutual interest and expertise such as ecosystem studies and extreme events.

viii. Resampling of historical (abandoned) sites (e.g., Sever sites, Russian boreholes).

ix. Rescuing data that are deemed valuable and likely to be lost.

x. Making more efficient use of remote sensing systems by
- improving data products for existing systems (e.g., TOVS [TIROS Operational Vertical Sounder], AVHRR [Advanced Very High Resolution Radiometer] and enhancing multisensor products; and
- ensuring continuity of expiring satellite sensors (e.g., those on MODIS [Moderate Resolution Imaging Spectroradiometer], and RADARSAT).

Progress on new systems could be made by

i. **Investing in new sensor and observer deployment to fill critical gaps.**

ii. **Investing in the incomplete areas of the AON through capacity building in local communities and other new observation programs.**

iii. Investing in new sensor and observer deployment to obtain optimized coverage in the "ideal" AON (as opposed to the "minimal" AON coverage that would be achieved in item [i]).

iv. Investing in new satellite sensor deployment.

v. Launching new field campaigns to validate satellite retrievals.

DATA MANAGEMENT, INTEGRATION, ACCESS, AND DISSEMINATION
(Essential Function 3)

This function ensures that all data within the AON are readily located, are of high quality, and are readily accessible. Potential collaborators on this function can be found in Annex Table 3A.4, which includes examples of data centers. In addition to data centers, there are international efforts for the electronic Geophysical Year (eGY) and IPY that already are generating momentum for this function. Progress on data management could be made by following the recommendations in Chapter 4, most of which need immediate attention. To reduce repetition, those ideas are not included here.

NETWORK MAINTENANCE AND SUSTAINABILITY
(Essential Function 4)

This function has four components: communication, coordination and integration regionally and globally, personnel development, and network and observation sustainability. These components collectively improve the efficiency and long-term continuity of the AON.

[5]These ideas provide details that support recommendation 3.2a.

Component 1: Communication

This component conveys information, ideas, and needs within and beyond the network. Potential collaborators on this component include the Arctic Council/COMAAR (Consortium for coordination of Observations and Monitoring of the Arctic for Assessments and Research), ARCUS (Arctic Research Consortium of the U.S.), CEON (Circumarctic Environmental Observatories Network), IASC (International Arctic Science Committee), and scientific organizations and academies.

Progress in communication could be made by

i. **Establishing and/or enhancing communication strategies and mechanisms between existing diverse members of the AON (e.g., networks, centers, community monitoring).**
ii. **Facilitating breakdown of international barriers including language barriers.**
iii. **Developing coordinated outreach by AON components.**
iv. Communicating what the AON is, how it can be used, and why it is worth using and/or participating in. This includes encouraging international cooperation in and understanding of the AON through events at international meetings (e.g., ASSW [Arctic Science Summit Week], and AGU and EGU (American and European Geophysical Union meetings, respectively).
v. Training people to use the network data products to build up the community of users.
vi. Expanding the communication role of groups like ARCUS to help with such items as contacts, links, and meeting announcements.
vii. Establishing feedback loops and intermediaries between disciplines, user groups, and scientists, and between science and indigenous knowledge (for quality control, gap identification, etc).
viii. Promoting communication through multiple channels (e.g., wiki sites,[6] portals, listservs, extranet, paper newsletters, and other "low tech" channels). A range of communications options will help build capacity for local communities to participate in the AON.
ix. Communicating to local observers the global implications, value, and interest in their observations.
x. Providing scientists who wish to start working in the Arctic with toolkits demonstrating successful ways to involve local communities.
xi. Creating opportunities for exchanges between scientists and local people. Such a forum could help both scientists and locals develop and test hypotheses, develop and troubleshoot new methods, post questions to be answered (e.g., Have you ever seen a caribou do X behavior? What does the ozone hole mean and does it affect me?) This could be achieved through a Web site or other ways to exchange information. There could be a role for partnering with schools (through science teachers). Teachers could help students link to information, questions, researchers on the AON and take this back to the elders or other community members to get local knowledge. This helps young people learn computer skills, science, and traditional knowledge.

[6]A wiki is a server program that allows users to collaborate in forming the content of a Web site.

Component 2: Coordination and Integration Regionally and Globally

This component connects related network activities and people with similar measurement needs and interests on both a regional and a global scale. It promotes sharing of common approaches and experiences. Further, it promotes consensus on actions that generate mutual benefit for the AON and its components. It relies heavily on the AON's communication component. Active and effective coordination keeps the flow of information and personnel development under continued growth but needs regularly fueled buy-in by users, operators, government, funding agencies, and others. Coordination can be achieved in two complementary areas: coordination of measurements and coordination of network-related activities (that may include measurements but also includes other functions of the network such as data management or gap identification). Potential collaborators on this component include funding agencies, the Arctic Council, GEO (Group on Earth Observations) partners, IASC (International Arctic Science Committee)/AOSB (Arctic Ocean Science Board), and United Nations technical agencies.

Progress on coordination of observations could be made by

i. **Making transparent and widely available what observations are being made in physical, biogeochemical, and human dimensions realms, and the data products arising from them.**
ii. **Coordinating efforts to develop, deploy, and manage assets in the AON. This could include pursuing opportunities for co-locating measurements and/or sharing platforms.**
iii. **Ensuring that individual AON observations are connected into existing global networks (such as GCOS [Global Climate Observing System], GOOS [Global Ocean Observing Network], GTOS [Global Terrestrial Observing System]) as appropriate.**

iv. Using data systems to provide the ultimate means for coordination and integration. For example, common protocols and intercalibration, standards, and conversion tools all contribute to coordinated measurements.
v. Pursuing a coordinated strategy for recording episodic events.

Progress on coordination of network-related activities could be made by organizing workshops, working groups, conference sessions, or other events or activities that bring together people with mutual interests and common challenges. For example, such activities might include identifying common gap-filling needs among various programs or focused activities (e.g., AHDR [Arctic Human Development Report], AMAP, Arctic NEON [National Ecological Observatory Network], CAFF [Conservation of Arctic Flora and Fauna), SEARCH] or learning about novel technologies from other disciplines (e.g., space studies, astronomers) at AGU or IUGG (International Union of Geodesy and Geophysics) annual meetings.

Progress on coordination with global networks could be made by

i. Making the AON the arctic component of GEOSS. As such, linking the AON into GEOSS as a separate, stand-alone network, as well as ensuring that individual observations are connected into other existing global networks such as GOOS, GCOS, and GTOS.
ii. Using fluxes in and out of the Arctic, and resultant impacts on climate, as a major rationale for coordination with global observing systems.
iii. Developing the intersection between routine local activities and global observing network components for mutual benefit.

Component 3: Network and Observation Sustainability

This component generates ideas and strategies for sustaining the network and the observations that contribute to it. Coordination, communication, and personnel development are related AON components that implement these strategies for sustaining the network. Potential collaborators on this component include science funding agencies, operational agencies, environmental agencies, UN technical agencies, private foundations, and NGOs.

Progress on improving buy-in and network usage could be made by

i. Maintaining continuity of datasets.
ii. Maintaining quality control and relevance of the network through use of network data in assessments and syntheses and subsequent feedback to the network so that monitoring activities, protocols, and technologies can be adapted as needs evolve, weaknesses are found, and gaps are identified.
iii. Developing performance assessment capabilities for network improvement.
iv. Maintaining regular contact among network partners.
v. Establishing the AON as a key arctic component of GEOSS.
vi. Maintaining and promoting a high level of user-friendliness, usability, reliability, efficiency, innovation, and excellence in all aspects of operation.
vii. Ensuring that derived products can easily be generated from the network data output to illustrate strong productivity and value for money spent.
viii. Recognizing that some observations are not sustainable unless there are local people who value the measurements.
ix. Maintaining the expertise base and identity of partners who may contribute to furthering pan-arctic understanding whereas funding and primary scope is focused on regional or thematic topics.
x. Including new partners over time to expand the expertise base of the network; improve weaknesses in disciplines, space, and time; and improve fundamental baseline datasets.

Progress on improving support for the AON could be made by

i. Ensuring involvement of many funding agencies, (e.g., IARPC [Interagency Arctic Research Policy Committee] members in the U.S. and similar entities and other organizations internationally).
ii. Ensuring involvement of governmental and non-governmental organizations.
iii. Making the AON the arctic component of GEOSS (see related idea under "Coordination").
iv. Working out international coordination of support for the network. The Arctic Council explicitly recognizes the importance of monitoring in the Arctic (e.g., Reykjavik Declaration) and could help facilitate and coordinate funding as an intergovernmental body, possibly through COMAAR. IASC and FARO (Forum of Arctic Research Operators) may be other important means by which international funding allocation could be facilitated. Each country involved in the AON could support and make their own observations and develop joint funding to build and support infrastructure to maximize integrative potential.
v. Promoting interdisciplinary integration. There is much momentum at the disciplinary level for the development of arctic observing networks, but a

major challenge is to build enthusiasm for interdisciplinary integration. This is needed for large-scale synthesis and integration across the Arctic.

Component 4: Personnel Development

This component recruits and trains human capital for the network. Potential contributors to this component include IPY for graduate students, the GLOBE (Global Learning and Observations to Benefit the Environment) program for K-12, the NOAA-Roshydromet joint observational program for Russia, government agencies, and universities (including the University of the Arctic).

Progress could be made on personnel development by

- **i. Utilizing LTK and observations, especially in monitoring themes that overlap with local interests and expertise such as ecosystem function and extreme events.**
- **ii. Breaking down barriers and finding parallels between science and LTK.**
- iii. Providing scientists who wish to start working in the Arctic with toolkits demonstrating successful ways to involve local communities.
- iv. Training people to use the AON to build up the community of users.
- v. Training the next generation of arctic scientists and local observers (including reversing the trend toward decreasing numbers of trained and active scientists in Russia).
- vi. Incorporating the younger generation into monitoring programs and encouraging them to persist with monitoring even if the short-term excitement of monitoring is less than that of research.
- vii. Improving mobility of researchers, and those involved in monitoring, between observation platforms, centers and programs, and data management centers.
- viii. Recognizing that year-round, in situ observations are highly dependent on local human resources.
- ix. Recruiting engineers to create robust sensor and observation infrastructure for the Arctic.

SUMMARY

The detailed implementation ideas presented in this chapter include accompanying examples of many potential contributing organizations. The Committee envisions multiple collaborations on the four essential functions under a common vision for the AON. The political will to do this will also be needed to make the AON a priority and to commit to work together on a long-term, pan-arctic basis.

7

Overarching Recommendations

The Committee has developed two overarching recommendations and a third, multifaceted recommendation on steps toward realizing an Arctic Observing Network (AON) that builds on and supports existing efforts so that the many ways of observing the Arctic are better integrated and available in a usable form for those who need the information. These broad recommendations summarize and are supported by detailed implementation ideas presented in the previous chapter.[1]

THE NEED FOR AN ARCTIC OBSERVING NETWORK

Recent rapid environmental changes in the Arctic are so pronounced that they have been identified despite historical and existing observing capabilities that are incomplete and uncoordinated. Lack of adequate and coordinated pan-arctic observations, however, limits society's capability to identify the geographic extent of ongoing changes, as well as the attribution of these changes. It limits society's responses to these ongoing changes and its capability to anticipate, predict, and respond to future changes that affect physical processes, ecosystems, and arctic and global residents. An efficient, complete, and integrated AON is needed to address these limitations. Such a network would be founded on existing platforms and observatories, starting with a set of key variables that are already measured at many locations but are not often collated. These measurements could contribute to a wide range of programs and activities including research studies, decision-support tools, and integrated environmental assessments that help decision makers understand what is happening and, as appropriate, to adopt adaptation and mitigation measures.

Recommendation 1: An Arctic Observing Network should be initiated using existing activities and with the flexibility and resources to expand and improve to satisfy current and future scientific and operational needs. In its initial phase, the network should monitor selected key variables consistently across the arctic system.

THE TIME IS NOW

A number of important, internationally coordinated efforts with relevance to observing the arctic system are being planned for the International Polar Year (IPY) 2007-2008. During the IPY, there will be a burst of new and intensive monitoring for a two-year period that will help jump-start the AON. Experience, knowledge, and infrastructure (in particular, new data, new data measurement and management approaches, and new logistical support) gained through the IPY could provide additional resources to advance the AON beyond its existing core components (e.g., AMAP, EMEP, IABP, ITEX, etc). In addition, there are ongoing or planned activities including the Global Earth Observation System of Systems, the Study of Environmental Arctic Change, the International Study of Arctic Change, the Arctic Council's Consortium for coordination of Observation and Monitoring of the Arctic for Assessment and Research that provide timely opportunities to enhance and coordinate the AON because they offer access to international partners and capabilities.

Recommendation 2: Work to design and implement an internationally coordinated Arctic Observing Network should begin immediately to take advantage of a unique window of opportunity created by a convergence of international activities during the International Polar Year that focus on observations.

[1] See also Chapter 4 for supporting details in the case of recommendation 3.3 on data management.

ESSENTIAL FUNCTIONS OF THE ARCTIC OBSERVING NETWORK

As conceived by the Committee, the AON would have four essential functions that operate in parallel, build on existing resources, and serve the interests of all participants:

1. observing system development (which includes assessing complete coverage, system design and optimization, technology development, and sensor and observer deployment);
2. data acquisition (including maintaining existing observational capabilities and filling critical gaps);
3. data management, integration, access, and dissemination; and
4. network maintenance and sustainability (which includes network and observation sustainability, personnel development, coordination and integration regionally and globally, and communication).

Parallel progress on all four of these functions is needed in part because different communities and disciplines are at different stages of development, but also because each function is critical to development of a comprehensive AON. Flexibility to accommodate technological improvements and changing sensor density is needed from the outset.

Observing System Development

There are existing platforms and observatories that can be built on and organized, although not all domains are equally developed (e.g., particularly poor coverage in the Arctic Ocean). Some elements of the AON already exist and provide a good starting point for its development, but these are generally not integrated spatially or across disciplines, and they frequently contain gaps in temporal and spatial coverage. Many of the AON components have not been optimized with respect to maximum observational efficiency, spatial and temporal coverage, or potential for interdisciplinary linkages and integration. Further, some critical elements of the AON require significant development (e.g., local observation networks). Although the Committee has provided a preliminary assessment of critical gaps in observing key variables for the arctic system, a more comprehensive, scientifically based, rigorous assessment is needed.

Recommendation 3.1a: A system design assessment should be conducted within the first two years of Arctic Observing Network development—that is, as a component of International Polar Year—to ensure a pan-arctic, multidisciplinary, integrated network. This effort should be undertaken by a diverse team, with participation and input from multiple disciplines, stakeholder groups, and those involved in related international observing activities. The assessment should use existing design studies, models, statistical approaches, and other tools.

The initial system design assessment, in conjunction with the pulse of new data from the International Polar Year projects, will provide valuable guidance for enhancing the AON and maximizing its potential utility, as will information on specific performance metrics and user feedback.

Recommendation 3.1b: The Arctic Observing Network should be continuously improved and enhanced by taking advantage of the findings and recommendations in the system design assessment and performance metrics and data provider and user feedback that will become an enduring component of the network.

Data Acquisition

Existing observatories and platforms will form the core of the AON if they are sustained. Furthermore, even though observing systems are deteriorating in some parts of the Arctic—especially noticeable in Russia—there is still some possibility to reverse this process and recover some of the infrastructure that was available recently.

Recommendation 3.2a: The first phase of Arctic Observing Network development will require sustaining existing observational capabilities (including those under threat of closure) and filling critical gaps.

The harshness of the arctic environment poses unique challenges to many types of data acquisition, distribution, and supporting infrastructure. Development of new tools will be important in overcoming these challenges and bolstering the AON.

Recommendation 3.2b: The Arctic Observing Network should support development, testing, and deployment of new sensors and other network-related technology. In parallel with recognizing the importance of systems engineering and instrument validation and calibration, this will require supporting (i) expert groups to track advances in technology that satisfy overarching network needs and (ii) centers of excellence and a technology incubator program to adapt and develop needed technology.

Data Management, Integration, Access, and Dissemination

An abundance and diversity of arctic observing systems and programs already exists, but the infrastructure to integrate results from these resources is lacking. A comprehensive data management system is needed for a successful, international AON that seamlessly links arctic sensors, data, and researchers and other users across space and time. Building this infrastructure requires accommodating a broad spectrum of users ranging from those who build and deploy instruments that collect data for a specific purpose to those who intend only to examine data or value-added data and information products. Accommodating all of these users will require building a data management system that is independent of nation, language, background, expertise, or scientific interest—no small feat—but the successful completion of this task is the most significant contribution necessary to create a truly integrated network. Such a data management system would need to provide for data standards, metadata, dataset documentation, discovery (the ability to find data), data rescue, access, preservation, and value-added products.[2]

Recommendation 3.3: A data management system initially built on existing data centers and resources must be designed and implemented immediately by an Arctic Observing Network data management committee to support major functions of the network. This system should be accessible through a single portal that connects data across disciplines and themes and should seamlessly link information from arctic sensors, historical datasets, and researchers and other users across space and time.

Network Maintenance and Sustainability

The current problems with lack of complete spatial and temporal coverage of observations have arisen in part because of a general lack of sustained support for long-term observations, networks, and data systems by regional, national, and international funding entities. Enhancing the AON requires dedicated and long-term resources for sustaining observing platforms, for providing incentives for observatories to contribute data to the network, and for network coordination and integration, communication, and human resource development. The AON needs to be founded on interagency and organizational support at the international level, including an international, multiparticipant structure that takes responsibility for the AON.

Recommendation 3.4a: For the Arctic Observing Network to realize its potential, long-term, coordinated international resources and efforts should be dedicated to sustaining observing platforms, providing incentives for contributions to the network, network coordination and integration, communication, and human resource development.

Human dimensions research and local and traditional knowledge (LTK) play important roles in the AON and the AON can be an important resource for arctic residents. The Committee recognizes that a key to the success of the AON will be building strong partnerships among physical, natural, and social scientists, human dimensions researchers, and arctic residents. Additionally, collaboration with local communities and incorporation of LTK will take significant investment of time and resources and careful consideration of proper communication, data collection methods, and access and control of information. The role that LTK will play in the AON will need to be defined by early and ongoing dialog with representatives from local and indigenous communities. Enhancing cooperation among all the diverse contributors and users of the AON will require a commitment to communication and a willingness to understand and accept the various and evolving needs and perspectives from around the Arctic that will drive the AON.

Recommendation 3.4b: Arctic residents must be meaningfully involved in the design and development of all stages of the Arctic Observing Network. From the outset, the system design assessment should cultivate, incorporate, and build on the perspectives of human dimensions research and arctic residents. The Arctic Observing Network must learn what is needed to facilitate the involvement of local communities and create an observing network that is useful to them as well as to scientists and other users.

CLOSING REMARKS

The Committee has drawn on many perspectives from within and outside the Arctic to formulate general and specific ideas about the design of an AON that evolves efficiently from the existing, somewhat disconnected and incomplete building blocks of networks, observatories, observers, data centers, etc., toward an integrated and complete network with intimate ties to global networks. The report presents many ideas in the hope that the arctic observation community and its stakeholders (i.e., data users) will begin to discuss these details and identify existing entities or consortia to refine and implement them. Some areas of the Arctic have more developed monitoring and information systems than others and for this reason it is critical to engage all arctic nations from the outset. The foundations of an AON already exist. The need to characterize the state of the Arctic and to identify, attribute, and respond to arctic change is acute. The time is right for major progress.

[2]See Chapter 4 for implementation ideas on these topics.

References

ACIA (Arctic Climate Impact Assessment). 2004. Impacts of a Warming Arctic, Arctic Climate Impacts Assessment. Cambridge University Press.

ACIA Scientific Report. 2005. Cambridge University Press.

AHDR (Arctic Human Development Report). 2004. Akureyri: Stefansson Arctic Institute.

AMAP (Arctic Monitoring and Assessment Programme). 1998. Assessment Report: Arctic Pollution Issues. Oslo, Norway: AMAP Secretariat.

AMAP. 2004. Persistent Toxic Substances, Food Security and Indigenous Peoples of the Russian North. Final report. Oslo, Norway: AMAP Secretariat. 192 pp.

ARCUS (Arctic Research Consortium of the United States). 2004. Guidelines for Improved Cooperation Between Arctic Researchers and Northern Communities. Fairbanks: Arctic Research Consortium of the United States. Available at: http://www.arcus.org/guidelines/index.html.

Arendt, A.A., K.A. Echelmeyer, W.D. Harrison, C.S. Lingle, and V.B. Valentine. 2002. Rapid wastage of Alaska glaciers and their contribution to rising sea level. Science 297:382-386.

Billings, W.D., J.O. Luken, D.A. Mortensen, and K.M. Peterson. 1982. Arctic tundra: A source or sink for atmospheric carbon dioxide in a changing environment? Oecologia 53:7-11.

Brown, J., K.M. Hinkel, and F.E. Nelson. 2000. The Circumpolar Active Layer Monitoring (CALM) program: Research designs and initial results. Polar Geography 24:165-258.

Burnside, R. 2005. Forest Health Update—A Decade of Beetle Activity in Alaska. Available at: http://www.borough.kenai.ak.us/sprucebeetle/New/Burnside.htm. Accessed on January 20, 2006.

Camill, P. 2005. Permafrost thaw accelerates in boreal peatlands during late-20th century climate warming. Climatic Change 68:135-152.

Carter, T. 1998. Changes in the thermal growing season in Nordic countries during the past century and prospects for the future. Agricultural and Food Science in Finland 7:161-179.

CAVM (Circumpolar Arctic Vegetation Map) Team. 2003. Circumpolar Arctic Vegetation Map (Scale 1:7,500,000). Conservation of Arctic Flora and Fauna (CAFF) Map No. 1. Anchorage, Alaska: U.S. Fish and Wildlife Service.

CCSDS (Consultative Committee for Space Data Systems). 2002. Reference Model for an Open Archival Information System (OAIS) CCDSD 650.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS Secretariat. [Equivalent to ISO 14721:2002].

Center for Arctic Cultural Research. 1989. Nordic Statement of Principles and Priorities in Arctic Research. Umea, Sweden.

Chapin, F.S., III. 2005. Oral communication to the committee, February, 2005. Available at: http://dels.nas.edu/prb/aon/pdfs/chapin.pdf.

Chapin, F.S., III, M. Sturm, M.C. Serreze, J.P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L.D. Hinzman, G. Jia, C.L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker. 2005. Role of land-surface changes in arctic summer warming. Science 310:657-660. doi: 10.1126/science.1117368.

Coakley, B.J., D. Chayes, A. Proshutinsky, and T. Weingartner. 2005. Objectives for a cabled observatory in Alaska's Beaufort Sea. Eos, Transactions, American Geophysical Union 86:177-182.

Cogley, J.G., and W.P. Adams. 2000. Remote-sensing resources for monitoring glacier fluctuations on Axel Heiberg Island. Arctic 53:248-259.

Comiso, J.C. 2003. Warming trends in the Arctic from clear sky satellite observations. Journal of Climate 16:3498-3510.

Cooper, L.W., ed. 2003. Land-Shelf Interactions: A Scientific Initiative in the Arctic Near-shore. RAISE/LSI Project Management Office, University of Tennessee. Available at: http://arctic.bio.utk.edu/screen_LSI_science_plan.pdf.

Couclelis, H. 2003. The Certainty of Uncertainty: GIS and the Limits of Geographic Knowledge. Transactions in GIS 7(2):165-175. Available at: http://ejournals.ebsco.com/direct.asp?ArticleID=H9HG6FM37MRBFQXB2YAC.

Derocher, A.E., N.J. Lunn, and I. Stirling. 2004. Polar bears in a warming climate. Integrative and Comparative Biology 44:163-176.

Déry, S.J., and E.J. Wood. 2005. Decreasing river discharge in northern Canada. Geophysical Research Letters 32, L10401, doi:10.1029/2005.

Dyurgerov, M.B. 2002. Glacier Mass Balance and Regime: Data of Measurements and Analysis. Occasional Paper #55. 268 pp. Available at: http://instaar.colorado.edu/other/occ_papers.html.

Dyurgerov, M.B., and C.L. Carter. 2004. Observational evidence of increases in freshwater inflow to the Arctic Ocean. Arctic, Antarctic, and Alpine Research 36:117-122.

Eamer, J. 2005. Testimony to committee. Available at: http://dels.nas.edu/prb/aon/meeting3.shtml.

Fagan, J.D. 1995. Sampling Designs for the Measurement of Active-Layer Thickness. M.S. thesis, Rutgers University, New Brunswick. 118 pp.

FGDC (Federal Geographic Data Committee). 1998. Content Standard for Digital Geospatial Metadata. Washington, D.C.: FGDC.

Fox, S. 2002. These Are Things That Are Really Happening: Inuit Perspectives on the Evidence and Impacts of Climate Change in Nunavut. Pp. 12-53 in The Earth Is Faster Now: Indigenous Observations of Arctic Environmental Change. I. Krupnik and D. Jolly, eds. Fairbanks, Alaska: Arctic Research Consortium of the United States.

Frey, K.E., and L.C. Smith. 2005. Amplified carbon release from vast West Siberian peatlands by 2100. Geophysical Research Letters 32, L09401, doi:10.1029/2004GL022025.

GEOSS (Global Earth Observation System of Systems). 2005. 10-year implementation plan reference document. Available at: http://earthobservations.org/docs/.

Gomersall, C., and K.M. Hinkel. 2001. Estimating the variability of active layer thaw depth in two physiographic regions of northern Alaska. Geographical Analysis 33:141-155.

Gray, J., D.T. Liu, M.A. Nieto-Santisteban, A.S. Szalay, G. Heber, and D. DeWitt. 2005. Scientific Data Management in the Coming Decade. Microsoft Research Technical Report (MSR-TR-2005-10). Available at: http://research.microsoft.com/research/pubs/view.aspx?tr_id=860.

Grenier, L. 1998. Working with Indigenous Knowledge: A Guide for Researchers. Ottawa, Canada: International Development Research Centre.

Grünzweig, J.M., S.D. Sparrow, D. Yakir, and F.S. Chapin III. 2004. The impact of agricultural land-use change on carbon storage in boreal forests. Global Change Biology 10, doi:10.1111/j.1365-2486.2004.00738.x, 454.

Hankin, S., and the DMAC Steering Committee. 2005. Data Management and Communications Plan for Research and Operational Integrated Ocean Observing Systems: I. Interoperable Data Discovery, Access, and Archive. Arlington, Virginia: Ocean.US. 304 pp. Available at: http://dmac.ocean.us/dacsc/imp_plan.jsp.

HARC (Human Dimensions of the Arctic System). 2005. Designing the Human Dimension into an Arctic Observing Network. Brochure produced by the HARC Science Steering Committee for AON. 2 pp.

Holloway, G., and T. Sou. 2002. Has arctic sea ice rapidly thinned? Journal of Climate 15:1691-1701.

Holmes, R.M., B.J. Peterson, V.V. Govdeev, A.V. Zhulidov, M. Meybeck, R.B. Lammers, and C.J. Vörösmarty. 2000. Flux of nutrients from Russian rivers to the Arctic Ocean: Can we establish a baseline against which to judge future changes? Water Resources Research 36:2309-2320.

Huntington, H.P., and S. Fox. 2005. The Changing Arctic: Indigenous Perspectives. Pp. 61-98 in Arctic Climate Impact Assessment (ACIA). Cambridge University Press.

ICSU (International Council for Science). 2004. ICSU Report of the CSPR Assessment Panel on Scientific Data and Information. Paris: ICSU.

IPCC (Intergovernmental Panel on Climate Change). 2000. Special Report on Land Use, Land-Use Change, and Forestry. R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken, eds. Cambridge University Press.

IPCC Third Assessment Report: Climate Change 2001. R.T. Watson, D.L. Albritton, T. Barker, I.A. Bashmakov, O. Canziani, R. Christ, U. Cubasch, O. Davidson, H. Gitay, D. Griggs, K. Halsnaes, J. Houghton, J. House, Z. Kundzewicz, M. Lal, N. Leary, C. Magadza, J.J. McCarthy, J.F.B. Mitchell, J.R. Moreira, M. Munasinghe, I. Noble, R. Pachauri, B. Pittock, M. Prather, R.G. Richels, J.B. Robinson, J. Sathaye, S. Schneider, R. Scholes, T. Stocker, N. Sundararaman, R. Swart, T. Taniguchi, and D. Zhou, eds. Cambridge University Press.

IPY (International Polar Year). 2005. IPY Data Policy Document (Draft of June, 2005). Available at: http://www.ipy.org/international/joint-committee/data-management.htm. Accessed on January 23, 2006.

Isaksen, K., P. Holmlund, J.L. Sollid, and C. Harris. 2001. Three deep alpine-permafrost boreholes in Svalbard and Scandinavia. Permafrost and Periglacial Processes 12:13-25.

ISO (International Standards Organization). 2003. Geographic information—Metadata. ISO 19115:2003(E). ISO Technical Committee (ISO/TC) 211: Geographic Information/Geomatics.

IWGEO (Interagency Working Group on Earth Observations). 2005. Strategic Plan for the U.S. Integrated Earth Observing System. Available at: http://usgeo.gov/docs/EOCStrategic_Plan.pdf. Accessed on January 18, 2006.

Jorgenson, M.T., C.H. Racine, J.C. Walters, and T.E. Osterkamp. 2001: Permafrost degradation and ecological changes associated with a warming climate in central Alaska. Climatic Change 48(4):551-571.

Keeling, C.D. 1998. Rewards and penalties of monitoring the Earth. Annual Review of Energy and Environment 23:25-82.

Keeling, C.D., J.F.S. Chin, and T.P. Whorf. 1996. Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. Nature 382:146-149.

Kelly, B.P. 2001. Climate change and ice breeding pinnipeds. Pp 43-55 in: "Fingerprints" of Climate Change: Adapted Behaviour and Shifting Species' Ranges. G.-R. Walther, C.A. Burga, and P.J. Edwards, eds. London and New York: Kluwer Academic/Plenum Publishers.

Krabill, W.B., W. Abdalati, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright, and J. Yungel. 2000. Greenland ice sheet: High-elevation balance and peripheral thinning. Science 289:428-430.

Krupnik, I., and D. Jolly, eds. 2002. The Earth Is Faster Now: Indigenous Observations of Arctic Environmental Change. Fairbanks, Alaska: Arctic Research Commission of the United States.

Krupnik, I., M. Bravo, Y. Csonka, G. Hovelsrud-Broda, L. Müller-White, B. Poppel, P. Schweitzer, and S. Sörlin. 2005. Social sciences and humanities in the International Polar Year 2007-2008: An integrating mission. Arctic 58(1):91-101.

Leicester, S., G.R. Major, L. Olsen, and L. Belbin. 2001. The Virtual Antarctic Master Directory: A portal to Antarctic data sets. Annual Proceedings of the Geoscience Information Society 32:143-154.

Liston, G.E., J.P. Mcfadden, M. Sturm, and R.A. Pielke. 2002. Modeled changes in arctic tundra snow, energy and moisture fluxes due to increased shrubs. Global Change Biology 8:17-32.

Loring, E. 2005. Testimony to committee. Available at: http://dels.nas.edu/prb/aon/meeting2.shtml.

Magnuson, J.J., D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Stewart, and V.S. Vuglinski. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289:1743-1746, doi: 10.1126/science.289.5485.1743.

Moore, G.E. 1965. Cramming more components onto integrated circuits, Electronics Magazine 38(8):114-117.

Nelson, F.E., and K.M. Hinkel. 2003. Methods for measuring active-layer thickness. In O. Humlum and N. Matsuoka, eds., Handbook on Periglacial Field Methods. Longyearbyen, Norway: University of the North in Svalbard. Available at: http://www.unis.no/RESEARCH/GEOLOGY/Geo_research/Ole/PeriglacialHandbook/ActiveLayerThicknessMethods.htm.

Nelson, F.E., J. Brown, T. Lewkowicz, and A. Taylor. 1996. Active layer protocol. Pp. 14-16 in U. Molau and P. Molgaard, eds., ITEX Manual, Second Edition. Copenhagen: International Tundra Experiment.

Nelson, F.E., K.M. Hinkel, N.I. Shiklomanov, G.R. Mueller, L.L. Miller, and D.A. Walker. 1998. Active-layer thickness in north-central Alaska: Systematic sampling, scale, and spatial autocorrelation. Journal of Geophysical Research 103:28963-28973.

Nelson, F.E., N.I. Shiklomanov, and G.R. Mueller. 1999. Variability of active-layer thickness at multiple spatial scales, north-central Alaska, U.S.A. Arctic, Antarctic, and Alpine Research 31:158-165.

Nelson, F.E., O.A. Anisimov, and N.I. Shiklomanov. 2001. Subsistence risk from thawing permafrost. Nature 410:889-890.

Nelson, F.E., O.A. Anisimov, and N.I. Shiklomanov. 2002. Climate change and hazard zonation in the circum-arctic permafrost regions. Natural Hazards 26:203-225.

NRC (National Research Council). 1995. Finding the Forest in the Trees: The Challenge of Combining Diverse Environmental Data. Washington, D.C.: National Academy Press.

NRC. 2001. Enhancing NASA's Contribution to Polar Science: A Review of Polar Geophysical Data Sets. Washington, D.C.: National Academy Press.

NRC. 2003. Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. Washington, D.C.: The National Academies Press.

NRC. 2004. A Vision for the International Polar Year 2007-2008. Washington, D.C.: The National Academies Press.

NRI (Nunavut Research Institute) and ITC (Inuit Tapirisat of Canada). 1998. Negotiating Research Relationships: A Guide for Communities. Iqaluit and Ottawa: Nunavut Research Institute and Inuit Tapirisat of Canada (now known as Inuit Tapiriit Kanatami - ITK).

NSB (National Science Board). 2005. Long-Lived Digital Data Collections: Enabling Research and Education in the 21st Century. National Science Board NSB-05-04.

NSF (National Science Foundation), Office of Polar Programs. 2005. Principles for the Conduct of Research in the Arctic. Available at: http://www.nsf.gov/od/opp/arctic/conduct.jsp.

NSF/LOC (National Science Foundation/Library of Congress). 2003. It's About Time: Research Challenges in Digital Archiving and Long-Term Preservation, Final Report. Workshop on Research Challenges in Digital Archiving and Long-Term Preservation, August 2003. Sponsored by the National Science Foundation, Digital Government Program and Digital Libraries Program, Directorate for Computing and Information Sciences and Engineering, and the Library of Congress, National Digital Information Infrastructure and Preservation Program.

NVO (National Virtual Observatory). 2005. Towards a National Virtual Observatory: Science Goals, Technical Challenges, and Implementation Plan. Available at: http://www.us-vo.org/pubs/files/white_paper.pdf.

OCEAN.US. 2005. Data Management and Communications Plan for Research and Operational Integrated Ocean Observing Systems I. Interoperable Data Discovery, Access, and Archive. Available at: http://dmac.ocean.us/dacsc/imp_plan.jsp. Accessed on February 16, 2006.

Osterkamp, T.E., and V.E. Romanovsky. 1999. Evidence for warming and thawing of discontinuous permafrost in Alaska. Permafrost and Periglacial Processes 10(1):17-37.

Otterå, O.H., H. Drange, M. Bentsen, N.G. Kvamstø, and D. Jiang. 2003. The sensitivity of the present-day Atlantic meridional overturning circulation to freshwater forcing. Geophysical Research Letters 30(17), 1898, doi:10.1029/2003GL017578.

Overland, J.E., M.C. Spillane, and N.N. Soreide. 2004. Integrated analysis of physical and biological Pan-Arctic change. Climatic Change 63:291-322.

Parsons, M.A., and R. Duerr. 2005. Designating user communities for scientific data: Challenges and solutions. Data Science Journal 4:31-38.

Petersen, M.R., W.W. Larned, and D.C. Douglas. 1999. At-sea distribution of Spectacled Eiders: A 120-year-old mystery resolved. The Auk 116 (4):1009-1020.

Peterson, B.J., R.M. Holmes, J.W. McClelland, C.J. Vörösmarty, I.A. Shiklomanov, A.I. Shiklomanov, R.B. Lammers, and S. Rahmstorf. 2002. Increasing river discharge to the Arctic Ocean. Science 298:2171-2173.

Pfeffer, W.T, and M. Dyurgerov. 2005. Testimony to committee. Available at: http://dels.nas.edu/prb/aon/meeting2.shtml.

Plag, H.-P. 2000. Arctic tide gauges: A status report. Report IOC/INF-1147. Paris: Intergovernmental Oceanographic Commission, UNESCO. Available at: http://unesdoc.unesco.org/images/0012/001216/121683e.pdf.

Proshutinsky, A., A. Plueddemann, J. Toole, and R. Krishfield, eds. 2004. Ice-Based Observatories: A Strategy for Improved Understanding of the Arctic Atmosphere-Ice-Ocean Environment within the Context of an Integrated Arctic Observing System. Woods Hole, Massachusetts: Woods Hole Oceanographic Institution.

Riedlinger, D. 1999. Climate change and the Inuvialuit of Banks Island, NWT: Using traditional environmental knowledge to complement Western science. InfoNorth (Arctic) 52(4):430-432.

Rignot, E., and R.H. Thomas. 2002. Mass balance of polar ice sheets. Science 297:1502-1506.

Rigor, I.G., and J.M. Wallace. 2004. Variations in the age of Arctic sea-ice and summer sea-ice extent. Geophysical Research Letters 31, L09401, doi:10.1029/2004GL019492.

Rigor, I.G., J.M. Wallace, and R.L. Colony. 2002. Response of sea ice to the Arctic Oscillation. Journal of Climate 15:2648-2662.

Romanovsky, V., M. Burgess, S. Smith, K. Yoshikawa, and J. Brown. 2002. Permafrost temperature records: Indicators of climate change. Eos, Transactions of the American Geophysical Union 83(50):589-594.

Ross, D.W., G.E. Daterman, J.L. Boughton, and T.M. Quigley. 2001. Forest health restoration in south-central Alaska: A problem analysis. Tech. Rep. PNW-GTR-523. Portland, Oregon: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Available at: http://www.fs.fed.us/pnw/pubs/gtr523.pdf.

Schiller, A., U. Mikolajewicz, and R. Voss. 1997. The stability of the North Atlantic thermohaline circulation in a coupled ocean-atmosphere general circulation model. Climate Dynamics 13(5):325-347.

Schlosser, P., W.S. Tucker, W. Warnick, and A. York, eds. 2003. Arctic Research Support and Logistics: Strategies and Recommendations for System-scale Studies in a Changing Environment. Fairbanks, Alaska: Arctic Research Consortium of the United States.

SEARCH (Study of Environmental Arctic Change) SSC (Science Steering Committee). 2001. Study of Environmental Arctic Change: Science Plan. Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle.

SEARCH SSC and IWG (Implementation Working Group). 2003. SEARCH: Study of Environmental Arctic Change, Implementation Strategy, Revision 1.0. Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle.

SEARCH. 2005. Study of Environmental Arctic Change: Plans for Implementation During the International Polar Year and Beyond. Report of the SEARCH Implementation Workshop, May 23-25, 2005. Fairbanks, Alaska: Arctic Research Consortium of the United States. Available at: http://www.arcus.org/search/meetings/2005/siw/report.php. Accessed on January 23, 2006.

SEEDS Formulation Team. 2003. Strategic Evolution of Earth Science Enterprise Data Systems (SEEDS) Formulation Team Final Recommendations Report. Available at: http://lennier.gsfc.nasa.gov/seeds/FinRec.htm.

Serreze, M.C., J.A. Maslanik, T.A Scambos, F. Fetterer, J. Stroeve, K. Knowles, C. Fowler, S. Drobot, R.G. Barry, and T.M. Haran. 2003. A record minimum Arctic sea ice extent and area in 2002. Geophysical Research Letters 30(3), doi: 10.1029/2002GL016406.

Shaver, G.R., T.V. Callaghan, C.E. Tweedie, and P.J. Webber. 2004. Flagship Observatories for Arctic Environmental Research and Monitoring. Report of a workshop held November 18-20, 2004, at the Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts.

She, J., and J.L. Høyer. 2004. Ad hoc sampling strategy design for T/S monitoring in the Baltic-North Sea. Technical Report 04-13. Copenhagen: Danish Meteorological Institute. Available at: http://ocean.dmi.dk/staff/jlh/PAPERS/Tr04-13.pdf.

Shiklomanov, A.I., R.B. Lammers, and C.J. Vörösmarty. 2002. Widespread decline in hydrological monitoring threatens Pan-Arctic research. Eos, Transactions of the American Geophysical Union 83(2):13.

Smith, L.C., Y. Sheng, G.M. MacDonald, and L.D. Hinzman. 2005. Disappearing Arctic lakes. Science 308:1429.

Smithwick, E., M.G. Turner, M.C. Mack, and F.S. Chapin III. 2005. Postfire soil N cycling in northern conifer forests affected by severe, stand-replacing wildfires, Ecosystems 8:163-181, doi: 10.1007/s10021-004-0097-8.

Smol, J.P., A.P. Wolfe, H.J.B. Birks, M.S.V. Douglas, V.J. Jones, A. Korhola, R. Pienitz, K. Ruhland, S. Sorvari, D. Antoniades, S.J. Brooks, M.A. Fallu, M. Hughes, B.E. Keatley, T.E. Laing, N. Michelutti, L. Nazarova, M. Nyman, A.M. Paterson, B. Perren, R. Quinlan, M. Rautio, E. Saulnier-Talbot, S. Siitonen, N. Solovieva, and J. Weckstrom. 2005. Climate-driven regime shifts in the biological communities of Arctic lakes. Proceedings of the National Academy of Sciences 102(12):4397-4402.

State Committee of the USSR on Hydrometeorology and Controlled Natural Environments. 1985. Arctic Atlas. Moscow: Arctic and Antarctic Research Institute. (In Russian).

Stroeve, J.C., M.C. Serreze, F. Fetterer, T. Arbetter, W. Meier, J. Maslanik, and K. Knowles. 2005. Tracking the Arctic's shrinking ice cover: Another extreme September minimum in 2004. Geophysical Research Letters 32, L04501, doi: 10.1029/2004GL021810.

Sturm M., C. Racine, and K. Tape. 2001. Climate change: Increasing shrub abundance in the Arctic. Nature 411:546-547.

Thomas, R.H., W. Abdalati, E. Frederick, W.B. Krabill, S. Manizade, and K. Steffen. 2003. Investigation of surface melting and dynamic thinning on Jakobshavn Isbrae, Greenland. Journal of Glaciology 49:231-239.

Uttal, T., J.A. Curry, M.G. McPhee, D.K. Perovich, R.E. Moritz, J.A. Maslanik, P.S. Guest, H.L. Stern, J.A. Moore, R. Turenne, A. Heiberg, M.C. Serreze, D.P. Wylie, O.G. Persson, C.A. Paulson, C. Halle, J.H. Morison, P.A. Wheeler, A. Makshtas, H. Welch, M.D. Shupe, J.M. Intrieri, K. Stamnes, R.W. Lindsey, R. Pinkel, W.S. Pegau, T.P. Stanton, and T.C. Grenfeld. 2002. Surface heat budget of the Arctic Ocean. Bulletin of the American Meteorological Society 83(2):255-276.

Vitousek, P.M., C.M. D'Antonio., L.L. Loope, M. Rejmánek, and R. Westbrooks. 1997. Introduced species: A significant component of human-caused global change. New Zealand Journal of Ecology 21:1-16.

Walker, D.A., H.E. Epstein,W.A. Gould, A.M. Kelley, A.N. Kade, J.A. Knudson, W.B. Krantz, G. Michaleson, R.A. Peterson, C.L. Ping, M.A. Raynolds, V.E. Romanovsky, and Y. Shur. 2004. Frost-boil ecosystems: Complex interactions between landforms, soils, vegetation, and climate. Permafrost and Periglacial Processes 15:171-188.

Weaver, A.J., C.M. Bitz, A.F. Fanning, and M.M. Holland. 1999. Thermohaline circulation: High-latitude phenomena and the difference between the Pacific and Atlantic. Annual Review of Earth and Planetary Science 27:231-285.

Weller, G., F.S. Chapin III, K.R. Everett, J.E. Hobbie, D. Kane, W.C. Oechel, C.L. Ping, W.S. Reeburgh, D. Walker, and J. Walsh. 1995. The Arctic Flux Study: A regional view of trace gas release. Journal of Biogeography 22:365-374.

Woodgate, R.A., and K. Aagaard. 2005. Revising the Bering Strait freshwater flux into the Arctic Ocean. Geophysical Research Letters 32, L02602, doi:10.1029/2004GL021747.

Zeeberg, J., and S.L. Forman. 2001. Changes in glacier extent on north Novaya Zemlya in the twentieth century. Holocene 11:161-175.

A

Contributors List

Aarup, Thorkild, Intergovernmental Oceanographic Commission, Paris, France
Ahlstrom, Andreas, Technical University of Denmark
Ashjian, Carin, WHOI, Woods Hole, Massachusetts
Balch, Gordon, Environmental and Resource Study Program, Trent University
Belbioch, Mathieu, Argo Information Centre, Ramonville, France
Berner, James, Alaska Native Tribal Health Consortium (ANTHC), Anchorage
Bernhard, Germar, Biospherical Instruments Inc. San Diego
Bert-Harte, Donnie, University of Alaska, Fairbanks
Bird, Nancy, Prince William Sound Science Center & Oil Spill Recovery Inst., Cordova Alaska
Bøggild, Carl Egede, Geological Survey of Denmark and Greenland
Bravo, Michael, Department of History and Philosophy of Sciences Scott Polar Institute, University of Cambridge
Brigham, Lawson, U.S. Arctic Research Commission, Anchorage, Alaska
Brown, Jerry, International Permafrost Association, Wood Hole, Massachusetts
Bryant, Toni, Alaska Native Harbor Seal Commission, Anchorage
Chan, Laurie, McGill University, Canada
Chapin, F. Stuart, III, University of Alaska, Fairbanks
Charpentier, Etienne, Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology Observing Platform Support Centre, Ramonville, France
Christopherson, Alan, Peratovich, Nottingham and Drague, Anchorage, Alaska
Clow, Gary, United States Geological Survey (USGS), Colorado
Collins, Charlie, Cold Regions Research and Engineering Laboratory, Wainwright, Alaska
Conlon, Dennis, National Science Foundation, Virginia
Correll, Robert, Harvard University/America Meterological Society
Couvillion, Annalie, Nature Conservancy, Anchorage, Alaska
Cowles, Cleve, Minerals Management Service, Alaska OCS Region, Anchorage
Crane, Kathleen, Arctic Research Office, NOAA, Silver Spring, Maryland
Crump, John, Arctic Council Indigenous Peoples Secretariat, Denmark
Dasher, Doug, Alaska Deptartment of Environmental Conservation, Fairbanks
Dickson, Bob, Centre for Environment, Fisheries and Aquaculture Science, UK
Donovan, Eric, University of Calgary, Canada
Durocher, Yves, Environment Canada
Dyer, Bob, Environmental Protection Agency, Washington, D.C.
Dyurgerov, Mark, Institute of Arctic and Alpine Research, University of Colorado, Boulder
Eamer, Joan, United Nations Environment Programme Global Resource Information Database, Norway
Eicken, Hajo, Geophysical Institute, University of Alaska, Fairbanks
Ely, Craig, USGS, Anchorage, Alaska
Erickson, Todd, SeeMore Wildlife Systems, Homer, Alaska
Forbes, Bruce, Arctic Center, University of Lapland, Finland
Forsberg, René, Danish National Space Centre
Foster, John, Milestone Hill & Haystack Observatories, Massachusetts Institute of Technology, Cambridge
Fuhs, Paul, Marine Exchange of Alaska
Furgal, Christopher, Nasivvik Centre, Ste-Foy, Quebec, Canada
Futsæter, Gunnar, Norwegian Pollution Control Authority, Oslo
Gerlach, Robert, Alaska Department of Environmental Conservation

Gerry, Guay, Alaska Department of Environmental Conservation
Goodison, Barry, Meteorological Service of Canada, Ontario
Goos, Tim, Meteorological Service of Canada (Prairie and Arctic Region), Edmonton
Grebmeier, Jackie, University of Tennessee, Knoxville
Greenwald, Ray, Applied Physics Laboratory, Johns Hopkins University
Gudmandsen, Preben, Technical University of Denmark
Guo, Laodong, International Arctic Research Center, University of Alaska, Fairbanks
Hanna, Magda, National Naval Ice Center, National Oceanic and Atmospheric Administration
Hansen, Bogi, Faroese Fisheries Laboratory, Faroe Islands
Hardi, Peter, International Institute for Sustainable Development, Canada
Hasholt, Bent, Sermilikstation, Greenland
Heavna, Matt, University of Alaska Southeast, Juneau
Hese, Soeren, Jena University, Germany
Hinzman, Larry, University of Alaska, Fairbanks
Hobbie, John E., Marine Biological Laboratory, Woods Hole, Massachusetts
Hufford, Gary, National Weather Service/National Oceanic and Atmospheric Administration, Homer, Alaska
Huntington, Henry, Huntington Consulting, Eagle River, Alaska
Hutchings, Jennifer, International Arctic Research Center, University of Alaska, Fairbanks
Jeffries, Martin, University of Alaska, Fairbanks
Jonas, Douglas, Matrix Management Group, Washington, D.C.
Jorgenson, Torre, Environmental Research and Services, ABR Inc.
Kane, Doug, University of Alaska, Fairbanks
Kelly, Brendan P., University of Alaska, Juneau
Kelly, John, SRI International, Menlo Park, California
Kendall, James, Minerals Management Service, Herdon, Ohio
Key, Jeffery, National Oceanic and Atmospheric Administration National Environmental Satellite Data and Information Service, Madison, Wisconsin
Kingston, Deanna, Oregon State University, Corvallis
Klein, David R., University of Alaska, Fairbanks
Kofinas, Gary, Institute of Arctic Biology and Department of Resources Management, University of Alaska, Fairbanks
Konstantinov, Yulian, Institute for Anthropological Field-Research, New Bulgarian University
Korhola, Atte, Environmental Change Research Unit, Finland
Kramer, Melinda, Pacific Environment, Alaska
Krapp, Rupert, Danish Natural History Museum
Kyrö, Esko, Finnish Meteorological Institute
Laine, Kari, Thule Institute, University of Oulu, Finland
Loeffler, Bob, Alaska Department of Natural Resources
Loring, Eric, Inuit Tapiriit Kanatami, Canada
MacCracken, Mike, Climate Change Programs, Climate Change Institute, Washington, D.C.
Macdonald, Rob, Institute of Ocean Sciences, Sidney, British Columbia
Major, Mark A., ConocoPhillips Alaska, Inc., Anchorage
Makshtas, Alexander, Arctic and Antarctic Research Institute, Russia
Mann, Ian, University of Alberta, Canada
McLaughlin, Joe, Alaska Division of Public Health, DHSS, Anchorage
Menefee, Wyn, Alaska Department of Natural Resources, Anchorage
Merculieff, Larry, Alaska Native Science Commission, Alaska
Mikkelsen, Naja, Geological Survey of Denmark and Greenland
Mitchell, Henry, Bering Sea Fisherman's Association, Alaska
Nelson, Frank, University of Delaware
Novik, Natalie, The Northern Forum, Anchorage, Alaska
Ödmark, Helena, Ministry for Foreign Affairs, Sweden
Olsen, Morten Skovgaard, Danish Environmental Protection Agency
Ørbæk, Jon Børre, Norwegian Polar Institute
Osterkamp, T.E., Geophysical Institute, University of Alaska
Page, Ed, Marine Exchange of Alaska, Juneau
Paine, John, Bureau of Land Management, Alaska
Parker, Walter B., Institute of the North, Anchorage, Alaska
Parkinson, Alan, Arctic Investigations Program, Centers for Disease Control and Prevention, Anchorage, Alaska
Parsons, Mark A., National Snow and Ice Data Center/ World Data Center for Glaciology, Boulder, Colorado
Partain, James, National Oceanic and Atmospheric Administration-National Weather Service Alaska Region Headquarters, Anchorage
Pautzke, Clarence, North Pacific Research Board, Anchorage, Alaska
Pedersen, Leif Toudal, Danish Centre for Remote Sensing
Petersen, Hanne, Danish Polar Centre, Copenhagen
Pfeffer, W.T., Institute of Arctic and Alpine Research, University of Colorado, Boulder
Pickart, Robert, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
Pilipenko, Slava, Institute of Physics of Earth, Moscow
Polyakov, Igor, International Arctic Research Center, Fairbanks, Alaska
Rachold, Volker, International Arctic Science Committee, Sweden

Rasch, Morten, Danish Polar Centre, Station Nord, Denmark
Reidel, Monica, Alaska Native Harbor Seal Commission
Rogne, Odd, International Arctic Science Committee, Norway
Schunk, Bob, Utah State University
Shaver, Gaius R., Marine Biological Laboratory, Massachusetts
She, Jun, Danish Meteorological Institute
Shearer, Russell, Indian and Northern Affairs Canada, Gatineau, Quebec
Sheehan, Glen, Barrow Arctic Science Consortium, Alaska
Shepson, Paul, Ocean-Atmosphere-Sea Ice-Snowpack Project, Purdue Climate Change Research Center, Purdue University, West Lafayette, Indiana
Skov, Henrik, National Environmental Reasearch Institute, Denmark
Smith, Patrick, National Science Foundation, Office of Polar Programs
Smolen, Michael, World Wildlife Fund, Washington, D.C.
Stauning, Peter, Danish Meteorological Institute
Streever, Bill, Environmental Studies Leader, BP Exploration (Alaska) Inc., Anchorage
Svendsen, Keld Hornbech, ASIAQ, Greenland
Taylor, Ken, North Slope Science Initiative, Anchorage, Alaska
Tornga, Craig, Crowley Maritime Corporation, Alaska Energy Support Services, Anchorage, Alaska
Truffer, Martin, University of Alaska, Fairbanks
Tyler, Kirk, Arctic Indigenous Peoples and Sami Research Office, Arctic Centre, University of Lapland, Finland
Vlassova, Tatiana, Russian Academy of Sciences, Moscow
Webber, Patrick, Michigan State University, East Lansing
Welker, Jeff, Environment and Natural Resources Institute, University of Alaska, Anchorage
Wookey, Phil, University of Stirling, Scotland
Yang, Daqing, University of Alaska, Fairbanks
York, Alison, The Arctic Research Consortium of the U.S., Fairbanks, Alaska
Zimov, Sergey, Cherski, Northeast Science Station, Pacific Institute of Geography, Russia

B

Biographical Sketches of Committee Members and Staff

W. Berry Lyons *(Committee Chair)* is the Director of the Byrd Polar Research Center at The Ohio State University and a Professor in the Department of Geological Sciences. Dr. Lyons received his Ph.D. in Chemical Oceanography from University of Connecticut in 1979. His research interests include the investigation of the biogeochemistry of trace metals, especially mercury, in the environment, the use of various chemical techniques to evaluate and describe climate and environmental change, and the understanding of the relationship between chemical weathering, tectonics, and human activity. He is currently the lead Principal Investigator (PI) for the National Science Foundation (NSF's) McMurdo Dry Valleys Long-Term Ecological Research project in Antarctica.

Keith Alverson is the director of the Global Ocean Observing System program office and head of operational management and sustainable development of the open and coastal ocean at the Intergovernmental Oceanographic Commission of UNESCO based in Paris, France. He received his bachelor's degree in Mechanical and Aerospace Engineering from Princeton University in 1988 and Ph.D. in Physical Oceanography from the M.I.T.-Woods Hole Joint Program in 1995. Dr. Alverson has participated in several ocean field expeditions, including to the Arctic and Antarctic, and carried out modeling, statistical and synthesis studies in physical oceanography and paleoclimatology. He was previously director of the Past Global Changes project of the International Geosphere Biosphere Programme.

David Barber is a Canada Research Chair in Arctic System Science at the University of Manitoba. Dr. Barber focuses his research on improving knowledge of physical and biological processes operating within the ocean-sea ice-atmosphere system and to developing tools that will allow predictions of changes within this system.

James G. Bellingham is the Director of Engineering at the Monterey Bay Aquarium Research Institute. He received his Ph.D. in Physics at the Massachusetts Institute of Technology in 1988. Dr. Bellingham's personal research interests revolve around the development and use of Autonomous Underwater Vehicles (AUVs). In the process of developing these vehicles, he spent considerable time at sea, leading over 20 AUV expeditions in locations such as the Arctic, North Atlantic, Mediterranean, South Pacific, and the Antarctic. Presently he is engaged in the development of distributed ocean observing systems, which are composed of heterogeneous mixes of mobile and fixed observation elements, often coupled to real-time ocean modeling systems. Dr. Bellingham is the co-founder of Bluefin Robotics Corporation, a leading manufacturer of AUVs for the military, commercial, and scientific markets.

Terry V. Callaghan is Professor of Arctic Ecology in the Department of Animal and Plant Sciences at the University of Sheffield, UK and the Department of Ecology at Lund University, Sweden. He is concurrently Director of the Royal Swedish Academy of Sciences' Abisko Scientific Research Station in the Swedish sub-Arctic. Professor Callaghan was awarded a Ph.D. in 1972 for research on plant ecology in the sub-Antarctic and Arctic, and since then has been awarded honorary Ph.D.s by Lund University, Sweden (1992) and Oulu University, Finland (2002), as well as a D.Sc. by Manchester University, UK (1992). He was elected as member of the Royal Swedish Academy of Sciences (2002). He is interested in arctic plant ecology and particularly in responses of arctic ecosystems to changes in climate and UV-B radiation. Professor Callaghan has worked in every arctic country and has spent part of almost each of the past 38 years in the Arctic. He is the chair of the SCANNET network of 14 North Atlantic research and monitoring infrastructures, and European co-chair of CEON (Circumarctic Environmental Observatories Network). He was lead author of the Terrestrial Ecosystems chapter of the Arctic Climate Impact Assessment and leads or contributes to many international research and monitoring initiatives focusing on arctic terrestrial ecosystems.

Lee W. Cooper is a Research Professor in the Department of Ecology and Evolutionary Biology at the University of Tennessee. He received his Ph.D. in Oceanography from the University of Alaska, Fairbanks in 1987 following undergraduate and graduate work at the University of California, Santa Cruz and the University of Washington. His research interests include biogeochemical cycling in high-latitude ecosystems through the use of isotopic and elemental tracers. He has extensive polar shipboard research experience on all three current U.S. Coast Guard icebreakers, including chief scientist coordinating multidisciplinary research programs in 1993, 2002, and 2004. He is also lead principal investigator for the Bering Strait Environmental Observatory, which involves local subsistence hunters in collection of samples and pilot-scale continuous seawater pumping operations in Bering Strait from Little Diomede Island. Dr. Cooper is chair of an international Russian-U.S. research science steering committee facilitating collaborative bi-national research in the Russian Arctic and he also participates as the U.S. delegate in an International Arctic Science Committee working group that exchanges information with other arctic countries on multinational research efforts in the Russian Arctic. Among his other recent activities was the lead role in editing the Land-Shelf Interactions science plan that provided guidance to the NSF on key coastal research priorities in the Arctic.

Margo Edwards is a Senior Research Scientist at the University of Hawaii and Director of the Hawaii Mapping Research Group. She received her Ph.D. in Marine Geology and Geophysics from the Lamont-Doherty Earth Observatory of Columbia University in 1992. Dr. Edwards' specializes in using acoustic and optical systems to map and image the seafloor throughout the world's oceans, focusing primarily on mid-ocean ridge systems and the Arctic Basin. Her research covers a broad spectrum of topics ranging from modeling the mechanics of volcanic eruptions in the deep ocean to unraveling paleoclimatic histories recorded in sediments of the Arctic Ocean. She has participated in dozens of oceanographic expeditions, and as chief scientist of the 1999 Science Ice Exercises became the first woman to sail onboard a U.S. Navy nuclear-powered submarine during an operation. Dr. Edwards presently serves as chair of the Arctic Icebreaker Coordinating Committee of the University-National Oceanographic Laboratory System.

Shari Gearheard is a Research Associate at the University of McGill and University of Western Ontario, Canada. Previously, she was a Postdoctoral Research Fellow hosted by Harvard University in the National Oceanic and Atmospheric Administration Postdoctoral Program in Climate and Global Change. For over a decade, Dr. Gearheard has worked with Inuit communities in Nunavut, Canada, on a variety of environmental issues and research topics—in particular, Inuit knowledge of climate and environmental change. Dr. Gearheard (nee Fox) was co-lead author of Chapter 3 ("The Changing Arctic: Indigenous Perspectives") of the Arctic Climate Impact Assessment and was part of the Coastal Working Group for ICARP II. Dr. Gearheard received her MES in Environmental Studies from the University of Waterloo, Canada and her Ph.D. from the Department of Geography/Cooperative Institute for Research in Environmental Sciences, at the University of Colorado at Boulder.

Molly McCammon is the Executive Director of the Alaska Ocean Observing System—the Alaska component of the U.S. Integrated Ocean Observing System—as well as the co-chair of the National Federation of Regional Associations for Ocean Observing. Ms. McCammon received her B.A. in Journalism from the University of California at Berkeley. She has more than 25 years of experience in Alaska natural resource management and policy development. Her past experience includes a decade as the Executive Director for the *Exxon Valdez* Oil Spill Trustee Council, administering the restoration fund established as a result of a court settlement between the U.S. government and the state of Alaska and Exxon Corporation following the 1989 Exxon Valdez oil spill. During her tenure at the Trustee Council, she helped establish the Gulf Ecosystem Monitoring Program—a permanently endowed, long-term ecological monitoring program for the northern Gulf of Alaska.

Jamie Morison is a research professor at the University of Washington. His main research focus is the study of environmental change in the Arctic. He heads the project office for the multi-government agencies' Study of Environmental Arctic Change program. In addition, he has spent the last three springs in the vicinity of the North Pole directing hydrographic analysis of ocean conditions for the North Pole Environmental Observatory program. Another aspect of his research has used AUVs to study turbulent vertical velocity and fluxes of heat and salt in the Arctic Ocean. He also served as University of Washington Representative to the Arctic Research Consortium of the United States (ARCUS), 1995-97; member ASA/NSF Antarctic Research Vessel Oversight Committee, 1995-98; member ARCUS Logistics Working Group, 1997-98; member NSF-Office of Polar Program Advisory Committee, 1997-99; member Polar Research Board of the National Academy of Sciences, 1997-2000.

Scott E. Palo is an Assistant Professor in the Department of Aerospace Engineering Sciences Colorado Center for Astrodynamics Research at the University of Colorado. He specializes in upper atmosphere research and he has significant hardware, data analysis, and data systems experience. The central overarching thrust of his research is to understand how both free and forced planetary-scale disturbances are generated in the Earth's atmosphere and how they effect the dynamics, thermal structure and composition of the coupled mesosphere-thermosphere-ionosphere system (ca. 50-400 km). Dr. Palo's active areas of research are: development, construction, and deployment of an inexpensive, portable, autonomous meteor radar system; use of a global circulation model to understand how planetary-scale disturbances interact in a coupled nonlinear atmosphere; understanding the complex sampling/aliasing relationships that occur when low Earth orbiting satellites are used to measure atmospheric parameters associated with planetary-scale disturbances; and analysis of observations, both ground and space based, of atmospheric parameters associated with planetary-scale disturbances in the mesosphere-thermosphere-ionosphere.

Andrey Proshutinsky is a Senior Scientist at Woods Hole Oceanographic Institution. He received his Ph.D. in Physical Oceanography at the Arctic and Antarctic Research Institute, Russia, in 1980. Dr. Proshutinsky's research interests include: climate change, physical oceanography, and numerical modeling of ice and water dynamics. He has investigated Arctic Ocean circulation regimes, tides, storm surges, and navigation conditions along the Northern Sea Route. Dr. Proshutinsky is a member of the Polar Climate, Climate Variability, and National Center for Atmospheric Research Climate System Model working groups and he is a PI of the international Arctic Ocean Model Intercomparison project. He is a Woods Hole Oceanographic Institution Arctic Research Coordinator and is involved in design, development, and implementation of drifting ice-based arctic observatories.

Lars-Otto Reiersen is the Executive Secretary of Arctic Monitoring and Assessment Program. In this capacity, he runs the contaminants monitoring and assessment work under the Arctic Council. He has extensive experience in creating integrated monitoring programs around the Arctic and, in particular, the monitoring needs for arctic contaminants and climate.

Vladimir E. Romanovsky is an Associate Professor of Geophysics in the Geophysical Institute and Geology and Geophysics Department with the University of Alaska, Fairbanks. He received his Ph.D. in Geology at the Moscow State University, Russia, in 1982. He also received Ph.D. in Geophysics at the University of Alaska Fairbanks in 1996. He is involved in research in permafrost geophysics, with particular emphasis on the ground thermal regime, active layer and permafrost processes, and the relationships between permafrost, hydrology, biota, and climate. He is also examining the scientific and practical aspects of environmental and engineering problems involving ice and permafrost, subsea permafrost, seasonally frozen ground, and seasonal snow cover. Dr. Romanovsky is also interested in the improvement of mathematical methods (analytical and numerical modeling) in geology and geophysics.

Peter Schlosser is the Vinton Professor of Earth and Environmental Engineering and professor of Earth and Environmental Sciences at Columbia University and senior research scientist at the Lamont-Doherty Earth Observatory. He also is the associate director of the Earth Institute at Columbia University. He received his Ph.D. in Physics at the University of Heidelberg, Germany, in 1985. Dr. Schlosser's research interests include studies of water movement and its variability in natural systems (oceans, lakes, rivers, groundwater) using natural and anthropogenic trace substances and isotopes as "dyes" or as "radioactive clocks"; ocean/atmosphere gas exchange; reconstruction of continental paleotemperature records using groundwater as an archive; and anthropogenic impacts on natural systems. He participated in seven major ocean expeditions, five to the polar regions. He was or presently is a member or chair of national and international science steering committees, including the World Ocean Circulation Experiment, the Climate Variability and Predictability Experiment, the World Climate Research Program, the Surface Ocean Lower Atmosphere Study, and the Study of Environmental Arctic Change.

Julienne C. Stroeve is a Research Scientist II with the National Snow and Ice Data Center. Her research interests include cryosphere-climate interactions, polar climatology, optical and microwave remote sensing of snow and sea ice, atmospheric and snow/ice radiative transfer modeling, and digital image processing. Dr. Stroeve is a member of the Program for Arctic Regional Climate Assessment. Her current research projects include monitoring trends in surface albedo and surface temperature from satellite data over Greenland; examining causes for recent thinning in the ablation regions of the Greenland ice sheet; development of algorithms to derive snow albedo from satellite instruments; cross-calibration of passive microwave satellites to produce consistent time series of ice extent and ice-covered areas; sensitivity studies of the effects of satellite incidence angles and atmospheric effects on ice concentrations derived from passive microwave instruments using different sea ice algorithms; and surface temperature over snow- or ice-covered surfaces and mountainous terrain from infrared satellite data.

Craig Tweedie is an Assistant Professor with the Department of Biology and the Environmental Science and Engineering Program at The University of Texas at El Paso. Dr. Tweedie also co-chairs CEON, a network of terrestrial and freshwater observation platforms, science experts, and network partners promoting the collection of environmental data from the Arctic. CEON's mission is to strengthen the capacity for emerging monitoring, research and policy needs at high northern latitudes by making data available that are adequate and suitable for answering and addressing a series of well-defined key scientific questions and uncertainties. Dr. Tweedie also conducts research focused on land cover change and the impact this has on terrestrial ecosystem structure and function in the north Alaskan and Beringian Arctic and in the Chihuahuan Desert.

John Walsh is a President's Professor of Global Change at the University of Alaska, Fairbanks. He is also the Director of the Cooperative Institute for Arctic Research and the Center for Global Change at the University of Alaska. He received his Ph.D. in Meteorology at the Massachusetts Institute of Technology in 1974, and served for 30 years on the faculty of the Department of Atmospheric Sciences, University of Illinois, Urbana. Dr. Walsh's research interests include the climate of the Arctic, especially interactions between the atmosphere and polar surfaces; extreme weather events as they relate to climate; and the variability of the cryosphere. He was a lead author of the Arctic Climate Impact Assessment (2001-2005), and is a lead author for the Polar Regions chapter of the Intergovernmental Panel on Climate Change's ongoing assessment. He has been a committee member of the Arctic Climate System Study and the Study of Environmental Arctic Change. He is a Fellow of the American Meteorological Society.

NRC Staff

Paul Cutler (*Study Director*) is a senior program officer for the Polar Research Board of the National Academies. He directs studies in the areas of polar science and atmospheric science. Before joining the Polar Research Board staff, Dr. Cutler was a senior program officer in the Academies' Board on Earth Sciences and Resources, where he directed the Mapping Science Committee and studies in Earth science and geographic information science. Before joining the Academies, he was an assistant scientist and lecturer in the Department of Geology and Geophysics at the University of Wisconsin, Madison. His research is in glaciology, hydrology, meteorology, and quaternary science, and he has conducted fieldwork in Alaska, Antarctica, arctic Sweden, the Swiss Alps, Pakistan's Karakoram mountains, the midwestern United States, and the Canadian Rockies. Dr. Cutler received an M.Sc. in geography from the University of Toronto, and a Ph.D. in geology from the University of Minnesota.

Matthew L. Druckenmiller (*Science and Technology Policy Graduate Fellow)* was a visiting fellow with the Polar Research Board of the National Academies during Fall 2005. Prior to his fellowship, he attended the University of Alaska, Fairbanks, where he researched glacier volume changes throughout Alaska and western Canada using small aircraft laser altimetry. His research interests include interdisciplinary environmental change studies in the Arctic, remote sensing of the cryosphere, and carbon sequestration. Mr. Druckenmiller received a B.Sc. in environmental systems engineering and an M.Sc. in geo-environmental engineering from The Pennsylvania State University, where he investigated geologic carbon sequestration in brine.

Rachael Shiflett (*Senior Program Assistant)* is a senior program assistant with the Polar Research Board. She received her M.Sc. in environmental law from Vermont Law School in 2001 and will complete her J.D. at Catholic University in May 2007. Ms. Shiflett has coordinated National Research Council studies that produced the reports *Vision for the International Polar Year 2007*-2008, and *International Polar Year 2007-2008 Report of the Implementation Workshop.* Her research interests include the Endangered Species Act, the Marine Mammal Protection Act, and the National Environmental Policy Act.

C

Acronyms and Abbreviations

AAGRUUK	Arctic Archive for Geophysical Research: Unlocking Undersea Knowledge
ABEKC	Arctic Borderlands Ecological Knowledge Co-op
ACD	Arctic Coastal Dynamics
ACIA	Arctic Climate Impact Assessment
ADCP	Acoustic Doppler Current Profiler
ADIS	ACSYS Data and Information Service
AEPS	Arctic Environmental Protection Strategy
AFOSR	Air Force Office of Scientific Research
AGU	American Geophysical Union
AHDR	Arctic Human Development Report
AICEMI	International Network of Arctic Indigenous Community-Based Environmental Monitoring and Information Stations
AIM	Aeronomy of Ice in the Mesosphere
ALIS	Auroral Large Imaging System
ALISON	Alaska Lake Ice and Snow Observatory Network
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AMAP	Arctic Monitoring and Assessment Programme
ANKN	Alaska Native Knowledge Network
AO	Arctic Oscillation
AOMIP	Arctic Ocean Model Intercomparison Project
AON	Arctic Observing Network
AOOS	Alaska Ocean Observing System
AOSB	Arctic Ocean Science Board
APDA	Arctic Precipitation Data Archive
ARCMIP	Arctic Regional Climate Model Intercomparison Project
ARCN	Arctic Network—National Park Services (United States)
ARCN I&M	Arctic Network Inventory and Monitoring Program
ARCSS	Arctic System Science (NSF-OPP)
Arctic-CHAMP	Arctic Community-wide Hydrological Analysis and Monitoring Program
ArcticNet	A Canadian multidisciplinary team of arctic scientists, Inuit, and government managers
ARCUS	Arctic Research Consortium of the United States
ARDB	Arctic Runoff Data Base
ARM	Atmospheric Radiation Measurement
ARN	Arctic Residents' Network
ASOF	Arctic-Subarctic Ocean Fluxes
ASR	Arctic System Reanalysis
ASSW	Arctic Science Summit Week
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer

AUV	autonomous underwater vehicle
AVHRR	Advanced Very High Resolution Radiometer
BEO	Barrow Environmental Observatory
BSEO	Bering Strait Environmental Observatory
BTF	Back to the Future
CABOS	Canadian Basin Observational System
CAFF	Conservation of Arctic Flora and Fauna
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CALM	Circumpolar Active Layer Monitoring
CANOPUS	Canadian Auroral Network for the Open Program Unified Study
CANTEX	Canadian Tundra Experiment
CARCMIP	Coupled Arctic Regional Climate Model Intercomparison Project
CARDS	Comprehensive Aerological Data Set
CARMA	Circumarctic Rangifer Monitoring & Assessment Network
CASES	Canadian Arctic Shelf Exchange Study
CAT-B	Circum-Arctic Terrestrial Biodiversity
CAVM	Circumpolar Arctic Vegetation Map
CBMP	Circumpolar Biodiversity Monitoring Program
CCIN	Canadian Cryospheric Information Network
CEDAR	Coupling Energetics and Dynamics of Atmospheric Regions
CEON	Circumarctic Environmental Observatories Network
CEON-IMS	Circumarctic Environmental Observatories Network Internet Map Server
CEOP	Coordinated Enhanced Observing Period
CEOP II	Coordinated Enhanced Observing Period II
CEOS	Committee on Earth Observation Satellites
C-GOOS	Coastal GOOS
CIFAR	Cooperative Institute For Arctic Research
CliC	Climate and Cryosphere
CLIVAR	Climate Variability and Predictability
COMAAR	Consortium for coordination of Observation and Monitoring of the Arctic for Assessment and Research
COOP	Coastal Ocean Observations Panel
CO-OPS	Center for Operational Oceanographic Products and Services
COPES	Coordinated Observation and Prediction of the Earth System
CSA	Canadian Space Agency
CTD	Conductivity, Temperature, Depth sensor
CUAHSI	Consortium of Universities for Advancement of Hydrologic Sciences
DAAC	Distributive Active Archive Centers
DAMOCLES	Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies
DARPA	Defense Advanced Research Projects Agency
DEMs	Digital Elevation Models
DISC	Data and Information Service for CliC
DMI	Danish Meteorological Institute
DMO	Distributed Marine Observatories
DOD	Department of Defense
DOE	Department of Energy
DQU	Detecting and Quantifying Unaami
DTO	Distributed Terrestrial Observatories
EGU	European Geophysical Union
eGY	electronic Geophysical Year
Eiscat	European Incoherent Scatter Radar
ELOKA	Exchange for Local Observations and Knowledge of the Arctic

EMEP	European Monitoring and Evaluation Programme
EMSO	European Multidisciplinary Seafloor Observatory
ENVINET	European Network for Arctic-Alpine Environmental Research
EOS	Earth Observing System
EOS AM	Earth Observing System Terra
EOS PM	Earth Observing System Aqua
EOSDIS	EOS Data and Information System
EPA	Environmental Protection Agency
EPPR	Emergency, Prevention, Preparedness and Response
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructure
EU	European Union
FAO	Food and Agriculture Organization
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FARO	Forum of Arctic Research Operators
F-MAP	Future of Marine Animal Populations
FPAR	Fraction of Photosynthetically Active Radiation
GAW	Global Atmosphere Watch
GCMD	Global Change Master Directory
GCOS	Global Climate Observing System
GCTE	Global Change and Terrestrial Ecosystems
GEMS	Global Environment Monitoring System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GINA	Geographic Information Network of Alaska
GIS	Geographic Information System
GLIMPSE	Global Implications of Arctic Climate Processes and Feedbacks
GLIMS	Global Land Ice Measurements from Space
GLOBE	Global Learning and Observations to Benefit the Environment
GLOSS	Global Sea Level Observing System
GOOS	Global Ocean Observing System
GOS	Global Observing System
GOSIC	Global Observing System Information Center
GPS	Global Positioning System
GSN	GCOS-Surface Network
GTN	Global Terrestrial Network
GTOS	Global Terrestrial Observing System
GUAN	GCOS Upper Air Network
HARC	Human Dimensions of the Arctic System
HD	Human Dimensions
HLEO	High Latitude Ecological Observatory
H-MAP	History of Marine Animal Populations
IABP	International Arctic Buoy Programme
iAOOS	Integrated Arctic Ocean Observing System
IARPC	Interagency Arctic Research Policy Committee
IASC	International Arctic Science Committee
IASC-WAG	International Arctic Science Committee-Working group on Arctic Glaciology
ICARP	International Conference on Arctic Research Planning
ICARP II	Second International Conference on Arctic Research Planning
ICES	International Council for the Exploration of the Sea
ICS	International Circumpolar Surveillance

ICSU	International Council for Science
IEOS	Integrated Earth Observation System
IGBP	International Geosphere Biosphere Programme
IGOS	Integrated Global Observing Strategy
IGY	International Geophysical Year
INCHR	International Network for Circumpolar Health Research
INPO	International Network of Permafrost Observatories
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual Property Rights
IPY	International Polar Year
IPY DIS	International Polar Year Data and Information Service
IPY IPO	IPY International Program Office
IRISs	Integrated Regional Impact Studies
ISAC	International Study of Arctic Change
ITC	Inuit Tapirisat of Canada
ITEX	International Tundra Experiment
IUGG	International Union of Geodesy and Geophysics
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
JCOMMops	JCOMM in situ Observing Platform Support Centre
JOSS	Joint Office for Science Support
JWACS	Joint Western Arctic Climate Study
LAI	Leaf Area Index
LAII	Land-Atmosphere-Ice Interactions
LAO	Large-scale Atmospheric Observatories
LTA	Long-term archival
LTER	Long Term Ecological Research Network
LTK	Local and traditional knowledge
MACCS	Magnetometer Array for Cusp and Cleft Studies
MAGICS	Mass balance of Arctic Glaciers and Ice sheets in relation to Climate and Sea level changes
MARS	Mars Arctic Research Station
MEMS	Microelectromechanical systems
Miracle	Magnetometers-Ionospheric Radars-Allsky Cameras Large Experiment
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSJ	Monitoring of Svalbard and Jan Mayen
MSU	Microwave Sounding Unit
NABOS	Nansen and Amundsen Basin Observational System
NAO	North Atlantic Oscillation
NARL	Naval Arctic Research Lab
NASA	National Aeronautics and Space Administration
NASA DAAC	NASA Distributive Active Archive Centers
NATEX	North American Tundra Experiment
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NDBC	National Data Buoy Center
NDVI	Normalized Difference Vegetation Index
NEMS	Nanoelectromechanical systems
NEON	National Ecological Observatory Network

NERC	Natural Environment Research Council
NGDC	National Geophysical Data Center
NILU	Norwegian Institute for Air Research
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOP	National Observer Program
NOW	North Water Polynya
NPEO	North Pole Environmental Observatory
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NRI	Nunavut Research Institute
NRPA	Norwegian Radiation Protection Authority
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSDC	National Space Science Data Center
NWS	National Weather Service
OCO	Orbiting Carbon Observatory
OGC	Open Geospatial Consortium
OMB	Office of Management and Budget
ONR	Office of Naval Research
OOPC	Open Ocean Panel for Climate
OPP	Office of Polar Programs
OSSEs	Observing System Sensitivity Experiments
OSTP	White House Office of Science and Technology Policy
PAGES	Past Global Changes project of IGBP
PAME	Protection of the Arctic Marine Environment
PAR	Photosynthetically Active Radiation
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PARCA	Program for Regional Climate Assessment
pCO_2	partial Carbon Dioxide
PI	Principle Investigator
PLUTO	Polar Links to Undersea Telecommunications and Observatories
POP	Persistent Organic Pollutant
PRB	Polar Research Board
R-ArcticNet	Regional-ArcticNet
RENNET	Reindeer Network
SBI	Western Arctic Shelf-Basin Interactions Project
SBIR	Small Business Innovation Research program
SCANNET	Scandinavian/North European Network of Terrestrial Field Bases
SCAR	Scientific Committee on Antarctic Research
SDO	Solar Dynamics Observatory
SDWG	Sustainable Development Working Group
SEARCH	Study of Environmental Arctic Change
SEEDS	Strategic Evolution of Earth Science Enterprise Data System
SEI	Social and Economic Interactions
SHEBA	Surface Heat Budget of the Arctic Ocean
SliCA	Survey of Living Conditions in the Arctic
SOOP	Ship of Opportunity Programme
SPOT	Satellite Probatoire d'Observation de la Terre

SST	Sea Surface Temperature
STTR	Small Business Technology Transfer program
SuperDARN	Super Dual Auroral Radar Network
TDC	Thematic Data Center
TEK	Traditional Ecological Knowledge
THORpex	The Observing-system Research and predictability experiment
TIMED	Thermospheric, Ionospheric, Mesospheric Energetics and Dynamics
TOVS	TIROS (Television and Infrared Observational Satellite) Operational Vertical Sounder
TSG	Thermosalinograph
TSP	Thermal State of Permafrost
UAF	University of Alaska, Fairbanks
UAV	Unmanned aerial vehicle
UCAR	University Corporation for Atmospheric Research
UNAVCO	University NAVSTAR Consortium
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US NCDC	United States National Climate Data Center
USGS	United States Geological Survey
UV	Ultraviolet
VGMO	Virtual Global Magnetic Observatory
VOS	Voluntary Observing Ship
VOSClim	Voluntary Observing Ships Climatology
VSO	Virtual Solar Observatory
WAG	Working Group on Arctic Glaciology
WCRP	World Climate Research Programme
WDC	World Data Center System
WGI	World Glacier Inventory
WGMS	World Glacier Monitoring Service
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Centre
WWW	World Weather Watch
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature Data
ZERO	Zackenberg Ecological Research Operations