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VOLUME 21 2007

ARCTIC RESEARCH OF THE UNITED STATES

INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

Cover Caption: With permanent observation sites in Barrow and Atqasuk, Alaska, the Atmospheric Radiation Measurement (ARM) Climate Research Facility is providing continuous data about cloud and atmospheric properties for the Arctic research community. In 2004, researchers sponsored by this user facility conducted the Mixed-Phase Arctic Cloud Experiment at the North Slope of Alaska. Evidence has shown that mixed-phase clouds are poorly represented in both regional and global climate models. Using both surface-based and airborne instrumentation, the researchers successfully obtained a comprehensive data set of Arctic boundary-layer and multi-level mixed-phase clouds. Featured on the cover are just a few of the surface instruments and aircraft probes used during the campaign; a sample flight path is visible in the background. Some initial results of the experiment are described in this report. Managed through the US Department of Energy (DOE), Office of Science, the ARM Climate Research Facility, is part of the Arctic Observing Network and is available to scientists worldwide for interdisciplinary studies of earth systems. (Image courtesy of Chris DeGraaf, Pacific Northwest National Laboratory, for the US DOE ARM Program.)

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VOLUME 21 2007

ARCTIC RESEARCH

OF THE UNITED STATES

Arctic Observing Network: Toward a U.S. Contribution to Pan-Arctic Observing

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Executive Summary

In April 2007 the US Interagency Research Policy Committee (IARPC) called for the development of an Arctic Observing Network (AON) to understand the causes and consequences of Arctic change. Under the joint leadership of NOAA and NSF, Committee staff prepared *Arctic Observing Network (AON): Toward a US Contribution to Pan-Arctic Observing,* a summary of ongoing and future Federal Arctic observing activities with a strategy for enhanced coordination and integration of these activities. This document constitutes the biennial update of the US Arctic Research Plan, focusing on observing needs. Enhanced coordination and integration of observing activities, and data and information management, will enable the agencies to respond with increased agility to the science questions posed by the Study of Environmental Arctic Change (SEARCH) program:

1. Is the Arctic system moving to a new state?
2. To what extent is the Arctic system predictable, i.e., what are the potential accuracies and/or uncertainties in predictions of relevant Arctic variables over different time scales?
3. To what extent can recent and ongoing climate changes be attributed to anthropogenic forcing rather than to natural modes of variability?
4. What is the direction and relative importance of system feedbacks?
5. How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and its interactions with human activities?
6. How do cultural and socio-economic systems interact with Arctic environmental change?
7. What are the most consequential links between the Arctic and Earth systems?

Federal agencies are contributing many important observations that enrich our knowledge of the physical, biological and human dimensions of the changing land, atmosphere, ice and ocean components of the Arctic environmental system. The agencies also recognize the importance of working with the State of Alaska, Arctic residents, maritime users and other stakeholders to support community-based research and knowledge systems in which Arctic societies are able to collect, preserve and exchange relevant and timely information. Agencies also recognize the need, in some cases, for near-real-time data and products.

To further the goal of a coordinated and integrated AON, IARPC has identified ten action items:

Action item 1. IARPC will continue to meet on a regular basis to examine ways to improve coordination and integration of agencies' Arctic observing activities in partnership with the academic community, northern residents, maritime users and other stakeholders, in order to answer the SEARCH questions and address the SEARCH priorities described in the SEARCH Implementation Plan.

Action item 2. IARPC will assess the integrated Arctic observing and research activities to determine the extent to which they are answering the SEARCH questions and addressing SEARCH priorities. Agencies will strive to align their Arctic observing and research activities with the SEARCH questions and priorities, while meeting their mission goals and evolving user needs, including the need for easy access to near-real-time data.

Action item 3. IARPC will enable the application of quantitative, objective tools, e.g., OSSEs (Observing System Simulation Experiments, also known as OSEs, Observing System Experiments), to guide the development of AON through system design exercises that identify optimal in-situ observing site locations and satellite observing networks, required measurement accuracy and frequency, and acceptable levels of uncertainty.

Action item 4. IARPC will also investigate the use of a Collaborative Observation and REsearch (CORE) strategy for optimization as well as coordination and integration of observing activities. In applying CORE, measurement frequency, accuracy and uncertainty would also be documented.

Action item 5. In consultation with related Federal interagency activities, such as the Climate Change Science Program and the US Group on Earth Observations (GEO), IARPC will explore the development of a user-friendly online portal, i.e., a single point-of-entry, to Federal Arctic data and information. A portal would have many advantages for IARPC and for users and stakeholders – it would raise the visibility of the data and information holdings, making them more openly and freely accessible to a broader audience and increasing their use, thereby maximizing the value-added services and societal benefits to be derived from AON. An Arctic data portal can also play a valuable role in the coordination and integration of AON.

Action item 6. As IARPC collaborates in the development AON, it will strive to maximize the use of cyberinfrastructure for coordination and integration from the moment of data acquisition through data discovery, analysis, synthesis and modeling, to the realization of Arctic and global value-added services and societal benefits.

Action item 7. IARPC will endeavor to increase engagement with northern people and communities to identify local observing needs as well as create mutually beneficial observing partnerships that build human and physical capacity. All observing activities will be guided by the Principles for the Conduct of Research in the Arctic (*http://www.nsf.gov/od/opp/arctic/conduct.jsp*) that were created at the direction of IARPC.

Action item 8. As part of the coordination and integration necessary to the development of AON, IARPC will discuss the issue of sustaining the entire program over the long-term, and explore ways for the effective transfer of research observing activities to the operational observing realm. Policy and strategy for the transition of research observing to operational observing will need to be developed. 'Transition' will require criteria for the identification of which research observing activities will cross over into operational observing, and processes to effect the transition.

Action item 9. NSF, representing IARPC and AON, will remain engaged internationally, working with regional partners to achieve a multinational, pan-Arctic observing network that is coordinated, integrated and sustained over the long-term. IARPC, in turn, will engage with GEO and the Global Earth Observing System of Systems (GEOSS) to ensure that the Arctic is represented at domestic and international planning and policy forums, and involved in the transition to implementation of coordinated national and international Earth observation efforts to benefit society.

Action item 10. The US contribution to a coordinated, integrated and sustained multinational, pan-Arctic observing network will be based on an intellectual framework that reflects the scientific goals, priorities and recommendations of the SEARCH and the International Study of Arctic Change (ISAC) programs.

Foreword

At the April 2007 IARPC meeting the Principals unanimously agreed to charge the Staff with the development of AON as part of the implementation of SEARCH (Study of Environmental Arctic Change) and as a US contribution to the legacy of the International Polar Year (IPY). The full text of the charge is:

The next biennial revision of the 5-year Arctic Research Plan is due in FY 2007. At the last Principals meeting in 2005, the Study of Environmental Arctic Change (SEARCH) was presented as an interagency IPY activity. As part of SEARCH implementation and a US contribution to the IPY legacy, the Principals of the Interagency Arctic Research Policy Committee charge the Committee staff with the development of the Arctic Observing Network. This activity should be the primary focus of the next biennial revision of the Arctic Research Plan. In developing the Arctic Observing Network, the staff should coordinate with other interagency groups, such as the US Group on Earth Observations, the US Climate Change Science Program's Observation Interagency Working Group, and the Interagency Committee on Ocean Science and Resource Management Integration. The staff should also reach out to local-State-Federal partnerships involved in Arctic research. Staff should prepare a draft for Principals' review by September 1, 2007.

NSF and NOAA assumed joint-leadership in responding to the IARPC Principals' charge, and the result of their efforts, in partnership with numerous IARPC staff members and others, is this report. It is presented as the 2007 biennial revision of Arctic Research Plan, and the first step in inter-agency collaboration in the development of AON and achieving the goals of SEARCH.

1. Introduction

The Arctic environment is changing. The changes are large, rapid and system-wide. They have few equals elsewhere on Earth, and some are occurring at greater rates than predicted by computer models. Arctic Change has regional and global implications, and continued changes will have significant Arctic and worldwide environmental and societal consequences.

Nothing illustrates the scale of Arctic Change, and its regional and global implications, better than the dramatic recession of the Arctic sea ice cover in summer 2007 (Figure 1). That this should have occurred early in International Polar Year (IPY) 2007-2009 exemplifies the global importance of the Arctic and the need for continued and greater vigilance via enhanced, coordinated and sustained observing infrastructure, i.e., AON.

The magnitude and rate of the system-wide changes in the Arctic are such that there is broad consensus that enhanced, coordinated and sustained observing is vital. Current observing capabilities are not adequate to support the synthesis and modeling that are essential for better understanding of the regional and global causes and consequences of Arctic Change. Without improved observing capabilities and understanding of Arctic Change, regional and global society's ability to anticipate, predict and develop effective adaptive responses to future changes will be severely limited. Improved observing capabilities will be needed for the assessment of the effectiveness of efforts to mitigate the effects of global change and regional feedbacks in the Arctic.

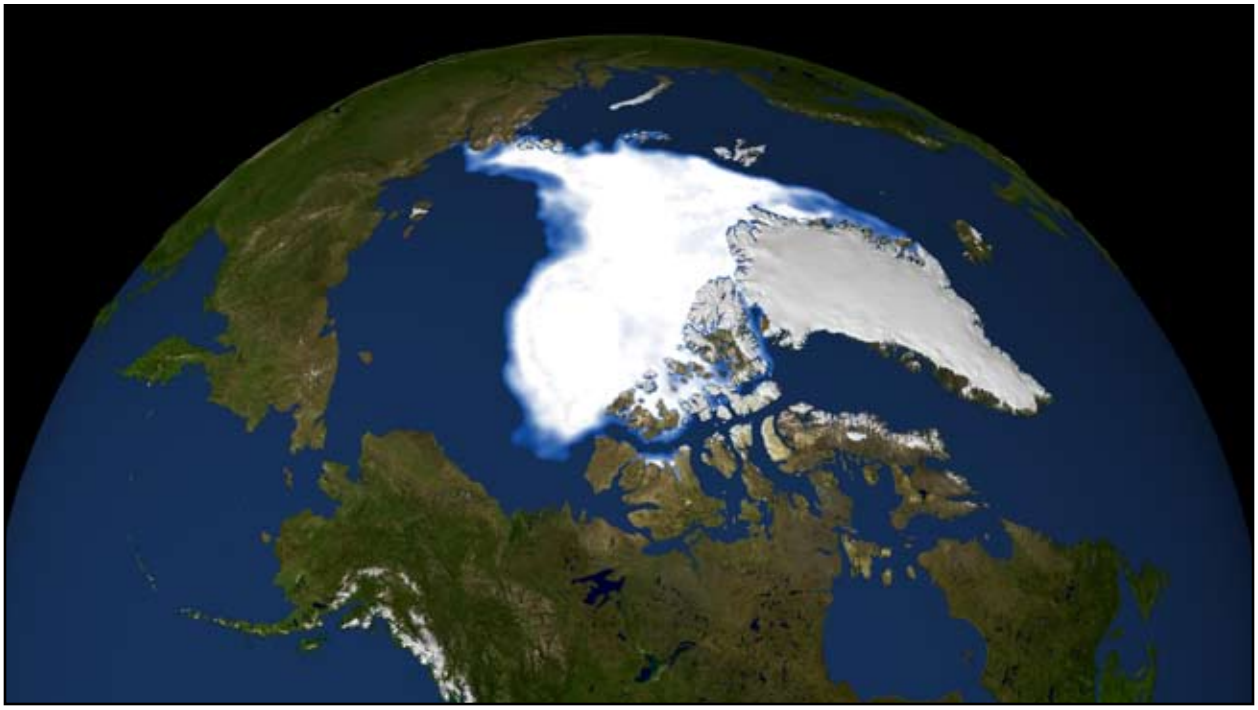

Figure 1. Arctic sea ice extent on 14 September 2007 as observed by the Special Sensor Microwave Imager (SSM/I) of the Defense Meteorological Satellite Program (DMSP). Source: NASA/Goddard Space Flight Center Scientific Visualization Studio.

This report focuses on US Federal observing activities in the Arctic as they relate to the development of AON to advance the goals of SEARCH. The report also describes many sub-Arctic observing activities. The Arctic is not isolated from the rest of the world, and AON must include the sub-Arctic observing sites. They are a vital to documenting northern environmental variation and change, and improving the understanding of interactions and feedbacks that occur between the Arctic and the rest of the world.

The report also shows that Federal Arctic observing activities extend beyond US territory. The need for enhanced Arctic observing capabilities is recognized by all Arctic countries, and also by many outside the Arctic. AON will be the US contribution to a multinational, pan-Arctic observing network to be developed in collaboration with other countries.

The report is organized as follows. Section 2 describes a few of the changes that are occurring in the Arctic; they illustrate the urgent need for improved Arctic observing. Section 3 provides some background to the development of consensus that the need for AON is indeed urgent. Section 4 offers a conceptual framework to guide the development of AON by defining, in broad terms, its participants, activities and outcomes.

Section 5 is a summary of the scope of current US Federal observing activities in the Arctic. Section 6 describes (a) Federal agencies' plans for future Arctic observing activities, (b) a conceptual framework for integration and coordination of existing and new observing activities, and (c) data and information management to meet the need for easy, free, open and timely access to all Federal Arctic observing data. Section 7 addresses the international cooperation necessary to realize the development of a multinational, pan-Arctic network. Section 8 concludes the report with a list of action items for Federal observing activities in the Arctic, particularly as they relate to the need for enhanced, coordinated and sustained observing to advance the goals of SEARCH.

2. An Urgent Need for Observations in the Changing Arctic

On 16 August 2007, satellite passive microwave monitoring of Arctic sea ice extent revealed that it had equaled the record minimum that had been achieved only two years earlier on 20 September 2005. Subsequently, on 16 September 2007, a new record minimum sea ice extent of 4.13 million square kilometers occurred (NSIDC, 2007; Figure 2). National Snow and Ice Data Center (NSIDC) scientists described the September 2007 ice extent as "quite astounding", and, having "completely shattered that old record", the ice is in a "strong spiral of decline".

On 2 October 2007, Polyakov et al. (2007) described a mooring-based observing system that shows the continued transition of the Arctic Ocean to a warmer state (Figure 3), and suggested that the lowest sea ice extent has yet to be seen. While it is reasonable to predict that continued warming of the Arctic Ocean will cause further loss of sea ice, the ice loss in 2007 was attributed to atmospheric influences, particularly a persistent high pressure system that promoted clear skies and warm, southerly air flow that combined to increase ice melting and movement away from the Siberian shore (NSIDC, 2007). Clearly, continued monitoring of the ocean and atmosphere are vital for determination of their relative influence on the sea ice cover.

The 2007 sea ice extent observations mean that the annual rate of sea ice loss continues to exceed even the most aggressive model predictions from the Intergovernmental Panel on Climate Change Fourth Assessment (IPCC, 2007). The latter currently predict that the sea ice will diminish to zero during summer as early as 2050 or as late the early 22nd

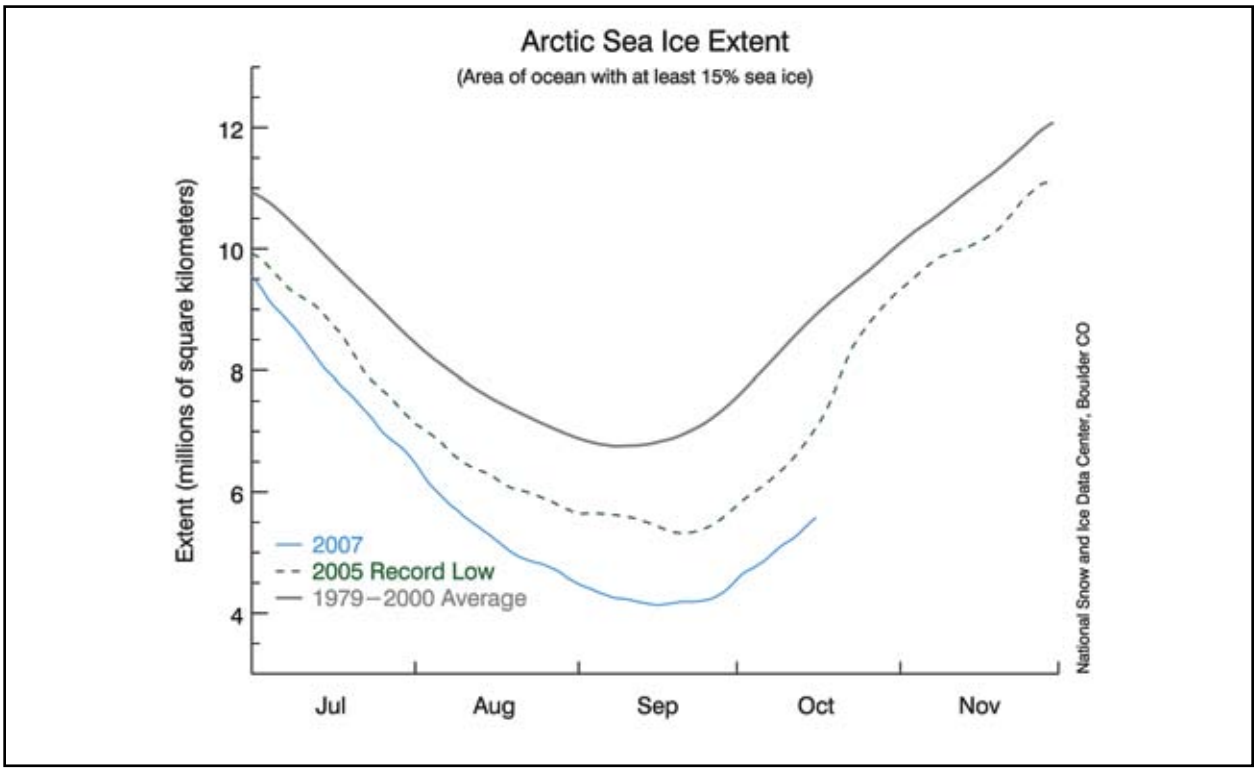

Figure 2. Arctic sea ice extent on 16 September 2007 was 23% lower than the previous record minimum in August 2005, and 39% lower than the long-term, 1979-2000, average. Source: NSIDC.

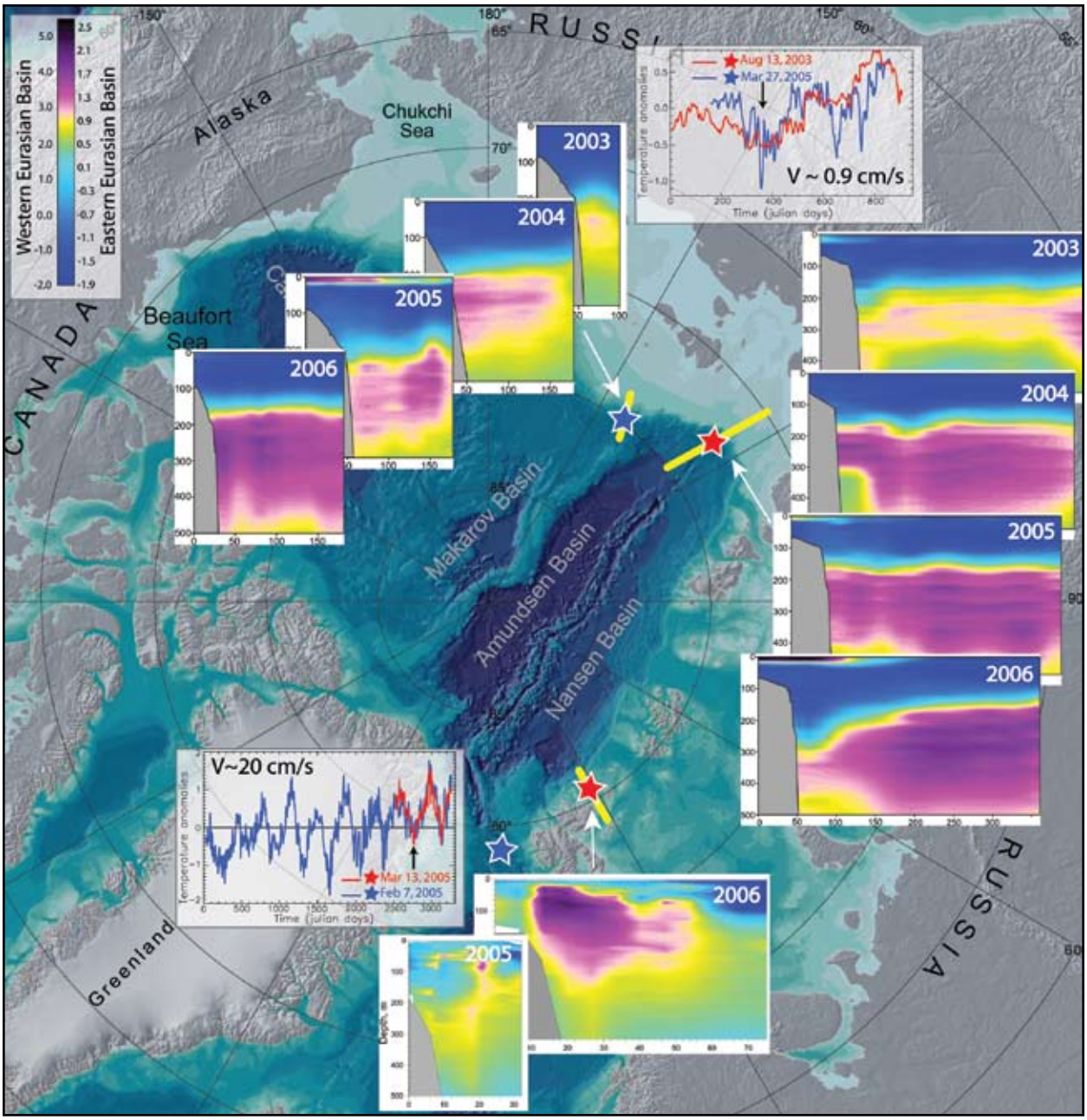

Figure 3. Water temperature as a function of depth, and time series of water temperature anomalies (°C) on the Laptev Sea slope and in the vicinity of Svalbard. Maximum lagged correlation is used to define anomaly propagation speed (V). These results are from the Nansen and Amundsen Basin Observing System (NABOS) sites, and were provided by I. Polyakov, International Arctic Research Center (IARC).

Century. Continued observation of sea ice extent, and improved spatial and temporal resolution in the observation of sea ice thickness and albedo will help to improve computer models and their predictions, lead to better understanding of the causes and consequences of the changing sea ice-climate system, and inform natural resource development and maritime transportation in an ice-diminished Arctic. There may be economic advantages in a much-reduced, or even zero, end-of-summer Arctic sea ice cover. For example, it is believed that it would allow increased natural resource exploitation and maritime transportation, with shorter routes between European, Asian and North American markets. In response to the potential for increased shipping in the Arctic, in 2004 the Arctic Council commissioned an Arctic Marine Shipping Assessment (AMSA). Increased access to the Arctic Ocean also raises questions about national security and sovereignty.

Increased ship traffic, however, increases the likelihood of pollution in waters where clean-up, of an oil spill, for example, would be difficult, to say the least. Pollution would compound the stress on marine ecosystems that are under pressure as they adjust to the receding ice cover. The possible consequences of sea ice change on the marine ecosystem are exemplified by the polar bear population, which, according to a US Geological Survey report on 7 September 2007, could be reduced by 66% by the middle of this century (USGS, 2007).

The IPCC4 report (IPCC, 2007) notes that "Understanding and evaluating sea ice feedbacks is complicated by the strong coupling to polar cloud processes and ocean heat and freshwater transport. Scarcity of observations in polar regions also hampers evaluation". IPCC4 stresses the importance of improving atmospheric observation, specifically aerosol and cloud measurements, since the largest uncertainty in climate sensitivity is due to cloud feedbacks, with low clouds making the largest contribution to uncertainty.

Continued observation and improved modeling of the Arctic sea ice-cloud-climate system will not be sufficient to address the issue of marine ecosystem response to Arctic Change. At the higher trophic levels (polar bear, walrus, whales, seals), for example, immediate needs include better observations of populations and their trends, and reproductive rates and feeding ecology. Since changes in the marine ecosystem are likely to affect indigenous communities that see marine living resources as integral to their cultures, such information will contribute to the identification of effective adaptive responses, including better tools for managing marine ecosystems in a changing climate.

The Arctic terrestrial ecosystem is also changing. The greening of the North Slope of Alaska (Figure 4) is consistent with an increase in the biomass of shrubs and climate warming (e.g., Sturm et al., 2001a, 2001b; Jia et al., 2003). Climate warming is also being manifested in rising permafrost temperatures, and even thawing in regions of discontinuous permafrost (e.g., Lachenbruch and Marshall, 1986; Clow and Urban, 2002; Osterkamp et al, 2000; Osterkamp, 2003). This has the potential for large quantities of methane to be emitted into the atmosphere, which would amplify the effects of global warming in the Arctic (Walter et al, 2006). Models will help to improve the understanding of the broader consequences of Arctic terrestrial methane emissions, but that requires the initiation of systematic, long-term measurements in order to quantify the magnitude, variation and trends of emissions in the first place.

Also on land, the area of surface melting on the Greenland ice sheet, the velocity of its outlet glaciers, and iceberg calving have increased, raising concerns about sea level rise and its global consequences. The Gravity Recovery and Climate Experiment (GRACE) observations show that the ice sheet is currently

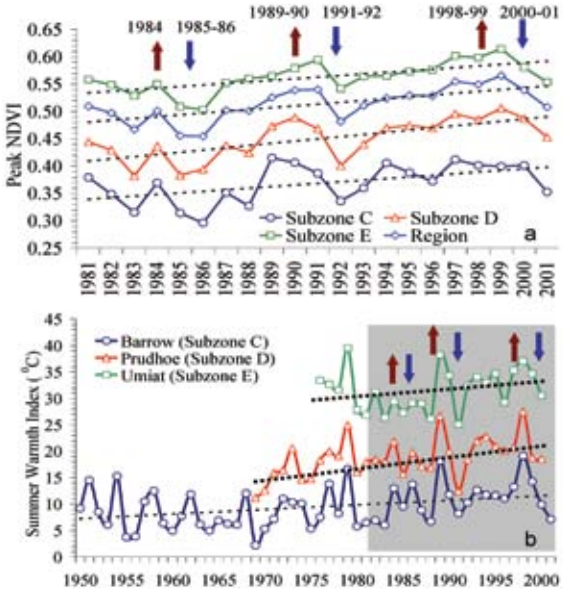

Figure 4. Increase in greenness (a) and summer warmth (b) in different regions of the North Slope of Alaska. Greening is illustrated by Normalized Difference Vegetative Index (NDVI) data derived from the NOAA Advanced Very High Resolution Radiometer. Source: J. Jia, University of Virginia.

losing mass at a rate of about 150 gigatons/year (Luthcke et al., 2006), and in 2007 melting on the ice sheet reached the highest altitudes observed during the satellite observation era (Figure 5; Tedesco, 2007). Improved observing systems, and models that adequately simulate ice sheet dynamics and thermodynamics, and are coupled to Global Circulation Models (GCMs), are needed. Observations and models will help to determine the state of the Greenland ice sheet and whether the global

consequences of changes in its mass balance will be manifested over decadal, centennial or millennial time scales.

Arctic Change is not limited to the examples given above. Change is occurring throughout the Arctic environmental system, and current observation systems are not adequate to detect the full suite of changes that are underway, nor the human responses

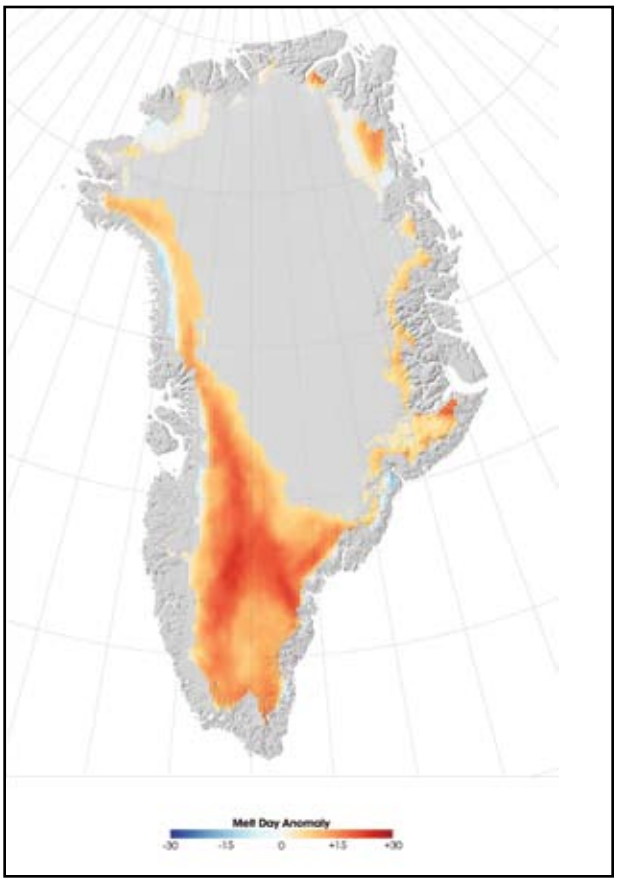

Figure 5. The extent of melting at the surface of the Greenland ice sheet in summer 2007 determined from SSM/I data. Source: M. Tedesco, University of Maryland Baltimore County and NASA Goddard Space Flight Center.

to change. Enhanced, coordinated and sustained observing sites, systems and networks in the Arctic will provide data on the magnitude, variation and rate of current and past environmental change, and for the initialization, calibration and validation of computer models that allow simulation of the Arctic environmental system and its global connections.

The Arctic is integral to the global environmental system, and models enable the Arctic system to be understood in the broader context of the Earth system. Models make it possible to study the interactions and feedbacks that occur within the Arctic system, and between the Arctic and the global, integrated Earth system. Models and modelers need observations, and both are required to (1) document the magnitude, variation and rate of changes that are currently occurring, and place them in the context of past environmental change, (2) understand the regional and global causes and consequences of current changes, (3) predict the magnitude, variation, rate and consequences of future Arctic Change, and (4) identify effective adaptive responses to Arctic Change.

3. AON: Vision Statements and Calls for Action

There is broad consensus for developing enhanced, coordinated and sustained observing sites, systems and networks in the Arctic. This consensus is represented by two widely-quoted reports: the SEARCH Implementation Plan (SEARCH, 2005) and a US National Academies report on AON (NRC, 2006). They are vision statements and calls for action, and the main focus of this section.

The Arctic Climate Impact Assessment (ACIA) and the Second International Conference on Arctic Research Planning (ICARP II) also call for improved observations and monitoring. These are summarized briefly at the end of this section.

a. SEARCH

SEARCH is a US Federal inter-agency program that relies on a strong partnership with academia. The SEARCH Implementation Plan is presented as a point of reference for IPY and AON planning. The implementation activities are organized into three categories: Observing; Understanding; Responding. The report also describes a data management strategy and the importance of education and outreach.

The SEARCH Implementation Plan (SEARCH, 2005) identifies seven key scientific questions that lie at the heart of SEARCH:

1. Is the Arctic system moving to a new state?
2. To what extent is the Arctic system predictable, i.e., what are the potential accuracies and/or uncertainties in predictions of relevant Arctic variables over different time scales?
3. To what extent can recent and ongoing climate changes be attributed to anthropogenic forcing rather than to natural modes of variability?
4. What is the direction and relative importance of system feedbacks?
5. How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and its interactions with human activities?
6. How do cultural and socio-economic systems interact with Arctic environmental change?
7. What are the most consequential links between the Arctic and Earth systems?

The SEARCH Implementation Plan identifies a wide range of observing activities required to aid in answering these questions: improvement of observation density, co-location and integration; improvement of coverage to close observation gaps; development of optimal observation and sampling strategies; observation of key processes and studies of feedbacks; acquisition of paleoenvironmental data over critical time periods; development of networks; data rescue; development of data archival and distribution systems; and, utilization of innovative and effective technology.

The SEARCH Implementation Plan begins to define the components of AON and places them in priority locations regardless of national boundaries. The priorities are summarized in six maps, which are reproduced here as Figures 6 through 11. Each map has a disciplinary focus – Atmosphere, Ocean and Sea Ice, Hydrology and Cryosphere, Terrestrial Ecosystems, Human Dimensions, and Paleoenvironment – and is intended to provide general guidance to the geographic priorities of each of the six disciplinary topics.

The SEARCH Implementation Plan recognizes that the development of AON as envisioned (Figures 6 through 11) will require close coordination and collaboration among US and international programs. To further international cooperation in the development of AON during IPY, SEARCH scientists entered into a Memorandum of Understanding with the leadership of DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies), an EU-funded IPY study of Arctic air-ice-ocean interactions. The SEARCH for DAMOCLES (S4D) partnership contributes to the development of ISAC.

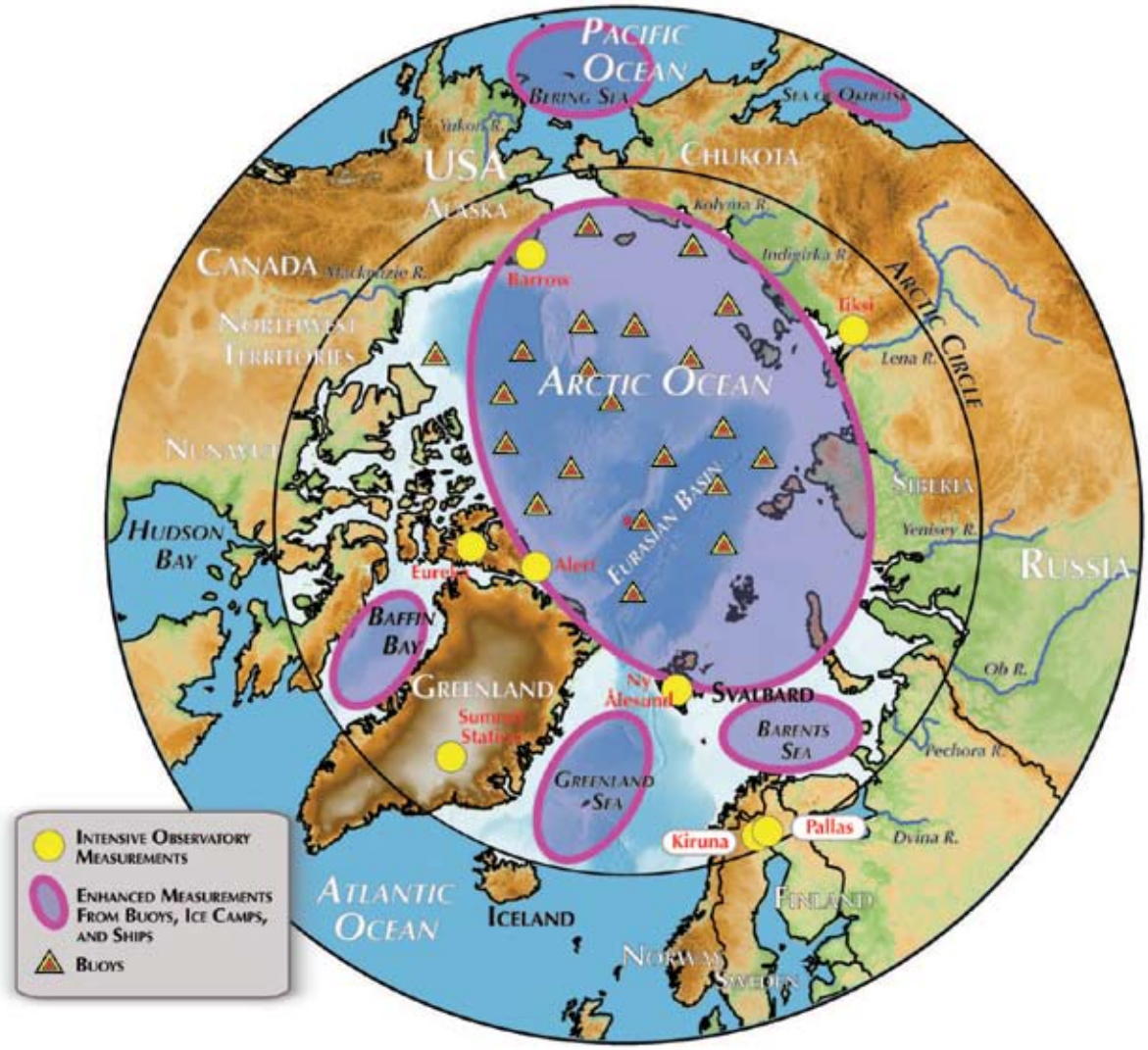

Figure 6. Priorities for atmospheric observing activities as illustrated in the SEARCH Implementation Plan.

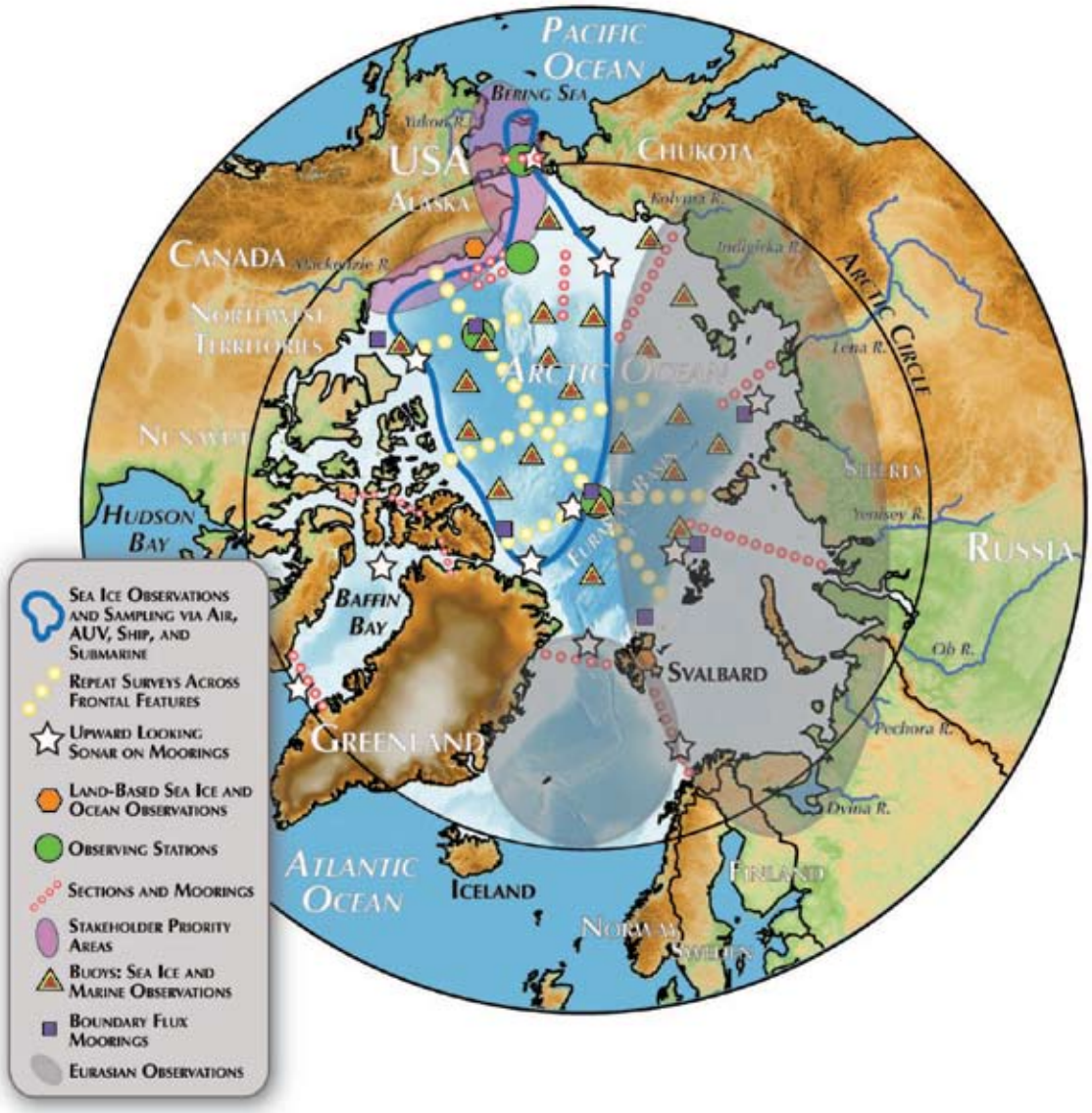

Figure 7. Priorities for ocean and sea ice observing activities as illustrated in the SEARCH Implementation Plan. The locations of all the sections, buoys and moorings are intended only as general suggestions for deployment schemes.

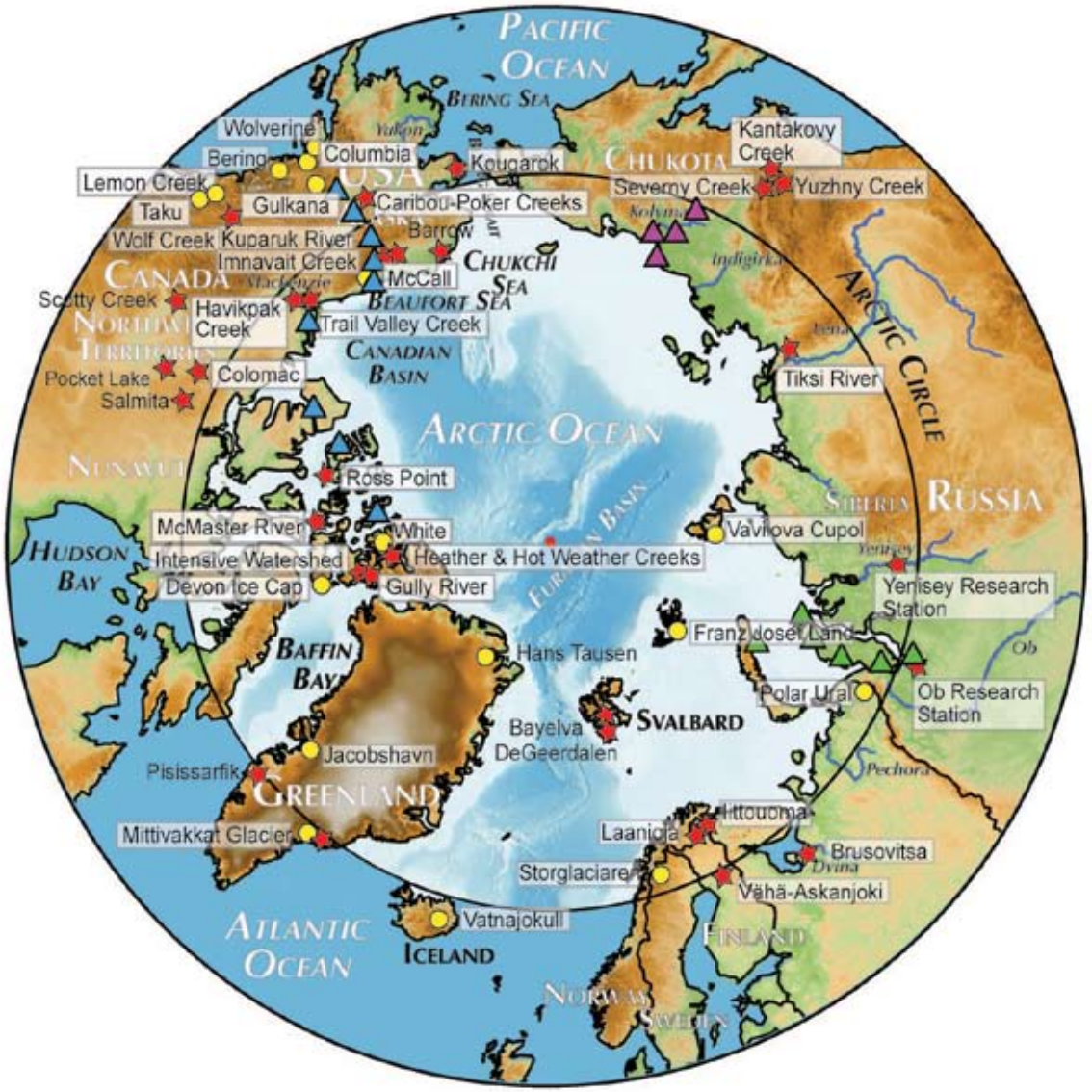

Figure 8. Priorities for hydrological and cryosphere observing activities as illustrated in the SEARCH Implementation Plan.

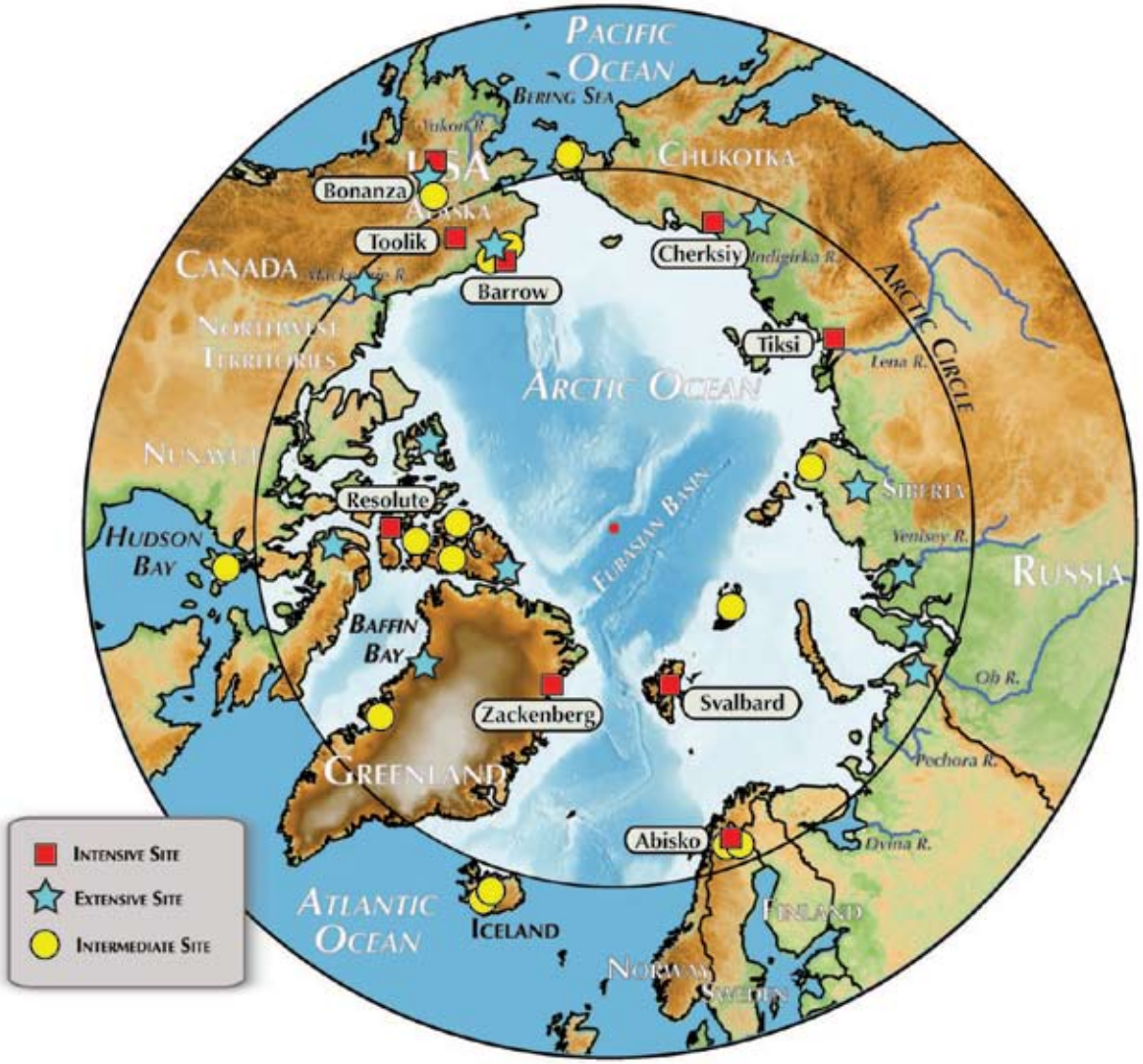

Figure 9. Priorities for terrestrial ecosystem observing activities as illustrated in the SEARCH Implementation Plan. Not all potential sites are shown. Observatories range from intensive, integrated "flagship" observatories to intermediate or extensive sites where only a few variables are measured.

Figure 10. Priorities for human dimensions observing activities as illustrated in the SEARCH Implementation Plan. The yellow line generally follows the boundary of the Arctic as used by the Arctic Monitoring and Assessment Program. Inside that boundary the SEARCH Implementation Plan calls for the compilation of data on the following: vital statistics and demographic measures; livelihood and economic data; health, education and other indicators of well-being; trends related to transportation, tourism, fisheries, mining, energy and other natural resource development.

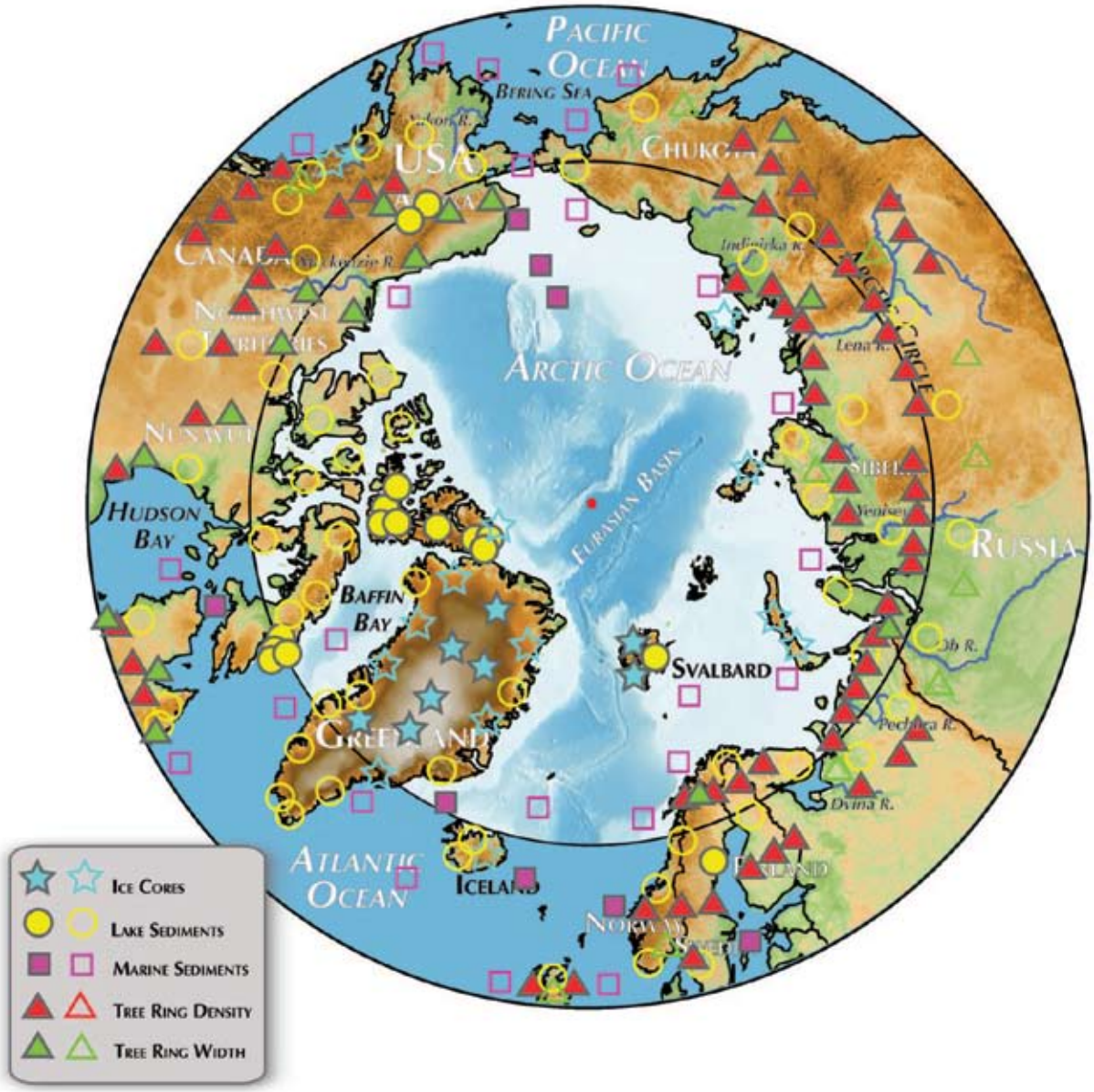

Figure 11. Priorities for paleoenvironment observing activities as illustrated in the SEARCH Implementation Plan. Solid symbols indicate locations of existing records. Open symbols indicate idealized distributions of records necessary for confident multi-proxy assessment of past natural climate variability.

Research-based initiatives such as SEARCH, S4D and ISAC, working with operational agencies and Arctic residents, have an important role to play in defining and coordinating an international approach to comprehensive Arctic observing.

b. Toward an Integrated AON

The SEARCH Implementation Plan was followed by a US National Academies report - *Toward an Integrated Arctic Observing Network*. The over-arching recommendations of the report (National Research Council, 2006: p. 96) are:

> "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."
>
> "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 NRC report recognizes that AON must be based on long-term, coordinated, international resources and efforts that are dedicated to sustaining the network. It calls for a "system design assessment" as an early step, along with efforts to sustain existing observing capabilities. AON would be continuously improved and enhanced through user feedback and infusion of new technologies and understanding. It would include a data and information management system, and involve Arctic residents in a meaningful way.

As noted at the beginning of this previous section, the SEARCH Implementation Plan and the NRC AON report are vision statements and calls for action. This IARPC report is a first step toward a coordinated, integrated and sustained AON based on a partnership among US Federal agencies, academia, Arctic residents and other stakeholders, and other countries.

c. ACIA and ICARP II

ACIA (2005) priorities include the "collection of data ranging from satellite, surface to paleo data on the climate and physical environment, to rates and ranges of change in arctic biota, and to the health status of people." ACIA notes that long-term time series of climate and climate-related parameters are available for only a few locations in the Arctic, and states that "continuing long-term acquisition of data is crucial, including upgrading of the climate observing system throughout the Arctic and monitoring snow and ice features, the discharge of major arctic rivers, ocean parameters, and changes in vegetation, biodiversity, and ecosystem processes."

ICARP II (2007) recommends "that an observation strategy be developed that integrates remote sensing, in situ observations/monitoring data, and modeling from the beginning, and enable feedbacks among them. This would involve development of calibration/validation strategies and effective sampling strategies, use models to inform observations and data to initialize, validate and improve models." ICARP II calls for "observations and models to describe how the Arctic system works, how it is changing and what those changes mean for the future."

4. AON: A Conceptual Framework for Participation, Activities, and Outcomes

The success of the AON implementation depends, in part, on individuals (e.g., a university professor, a government scientist, a northern resident) and institutions (e.g., a university, a government agency, a northern non-governmental organization) understanding the goal of AON, and recognizing the role they have to play and the contributions they can make to achieving the goal. This section describes a conceptual framework (Figure 12) that has been developed to help individuals and institutions see where they can fit into and be part of AON by defining, in broad terms, its core components and the activities that contribute to its goal.

The conceptual framework identifies Arctic and Global Value-added Services and Societal Benefits as the over-arching goal or outcome of AON. That goal is defined by five activities, of which two are outcomes of the other three. That is, decision- and policy-making rely on scientific research and education, technology and data product development, and forecasting and prediction. Decision- and policy-making can also inform the other three activities; hence the horizontal arrows in both directions (Figure 12). Any of the five activities that define the goal of AON can also inform AON itself; hence the vertical arrows in both directions (Figure 12).

In the context of the three pillars of SEARCH, decision- and policy-making are synonymous with responding to change, while scientific research and education, technology and data product development, and forecasting and prediction represent knowledge and understanding. Understanding and responding require basic information, and AON is the source of that information. Thus AON is a fundamental pillar of SEARCH.
As Figure 12 shows, AON has four core components: operational observing; research observing; community-based observing/local and traditional knowledge;

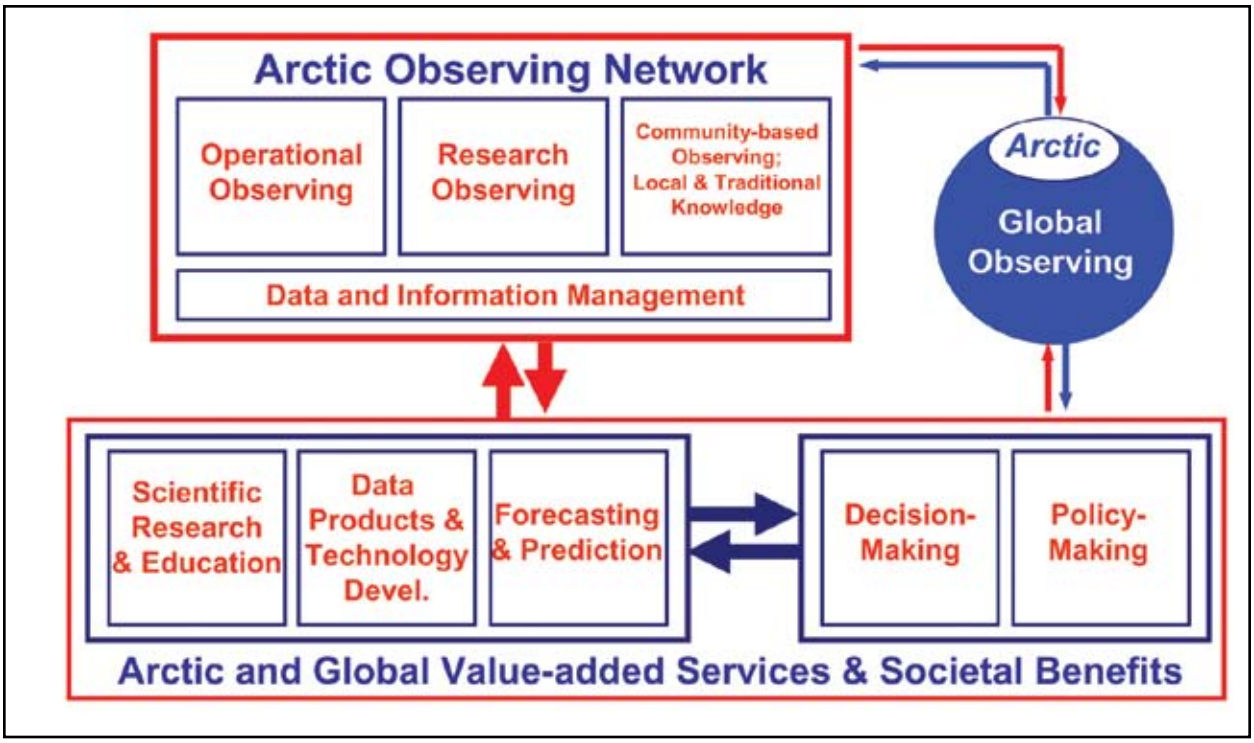

Figure 12. Conceptual framework for AON. Arrows represent flows and exchanges of data and information that are necessary to realize value-added services and societal benefits for the Arctic and the World.

and data and information management. It must be understood that these are not isolated from each other; there are overlaps and connections, but for the sake of simplicity these are omitted from the diagram.

Operational observing programs are exemplified by NOAA/National Weather Service (NWS) stations that make long-term, routine, standardized meteorological observations that are coordinated with other nations through the World Meteorological Organization (WMO). Research observing is supported by several Federal agencies, and is typically short-term in nature. However, research observing projects and data can be baseline data sets when properly archived and made available at some future date for comparison with new observations. For example, the National Aeronautics and Space Administration (NASA) designs, builds, launches and operates satellites and instruments, often in partnership with industry and academia in the US and other nations, primarily for the purpose of scientific research, and to gather long term climate data. The current NASA constellation of fourteen orbiting satellites is shown in Figure 13.

NASA Arctic science and technology encompass Earth's atmosphere from the surface of the land and sea to the top of the stratosphere; the oceans including sea ice; land surfaces including snow and ice; the solid Earth beneath the ocean; the ecosystems in the air, oceans, and land; and all the interactions between the atmosphere, oceans, land, snow, ice, and associated ecology, including humans. NASA also studies the Sun and the interaction of its radiation with the Earth's upper atmosphere. To study the components of the global integrated Earth system and interactions between components, NASA has developed and deployed a constellation of satellites (Figure 13). NASA also deploys aircraft- and surface-based instruments for calibration, validation, and increased level of interpretation of satellite data that are required for development of sustained high-accuracy, climate-quality, stable satellite measurements.

NSF also funds research observing, as exemplified by the Long Term Ecological Research (LTER) Network sites in Alaska, and the awards made to initiate AON during the IPY (see Appendix I for a complete list of NSF AON projects). The latter observing projects are driven by science questions that need long-term observations, including human observations and indigenous knowledge, and which enable SEARCH by measuring the continuing changes that are underway in the Arctic. The DOE ARM site on the North Slope of Alaska focuses on making observations designed for research to improve and evaluate the representation of clouds in the climate models.

As noted in Section 3, the Academies' report on AON (NRC, 2006) recommends meaningful involvement for Arctic residents. Thus, the AON conceptual framework (Figure 12) deliberately places community-based observing and local & traditional knowledge in a category alongside operational and research observing. However, none of these three categories are mutually exclusive. Researchers, for example, often work in partnership with Arctic residents, who maintain equipment and continue observations in the scientist's absence. Likewise, the NOAA/NWS Cooperative Observer Program relies on individuals to make observations that are integrated into weather and climate analyses, and other public service programs, and which define the regional climate of the USA and help measure long-term change.

Each of the three observing groups has different ways of operating and sees different immediate benefits. But, the integration of all three provides greater power and mutual benefits than any one alone. Moving data, information, experience and expertise among the three observing groups has obvious value. Moreover, this value is most likely to be realized when data and information from each group are available in free, open and timely fashion. Hence, data and information management are integral to AON (Figure 12); or, to put it another way, effective data and information management, and data policy are essential to achieving the goals of AON and SEARCH. Data and information management, and data policy are discussed at greater length in sections 5g and 7c.

While the development of AON is focused on advancing the goals of SEARCH, it is not for the exclusive use and benefit of the SEARCH community. Just as AON and SEARCH must draw on operational observing activities such as NOAA

Figure 13. NASA constellation of operating satellites recording biological, chemical, physical and ecosystem measurements in the circum-Arctic with high fidelity space and time scales for studies of the changes in the circum-Arctic and for understanding the connectivity between the pan-Arctic region and the global integrated Earth system. Examples of measurements are stratosphere ozone (Ozone Monitoring Instrument/Aura), troposphere chemistry and composition (Tropospheric Emission Spectrometer/Aura), polar stratosphere clouds (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation or CALIPSO), troposphere aerosols (Multi-angle Imaging SpectroRadiometer/Terra), clouds (Cloudsat), ocean surface vector winds (QuikSCAT or Quick Scatterometer), sea ice temperature (MODIS or Moderate Resolution Imaging SpectroRadiometer/Aqua), sea surface temperature (Advanced Microwave Scanning Radiometer-E/Aqua and MODIS/Aqua), ocean color (MODIS/Aqua), total solar irradiance at the top of the atmosphere (Solar Radiation and Climate Experiment or SORCE), Greenland ice sheet mass (GRACE), Greenland ice sheet thinning (ICESat), rainfall (AMSR-E/Aqua), land imagery (Landsat-7), snow distribution on land (MODIS/Aqua), sea ice coverage (AMSR-E/Aqua), sea ice thickness (ICESat), and other variables.

NWS, for example, AON can contribute to broader, day-to-day operational and event-/incident-driven mission needs. For example, in the case of an oil spill, a particular suite of AON instruments could inform responders' decision-making, provide inputs to spill trajectory models and weather and safety information for overflights, and guide species monitoring during and after a spill. As section 5c and 7g make clear, there is a broad spectrum of AON users and stakeholders, and they must have easy, free and open access to AON for it to achieve Arctic and global value-added services and societal benefits.

Just as the combination of the three observing groups with data and information management will increase the power and mutual benefits of AON, so too will the combination of AON with global observing (Figure 12). The United States is one of many countries participating in the development of the international GEOSS, an effort to link together existing technologies in space, atmosphere, ocean and terrestrial observing and support new observing capacity as needed. GEOSS promises to provide a framework for compatible and accessible earth observations. As part of this global effort, the United States created an inter-agency Group known as GEO or USGEO. IARPC is coordinating with GEO and with other Federal entities such as the Interagency Committee on Ocean Science and Resource Management Integration (ICOS-RMI), a group co-chaired by the Office of Science and Technology Policy and the Council on Environmental Quality.

The recently issued report, *Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy* (National Science and Technology Council/ Joint Subcommittee on Ocean Science and Technology, 2007), identifies three critical elements of ocean science and technology: developing understanding and capability to forecast ocean processes and phenomena; providing science support for ecosystem-based management; and deploying an ocean observing system to enable the promise of forecasting and ecosystem-based management. The development of AON contributes to these comprehensive Federal and international efforts to improve forecasting and resource management through science and technology.

5. Federal Arctic Observing Activities: Today

To describe current Federal Arctic observing activities, this section is organized according to the SEARCH Implementation Plan (SEARCH, 2005) categories: Atmosphere; Ocean and Sea Ice; Hydrology and Cryosphere; Terrestrial Ecosystems; Human Dimensions; Paleoenvironment; and Data and Information Management. Each subsection includes a general description of each agency's activities, maps of observing sites, a list of Web links for data and information sources, and other useful links.

As America's Arctic state, Alaska can play an important role as an AON partner and contributor. Relevant observing activities of State of Alaska and local government agencies are described in Appendix 2. The USGS has significant Earth Science (earthquakes, volcanoes, geomagnetism) observing activities in Alaska. Though not directly related to SEARCH, these activities are described in Appendix 3.

a. Atmosphere

Land- and space-based observations of the Arctic atmosphere are made by numerous Federal agencies. The NASA satellite constellation is illustrated in Figure 13, and the observing sites at the Earth's surface are illustrated in Figures 13, 14, 15 and 16 at the end of this section. In addition to land-based observing activities, the NOAA Marine Observational Programs monitor atmospheric variables along the near-shore and oceanic waterways.

The NOAA focus is on data to support weather forecasts, monitor atmospheric constituents that change the radiative balance of the atmosphere, and contribute to other climate products and services. The Federal Aviation Administration (FAA) also supports the acquisition of weather data. The DOE focus is on analysis of cloud and radiative processes to improve climate models. National Park Service (NPS) atmosphere observing activities focus on air quality, including aerosols, chemistry, contaminants and ultraviolet radiation. A large inter-agency group consisting of the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), NPS, US Fish and Wildlife Service (USFWS), and US Forest Service (USFS) maintains a Remote Automated Weather Station (RAWS) network in Alaska for monitoring air quality, rating fire danger and research applications. NSF objectives are improved understanding of climate processes and development of new technologies and approaches for observing.

The NOAA and FAA land-based and marine weather observations are considered "operational" and are performed continuously and reliably to support weather forecasts that are updated every 6 hours or more often as conditions warrant. The primary observing systems include ASOS (Automated Surface Observing System), weather radars, radiosondes and wind profilers. All of the other observations fall into the "research" category, with variable periods of observation, and without a specific requirement to support a forecast or other product. NOAA's newest network in Alaska, the Climate Reference Network (CRN), is designed to measure a few key climate variables with very high quality and reliability, and report data in real-time; it is still classified as a research system at this time.

A highlight of the research observations is a network of atmospheric observatories whose results have greatest applicability to climate-scale processes. NOAA, DOE and NSF are supporting observations and data analysis at Barrow, Alaska. The NOAA facility collects data primarily on trace gases and aerosols and also hosts a number of visiting activities supported by NSF and other agencies. NOAA, NSF and Canadian agencies are supporting similar observations and analysis at Eureka and Alert in Nunavut, Canada. The DOE ARM Climate Research Facility (ACRF) site at Barrow extends south to the vicinity of *Atqasuk* and collects cloud, aerosol and radiation data continuously, and reports data in near real-time. The ACRF is a national user facility that provides logistics support to national and international users

for ground-based and aerial measurements in support of short-term field campaigns or long-term guest instrument deployment at the Barrow and Atqasuk sites and/or adjacent Arctic and ocean areas. NASA and NSF support the Greenland Climate Network (GC-Net), a series of automatic weather stations that monitor conditions on the ice sheet.

At Tiksi in Yakutia, Russia, NOAA, NSF and Russian agencies are developing an observatory to match the efforts at Eureka and Alert. NSF and NOAA operate the Summit, Greenland, Observatory that is occupied year round (NASA has a small atmospheric aerosol monitoring program at Summit). Together, these and a few observatories operated by other countries constitute a network called "International Arctic Systems for Observing the Atmosphere" (IASOA), a network developed for the International Polar Year. A primary objective of this network is to provide high quality data that can serve to validate satellite observations and model outputs, as well as provide new insights for understanding how the Arctic atmosphere operates.

The Minerals Management Service (MMS), in cooperation with the University of Alaska Fairbanks, maintains meteorological stations on barrier islands along the Beaufort Sea coast, and collects and synthesizes wind time-series data from other North Slope stations into compatible data sets as part of its Beaufort Sea observations. These coastal stations contribute to the planned larger network of operational observing stations that will span the entire North Slope. The MMS atmospheric science program component includes integration of the empirical data in the development and testing of mesoscale forecast models that will provide wind fields across the Beaufort Sea and a portion of the Chukchi Sea.

NPS monitors aerosols at Denali National Park and Preserve (DNPP) to calculate and track visibility trends (1988 to present). The aerosol program is part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Wet deposition has been monitored at DNPP (Site ID AK03) since 1980 as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). In order to estimate dry deposition at DNPP (Site DEN417), weekly concentrations of sulfur and nitrogen compounds have been measured since 1998 as part of the Clean Air Status and Trends Networks (CASTNet). UV-B radiation has been monitored at DNPP since 1997 as part of the EPA UV-B Monitoring Program. The NPS Western Airborne Contaminants Assessment Project (WACAP) is currently evaluating water, snow, sediments, willow bark, fish, and moose tissue in a number of western US and Alaska national parks, including DNPP, for the presence of metals (including mercury) and organic compounds.

NSF is contributing to the development of atmosphere observing activities that are driven by science questions that underline the need for long-term observations that enable SEARCH by measuring changes occurring in the Arctic. NSF AON projects include: core atmospheric measurements at Summit, Greenland; UV spectral irradiance monitoring at Barrow, Alaska, and Summit; development of data products from the high spectral resolution lidar at Eureka, Canada; surface and satellite measurements of clouds across the Arctic Basin; lidar studies of pan-Arctic coupling of tropospheric, stratospheric and mesospheric circulation; development of atmospheric chemistry sensors for deployment on sea ice floes; halogen chemistry and *ocean-atmosphere-sea ice-snowpack (OASIS) chemical exchange.*

Both NOAA and NASA operate satellites with coverage of the Arctic region. The major observations and products are:

1. Daily, near real-time plots of surface, cloud, and radiative properties from AVHRR;
2. Near real-time MODIS and AVHRR polar winds;
3. Daily, near real-time plots of clear sky, low-level temperature inversions from MODIS;
4. Daily profile plots of Arctic temperature, humidity and winds;
5. Near-daily plots of surface winds over open water; and
6. Surface temperatures for land, sea and sea ice.

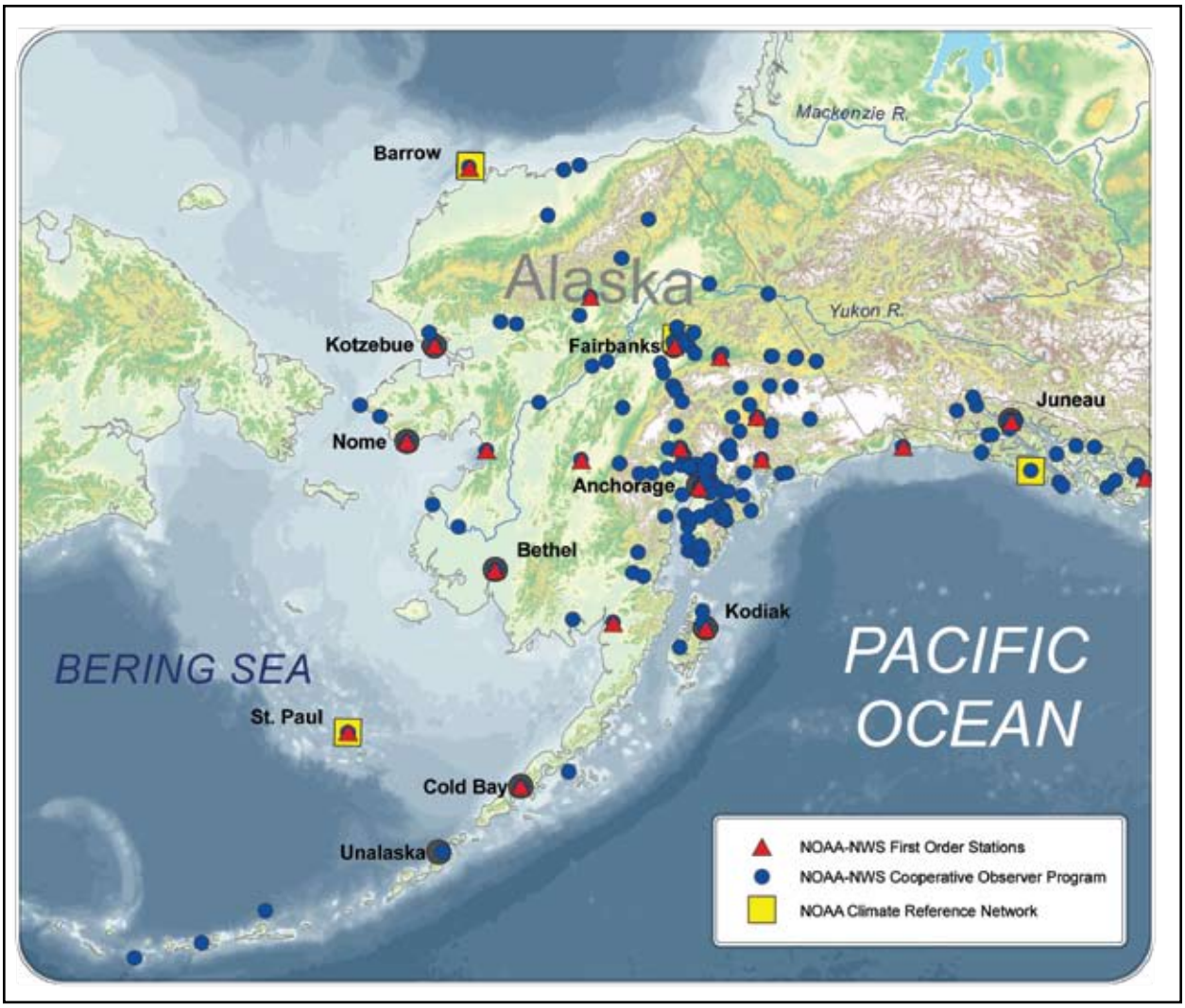

Figure 14. Location of NOAA-NWS first-order weather stations and Cooperative Observer Program participants, and NOAA CRN sites in Alaska. The Cooperative Observer Program locations are those that reported in FY07 (October 2006 – September 2007).

Figure 15. Location of automated weather stations in Alaska. ASOS includes equipment supplied and maintained by NWS, FAA, US Air Force, US Army and corporations. The RAWS program is supported by BIA, BLM, NPS, USFS and USFWS.

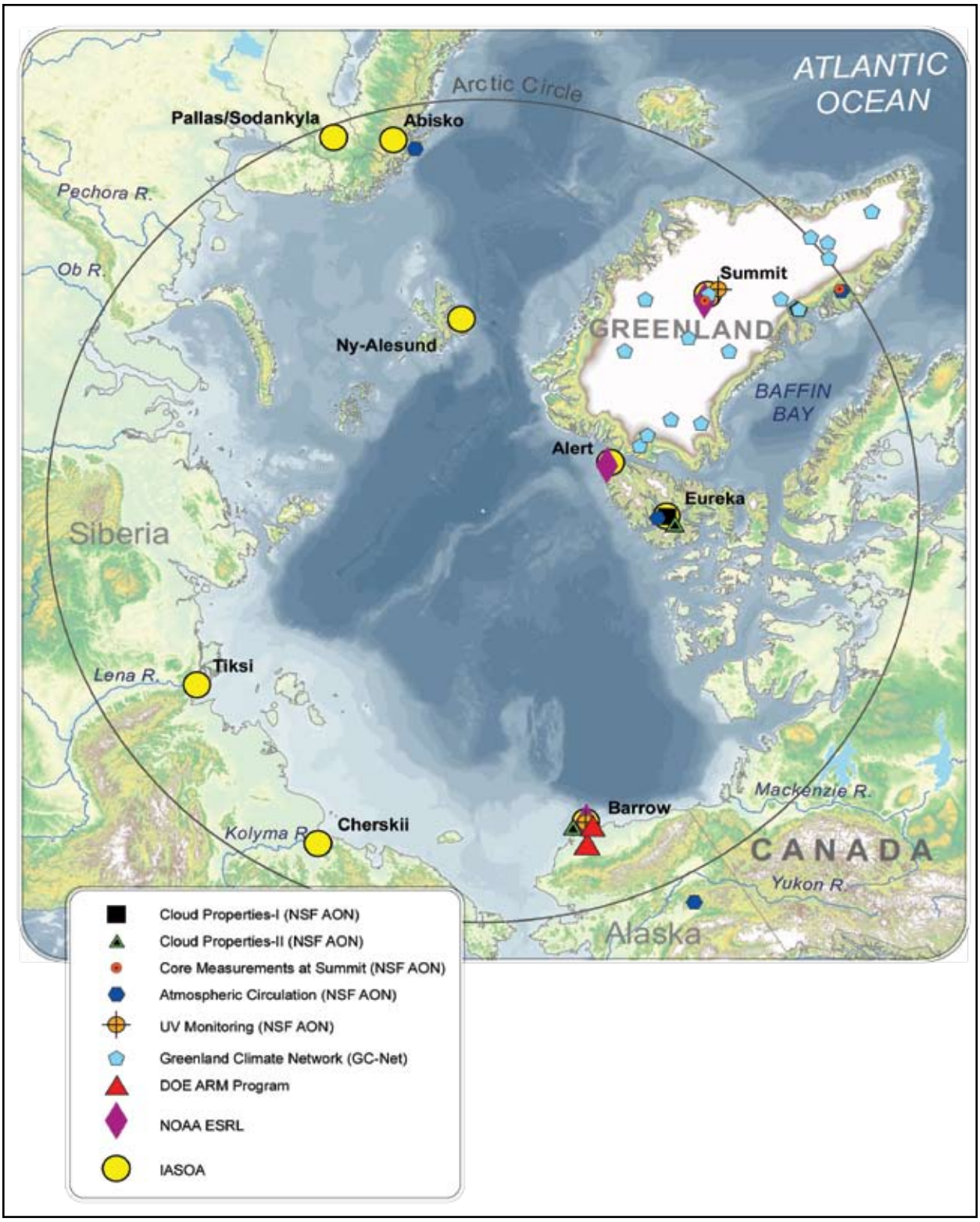

Figure 16. Location of circum-Arctic atmosphere observing sites.

Data and Information Management

Atmosphere data and information are available at the following Web sites:

Alaska Ocean Observing System
ASOS: *http://ak.aoos.org/op/data.php?region=AK&name=met_awos*
RAWS: *http://ak.aoos.org/op/data.php?region=AK&name=met_raws*

Denali National Park and Preserve, Air Quality
http://www2.nature.nps.gov/air/Permits/ARIS/dena/

DOE Atmospheric Radiation Measurement Program
http://www.arm.gov/data/

Greenland Climate Network (GC-Net)
http://cires.colorado.edu/science/groups/steffen/gcnet/order/admin/station.php

NASA Goddard Earth Sciences Data and Information Services Center
http://daac.gsfc.nasa.gov/

NASA MODIS Level 1 and Atmosphere Archive and Distribution System
http://ladsweb.nascom.nasa.gov/"

NASA Atmospheric Science Data Center
http://eosweb.larc.nasa.gov/

NOAA Climate Reference Network
http://www.ncdc.noaa.gov/oa/climate/uscrn/

NOAA ESRL Global Monitoring Division
Data products
http://www.esrl.noaa.gov/gmd/dv/
Data archive
http://esrl.noaa.gov/gmd/dv/ftpdata.html

NOAA National Climatic Data Center
http://www.ncdc.noaa.gov/oa/ncdc.html

NSF UV Monitoring Network
http://www.biospherical.com/nsf/login/login.asp

Polar Satellite Meteorology and Climatology at the Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, Madison
http://stratus.ssec.wisc.edu/

Remote Automated Weather Stations – Alaska
http://www.raws.dri.edu/wraws/akF.html

NASA Goddard Earth Sciences Data and Information Services Center
http://daac.gsfc.nasa.gov/

NASA MODIS Level 1 and Atmosphere Archive and Distribution System
http://ladsweb.nascom.nasa.gov/

NASA Atmospheric Science Data Center
http://eosweb.larc.nasa.gov/

National Snow and Ice Data Center (NSIDC)
http://nsidc.org/

Other Useful Links

Alaska Climate Research Center
http://climate.gi.alaska.edu/

Alaska State Climate Center
http://climate.uaa.alaska.edu/

International Arctic Systems for Observing the Atmosphere
http://iasoa.org/iasoa/

MMS Beaufort Sea Meteorological Study
http://mms-meso.gi.alaska.edu

NSF UV Monitoring Network
Barrow
http://www.biospherical.com/nsf/barrow/barrow.asp
Summit
http://www.biospherical.com/nsf/summit/summit.asp

NOAA ESRL Global Monitoring Division, Barrow
http://esrl.noaa.gov/gmd/obop/brw.html

NOAA National Weather Service Alaska Region Headquarters
http://www.arh.noaa.gov

OASIS, Ocean-Atmosphere-Sea Ice-Snowpack
http://www.oasishome.net/

Remote Automated Weather Stations
http://www.fs.fed.us/raws/

Summit, Greenland
http://www.summitcamp.org/

b. Ocean and Sea Ice

In the SEARCH Implementation Plan, ocean and sea ice observing includes marine ecosystems (ocean and ice), as well as the physical characteristics of the ocean and ice. Ocean and sea ice observations are currently being made by several agencies, including the US Coast Guard (USCG), within the Department of Homeland Security; the Department of Defense, the Department of Interior (DOI MMS); NASA, NOAA and NSF. Ocean and sea ice observing activities are illustrated in Figures 17, 18, 19 and 20 at the end of this section.

The USCG contributes to ocean and sea ice observations through a number of activities. First, USCG supports Arctic research through its icebreaking operations. Assets include three polar class icebreakers, of which HEALY operates in the Arctic, POLAR SEA has recently completed drydock work, and POLAR STAR is in caretaker status pending an Administration decision on how the US can best meet polar icebreaking requirements.

USCG carries out the annual International Ice Patrol (IIP). The activities of the IIP are governed by treaty and US law to encompass only those ice regions of the North Atlantic Ocean through which the major trans-Atlantic shipping lanes pass. There remain other areas of ice danger where shipping must exercise extreme caution. Information concerning ice conditions is collected primarily by air surveillance flights and from ships operating in the ice area. All iceberg data, together with ocean current and wind data, are entered into a computer model that predicts iceberg drift. Every 12 hours, the predicted iceberg locations are used to estimate the limit of all known ice. This limit, along with a few of the more critical predicted iceberg locations, is broadcast as an "Ice Bulletin" from radio stations around the US, Canada, Europe and over the Worldwide Web for the benefit of all vessels crossing the north Atlantic. In addition to the Ice Bulletin, a radio facsimile chart of the area, depicting the limits of all known ice, is broadcast twice daily.

USCG has begun the Arctic Domain Awareness (ADA) program to prepare for increased maritime activity as climate changes provide greater access to the Arctic. Understanding the Arctic Maritime Domain is part of a DOD and DHS effort to improve Maritime Domain Awareness (MDA) by developing an effective understanding of the global maritime domain and supporting effective decision-making as outlined in the National Strategy for Maritime Security. MDA includes both environmental conditions and human activities that could affect maritime safety, security, the economy or environment. As MDA is expanded to the Arctic, there are likely overlaps in resource needs and sensors that could apply to both MDA/ADA and AON, and coordination of their activities will be mutually beneficial.

The IIP works closely with the National Ice Center (NIC), a multi-agency operational center operated by the US Navy, NASA, NOAA and the USCG. The NIC mission is to provide the highest quality strategic and tactical ice services tailored to meet the operational requirements of Federal agencies. The NIC also coordinates and represents the many funding agencies and partners of the US Interagency Arctic Buoy Program (IABP). NIC also funds the coordinator of the program, and NSF supports IABP data management and coordination at the University of Washington. US buoy contributions to the IABP are funded by NOAA and the Office of Naval Research (ONR). NSF supports the fabrication and deployment of drifting ice mass balance buoys by the Cold Regions Research and Engineering Laboratory (CRREL), US Army Corps of Engineers.

The Department of Defense (US Submarine Force, ONR, and Arctic Submarine Laboratory) and NSF have been supporting the Submarine Arctic Science Program (SCICEX). The overall goal of SCICEX, now in its second phase, is to improve understanding of Arctic Ocean processes and their role in the earth's climate system. This is accomplished by dual use of nuclear submarines, capitalizing on existing national platform capabilities and planned submarine missions, to mutually support the objectives of both the civilian science and military communities. The primary focus of the accommodation cruises is to collect baseline data, providing continued monitoring of evolving oceanographic and seafloor conditions, ice distribution, and contaminant concentrations in the Arctic Ocean. All data collected as part of SCICEX are made publicly available as soon as possible after collection.

MMS Arctic research program observing activities complement AON and SEARCH. Historical data from the 1970s through the 1990s have been digitized and compiled into a sea ice atlas. Using satellite imagery and field data, MMS is characterizing the recurrence of spring leads and landfast ice in the Beaufort and Chukchi Seas, and the overflood phenomenon on Beaufort Sea nearshore landfast ice. Also, MMS has partnered with NASA and ONR to improve sea-ice modeling to accurately depict ice lead openings and the range of ice thickness one that might be encountered.

MMS continues to observe ocean circulation, principally in the nearshore Beaufort and Chukchi seas. Deployment of HF radar through a National Ocean Planning Partnership (NOPP) with NOAA to map nearshore circulation provides the groundwork for future continued activity. Instrumented moorings deployed in the nearshore Beaufort Sea are obtaining current, temperature and salinity information in the landfast ice zone to quantify the magnitude of current variability and describe the relationship between currents and local winds. These observations will be extended to the nearshore Chukchi in the future, and have already been expanded to the offshore shelf region through joint funding with ONR and NSF under the 2007 NOPP program on "Coastal Effects of a Diminished-Ice Arctic Ocean". By using field observation data for model assimilation, MMS model development considers long-term hindcast data for oil-spill risk assessment.

MMS is currently sponsoring monitoring of living marine resources including marine mammals (bowhead whale, right whale, polar bear, ringed seal) marine birds (loons, eiders) and marine fishes. Field surveys broadly describe population, distribution and abundance, and reproduction and health. Much of the research is undertaken in collaboration with federal partners including NOAA and USGS.

NASA satellites (Figure 13) and numerous instruments provide high accuracy, stable, circum-Arctic measurements for ocean and sea ice observing, including surface vector winds over the ice-free ocean, sea surface temperature, marine phytoplankton and sea ice temperature. The NASA satellites and ocean and sea ice data sets include:

1. Passive microwave time series of sea ice extent begin in 1978 and are archived at NSIDC.
2. The major Synthetic Aperture Radar (SAR) time series is from the Canadian RADARSAT satellite launched in 1995. RADARSAT data of the Arctic Ocean are processed by the RGPS (RADARSAT Geophysical Processing System, yielding high-resolution charts of ice motion, age/thickness and deformation. All RGPS data are archived at the NASA-supported Alaska Satellite Facility (ASF), University of Alaska Fairbanks.
3. GRACE is a joint NASA/German mission that measures the changes in gravity associated with the changing mass of the ocean, land, and ice sheets. In experimental measurements, GRACE has measured the changes of mass associated with the shift of ocean currents in the Arctic Ocean.
4. The ICESat satellite is in a high latitude orbit (86°N) and can determine the free surface height of the Arctic Ocean up to that latitude. These laser measurements can be used to determine the geostrophic flow. ICESat also measures the height of the snow/air interface of the sea ice, which can be used to estimate sea ice thickness when combined with other data, e.g., snowfall and ice motion, or radar altimeter measurements of the sea ice freeboard.
5. Sea surface temperature (SST) and ice surface temperature (IST) are measured by NASA with the MODIS instrument aboard the Aqua and Terra satellites. The AMSR-E instrument on Aqua measures all-weather sea surface temperature. The follow-on instrument to MODIS is the Visible Infrared Imaging Radiometer Suite (VIIRS), scheduled for launch in 2010 on NPP (NPOESS Preparatory Project). The NPP follow-on satellite is the NPOESS (National Polar-orbiting Environmental Satellite System) series beginning in 2013.
6. Satellite-derived ocean color is used in combination with environmental data to provide primary productivity. NASA currently provides ocean color from observations taken by the MODIS instrument on Aqua. Under present plans, the

MODIS replacement is VIIRS on the NPP and NPOESS satellites. Because VIIRS on NPP is not expected to yield the same high quality of ocean color measurements as MODIS, there may be a gap in the high accuracy of these measurements.

Current NOAA Arctic Ocean observations include the following external-grant funded programs: the deployment of the IABP's buoys (funded by the NOAA Climate Program Office and NIC, see below); Ice Mass balance buoys (through CRREL, Department of Defense); deployment of eight moorings across the Bering Strait (NOAA's Climate Office together with NSF and Russian Agencies and Institutions); and RUSALCA (Russian-American Long-term Census of the Arctic) Ecosystem Census and oceanographic change in the Chukchi Sea and Bering Strait region, (NOAA Climate Office, Ocean Exploration, and Russian Agencies). The goals of the latter include: quantify oceanic throughflow from the Pacific to the Arctic via the Bering Strait, including fluxes of volume, heat, freshwater, nutrients and chlorophyll biomass; quantify change in the throughflow; design an optimum monitoring system for the Bering Strait throughflow; and to understand ecosystems changes in this region as a function of climate change. NSF also supports the RUSALCA Bering Strait mooring program.

The NOAA Office of Ocean Exploration has carried out baseline observations in the Arctic which have contributed significantly to the Census of Arctic Marine Life in the Canada Basin in 2002 and 2005, and with the RUSALCA program in 2004 in the Chukchi Sea. These data are fundamental to long term monitoring of Arctic ecosystems (including many formerly unknown species), which are being subjected to climate change and a dramatic loss of sea ice cover.

The Alaska Fisheries Science Center (AFSC), under NOAA's National Marine Fisheries Service (NMFS) is responsible for the development and implementation of NOAA's scientific research on living marine resources in Alaskan waters. Research addresses more than 250 fish and 42 marine mammal stocks distributed on the US continental shelf and in adjacent pelagic waters. Twenty-seven commercially-important fish and crab stocks are assessed annually. The study of the effects of climate change on marine resources evidenced by loss of sea ice and ocean acidification in the Bering and Chukchi seas is a key research area.

The AFSC leads a suite of fisheries research and assessment cruises in the Gulf of Alaska, Aleutian Islands and Bering Sea, which include:

1. Annual eastern Bering Sea shelf bottom trawl survey
2. Biennial (even number years) survey, eastern Bering Sea
3. Biennial (even number years) bottom trawl survey, Aleutian Islands
4. Biennial (even number years) summer Pollock survey, eastern Bering Sea shelf
5. Annual winter Aleutian basin Pollock survey
6. Annual winter Shumagin Islands Sanak Trough Pollock survey
7. Annual winter Shelikof Strait Pollock survey
8. Annual sable fish longline survey
9. Bering-Aleutian Salmon International Survey extended to the Chukchi Sea and the Eastern Bering Sea Shelf (BASIS).

BASIS is a gridded fisheries oceanography survey that includes CTD and NPZ observations in addition to catches from epipelagic (0-20m) trawls. The AFSC is expanding marine fish survey effort in the Arctic Ocean, including:

1. Beaufort Sea Marine Fish Survey planned for August 2008, a cooperative project of NOAA, UA, UW and MMS (providing funding);
2. Inter-tidal and sub-tidal Marine Fish and Habitat ("ShoreZone") Surveys near Point Barrow (Beaufort and Chukchi Seas) in 2006 and 2008; and
3. Chukchi Sea Marine Fish Survey, an extension of BASIS possible for August 2008, contingent on NOAA ship availability.

In conjunction with these activities, the North Pacific Fishery Management Council (NPMC) is developing a fishery management plan (FMP) for the Arctic. The Council does not currently have a FMP for the Arctic region and the proposed plan would cover Federal marine waters 3-200 nm offshore Alaska in

the Chukchi and Beaufort Seas. If an Arctic FMP is adopted, long-term plans for fisheries surveys will follow. Finally, the AFSC and Alaska Region provide observations of nearshore fish species over the Web via Fish Atlas, with plans to include observing stations occupied by the RUSALCA network, if possible.

FOCI (Fisheries Oceanography Coordinated Investigations) is a joint research program between the NOAA AFSC and the NOAA Pacific Marine Environmental Laboratory PMEL). The goal is to improve understanding of ecosystem dynamics and apply that understanding to the management of marine resources. Much of the information that FOCI collects about the biophysical environment is gathered by oceanographic-biophysical moorings. Mooring sensors include: wind and temperature gauges; sea water temperature sensors; salinity sensors; current, light, nitrate and chlorophyll meters; sediment samplers; and others. Since 2004, autonomous recorders have been included on FOCI moorings on the Bering Sea middle shelf to provide year-round observations of marine mammal calls and underwater ambient noise. Calls of endangered whale species have been detected, in some cases year round. These recorders complement temporary deployments in the Gulf of Alaska and Beaufort Sea, and are part of the nascent Passive Acoustics Ocean Observing System (PAOOS) in development at NOAA Fisheries Office of Science & Technology. When equipped with satellite transmitters, such moorings can relay information about the current environmental state. Moorings such as these are imperative for any program that requires long-term, systematic monitoring of the marine environment in the Arctic.

The NOAA Center for Operational Oceanographic Products and Services (CO-OPS) currently operates 200 permanent National Water Level Observation Network (NWLON) stations with continuous, real-time coastal oceanographic and meteorological data collection throughout the US and island territories. This network provides high quality, long term water level and meteorological data for climate and sea level change monitoring, in addition to validation for satellite sea surface height observations and oceanographic model outputs. There are 28 NWLON stations in Alaska. Continuously operating stations located in or near the Arctic Circle include Prudhoe Bay (since 1988), Red Dog Mine (since 2003) and Nome (since 1992). CO-OPS has been investing in new methods, state-of-the-art sensor technologies and innovative designs for the harsh polar environment. These include the impending installation of two submerged water level systems offshore of Barrow, Alaska, and two control stations onshore. There is a plan to determine the rate of relative mean sea level change at the Arctic stations; this will complement work already completed elsewhere in NWLON (Zervas, 2001).

The NOAA National Data Buoy Center (NDBC) has three moored buoys in the Bering Sea; measurements include sea level pressure, wave height and period, and surface water temperatures.

NOAA's NWS Weather Forecast Office (WFO) in Fairbanks provides marine forecasts and warnings for northwest Alaska and the Arctic coastal waters. These products and services extend out to 100 nautical miles. The WFO Anchorage Ice Desk produces graphic analyses of sea surface temperatures and sea ice as well as five day sea ice forecasts year round. Scheduled sea ice analyses and 5-day sea ice forecasts are also produced as well as a sea surface temperature chart of Alaskan waters.

NSF is contributing to the development of ocean and sea ice observing activities that are driven by science questions that require long-term observations to meet the research goals of SEARCH. NSF AON projects include: the Seasonal Ice Zone Network (SIZONET); the Arctic Ocean ice mass balance buoy network; ice-tethered profilers to sample upper Arctic Ocean properties and heat/salt fluxes; Arctic Ocean aerial hydrographic surveys; the North Pole Environmental Observatory; the Beaufort Gyre Observing System; the Switchyard project in the waters between the North Pole and Ellesmere Island/Greenland; moorings and sea-gliders in Davis Strait between Baffin Island and Greenland; and moorings in the Bering Strait (with NOAA).

NOAA, NSF and ONR fund the NABOS program, a major initiative involving IARC and international partners (Canada, Germany, Japan, Poland, Russia). It is a long-term program intended to provide a

quantitative, observation-based assessment of circulation, water mass transformations, and transformation mechanisms along the principal pathways transporting water from the Nordic Seas into the central Arctic Basin. The primary monitoring tool of the NABOS program is the series of moorings along the edge of the continental margin from the Barents Sea to the East Siberian Sea. Analysis of NABOS data has already provided evidence that the Arctic Ocean has entered a new warm state, with potential implications for the melting of Arctic sea ice (Figure 3; Polyakov et al., 2007).

NSF and the North Pacific Research Board (NPRB) are partners in the "Bering Sea Ecosystem Study" (BEST) and the "Bering Sea Integrated Ecosystem Research Program". They will collect large amounts of data over the next few years throughout all levels of the Bering Sea ecosystem. Although they are not observing programs *per se*, the data will be a baseline for the future and perhaps provide guidance for future monitoring efforts, e.g., what ecosystem components are most important to monitor.

The Alaska Ocean Observing System (AOOS) is the umbrella association for multiple regional observing networks (Gulf of Alaska, Bering Sea/Aleutian Islands, Prince William Sound, Cook Inlet, Southeast and Arctic) that are being developed as part of the national Integrated Ocean Observation System (IOOS) under the NOPP and Ocean.US. AOOS began operations in July 2003 with support from university, federal and private partners, as well as several NOAA planning grants. The observing system gathers physical and biological data related to the state of the weather (via weather stations, buoyed weather stations, surface current measurements, ocean moorings, satellite imaging, SAR) and to the state of the marine ecosystem (nutrients, phytoplankton, zooplankton, benthic plants and animals, fishes and shellfishes, aquaculture, marine birds, and marine mammals). Year-round acoustic observations of marine mammals in the Bering Sea are planned for 2008 and beyond via inclusion of autonomous recorders on AOOS moorings.

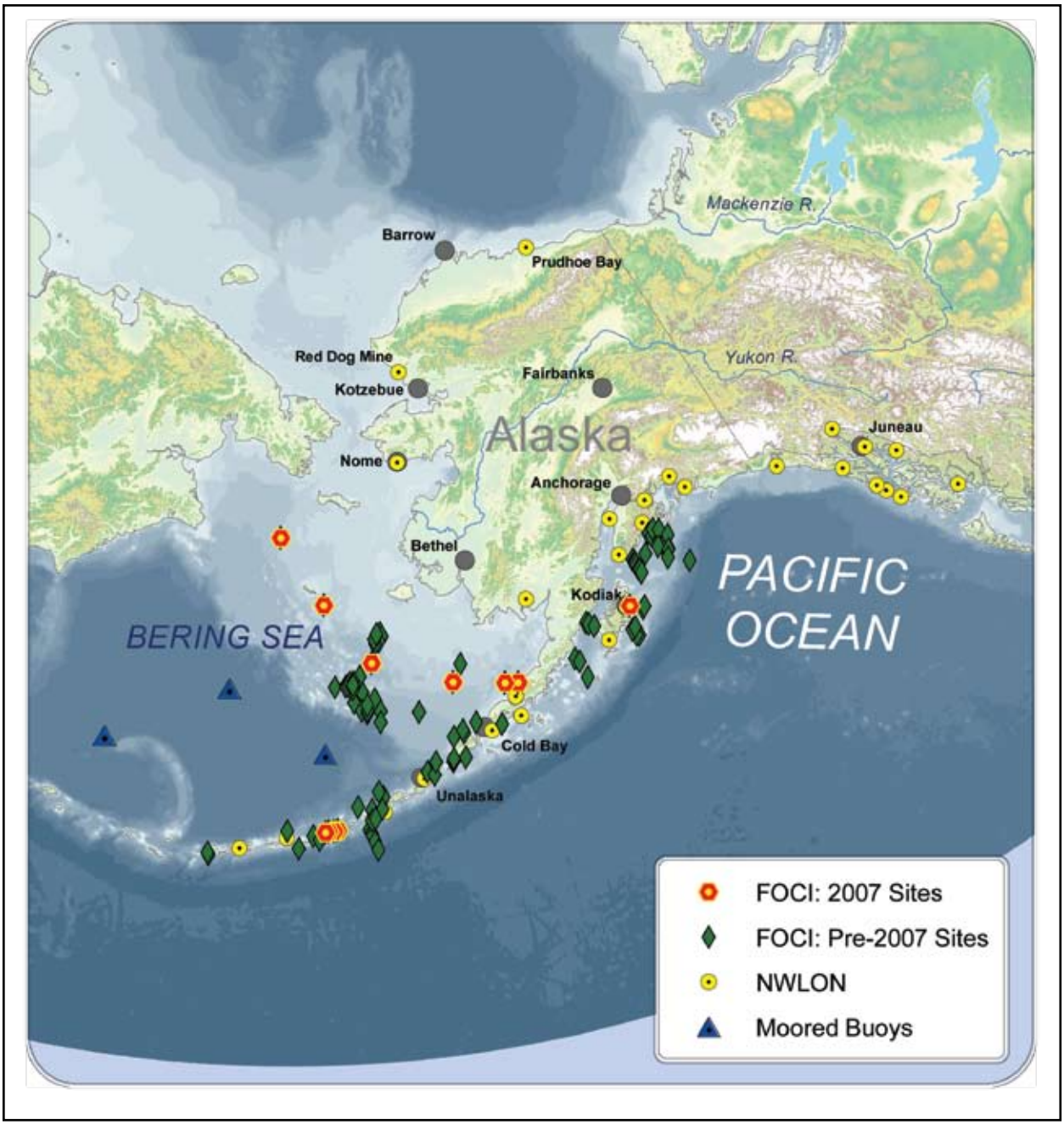

Figure 17. NOAA operational ocean observing activities in Alaska and adjacent waters, including FOCI (Fisheries Oceanography Coordinated Investigations) and NWLON (National Water Level Observation Network).

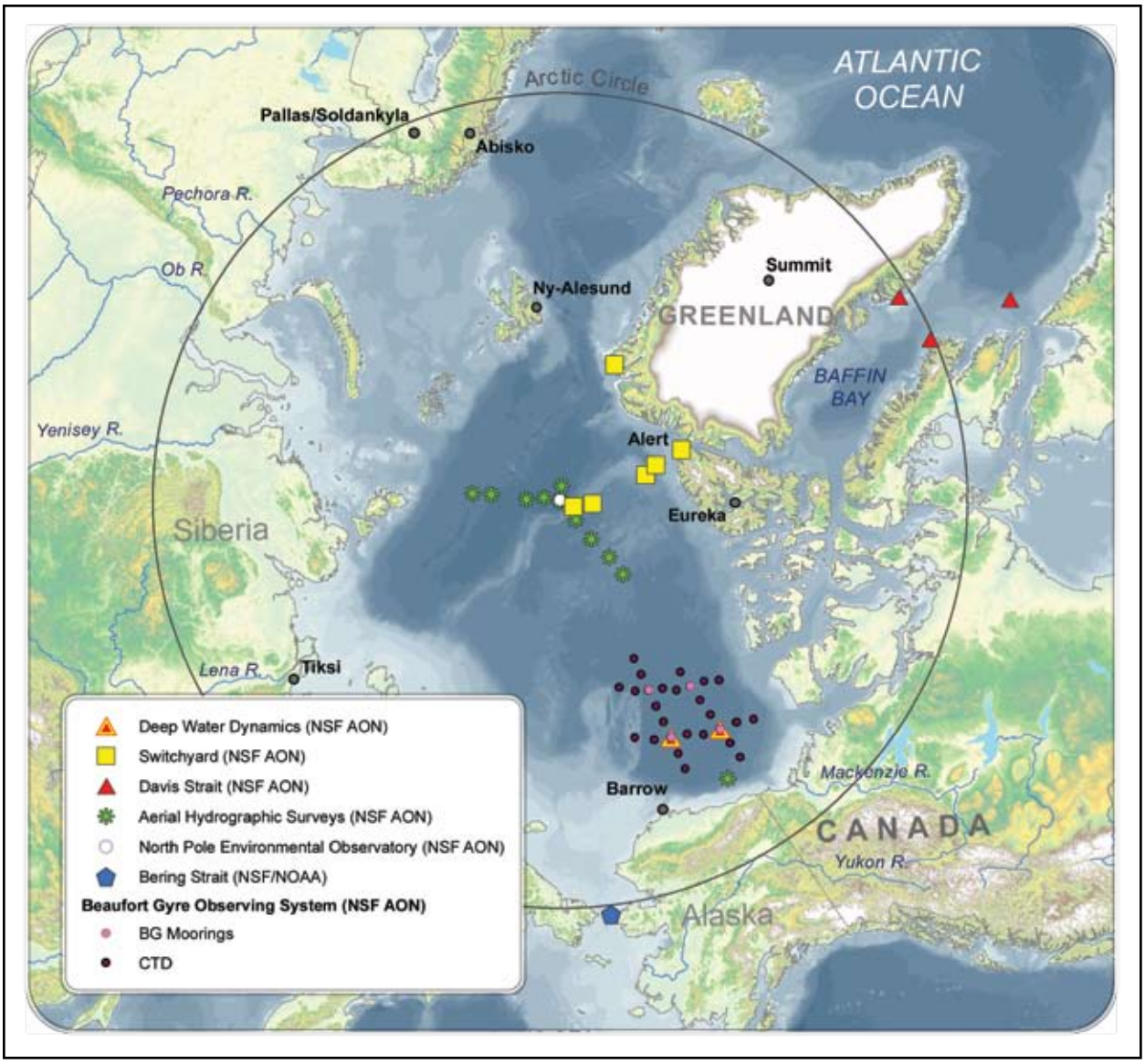

Figure 18. Instrument moorings and hydrographic stations supporting oceanographic investigations in the Arctic Ocean and adjacent seas.

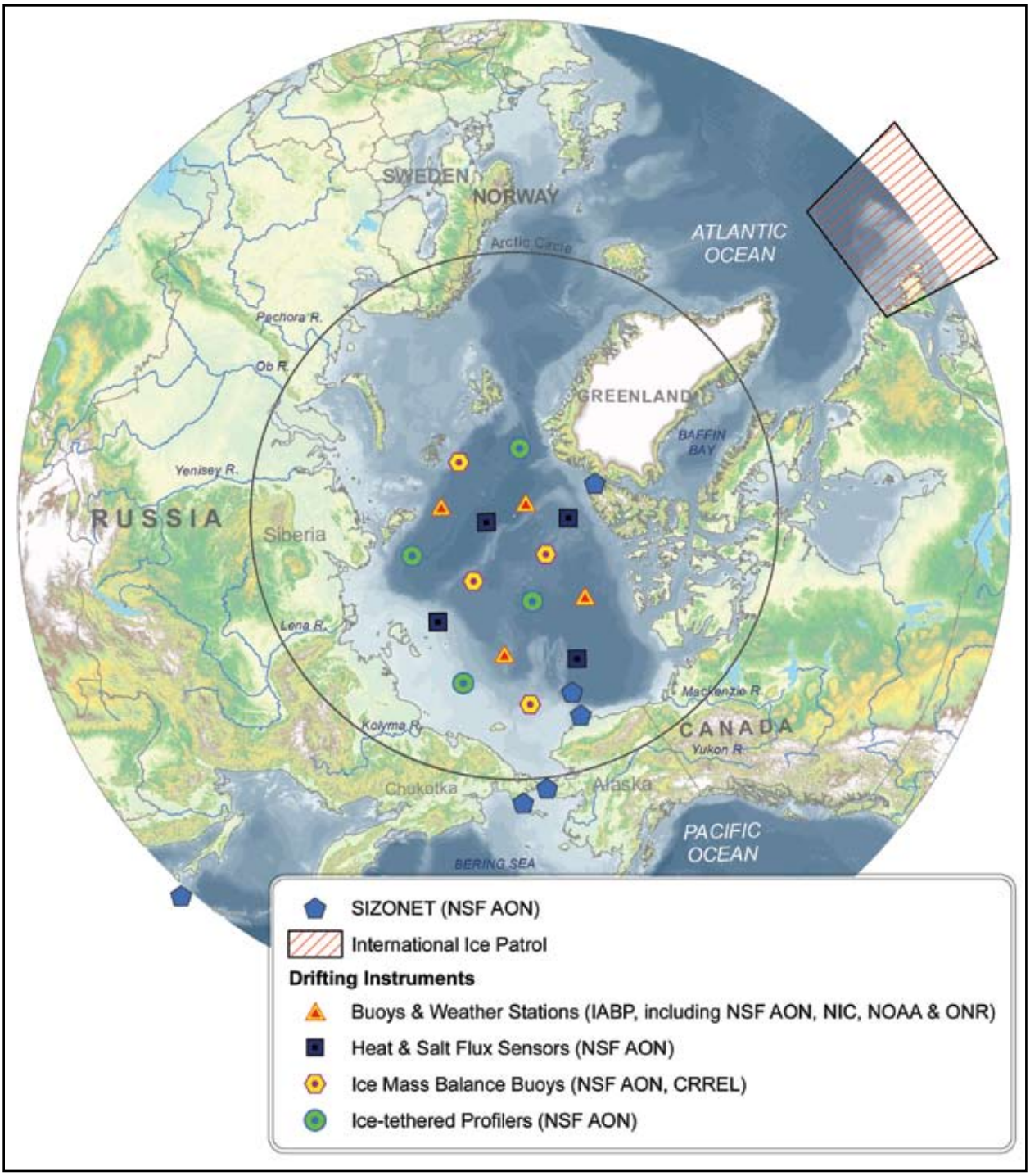

Figure 19. Location of the IIP operations area, the SIZONet, and instruments drifting with the sea ice in the Arctic Ocean. The locations of the drifting instruments are not actual positions; the symbols are intended only to represent the different types of instruments and their broad distribution around the Arctic Basin.

Figure 20. RUSALCA 2004 oceanographic moorings and hydrographic stations in the Chukchi Sea, and the NOAA 2007 Salmon Survey in the northern Bering Sea and the southeastern Chukchi Sea.

Data and Information Management

Ocean and sea ice data and information are available at the following Web sites:

Alaska Ocean Observing System
http://ak.aoos.org/

Alaska Satellite Facility
http://www.asf.alaska.edu

Autonomous Ocean Flux Buoy Program, Naval Postgraduate School
http://www.oc.nps.navy.mil/~stanton/fluxbuoy/deploy/deploy.html

Beaufort Gyre Observing System (NSF AON)
http://www.whoi.edu/beaufortgyre/data.html

Bering Strait, Pacific Gateway to the Arctic (NSF AON)
http://psc.apl.washington.edu/HLD/Bstrait/Data/BeringStraitDownloadregister.html

Cooperative Arctic Data and Information System (NSF AON)
http://www.eol.ucar.edu/projects/aon-cadis/

Davis Strait Project, University of Washington (NSF AON)
http://iop.apl.washington.edu/projects/ds/html/overview.html

Freshwater Switchyard of the Arctic Ocean (NSF AON)
http://psc.apl.washington.edu/switchyard/index.html

International Arctic Buoy Program (NSF AON)
http://iabp.apl.washington.edu/

International Ice Patrol
http://www.uscg.mil/lantarea/iip/General/data_archive.shtml

Nansen and Amundsen Basins Observational System (NABOS)
http://nabos.iarc.uaf.edu/data/registered/main.php

NASA Ocean Biology Processing Group
http://oceancolor.gsfc.nasa.gov/

NASA Physical Oceanography DAAC
http://podaac-www.jpl.nasa.gov/

National Ice Center
http://www.natice.noaa.gov/

NOAA Alaska Fisheries Science Center
http://www.afsc.noaa.gov/

NOAA Fisheries Oceanography Coordinated Investigations (FOCI)
http://www.pmel.noaa.gov/foci/FOCI_data.html

NOAA National Coastal Data Development Center
http://www.ncddc.noaa.gov/

NOAA National Data Buoy Center – Alaska
http://www.ndbc.noaa.gov/maps/Alaska.shtml

NOAA Nearshore Fish Atlas of Alaska
http://www.fakr.noaa.gov/habitat/fishatlas/

NOAA National Ocean Data Center
http://www.nodc.noaa.gov/

NOAA Center for Operational Oceanographic Products and Services:
http://www.tidesandcurrents.noaa.gov/

NOAA Center for Operational Oceanographic Products and Services, Mean Relative Sea Level Trends, Alaska
http://www.tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ak

National Snow and Ice Data Center
http://www.nsidc.org/

North Pole Environmental Observatory (NSF AON)
http://psc.apl.washington.edu/northpole/Data.html

NASA Ocean Biology Processing Group
http://oceancolor.gsfc.nasa.gov/

NASA Physical Oceanography DAAC (Distributed Active Archive Center)
http://podaac-www.jpl.nasa.gov/

Other Useful Links

Bering Strait Environmental Observatory
http://arctic.bio.utk.edu/AEO/

MMS Alaska Activities
http://mms.gov/alaska/ess/ongoing_studies/ongoing_studies.HTM

NOAA Fisheries Office of Science & Technology (S&T)
http://www.st.nmfs.noaa.gov

NOAA National Weather Service Weather Forecast Office Fairbanks
http://pafg.arh.noaa.gov/

NOAA National Weather Service Ice Forecast - Alaska
http://pafc.arh.noaa.gov/ice.php

North Pacific Fishery Management Council
http://www.fakr.noaa.gov/npfmc

RUSALCA: Russian-American Long-term Census of the Arctic
http://www.arctic.noaa.gov/aro/russian-american/

c. Hydrology and Cryosphere

For the purpose of this report, hydrology includes the stocks, fluxes and geochemistry of freshwater, including soil moisture, of the Arctic land mass. The cryosphere includes snow, permafrost, lake ice and river ice (freshwater ice), and glaciers and ice sheets. Sea ice observing activities have been described in sub-section b. Ocean and sea ice. Hydrology and cryosphere observing activities are illustrated in Figures 21, 22 and 23 at the end of this section.

DOD, EPA, HHS, NASA, NOAA, NPS, NSF, USDA and USGS currently contribute to Arctic terrestrial hydrology and cryosphere observing. The North Slope Science Initiative (NSSI) - a local, state and federal government partnership that addresses research, inventory and monitoring needs on the North Slope of Alaska) is also contributing to hydrological observation activities.

DOD observing activities related to Arctic terrestrial hydrology and cryosphere focus mainly on permafrost at two facilities maintained by CRREL: the Permafrost Tunnel at Fox, Alaska, and the Permafrost Research Station at Fairbanks, Alaska. The permafrost tunnel is primarily a research facility, where ground temperatures have been monitored continuously since 1963. At the Permafrost Research Station, ground and air temperatures have been monitored intermittently since 1947; continuous measurements resumed in 2006 and a Circumpolar Active Layer Monitoring (CALM) site was added in 2004. CRREL also monitors shallow ground temperatures at research sites at Shishmaref and Fort Wainwright, Alaska.

The EPA National Aquatic Resource Survey (NARS) assesses the condition of the Nation's aquatic resources, including those in Alaska. NARS is an integrated and comprehensive program that monitors five different categories of aquatic resources: coasts, streams, rivers, lakes, and wetlands. Each of the five aquatic resource categories sample specific indicators to provide information on the physical, chemical and biological condition of the resource. Examples include: coasts (water chemistry, sediment quality, benthic condition, fish tissue contaminants, habitat condition); streams (benthic condition, nutrients, sedimentation, fish habitat, riparian vegetation); rivers (fish, benthos, periphyton, nutrients, sedimentation, recreational indicators); lakes, including ponds and reservoirs (zooplankton, phytoplankton, sediment diatoms, sediment mercury, nutrients, microcystin, enterococcus, fish tissue chemistry); wetlands (to be determined). Sampling was conducted for the National Coastal Assessment in south central Alaska in 2002, in southeast Alaska in 2004, and the Aleutians in 2006-2007. Pilot surveys were conducted for the National Wadeable Streams Survey in the Tanana basin in 2004-2005, and for the National Wadeable Lakes Survey in the Kenai region in 2007-2008.

NASA satellites (Figure 13) support an extensive Global Water Cycle science focus area and contribute to high accuracy, stable, sustained observations and associated modeling for terrestrial hydrology and cryosphere studies. Derived geophysical products for terrestrial hydrology and cryosphere are available from the NSIDC's Distributed Active Archive Center (DAAC). They include: soil moisture and snow water equivalent from AMSR-E; Greenland ice sheet altimetry and global land surface altimetry from ICESat/GLAS; snow cover extent/area from MODIS; surface albedo and temperature from AVHRR Pathfinder. SAR data obtained from a variety of foreign satellites since 1991 are archived at the ASF DAAC. SAR data provide opportunities for change detection, including interferometric SAR (InSAR) studies of glacier and ice sheet surface elevation and dynamics (ice velocity maps), land surface elevation, and soil moisture.

GRACE has been used to determine the mass loss from the Greenland ice sheet and from glaciers in southeast Alaska. The surface elevation of the Greenland ice sheet is mapped using ICESat, and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is used to acquire imagery and topography of the ice sheet.

NOAA observations for Arctic hydrology and cryosphere in Alaska include snow depth and precipitation at NWS weather stations and Cooperative Observer locations, precipitation at NCDC CRN sites, and river forecasting. The latter is the responsibility of the Alaska-Pacific River Forecast Center

(APRFC), which monitors water levels and spring ice conditions on the major rivers in Alaska primarily for the purpose of flood and high water forecasting. The NPS Inventory and Monitoring Program in the Alaska Region includes hydrology and cryosphere observing activities. The purpose of the program includes the development of scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems. The Program aims are: (1) to provide a consistent database of information about natural resources, including species diversity, distribution and abundance [basic inventories]; and (2) to determine the current condition of resources and how they are changing over time (vital signs monitoring). In the NPS Arctic Region, the conceptual framework for inventory and monitoring includes two 'vital signs' for hydrology and cryosphere monitoring: surface water dynamics and distribution; and permafrost and thermokarst. The Central Alaska Region has five vital signs for hydrology and cryosphere monitoring: snowpack, glaciers, permafrost, flood frequency and discharge, and river/stream flow.

NSF is contributing to the development of hydrology and cryosphere observing activities that are driven by science questions that underline the need for long-term observations that enable SEARCH by measuring changes occurring in the Arctic. NSF AON projects include: hydro-meteorological measurements at the Kuparuk River watershed on the North Slope of Alaska; permafrost temperature measurements at deep boreholes in Alaska and Russia; and, a prototype network for snowfall and snow accumulation measurements.

NSF also funds (1) the Center for Remote Sensing of Ice Sheets (CReSIS), a NSF Science and Technology Center established in 2005; and, (2) POLENET in Greenland. CReSIS will engage in technology development, and create times series datasets of accumulation rate, surface elevation, ice thickness and velocity, and melt rate for the Greenland ice sheet. POLENET is deploying a network of GPS sensors (GNET) that will allow scientists to 'weigh' the ice sheet and detect changes in its mass. CReSIS also benefits from NASA support for aerial missions over Greenland, and for some instrument development. NSSI is funding the installation of several stream gauges in the National Petroleum Reserve Alaska and the Arctic National Wildlife Refuge. USGS will be responsible for gauge maintenance and data archive. The data will be available from the USGS and from the Geographic Information Network of Alaska (GINA) at the University of Alaska Fairbanks.

USDA data collection activities related to Arctic terrestrial hydrology and cryosphere are coordinated by the Natural Resources Conservation Service (NRCS). The primary operational data-collection activities are the Alaska Snow Survey Program, Soil Climate Analysis Network, and the National Soil Survey Center. The Snow Survey Program uses snow courses, precipitation gages, and SNOTEL (SNOwpack TELemetry) sites to obtain data necessary for water supply management, flood control, climate modeling, recreation, and conservation planning. The six SCAN sites in Alaska provide data on soil moisture and meteorological parameters and serve this data real-time through the NRCS National Water and Climate Center to support many of the same activities as the Snow Survey Program. The National Soil Survey Center and academic partners monitor soil moisture, soil temperature and air temperature at nine sites on the North Slope of Alaska.

USGS Arctic hydrology and cryosphere observing activities include: (1) permafrost temperature, soil moisture and vegetation change measurements at the DOI/GTN-P (Global Terrestrial Network-Permafrost) active-layer monitoring sites in northern Alaska; (2) permafrost temperature measurements in the DOI/GTN-P deep borehole array in the National Petroleum Reserve-Alaska Alaska; (3) benchmark glacier monitoring, particularly bi-annual mass balance measurements, at Gulkana and Wolverine glaciers; and (4) stream gauging at locations throughout Alaska. The USGS National Stream Quality Accounting Network (NASQAN) includes the Yukon River, where baseline and process-based data on the concentrations and fluxes of sediments and chemicals are collected to understand the basin response to climate change. The HHS Administration for Native Americans also supports Yukon River water quality monitoring through the Yukon River Inter-Tribal Watershed Council. USGS publishes the Satellite Image Atlas of the Glaciers of the World, a multi-volume publication that establishes a baseline for the areal distribution of the Earth's glaciers.

Figure 21. Location of hydrological observing sites in Alaska. The APRFC (Alaska Pacific River Forecasting Center, NOAA-NWS) monitors the highlighted rivers from the air and by satellite in spring, and also receives information in autumn (freeze-up), winter (ice thickness) and spring (break-up) from observers in villages by the rivers. No information was provided for NPS hydrological observing locations.

Figure 22. Location of snow and glacier observing sites in Alaska. No information was provided for NPS glacier observing locations.

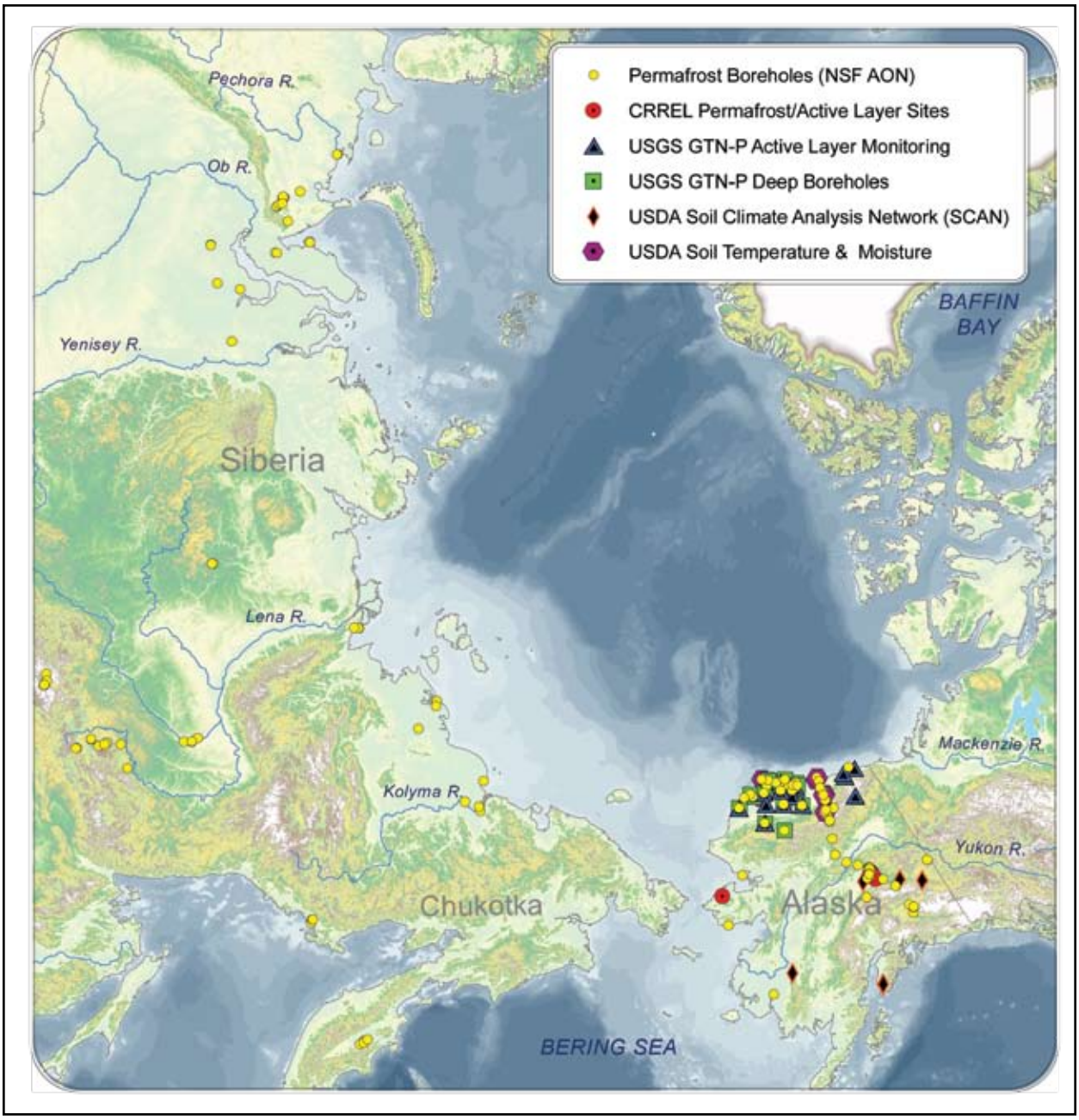

Figure 23a. Location of permafrost and active layer observing sites in Alaska and Russia. The Alaska sites are shown in more detail in Figure 22b.

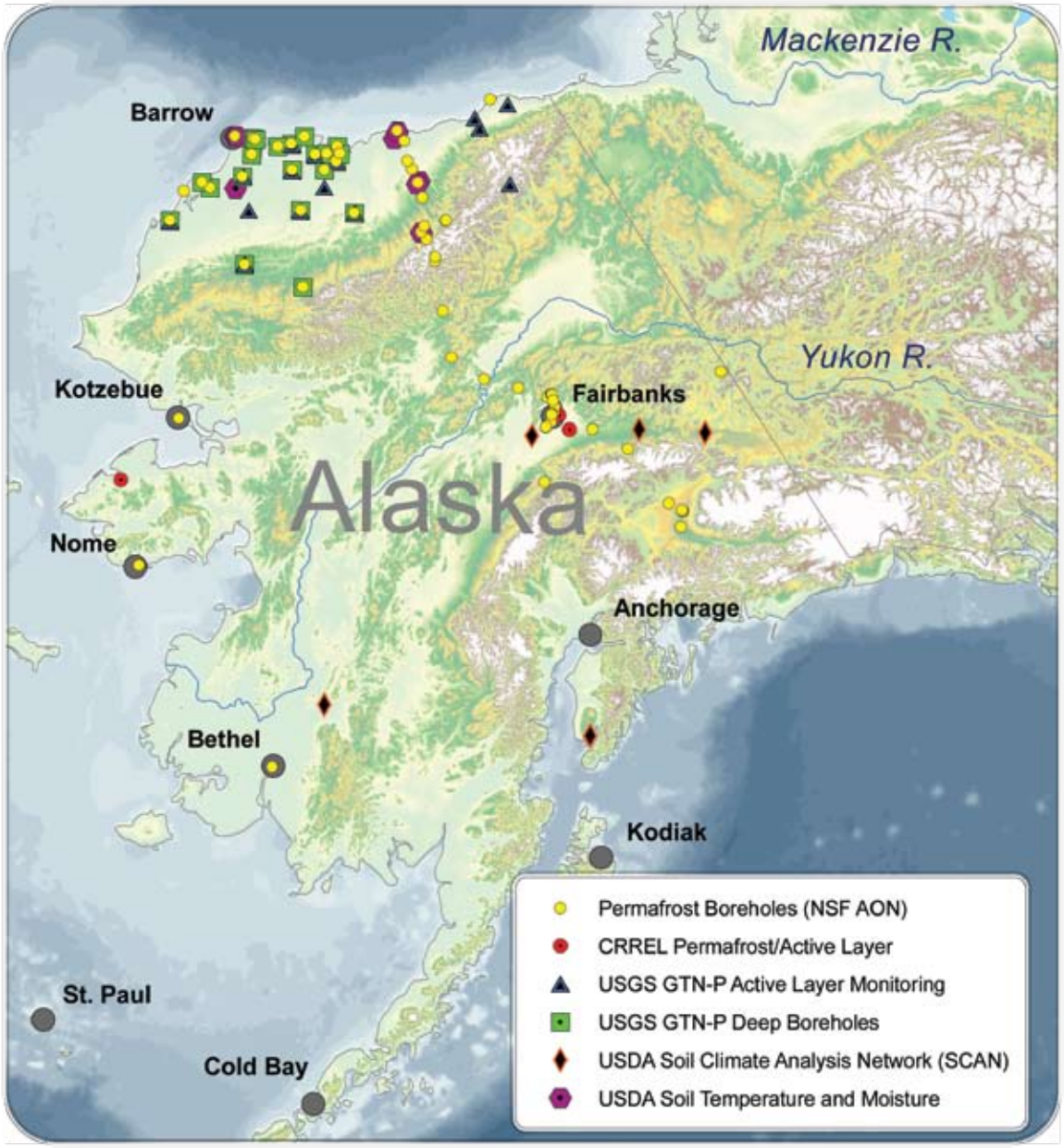

Figure 23b. Location of permafrost and active layer observing sites in Alaska. No information was provided for NPS permafrost and active layer observing locations.

Data and Information Management

Hydrology and cryosphere data and information are available at the following Web sites:

Alaska Satellite Facility
http://www.asf.alaska.edu

Geographic Information Network of Alaska
http://www.gina.alaska.edu/

NASA Global Change Master Directory
http://gcmd.gsfc.nasa.gov/

NASA Earth Observing System Data Gateway
http://delenn.gsfc.nasa.gov/~imswww/pub/imswelcome/

NOAA National Climatic Data Center
http://www.ncdc.noaa.gov/oa/ncdc.html

NOAA National Geophysical Data Center
http://www.ngdc.noaa.gov/

NOAA National Weather Service, Alaska-Pacific River Forecast Center
http://aprfc.arh.noaa.gov

National Park Service, Inventory and Monitoring Program - Alaska Region
http://www.nature.nps.gov/im/units/akro/index.cfm

National Snow and Ice Data Center (NSIDC)
http://www.nsidc.org/

USDA Alaska Snow Survey Program
http://www.ak.nrcs.usda.gov/Snow/data/

USDA Alaska Snow, Water and Climate Services
http://ambcs.org

USDA Snow Course Data
http://www.wcc.nrcs.usda.gov/snowcourse

USDA SNOTEL Data and Products
http://www.wcc.nrcs.usda.gov/snow/

USDA Soil Climate Analysis Network (SCAN)
http://www.wcc.nrcs.usda.gov/scan/Alaska/alaska.html

USGS Alaska Borehole (Permafrost) Temperature Logs
http://esp.cr.usgs.gov/data/bht/alaska/

USGS Alaska Science Center – Water Resources
http://alaska.usgs.gov/science/water/index.php

USGS Alaska Streamflow Statistics
http://ak.water.usgs.gov/Projects/FloodFrq/index.php

USGS Benchmark Glaciers
http://ak.water.usgs.gov/glaciology/

USGS Water Data for Alaska
http://waterdata.usgs.gov/ak/nwis/

USGS and NASA Land Processes Distributed Active Archive Center (LP DAAC)
http://edcdaac.usgs.gov/main.asp

Other Useful Links

Center for Remote Sensing of Ice Sheets
https://www.cresis.ku.edu/

Cold Regions Research and Engineering Laboratory: Permafrost Tunnel
http://www.crrel.usace.army.mil/alaska-office/foxtunl.html

Cold Regions Research and Engineering Laboratory - Permafrost Research Facility
http://www.crrel.usace.army.mil/alaska-office/flroad.html

POLENET – Polar Earth Observing Network
http://www.polenet.org/

USDA NRCS National Water and Climate Center
http://www.wcc.nrcs.usda.gov

USGS Alaska Science Center
http://alaska.usgs.gov/portal/

USGS Satellite Image Atlas of the Glaciers of the World
http://www.glaciers.er.usgs.gov/html/project.html

Yukon River Inter-Tribal Watershed Council – Yukon River Water Quality
http://www.yritwc.com/programs/waterQuality.htm

d. Terrestrial Ecosystems

For the purpose of this report, terrestrial ecosystems encompass both the land and freshwater. Freshwater geochemistry is in the previous section on Hydrology and Cryosphere section. Terrestrial ecosystems observing activities are illustrated in Figure 24 at the end of this section.

BLM is responsible for the Alaska Inter-Agency Coordination Center (AICC) for wildland fire management and suppression in Alaska. Other federal agencies contributing to this operational center include NPS, US Fish and Wildlife Service, US Forest Service, Bureau of Indian Affairs, and USGS (indirectly via the National Inter-Agency Coordination Center for wildland fire). The AICC uses NASA MODIS data distributed by GINA to support its operations. As noted in Section 5a, a large interagency group (BIA, BLM, NPS, USFS, USFWS) maintains the RAWS network for rating fire danger in Alaska.

NASA operates a number of satellites (Figure 13) and instruments that contribute to Arctic observing and establishment of baseline datasets for studies of terrestrial ecosystems and their interactions with other components of the global integrated Earth system.

The NPS Inventory and Monitoring Program in the Alaska Region includes numerous terrestrial ecosystems observing activities in the Arctic Region and the Central Alaska Region. In the Arctic Region, for example, the conceptual framework for inventory and monitoring includes 12 'vital signs' for terrestrial and freshwater ecosystems monitoring: small mammals, brown bear, caribou, muskox, moose, Dall's sheep, fire extent and severity, permafrost and thermokarst, terrestrial vegetation and soils, terrestrial landscape patterns and dynamics, fish assemblages, stream communities and ecosystems, lake communities and ecosystems, and surface water dynamics and distribution. The Central Alaska Region has 22 vital signs for terrestrial ecosystems monitoring.

NSF is contributing to the development of terrestrial ecosystem observing activities that are driven by science questions that underline the need for long-term observations that enable SEARCH by measuring changes occurring in the Arctic. NSF AON projects include: (1) International Tundra Experiment (ITEX) plant phenology and community composition; (2) carbon, energy and water fluxes at flagship sites in Alaska and Russia; and (3) the Circumpolar Environmental Observatories Network (CEON). Also, NSF is the primary funding agency for the LTER sites at Toolik Lake (Arctic LTER) on the North Slope of Alaska and Bonanza Creek/Caribou-Poker Creeks in the boreal forest of central Alaska.

The USDA Forest Service is a partner in the Bonanza Creek LTER. The USDA also manages the Alaska Soil Survey, a scientific inventory of soil resources in 31 different regions of the state. The data are used for making maps, identifying physical and chemical properties of soils, and supplying current information on potential uses and limitations of soils. The Soil Survey contributes to the Natural Resources Inventory that involves monitoring of the changes and trends in natural resource use and condition.

The NSSI is also contributing to terrestrial ecosystems observation activities through its support for a land cover change detection project that covers the entire North Slope of Alaska. Data will be available via GINA.

USFWS is the lead US representative to the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) program. In the eight national wildlife refuges that fall within the CAFF-designated Arctic region, USFWS is conducting approximately 150 monitoring projects; the majority are bird and mammal studies, but there are also fish, vegetation, insect and hydrological studies. Outside the wildlife refuges, but still within the CAFF-designated Arctic region, USFWS is conducting over 100 monitoring projects; the majority are fish, bird and marine mammal studies, but there are also some contaminant, insect and vegetation studies.

The USGS maintains the Landsat satellite operations and archive mission components of the Landsat system. These data are used for a wide variety of applications including multi-temporal monitoring of Arctic and Sub-Arctic landscape conditions (coastal

erosion and land cover mapping). Since 1972, the Landsat series of satellites have captured over 2 million images of the Earth's surface (*http://landsat.usgs.gov/*)."

USGS Arctic terrestrial ecosystems observing activities are concerned with Arctic landscape response to changing climate. Geographically, the focus is on the North Slope of Alaska and two projects in particular: (1) spatio-temporal variation of terrestrial and coastal habitats on the Arctic Coastal Plain; and (2) consequences of changing habitats for fish and wildlife.

Figure 24. Location of terrestrial ecosystem observing activities in Alaska, Russia and Greenland. No information was provided for NPS terrestrial ecosystem observing sites.

Data and Information Management

Terrestrial ecosystems data and information are available at the following Web sites:

Arctic LTER
http://ecosystems.mbl.edu/ARC/; *http://www.lternet.edu/sites/arc/*

Bonanza Creek LTER
http://www.lter.uaf.edu/; *http://www.lternet.edu/sites/bnz/*

Bureau of Land Management, Wildland Fire Dataset for Alaska
http://agdc.usgs.gov/data/blm/fire/index.html

Circumpolar Environmental Observatories Network (CEON)
http://www.ceoninfo.org/

Conservation of Arctic Flora and Fauna (CAFF)
http://arcticportal.org/en/caff/

Geographic Information Network of Alaska
http://www.gina.alaska.edu/

Long Term Ecological Research (LTER) Network
http://www.lternet.edu/

National Park Service Inventory and Monitoring Program
http://science.nature.nps.gov/im/

National Park Service Inventory & Monitoring Program: Arctic Network
http://www1.nature.nps.gov/im/units/arcn/index.cfm

National Park Service Inventory & Monitoring Program: Central Alaska Network
http://www1.nature.nps.gov/im/units/cakn/index.cfm

National Snow and Ice Data Center – ITEX
http://nsidc.org/cgibin1/dynomatic.pl?file=quick_sch_rslt.html&form_name=quick_search&broker1=NULL&quick_search_2_keyword=itex&lat2=90&lon1=-180&lon2=180&lat1=-90&submit=Search

USDA Alaska Soil Survey
http://www.ak.nrcs.usda.gov/soils/index.html

USDA Soil Data Mart
http://soildatamart.nrcs.usda.gov

USDA Web Soil Survey
http://websoilsurvey.nrcs.usda.gov/app

USGS and NASA Land Processes Distributed Active Archive Center
http://edcdaac.usgs.gov/main.asp

Other Useful Links

Alaska Inter-Agency Coordination Center (for wildland fire)
http://fire.ak.blm.gov/

International Tundra Experiment (ITEX)
http://www.geog.ubc.ca/itex/

National Inter-Agency Coordination Center (for wildland fire)
http://www.nifc.gov/nicc/

USGS Alaska Science Center
http://alaska.usgs.gov/science/biology/index.php

e. Human Dimensions

Any viable observation system, no matter how sophisticated the technology, relies on people. The needs, aspirations and knowledge of Arctic residents, as well as information needs of industries active in the Arctic, must be considered in planning and carrying out environmental observations. Human dimension observing activities are illustrated in Figure 25 at the end of this section.

Young people in the Arctic become involved in environmental observing through school-based programs such as those based on GLOBE: Global Learning and Observations to Benefit the Environment. For example, the "Seasons and Biomes" Project is a partnership among Alaska elementary and secondary schools, IARC, the NASA Landsat Data Continuity and Terra Satellite Missions and NSF. This partnership uses GLOBE protocols to monitor seasonal environmental changes in different biomes, such as taiga and tundra. Efforts such as these to link environmental observing with education at the pre-college level can heighten the interest of young Arctic residents in science careers.

Over the last decade or so, Arctic residents have become increasingly involved in research as active participants. Therefore, AON must include community-based research and knowledge systems in which Arctic societies are able to collect, preserve, and exchange relevant and timely information.

The SEARCH Implementation Plan identified several aspects of environmental change of concern to Arctic societies, including the extent and nature of sea ice, storminess and erosion, marine and terrestrial ecosystems (especially fish and mammal populations), permafrost, and vegetation. The Plan considers people, both individuals and institutions, as part of the Arctic ecosystem and recognizes the importance of interactions between humans and the rest of the ecosystem to predicting social outcomes and ecosystem feedbacks.

Community Change and Arctic Development

Ongoing efforts to preserve and exchange community-based information include the Exchange for Local Observations and Knowledge of the Arctic (ELOKA). During IPY, NSF is supporting this project in addition to two others relevant to people and communities in the Arctic: the Bering Sea Sub-Network (BSSN), a pilot project for a community-based observing network focusing on marine species of subsistence interest; and 'Arctic Observation Network: Social Indicator Project'. The goal of the latter project is to identify knowledge that will help people respond to environmental change, with a focus on four arenas likely to involve climate-human interactions: marine mammal hunting; oil, gas, and mineral development; tourism; and fisheries. A fifth project focus is on indicators of social outcomes of human interactions with environmental change.

The Arctic Borderlands Ecological Knowledge Cooperative monitors and assesses change in the range of the Porcupine Caribou Herd and adjacent Mackenzie Delta area in the Northwest Territories, the Yukon, and Alaska. The Borderlands Co-op is run by a non-profit society. Funding and support has come from Canadian, territorial and several US government agencies, co-management boards, and Inuvialuit and First Nation councils. Additional project funding is currently from Indian and Northern Affairs Canada, and the University of Alaska. Environment Canada provides in-kind support for overall program coordination. The program focuses on four main issues: ecological monitoring, climate change, contaminants, and regional development. The program brings together science and local and traditional knowledge. Community researchers conduct interviews with local experts each year. Observations about fish, berries, caribou, unusual animal sightings, weather conditions, and other aspects of the environment and communities, are drawn together and made available to the public through reports and presentations.

NMFS, and particularly the AFSC, conducts field and laboratory research on living marine resources. Scientists compile and analyze databases on fishery,

oceanography, marine mammal, and environmental research. The results of this research are of utmost importance to Alaska coastal communities.

DOI has a large and complex management and research role in Alaska. Below are just a few examples of ongoing DOI activities with respect to people and communities.

USFWS has a monitoring program to help provide information needed for effective management of subsistence fisheries on Federal public lands in Alaska. The program funds projects to address research priorities identified by management agencies and local users from around the state. Funding has been awarded to more than 70 Alaska Native organizations, rural organizations, universities, and Federal and State agencies. Projects include studies of the status of fish stocks, subsistence harvest patterns, and traditional ecological knowledge.

The Fisheries Monitoring Program also works to integrate Alaska Native and rural organizations into the management of subsistence fisheries resources through the Partners for Fisheries Monitoring Program. This program was established to help Alaska Native and rural organizations participate in subsistence fisheries management and research. Alaska Native and rural organizations represent those who depend upon subsistence fisheries resources and have perspectives and knowledge that can be valuable in identifying issues, conducting research, and managing subsistence fisheries.

The MMS, Alaska Outer Continental Shelf Region, conducts ongoing environmental studies, including socioeconomic research and multidisciplinary, participatory work to assess the potential effects of oil and gas development. The MMS incorporates local and traditional knowledge in study planning, field work, and interpretation of results, with the goal of providing better information for decision-making. Community based observations are currently collected through a continuing multiyear study which records the status of subsistence hunting activities on Cross Island during the fall bowhead whale hunt. Similar studies are planned for Chukchi sea coastal villages.

Human Health

Human health is an integral component of the Arctic ecosystem. Life expectancy in arctic populations has greatly improved over the last 50 years due to a reduction in morbidity and mortality from infectious diseases, such as tuberculosis, and the vaccine preventable diseases of childhood and improved living condition and access to health care. However, significant health disparities remain between the indigenous and non indigenous populations in the arctic. Indigenous populations experience lower life expectancy, higher infant mortality; higher suicide rates higher rates of infectious diseases such as hepatitis b and tuberculosis and higher rates of some cancers. Health concerns of arctic peoples also include potential health impacts of environmental pollution, climate variability, and the rapid rate of modernization and associated social and cultural changes which may result in higher rates of obesity, diabetes, cardiovascular diseases and suicides.

The Centers for Disease Control and Prevention, Arctic Investigations Program, has established an International Circumpolar Surveillance (ICS) system for infectious diseases by creating a network of hospital and public health laboratories throughout the Arctic. The network allows collection and sharing of uniform laboratory and epidemiologic data among Arctic countries that will describe the prevalence of infectious diseases of concern to Arctic residents and assist in the formulation of prevention and control strategies. While currently focused on prevention and control of infectious disease the system also provides a model for standardized monitoring and respond to other non infectious health conditions of concern within Arctic regions.

Many regional and national surveillance networks exist for monitoring health conditions of concern. Within the State of Alaska, the Alaska Surveillance, Epidemiology and End Results (SEER) program collects and publishes cancer data as part of the National Cancer Institute's overall SEER program, and the Alaska Native Stroke Registry is a project to increase the understanding of stroke in Alaska Natives, with the goal of improving stroke care. Circumpolar linkage of such networks would facilitate international collaboration, international standardization of data

collection international comparison of comparable data, thereby greatly adding to our knowledge of Arctic health, and enhancing design of treatment and prevention.

The above summary of Federal observing activities is far from exhaustive, but rather gives exemplars of current foci in environmental observations that are done by and/or have great consequence for Arctic residents.

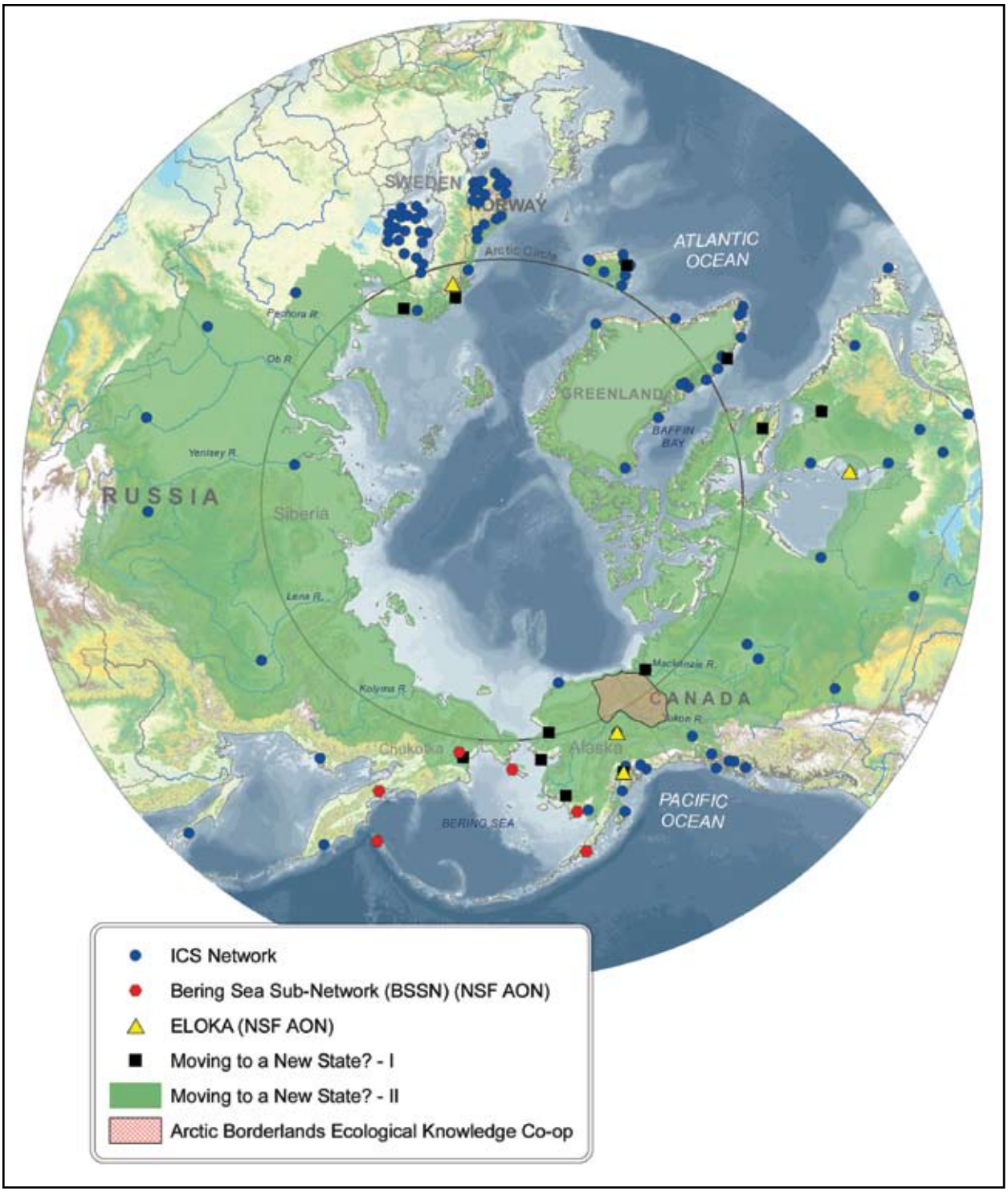

Figure 25. Community-based observing projects include the Bering Sea Sub-Network (BSSN), the Exchange for Local Observations and Knowledge in the Arctic (ELOKA), and the Arctic Borderlands Ecological Knowledge Coop. Also shown are the locations of participating and proposed hospitals and public health laboratories in the International Circumpolar Surveillance (ICS) system, and the region and locations covered by the NSF-funded project "Is the Arctic Human Environment Moving to a New State?".

Data and Information Management:

Community Change and Arctic Development

Alaska Department of Fish and Game: Subsistence, Community Profiles
http://www.subsistence.adfg.state.ak.us/

Alaska Fisheries Science Center
http://www.afsc.noaa.gov/default.htm

Alaska Native Knowledge Network
http://www.ankn.uaf.edu/

Alaska Outer Continental Shelf Region, US Minerals Management Service
http://www.mms.gov/alaska/

Arctic Borderlands Ecological Knowledge Cooperative
http://www.taiga.net/coop/index.html

Exchange for Local Observations and Knowledge of the Arctic
http://ipydis.org/eloka/

Fisheries Monitoring Program: US Fish and Wildlife Service
http://alaska.fws.gov/asm/fisindex.cfm

NASA Socioeconomic Data and Applications Center
http://sedac.ciesin.columbia.edu/

Health

Alaska Surveillance, Epidemiology, and End Results (SEER) Program
http://seer.cancer.gov/

Alaska Native Stroke Registry
http://alaskastroke.com/

Arctic Health: An Information Portal (National Library of Medicine)
http://www.arctichealth.org/

International Circumpolar Surveillance of Infectious Diseases (ICS)
http://www.cdc.gov/eid/content/14/1/18.htm

Other Useful Links

International Arctic Social Sciences Association
http://www.iassa.gl/index.htm

Principles for the Conduct of Research in the Arctic
http://www.nsf.gov/od/opp/arctic/conduct.jsp

f. Paleoenvironment

For the purpose of this report, the primary sources of proxies for paleoenvironment observations are non-instrumental records obtained from ice cores, marine and lake sediment cores, and tree rings. The paleoenvironment network is considered to consist of (1) the sampling locations, e.g., an ice core site, (2) the samples themselves, e.g., an ice core, and (3) the sample repositories, e.g., a managed ice core repository.

In the context of SEARCH, proxy records of past climate and environmental variation and change enable investigations of key questions about the present state of the Arctic system (SEARCH, 2005). For example,

1. Is the current arctic system state unprecedented with respect to the range of natural background variability and change?
2. What are the forcing mechanisms [natural versus anthropogenic, plus intrinsic oscillations and feedbacks] and what are the links to global system variability [e.g., Pacific Decadal Oscillation, North Atlantic Oscillation, El Nino-Southern Oscillation, monsoons]?

NSF has supported Arctic paleoenvironment networks and research for many years. Examples include the Greenland ice cores and the PALE (Paleoclimates from Arctic Lakes and Estuaries) program, which combined to become PARCS (Paleoenvironmental Arctic Sciences, 2000-2005). Another significant NSF contribution to the Arctic paleoenvironment network was the IODP (Integrated Ocean Drilling Program)-supported Arctic Coring Expedition (ACEX)/Expedition 302 to the Lomonosov Ridge in 2004. USGS was also a major participant in ACEX, and it has also conducted other sediment core recovery projects, particularly in the Chukchi Borderland region.

The NSF contribution to the Arctic paleoenvironment network during IPY and beyond focuses on the North Eemian ice core project (NEEM) in Greenland. NEEM is an international effort, and the initial US contribution is a surface-based radar survey and depth/age scale modeling at the drill site in summer 2007 by CReSIS.

NSF continues to co-fund, with USGS, the US National Ice Core Laboratory, a repository for storage, curation and study of ice cores. Marine core repositories are coordinated by the IODP, of which NSF is the co-lead funding agency.
Data and Information Management

Paleoenvironment data and information are available at the following Web sites:

Index to Marine and Lacustrine Geological Samples
http://www.ngdc.noaa.gov/mgg/curator/curator.html

Integrated Ocean Drilling Program (IODP)
http://www.iodp.org/

US National Ice Core Laboratory
http://nicl.usgs.gov/

World Data Center for Paleoclimatology
http://www.ncdc.noaa.gov/paleo/data.html

Paleoenvironmental Arctic Sciences (PARCS)
http://www.ncdc.noaa.gov/paleo/parcs/index.html

g. Data and Information Management

As the many URLs in previous sections show, Federal agencies hold Arctic data and information in their own archives, or provide support to other organizations that manage archive services. DOE, for example, archives ARM Program data obtained at its North Slope of Alaska and Eureka sites. NASA has extensive high accuracy, stable Arctic remote sensing data sets, including those at NSIDC, the ASF, and at other NASA DAACs. NOAA archives all NWS data, including those from the Arctic, at its own National Climatic Data Center (NCDC), and provides support to NSIDC to manage many other NOAA Arctic datasets. NSF has provided support to NSIDC to archive data generated by Arctic System Science projects, and many other NSF-funded investigators have also deposited their data at NSIDC. Alternatively, many NSF grantees maintain their own data and information archives, which are often accessible via the Web.

As part of its IPY investment in AON, NSF is funding the development of the Cooperative Arctic Data and Information Service (CADIS: Figure 26), a joint project of NSIDC and the Earth Observing Laboratory at NCAR. Initially, CADIS is being developed to support the NSF AON projects, and their users and stakeholders. It will be a Web-based service that enables data discovery, access and use by providing a metadata archive and portal for data discovery, a data and products archive, and tools for data manipulation and analysis. The data and products archive will not hold content from all AON projects. Many projects will archive their own data and CADIS will be a portal to those distributed archives as well as to data and information held in the CADIS data and products archive. While CADIS is being developed initially to support the NSF AON projects, and their users and stakeholders, the CADIS architecture and framework are designed to

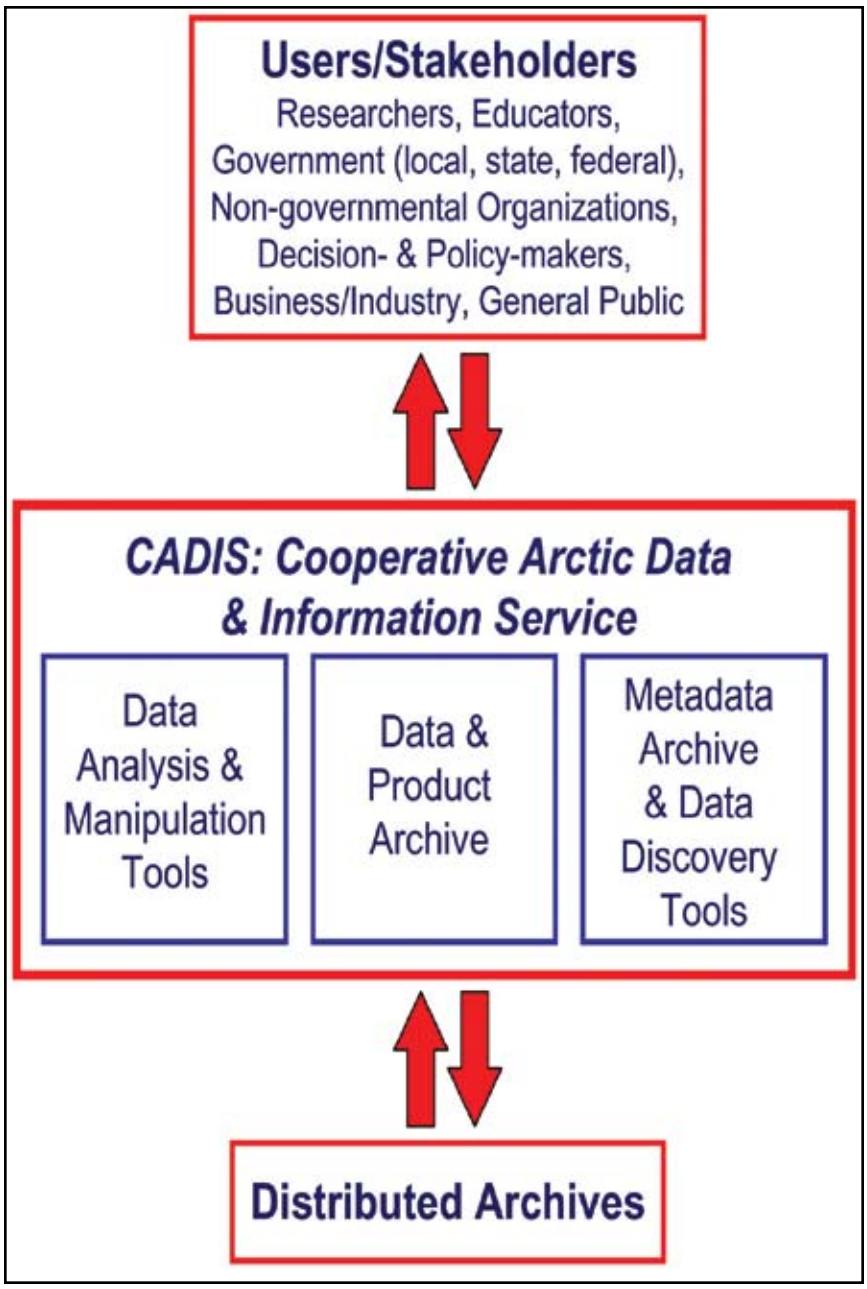

Figure 26. Conceptual diagram of CADIS, with arrows representing flows and exchanges of information among CADIS and its users/stakeholders and distributed (external) data archives and centers.

be extensible. That is, CADIS is designed to meet immediate needs during and immediately after IPY, while providing building blocks for an over-arching, interdisciplinary, and unified data and information system for the future.

NSF is also funding the ELOKA project during IPY. ELOKA is a pilot project that will provide a data management and networking service for community-based research that keeps control of data in the hands of community data providers, while still allowing for broad searches and sharing of information. NSF is also funding NSIDC participation in IPYDIS (International Polar Year Data and Information Service), a global partnership of data centers, archives and networks working to ensure proper stewardship of IPY and related data.

The NSSI is funding a node of GINA to create a portal to a distributed network of comprehensive information specific to the North Slope of Alaska and adjacent marine environments. The operations plan calls for a fully operational system by the end of FY11.

Useful links

Arctic Research Mapping Application (ARMAP)
http://armap.org

Cooperative Arctic Data and Information Service (CADIS)
http://www.eol.ucar.edu/projects/aon-cadis/

Exchange for Local Observations and Knowledge (ELOKA)
http://ipydis.org/eloka/

Geographic Information Network of Alaska
http://www.gina.alaska.edu/

International Polar Year Data and Information System (IPYDIS)
http://www.nsidc.org/ipydis

National Climatic Data Center (NCDC)
http://www.ncdc.noaa.gov/oa/ncdc.html

NASA Distributed Active Archive Centers (DAAC)
http://nasadaacs.eos.nasa.gov

National Park Service Data Store
http://science.nature.nps.gov/nrdata/docs/NPS_DataStore_20061030.pdf

National Snow and Ice Data Center
http://nsidc.org

North Slope Science Initiative
http://quickplace.altarum.org/QuickPlace/northslope/Main.nsf/

USGS Biological Information Infrastructure (NBII)
http://www.nbii.gov

USGS Geospatial One Stop
http://www.geodata.gov

6. Federal Arctic Observing Activities: Tomorrow

a. Agencies' Future Plans

BLM

BLM is responsible for the National Petroleum Reserve-Alaska (NPRA), an area nearly 24-million acres, all of which is above the Arctic Circle. Most of the area has been mapped using Landsat Thematic Mapper in the mid-1990s. BLM is developing a long-term monitoring strategy relative to mitigation effectiveness of permitted activities for oil and gas exploration and development of the NPRA. In addition, BLM as a member of NSSI is currently working to monitor the long-term effects of climate change such as coastal erosion, hydrology and land cover change. Most of the BLM's current activities in the NPRA are providing information to establish a baseline of conditions in which to measure trends in the future.

CDC

Currently focused on the invasive bacterial diseases, the ICS network will expand to include a surveillance system for tuberculosis in Arctic countries in 2007. Expansion of participating public health entities to include northern regions of the Russian Federation is planned for 2008-9. Other potential areas of expansion could include surveillance of climate sensitive infectious diseases, intentional and unintentional injuries, birth defects, and chronic diseases such as cancer, cardiovascular diseases, obesity and diabetes.

DOD

The IABP is expected to continue and become an integral part of AON. Ground temperature measurements to monitor permafrost are also expected to continue, with the goal of upgrading sites to include automated data collection and reporting system, and incorporating sites into a larger, coordinated network.

At CRREL's Fox Permafrost Tunnel, major renovation and upgrades are planned over the next three to five years to allow the tunnel to continue to be a major research facility.

DOD, in collaboration with NSF, is developing a plan to continue the SCICEX program, looking to maximize the opportunities to use the unique research platforms offered by submarines operating in the Arctic Ocean.

DOE

DOE observing plans include continued support of the measurement capabilities at the DOE ACRF sites (Barrow, Atqasuk) on the North Slope of Alaska. Plans for the continued development of the Barrow site include a multi-scale observing facility for characterizing the 3-D structure of clouds. Plans for the continued development of the Atqasuk site include support for NOAA CRN precipitation measurement instrumentation, and possible aerosol and gas chemistry instruments to provide baseline air quality measurements related to oil and gas exploration and production in the area.

The ACRF also plans to enhance its measurement capabilities by supporting the use of unmanned aerial vehicles and tethered balloons in the Barrow, Atqasuk and Prudhoe Bay/Oliktok areas. These deployments would include airborne instrument packages for *in situ* cloud properties, aerosol size and chemical composition, and remote sensing to measure water vapor and other parameters.

DHS

USCG will continue operating polar icebreakers, conducting the IIP and participating with the US Navy and NOAA in NIC. USCG will also prepare for increased maritime activity in the Arctic by continuing the ADA program and beginning plan-

ning for Forward Operating Locations on the North Slope of Alaska. This has created the possibility of science-of-opportunity projects on ADA C-130 flights.

USCG envisions significant growth in all of its missions in the Bering Sea and north of the Arctic Circle. It is important that operational observing products useful to all elements of the maritime community - commercial, scientific, and military - be available. Thus, organizations from these communities also need to be involved in the development of AON data collection and products.

EPA

EPA plans to continue NARS, a program that monitors coasts, streams, rivers, lakes, and wetlands. The NARS final report for lakes is scheduled for completion in 2009, for rivers and streams in 2011, for coasts in 2012, and for wetlands in 2013.

MMC

MMC currently is developing circumpolar monitoring plans for Arctic marine mammals in conjunction with relevant US, foreign and international agencies. The Commission held a workshop in March 2007 to initiate development of plans for ringed seals and beluga whales, with the goal of identifying key biological and ecological parameters to monitor for the purpose of characterizing the impacts of changing oceanographic, sea ice and climate conditions on marine mammals and their ecosystems. These plans are intended to contribute to AON and other similar efforts, particularly the Arctic Council's CBDP. One of the key findings from this effort to date is the need for monitoring of key ecosystem components in addition to marine mammals, especially important lower trophic organisms like arctic cod (*Boreogadus saida*), which is a dominant food item for many upper trophic organisms in the Arctic and is tightly linked to sea ice and cold water temperatures.

MMC will continue its efforts to develop circumpolar monitoring plans for Arctic marine mammals and to integrate those plans with other ongoing efforts to monitor other components of the ecosystem. As the Arctic changes, marine mammals and their host ecosystems will be impacted not only by environmental changes but also by new and increased human activities. The Commission will initiate efforts to develop a framework for assessing the cumulative impacts of increasing human activities on marine mammals as the Arctic becomes more accessible. To effectively manage human activities, it will be necessary to determine not only the individual impact of each activity but also the combined and perhaps synergistic impacts of all activities together (e.g., fishing, coastal development, oil and gas development, commercial shipping, military activities, subsistence harvest, and tourism).

MMS

MMS will continue its history of research monitoring to obtain information for resource management decisions related to oil and gas leasing, exploration and development in the Beaufort and Chukchi Seas, and potential leasing in the southeast Bering Sea. These efforts include continuation of aerial surveys of Bowhead whales in the Beaufort, which, in partnership with NOAA, will now expand into the Chukchi Sea. These annual aerial surveys focus on the Bowhead whale migration, but gather observational information on all marine mammals observed in the survey area. MMS will also continue periodic sediment and benthic surveys and chemical analyses in the Beaufort Sea and expand collections to the Chukchi Sea.

MMS will also undertake short term fishery surveys and bird surveys, in cooperation with its federal partners, which will take advantage of and complement longer term monitoring undertaken by others. MMS will continue to utilize its partnership with the University of Alaska Fairbanks Coastal Marine Institute to collaborate on interdisciplinary arctic research and monitoring in the near shore ocean, atmosphere, and human environment.

NASA

In the immediate future, NASA will continue to operate the satellite constellation currently in orbit (Figure 13), which includes GRACE and ICESat.

NASA also has seven satellite missions in development that will be launched in 2008-2014. Satellite missions of Arctic interest include the Orbiting Carbon Observatory (OCO) atmospheric carbon dioxide, Glory aerosol characteristics, NPP ocean color, GPM (Global Precipitation Measurement) rainfall, LDCM land imagery, OSTM (Ocean Surface Topography Mission) global mean sea level, and Aquarius sea surface salinity. These missions are described in the 2007 NASA Science Plan.
For 2014 and beyond, future Arctic observing missions are described in the NRC report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (NRC, 2007). NASA is planning to start the SMAP (Soil Moisture Active Passive) and ICESat-II ice sheet mass missions as quickly as feasible and is planning to initiate other NRC Decadal Survey missions as feasible. SMAP and ICESat-II launch dates are expected to be 2012 and 2015, respectively. ICESat-II is a follow-on mission to the current ICESat mission to measure the topography of Greenland, and in coordination with radar altimeter observations, will measure sea ice thickness. SMAP will provide valuable observations of soil moisture and freeze/thaw state of the soil.

As part of its IPY activities in cooperation with other Federal agencies and international partners, NASA will conduct the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in April and July 2008. ARCTAS has four scientific themes: (1) long-range transport of pollution to the Arctic including arctic haze, tropospheric ozone, and persistent pollutants such as mercury; (2) boreal forest fires and their implications for atmospheric composition and climate; (3) aerosol radiative forcing from arctic haze, boreal fires, surface-deposited black carbon, and other perturbations; (4) chemical processes with a focus on ozone, aerosols, mercury and halogens. ARCTAS is a contribution to the larger POLARCAT experiment that also includes NSF, NOAA (Aerosol, Radiation and Cloud Processes affecting Arctic Climate-ARCPAC), DOE (Semi-Direct Aerosol Campaign-ISDAC) and international partners.

More information about ARCTAS, POLARCAT, ARCPAC and ISDAC is available online at:

ARCTAS: *http://www.espo.nasa.gov/arctas/*
POLARCAT: *http://www.polarcat.no*.
ARCTAS: *http://www.esrl.noaa.gov/csd/arcpac/*
ISDAC: *http://acrf-campaign.arm.gov/isdac/*

NOAA

NOAA envisions that its Arctic Ocean contribution to AON will follow the implementation design presented in the SEARCH Implementation Plan (SEARCH, 2005).

NOAA will continue to support the 13 radiosonde stations in Alaska and possibly update many stations with the Radiosonde Replacement System in the coming years.

NOAA is in the process of revitalizing its Cooperative Observer Program by providing new observation systems to the sites with long records and reliable results, while phasing out or redirecting other sites to support operational programs. NOAA's CRN has four of 29 planned sites operating.

The international network of atmospheric observatories consists of the sites at Eureka and Alert in Canada and at Tiksi in Russia. The sites in Canada depend greatly on support by Canadian research programs that end in 2012. At Tiksi, the basic instrumentation has been installed, but top-end instruments, e.g., cloud radar and profiling lidar, are lacking. The Summit Greenland site is functioning at a low level and requires significant instrumentation. No work has been done on the planned sites in northern Finland and Svalbard.

NOAA is working with external partners and stakeholders to update the precipitation frequency estimates (PFE) for the State of Alaska. PFEs are a climate-related precipitation tool for proper infrastructure development included in regulations of many Federal, state and local agencies. They are statistically-derived precipitation amounts for a range of durations and recurrence intervals. The statewide PFE data currently available for Alaska are contained

in two reports by the Department of Commerce called Technical Papers 47 and 52, last revised in 1963 and 1965, respectively. These were based upon data from a sparse network of gauges with a short period of record.

The PFE data are commonly used to reduce the risk of runoff-related loss of life and property, and to prevent pollution. They provide rainfall related criteria used extensively by the engineering and environmental communities for the design of structures such as sewers and drainage systems, for environmental studies and design, and for sediment control. The criteria are used by the Federal Emergency Management Agency to update National Flood Insurance rate maps and by the EPA National Pollution Discharge Elimination System Program to regulate pollution control in streams. Results from climate change investigations in Alaska suggest the seasonality, amount, and type of precipitation are changing in many locations. NWS uses these criteria for comparison during rainstorms that could produce flash flooding.

NPS

NPS continues to expand its vital signs monitoring across 54 million acres of NPS lands in Alaska (including two thirds of the entire National Park System). Phased development, field testing, and implementation of long-term monitoring plans are underway in all four of Alaska's Inventory and Monitoring networks (Arctic, Central Alaska, Southeast Alaska, Southwest Alaska). Monitoring to determine resource status and trends, and research to understand natural and anthropogenic processes will be critical to inform decision-makers and preserve park ecosystems. The NPS Alaska Regional Science Strategy identified five primary resource management challenges for the 21st Century, including climate change, global and local contaminants, exotic species, increasing human use, and development within and surrounding parks. The NPS is currently working with the USGS, University of Alaska, and others on proposals to model the probable future effects of climate change on park resources and operations.

NSF

NSF sees AON is seen as integral to SEARCH and fundamental to achieving its contribution to the goals of SEARCH. NSF investments in AON will be guided by the SEARCH Implementation Plan, and based on peer and panel review of proposals submitted in response to either special AON solicitations or the annual Arctic Research Opportunities solicitation. NSF will contribute to the development of a multinational, pan-Arctic AON through SEARCH and ISAC.

NSF observing plans in the Arctic also include NEON (National Ecological Observatory Network) tundra and taiga sites, respectively, at (1) Toolik Lake (currently an LTER site) on the North Slope of Alaska and (2) Caribou-Poker Creeks Research Watershed near Fairbanks (currently part of the Bonanza Creek LTER site). Information about NEON is available at *http://www.neoninc.org/* and *http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13440&org=DBI*.

NSF is coordinating cyberinfrastructure (CI) for NSF-supported environmental observatories, e.g. LTER, NEON, OOS and AON. The main goals are to identify common areas of CI needs and potential areas of coordinated development, possibly even leading to shared cyberinfrastructure.

Continued NSF support for the National Ice Core Laboratory, and US participation in the NEEM ice core and the POLENET/GNET projects will be based on the submission and review of proposals. The award for the CReSIS Science and Technology Center is nominally for 10 years (FY05-FY14) with a site review due to occur in FY2008.

USDA

USDA is committed to maintaining its current observation programs in Alaska for the coming years.

USFWS

The USFWS National Wildlife Refuge system in Alaska is developing an intranet-based database that will enable the following:

1. Allow USFWS biologists, and others, to determine quickly what monitoring efforts are occurring (and have been done recently) in the region, by species, information objective (abundance versus demography like survival or fecundity rates), area, and perhaps broad method class (telemetry, mark recapture, physiology, aerial surveys);
2. Allow the refuges' supervisory biologists to enter their inventory and monitoring study-specific details only once and automatically export them for inclusion in the refuge's Inventory and Monitoring Plan and other organizational data calls;
3. Allow for efficient updating and archiving of monitoring plans and efforts;
4. Support development of region-wide inventory and monitoring strategies for efficiency and region-scale insight.

USGS

USGS has several ongoing monitoring programs within the Arctic and Sub-Arctic environment that will continue for the foreseeable future. These programs are explained in detail at the USGS Alaska Science Center Website (*http://alaska.usgs.gov*), and include biological (ecosystems and habitats, mammal, birds and fisheries), hydrological, geographical and meteorological data collection and analysis at a range of temporal and spatial scales. For example, USGS water gauges are currently operational at 113 stream and river stations, with records ranging from 88 years at Fish Creek near Ketchikan to the recently installed gage on Bonanza Creek near McCarthy. Median length of streamflow record in Alaska is 19 years. Several of these ongoing data collection and research activities will serve as a foundation for new monitoring and research in support of an integrated assessment of permafrost thaw and its effects on carbon flux, ecosystem stability and the sustainability of native culture in the Yukon River basin beginning in 2008.

b. A Conceptual Framework for Integration and Coordination of Existing and New Observing Activities

Section 5 clearly shows that Federal agencies are engaged in myriad observing activities in each of the SEARCH Implementation Plan categories. However, most of these disparate activities pre-date SEARCH and were designed to meet the specific mission of a particular agency rather than address a broader goal, i.e., enabling SEARCH. Moreover, with few exceptions, there is little inter-agency coordination and integration of Arctic observing activities. This section presents a conceptual framework (referred to as "CORE," Committee on Environmental and Natural Resources, 1997) for organizing data from disparate programs so that data synthesis can be performed in order to address common questions, e.g., the seven core SEARCH questions presented in Section 3a.

In addition to the lack of coordination of the many different Arctic observing elements, logistical limitations impose inherent tradeoffs between the number of variables that can be measured, the frequency at which they can be measured, and the number of measurement sites. Different methods, at different scales, are required to understand the myriad interactive processes and their consequences for specific systems. No single method can provide the complete suite of information that scientists and resource managers need. These constraints lead to a hierarchical structure for data collection, which can be represented by a triangle, with the measurements that can be made at the greatest number of sites at the base and the measurements that, because of their complexity, number and frequency can only be made at a limited number of sites, at the apex (Figure 27). The types of monitoring within the framework are divided into four general classes: Tier 1 - Intensive integration and research areas; Tier 2 – Condition gradient network; Tier 3 – National and regional surveys; and Tier 4 – Inventories and remote sensing programs. Each is described below.

Tier 1 - Intensive integration and research areas typically measure a greater number of properties and at a higher frequency than any of the higher-numbered tiers, but at a small number of locations. The critical feature of this level is that all of the major potential causes of environmental change are measured at the same locations where environmental responses of concern to society are also measured. This level is essential for understanding processes that occur at local scales, for integrating the effects of multiple processes, for understanding the causes of changes detected by programs at Tiers 2, 3 and 4 of the Framework, and for developing and testing predictive models of environmental response. Measurements at this level also provide information for determining the level of uncertainty associated with inventory, remote sensing and survey results, as well as of model predictions.

Tier 2 – Condition gradient network studies monitor common variables at several locations representing the range of condition relative to a specific environmental issue or ecosystem state and process in order to determine the range and variability of possible responses to a given environmental condition or stressor. Regression relationships relating stress and response variables typically are used to estimate spatial or temporal variability in system condition. The results from gradient studies are also used to evaluate the application of models that incorporate information from Tier 1 studies. Such evaluation is important for reconciling scaling issues in the spatial application of models developed from fine-scale knowledge.

Tier 3 – National and regional surveys are designed to characterize specific properties of a region by sampling a subset of the total area, rather than the entire area. These programs are typically designed to address specific resources or environmental issues, and may cover the entire country, or only the region where a specific issue is important. Integration between Tiers 2 and 3 can help identify changes in the environment detected by remote sensing (i.e., provide "ground truth"), but generally cannot indicate why a specific change has occurred. These two levels are essential for quantifying the extent, distribution, condition, and rate of change of specific environmental properties, and for understanding processes that occur over large areas.

Tier 4 – Inventories and remote sensing programs involve basin-scale, wall-to-wall monitoring and analysis such as satellite remote sensing and aerial photography. The primary objectives are development of spatially- and temporally-continuous information, such as land use and land-cover change, forest species distributions, forest fragmentation, fire occurrence and history, albedo, ecosystem performance (e.g., production), seasonal phenology and ecosystem metrics, snow cover, and lake area.

With the tier design as a template, AON could categorize existing capabilities and determine the additional data collection necessary to meet SEARCH objectives. Application of enhanced system models using the data collected could then be used to create regional observing strategies. Each tier of this framework provides unique observations that contribute to a comprehensive, multi-component, multi-scale information system. For example, intensive monitoring and research sites are necessary for developing process-level, cause-and-effect understanding that underpins predictive models. These models are critical to predict changes in temperature, precipitation, fire risk, water supplies, and other features that are central to management decisions.

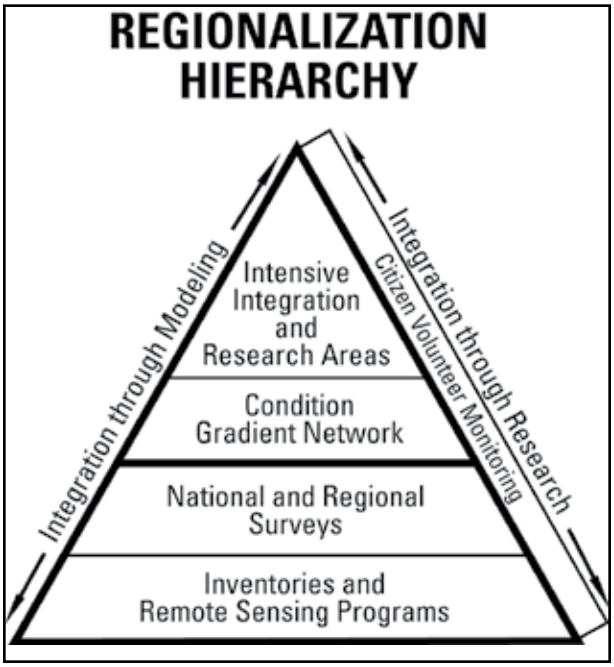

Figure 27. Conceptual framework for achieving the multiple goals of environmental monitoring and research; distribution, condition, and rate of change of specific environmental properties; and for understanding processes that occur over large areas.

Spatially-distributed observations are then needed to calibrate the models to new areas and to scale results up to a regional or national scale. New remote sensing tools developed through calibration with this ground-based network will eventually lead to earlier detection and more cost-effective tracking than has been possible to date. Scientists and managers have long recognized the inadequacy of existing data for solving complex ecosystem problems, and the need for a more integrative and synthesis-based understanding that is designed to address key management issues. The purpose of the framework is, therefore, to create a structure within which the complex effects of climate change can be addressed in a systematic and long-term manner.

c. Data and Information Management

Data and information management is integral to AON (Figure 12). The data and information must be digitally archived and preserved over the long-term, while remaining easily, freely and openly accessible to a broad range of users and stakeholders. Free, open and guaranteed access to data and information are vital for maximizing the value-added services and societal benefits of AON.

The Federal Arctic observing activities described in Section 5 produce large volumes of data and information from multiple sources and operators. Most Federal Arctic data and information holdings are widely distributed, and relatively easy to access online via the Worldwide Web (URLs for many federal and federally-supported online data and information sources are given in Section 5). However, there is no portal, i.e., a single point-of-entry, to Arctic data and information. A portal would have numerous advantages for the agencies and for their users and stakeholders – it would raise the visibility of the data and information holdings, making them more accessible to a broader audience and increasing their use (as both sinks and sources of data), thereby maximizing the value-added services and societal benefits to be derived from AON.

As a coordinated service providing a coherent, cohesive, and integrated approach to long-term Arctic data and information management, CADIS has the potential to be the portal to all US Federal agencies' Arctic data and information. CADIS would not replace or make redundant existing federal systems for Arctic data and information management. Rather, CADIS would enhance them, as described in the previous paragraph. CADIS is currently funded solely by NSF. If it is to become the portal to Federal Arctic data and information it will need to be adapted, upgraded and maintained with funding from multiple agencies.

CADIS would focus on being a portal to Arctic data and information obtained by federal agencies, and their grantees and contractors. Its value would increase if it is linked to data and information centers in the seven other Arctic countries (Canada, Greenland/Denmark, Norway, Sweden, Finland, Iceland, Russia), and also provide links to any data and information centers outside the Arctic that have relevant holdings. Since AON will be a significant addition to global environmental observing capabilities, CADIS would also be linked to the data and information management systems of the USGEO and GEOSS.

To realize the advantages of CADIS as a portal to federal Arctic data and information will require coordinated technical approaches to enable ready exchange of data and metadata across organizations and disciplines, i.e., inter-operability among data systems and centers. A data policy that ensures free and open access will also be required. Federal agencies, and/or those operating on behalf of an agency, must strive towards open, timely, and equitable access when working with Federal government information. This includes private entities or universities contracted by an agency to perform R&D by a Federal agency. In this context, the SEARCH data policy would be an appropriate model for inter-agency collaboration in the development of CADIS as a portal to all federal Arctic data and information. The SEARCH data policy is currently available in draft form at *http://www.arcus.org/search/downloads/SEARCH_Data-Policy_051207.pdf.*

An Arctic data and information portal could also play a role in coordination and integration of Federal Arctic observing activities and the development of a coherent AON. NSF, for example, views CADIS as one approach to using cyberinfrastructure to realize coordination and integration of its AON projects (Appendix 1) into a virtual observatory.

One possible model for an Arctic data portal, and one to which it could be linked, is the Global Observing Systems Information Center (GOSIC, *http://gosic.org*), a facility operated by the US Global Climate Observing System (GCOS) program at the NOAA NCDC. Run on behalf of the international observing community, GOSIC provides a broad spectrum of users with a centralized resource to aid in finding international observing system datasets and related information in a consistent fashion across a diverse array of international data centers and observing domains (e.g., atmospheric, oceanic, and terrestrial). Access tools are provided for data discovery and retrieval of global climate, ocean and terrestrial data such as the Essential Climate Variable Data and Ocean Data Access Matrices. As the GOSIC evolves it will form part of the overall data management structure associated with GEOSS.

7. International Cooperation

Arctic observing, in order to be comprehensive, must be pan-Arctic and involve cooperation with international partners. Recognizing the need for international cooperation in the enhancing Arctic observing capabilities, SEARCH, with the help of the International Arctic Science Committee (IASC) and the Arctic Ocean Sciences Board (AOSB), initiated ISAC, a multilateral effort that, like SEARCH, is designed as a long-term, cross-disciplinary, pan-arctic program that will document and increase understanding of changes in the Arctic. As such, ISAC should play an important role in developing AON and ensuring it is well coordinated with other international Arctic observing efforts.

Additionally, SEARCH has entered into a Memorandum of Understanding (MOU) with the European Union's DAMOCLES program which will study air-ice-ocean interactions during the IPY. The SEARCH 4 DAMOCLES (S4D) MOU emphasizes the importance of integration of SEARCH and DAMOCLES observational data, and forms the basis for an international approach to comprehensive pan-Arctic observing.

SEARCH and DAMOCLES are strongly represented on the ISAC scientific steering group which reports to IASC and AOSB, at least in the near term. Thus, these organizations will provide leadership in science-driven observations and scientific research, and will have an important role to play in the coordination of international science in the North.

Bilateral and regional partnerships involving government agencies are important. Bilateral arrangements can provide a basis for coordination among nations on a site- or discipline-specific basis. For example, partnerships between NASA and its counterparts in other nations make possible coordinated campaigns to collect remote sensing data critical to monitoring and measuring change in the Arctic. A partnership among NOAA, NSF, and the Russian Federal Service for Hydrometeorology and Environment Monitoring (Roshydromet) provides the basis for supporting the international observing station at Tiksi, Russia. NOAA and NSF are also cooperating with Russia in the RUSALCA program. The parties intend this program to be a pilot for international cooperation in AON development.

Regional arrangements are crucial for access to and understanding of the Arctic environment, particularly in multi-site and multi-disciplinary contexts. European-US linkages are strong in ISAC and S4D, but those programs need to engage with Canada, Russia and Asian countries. The latter have growing Arctic research and observation programs, and regional groups such as the Pacific Arctic Group (PAG), founded by IASC in 2003, provide a crucial forum to coordinate activities initiated and implemented by research organizations in Asian nations, Canada and the USA (NOAA plays an active role in the PAG organization). As the lead US representative to the Arctic Council's CAFF program, USFWS is contributing to the development and implementation plan for the Circumpolar Biodiversity Monitoring Program (CBMP) (CAFF, 2007).

On a global basis, Arctic observing contributes to internationally-coordinated observing frameworks. Cooperation with global observing programs such as GCOS and its component programs — among them the Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS) — will be important. Representatives from US federal agencies such as NASA, NOAA and NSF serve on the boards and/or scientific steering groups for these global programs providing the necessary link between AON and these programs. Similarly, the Federal inter-agency GEO, co-chaired by NASA and NOAA, provides a link to GEOSS.

All of the eight Arctic countries, as well as many other countries, are actively engaged in observing and monitoring. Coordination with these programs, where appropriate, will lead to more comprehensive data and information for the scientific and policy community to consider. Sustaining networks with

infrastructure, personnel, and sophisticated instrumentation requires international cooperation and a commitment of resources. International efforts to coordinate and sustain observing networks are underway. ISAC, IASC and AOSB are all members of the Sustained Arctic Observing Networks Initiating Group (SAON IG). NSF is also a member of the SAON-IG. An IPY project lead by the Arctic Council's Arctic Monitoring and Assessment Program (AMAP), the SAON-IG was formed in response to an Arctic Council (AC) declaration of November 2006 urging all eight AC member countries to maintain and extend long-term monitoring of change in all parts of the Arctic.

SAON IG has initiated a process to develop a set of recommendations for the future coordination and promotion of sustained, integrated Arctic observing activities that provide free, open and timely access to high quality data that will realize value-added services and provide pan-Arctic and global societal benefits. The SAON process includes three workshops (to be held in Sweden, Canada and Finland) that are open to all interested individuals and organizations, including the research observing community, the operational observing community, and northern residents engaged in community-based observing programs and documenting local and traditional knowledge. The SAON IG recommendations will be presented to the AC and other entities at the end of the IPY.

Useful links

Arctic Monitoring and Assessment Program
http://www.amap.no/

Arctic Ocean Sciences Board
www.aosb.org

Conservation of Arctic Flora and Fauna (CAFF)
http://arcticportal.org/en/caff/

Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) *http://www.damocles-eu.org/index.shtml*

IPY Workshops on Sustaining Arctic Observing Networks
http://www.arcticobserving.org/

Global Climate Observing System
http://www.wmo.ch/pages/prog/gcos/index.php

Group on Earth Observations and GEOSS (Global Earth Observing System of Systems)
http://www.earthobservations.org/index.html

International Arctic Science Committee
http://www.iasc.se

International Polar Year
http://www.ipy.org

International Study of Arctic Change
http://www.aosb.org/isac.html

Pacific Arctic Group
http://www.pagscience.org/

Sustained Arctic Observing Networks Initiating Group (SAON IG)
http://www.arcticobserving.org/index.php?option=com_content&task=view&id=14&Itemid=28

United States Group on Earth Observations
http://usgeo.gov/

8. Summary and Action Items

The dramatic retreat of the Arctic sea ice cover in summer 2007, during the first quarter of the International Polar Year, drew further attention to the Arctic and the large, rapid, system-wide changes that are occurring there. Notwithstanding the fact that it was possible to watch the sea ice retreat in near-real-time, thanks to the NASA cyberinfrastructure that links the satellites to a global audience via Worldwide Web, the Arctic remains one of the most data-sparse, under-observed regions on Earth.

A lack of observations hinders the ability to identify and understand the global and regional causes and consequences of Arctic Change, and predict the future course of events, via knowledge synthesis and numerical modeling. Incomplete understanding and limited predictive capability are, in turn, obstacles to the identification of global and regional adaptive responses to Arctic Change. Improved observing capability in the Arctic will not only enable understanding and prediction of, and response to, Arctic Change, it will permit the assessment of the effectiveness of efforts to mitigate the effects of global warming and regional feedbacks in the Arctic.

Improved observing capability in the Arctic can be realized by coordinating, integrating and maintaining existing observing activities, adding new observing activities to fill spatial, temporal and disciplinary gaps, and sustaining and continuing to enhance the whole over the long-term. This report is the first step toward achieving the goal of improved observing capability in the Arctic through the development of AON.

An important feature of the report is the comprehensive inventory of Federal and other observing activities in the Arctic (Section 5) that shows that a nascent AON exists. However, it is evident that inter-agency coordination and integration of the myriad Arctic observing activities can be improved. Moreover, most of these disparate observing activities pre-date SEARCH and were designed to meet the specific mission of a particular agency rather than address a broader goal, i.e., enabling SEARCH. The transition from a nascent to an actual AON that enables SEARCH observing, understanding and responding will require the continued attention of the Federal agencies and their staff.

Action item 1. IARPC will continue to meet on a regular basis to examine ways to improve coordination and integration of agencies' Arctic observing activities in partnership with the academic community, northern residents, maritime users and other stakeholders, in order to answer the SEARCH questions and address the SEARCH priorities described in the SEARCH Implementation Plan.

Action item 2. IARPC will assess the integrated Arctic observing and research activities to determine the extent to which they are answering the SEARCH questions and addressing SEARCH priorities. Agencies will strive to align their Arctic observing and research activities with the SEARCH questions and priorities, while meeting their mission goals and evolving user needs, including the need for easy access to near-real-time data.

The report documents the wide variety of Federal Arctic observing activities that have the potential to become a coordinated and integrated AON, but it does not provide information on the frequency, accuracy and uncertainty of the many measurements being made. Moreover, the report does not fully address whether the right measurements are being made in the right places at the right times for the purpose of SEARCH. A qualitative comparison of the SEARCH observing location priorities maps (Figures 6 to 11) with actual observing locations (Figures 13 to 24) indicates that the nascent AON is far from optimized.

Action item 3. IARPC will enable the application of quantitative, objective tools, e.g., OSSEs (Observing System Simulation Experiments, also known as OSEs, Observing System Experiments), to guide the development of AON through system design

exercises that identify optimal in-situ observing site locations and satellite observing networks, required measurement accuracy and frequency, and acceptable levels of uncertainty.

Action item 4. IARPC will also investigate the use of a Collaborative Observation and REsearch (CORE) strategy for optimization as well as coordination and integration of observing activities. In applying CORE, measurement frequency, accuracy and uncertainty would also be documented.

A valuable feature of the report is the comprehensive list of Federal Arctic data and information holdings that are available online via the Worldwide Web. It is evident that Federal agencies hold large amounts of accessible and scientifically-useful data and information. However, they are in widely-distributed archives that operate largely independently of each other. Free, open and timely access to data can be improved further.

Action item 5. In consultation with related Federal interagency activities, such as the Climate Change Science Program and the US Group on Earth Observations, IARPC will explore the development of a user-friendly online portal, i.e., a single point-of-entry, to Federal Arctic data and information. A portal would have many advantages for IARPC and for users and stakeholders – it would raise the visibility of the data and information holdings, making them more openly and freely accessible to a broader audience and increasing their use, thereby maximizing the value-added services and societal benefits to be derived from AON. An Arctic data portal can also play a valuable role in the coordination and integration of AON.

An online portal to Federal Arctic data and information would represent the use of cyberinfrastructure to enable data discovery, an essential first step in the process of analysis, synthesis and modeling that lead to understanding of Arctic Change and identification of responses to that change. An online portal would be just one among many possible uses of cyberinfrastructure for developing a coordinated and integrated AON that enables scientific discovery and innovation that inform decision- and policy-making.

Action item 6. As IARPC collaborates in the development AON, it will strive to maximize the use of cyberinfrastructure for coordination and integration from the moment of data acquisition through data discovery, analysis, synthesis and modeling, to the realization of Arctic and global value-added services and societal benefits.

The report describes a small number of community-based observing projects and programs, e.g., the NWS Cooperative Observer Program and the NSF-funded BSSN in Alaska, which engage the people of the north directly in environmental observing. The report also refers to the traditional knowledge of northern residents. Though the level of activity is small relative to research and operational observing, community-based observing and traditional knowledge have an important role to play in AON.

Action item 7. IARPC will endeavor to increase engagement with northern people and communities to identify local observing needs as well as create mutually beneficial observing partnerships that build human and physical capacity. All observing activities will be guided by the Principles for the Conduct of Research in the Arctic (*http://www.nsf.gov/od/opp/arctic/conduct.jsp*) that were created at the direction of IARPC.

Most of the observing activities described in Section 5 are either in the operational observing (e.g., NWS weather stations, NOAA satellites, USGS stream gauges) or research observing (e.g., NASA satellite missions, NSF AON projects [Appendix 1]) categories. Research observing activities are typically short-term and not intended to be sustained over long periods of time. Nevertheless, they are essential to AON, e.g., as test-beds for experimentation and equipment testing, proving a concept, establishing baseline data sets, improving models and testing predictions, etc. Research observing activities can make the transition to operational observing, but this is not always straightforward, as the NASA/NOAA experience shows (NRC, 2000, 2003). USGEO is also considering the issue, e.g., the USGEO Research-To-Operations Federal Roundtable held on 11 September 2007 in Washington, DC.

Action item 8. As part of the coordination and integration necessary to the development of AON, IARPC will discuss the issue of sustaining the entire program over the long-term, and explore ways for the effective transfer of research observing activities to the operational observing realm. Policy and strategy for the transition of research observing to operational observing will need to be developed. 'Transition' will require criteria for the identification of which research observing activities will cross over into operational observing, and processes to effect the transition.

USGEO is a leader in and major contributor to GEOSS. USGEO is composed of all of the observing components of the US federal agencies. AON is a focused, regional component that has much to offer USGEO and GEOSS, and all three share the same ultimate goal – achieving value-added services and benefits to society. In the Arctic alone, almost 4 million people from more than 30 different societies living in 8 countries (Canada, Finland Greenland/ Denmark, Iceland, Norway, Sweden, Russia, USA) stand to gain from those services and benefits. The Arctic eight countries are, in turn, working with other countries, e.g., EU members, China, Japan and Korea, during International Polar Year 2007-2009 to observe and understand the changing Arctic.

Action item 9. IARPC will remain engaged internationally, working with regional partners to achieve a multinational, pan-Arctic observing network that is coordinated, integrated and sustained over the long-term. IARPC, in turn, will engage with USGEO and GEOSS to ensure that the Arctic is represented at domestic and international planning and policy forums, and involved in the transition to implementation of coordinated national and international Earth observation efforts to benefit society.

The intellectual framework for the development of the US contribution to pan-Arctic observing is the SEARCH program. The international counterpart of SEARCH is ISAC, a long-term program initiated by IASC, the International Arctic Science Committee. The core activities of both SEARCH and ISAC are observing change, understanding change and responding to change. ISAC, therefore, provides an intellectual framework for the entire multinational pan-Arctic observing network that is envisioned as a lasting legacy of IPY.

Action item 10. The US contribution to a coordinated, integrated and sustained multinational, pan-Arctic observing network will be based on an intellectual framework that reflects the scientific goals, priorities and recommendations of the SEARCH and ISAC programs.

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Appendices

Appendix 1: NSF AON Projects

Atmosphere

Core Atmospheric Measurements at Summit, Greenland Environmental Observatory
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0336450

Cloud Properties Across the Arctic Basin from Surface and Satellite Measurements - An Existing Arctic Observing Network.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632177

Pan-Arctic Studies of the Coupled Tropospheric, Stratospheric and Mesospheric Circulation.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632387

The Collaborative O-Buoy Project: Deployment of a Network of Arctic Ocean Chemical Sensors for the IPY and Beyond.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0612331

Development of Data Products for the University of Wisconsin High Spectral Resolution Lidar.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0612452

Halogen Chemistry and Ocean-Atmosphere-Sea Ice-Snowpack (OASIS) Chemical Exchange During IPY
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0732556

NSF UV Monitoring Network
http://www.biospherical.com/NSF/default.asp

Ocean and Sea Ice

The State of the Arctic Sea Ice Cover: An Integrated Seasonal Ice Zone Observing Network (SIZONET).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632398

Ice Mass Balance Buoy Network: Coordination with DAMOCLES.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0612391

Collaborative Research: North Pole Station: A Distributed Long-Term Environmental Observatory.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0352754

The Beaufort Gyre System: The Flywheel of the Arctic Climate?
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0424864

Coordination, Data Management and Enhancement of the IABP (International Arctic Buoy Program).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0520287
A Modular Approach to Building an Arctic Observing System for the IPY and Beyond in the Switchyard

Region of the Arctic Ocean.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0633878

An Innovative Observational Network for Critical Arctic Gateways: Understanding Exchanges through Davis and Fram Straits.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632231

Comparison of Water Properties and Flows in the US and Russian Channels of the Bering Strait - 2005 to 2006
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0528632

The Pacific Gateway to the Arctic- Quantifying and Understanding Bering Strait Oceanic Fluxes.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632154

Observing the Dynamics of the Deepest Waters in the Arctic Ocean.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632201

Design and Initialization of an Ice-Tethered Array Contributing to the Arctic Observing Network.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0519899

Towards an Arctic Observing Network: An Array of Ice-Tethered Profilers to sample the upper ocean water properties during the International Polar Year.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0631951

Ocean-Ice Interaction Measurements Using Autonomous Ocean Flux Buoys in the Arctic Observing System.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0520328

Toward Developing an Arctic Observing Network: An Array of Surface Buoys to Sample Turbulent Ocean Heat and Salt Fluxes During the IPY.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632041

Aerial Hydrographic Surveys for IPY and Beyond: Tracking Change and Understanding Seasonal Variability.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0634226

Hydrology/Cryosphere

Long Term Measurements and Observations for the International Arctic Research Community on the Kuparuk River Basin, Alaska.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0335941

A Prototype Network for Measuring Arctic Winter Precipitation and Snow Cover (Snow-Net).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632131

Thermal State of Permafrost (TSP): The US Contribution to the International Permafrost Observatory Network.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0520578

Development of a Network of Permafrost Observatories in North America and Russia: The US Contribution to the International Polar Year.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632400

Terrestrial Ecology

Development and Implementation of the Terrestrial Circumarctic Environmental Observatories Network (CEON).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0622406

Carbon, Water, and Energy Balance of the Arctic Landscape at Flagship Observatories and in a Pan-Arctic Network.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632139

Collaborative Research: Study of Arctic Ecosystem Changes in the IPY Using the International Tundra Experiment.
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632277

Human Dimensions/People and Communities

Is the Arctic Human Environment Moving to a New State?
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0638408

Bering Sea Sub-Network: International Community-Based Observation Alliance for Arctic Observing Network (BSSN).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0634079

Data and Information

Exchange For Local Observations and Knowledge in the Arctic (ELOKA)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632345

A Cooperative Arctic Data and Information Service (CADIS).
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0632313

Appendix 2: State and Local Government Observing Activities in Alaska

The State of Alaska Department of Transportation and Public Facilities (DOTPF) monitors several environmental variables throughout Alaska via its Road Weather Information System (RWIS), a network of 48 meteorological and pavement sensors located along the highway system. RWIS stations are located in strategic locations to provide accurate real-time road weather information and critical observations for forecasts. This and other weather information helps DOTPF improve timeliness of maintenance actions, like when to snowplow or deposit anti-icing/de-icing chemicals on the highways.

Real-time RWIS data are available at AOOS and the US Department of Transportation 'Clarus' system. RWIS data also sent to NCAR, where they are used and archived by MADIS (Meteorological Assimilation Data Ingest System). An archive of raw data with a 30-minute sampling interval DOTPF is maintained in Juneau, Alaska; these data have not been quality-checked and flagged, but they are available on request.

The State of Alaska Department of Natural Resources (DNR) monitors soil temperature, active layer depth and snow depth at stations within the North Slope oil fields for the purpose of determining when conditions are suitable for ice road construction and winter off-road travel by heavy equipment. These monitoring stations were established in 2005. These data are not available on line, but can be obtained by contacting the DNR Northern Regional Office at 907-451-2740.

The Clean Water Act (CWA) mandates that each state develop a program to monitor the quality of its surface and groundwaters and prepare a report describing the status of its water quality. As part of these efforts, the State of Alaska Department of Environmental Conservation (DEC) and EPA perform field monitoring in South-central and Southeast Alaska, and plan to perform field monitoring in the Arctic in the near future. Until an assessment comparable to that underway for South-central and Southeast Alaska coastal waters is completed, DEC has no independent baseline water quality data for the Arctic Ocean.

The State of Alaska Department of Natural Resources (DNR) authorizes specific volumes of water to be withdrawn from lakes for ice road construction on the North Slope, determines the presence or absence of fish in lakes from which water is withdrawn, and ensures that withdrawal techniques do not adversely affect fish. DNR also has a statutory responsibility to protect anadromous waterbodies and ensure free passage of fish. DNR is also responsible for issuing permits for activities such as culvert or bridge installation in streams and rivers. The Office of Habitat Management and Permitting maintains a database of all of these activities in Alaska.

The State of Alaska Department of Fish and Game (DFG) conducts research and monitoring activities on resident fish and wildlife species. Most wildlife activities have focused on the four arctic caribou herds, which have been surveyed and monitored since the 1970s. Considerable work has also been done on muskox, moose, brown bears, and other species. Populations are generally reported on the basis of game management units (GMU). The Arctic game management units are 26A, 26B and 26C.

The North Slope Borough, Department of Wildlife Management, is also engaged in fish and wildlife monitoring for the purpose of facilitating sustainable subsistence harvests. The monitoring activities include: (1) collection of subsistence harvest data; (2) monitoring the movements of Arctic fox and the Teshekpuk Lake caribou herd; (3) estimating the size of the Bowhead whale population, and documenting the movement of Beluga whales; and (4) monitoring Lesser Snow and Black Brant goose colony size and habitat quality. The monitoring is often done in partnership with the State of Alaska Department of Fish and Game and the US Fish and Wildlife Service. The Department of Wildlife Management also has a long history of working with native co-management

groups, e.g., Alaska Eskimo Whaling Commission and Alaska Nanuq Commission, and international bodies such as the International Whaling Commission.

The Barrow Arctic Science Consortium (BASC) organization based in Barrow, Alaska, combines North Slope Borough, Ukpeagvik Iñupiat Corporation, and Ilisagvik College efforts to encourage research and educational activities pertaining to Alaska's North Slope and the adjacent portions of the Arctic Ocean. BASC maintains the Barrow Environmental Observatory (BEO).

The Clean Air Act requires the EPA to set National Ambient Air Quality Standards (NAAQ, 40 CFR Part 50) for pollutants considered harmful to public health and the environment. EPA has set NAAQs for six principal pollutants, which are called "criteria" pollutants: carbon monoxide (CO), lead (Pb), Nitrogen Dioxide (NO_2), ozone (O_3), Particulate Matter (PM), and Sulfur Dioxide (SO_2). In Alaska, the primary air monitoring network evaluates the level of these criteria pollutants and focuses on six separate and distinct monitoring issues, as described in the Alaska draft 2008 Air Monitoring Network Plan: seasonal (October – March) CO monitoring in Anchorage and Fairbanks; coarse PM (PM_{10}) monitoring in Juneau, Anchorage and the central Matanuska-Susitna Valley (Mat-Su); fine PM ($PM_{2.5}$) monitoring in Juneau, Fairbanks, Anchorage and the Mat-Su Valley; statewide $PM_{2.5}$ monitoring during the summer fire season (May – September); $PM_{2.5}$ slash burning monitoring for agricultural and beetle kill (August – May); rural community/tribal village dust monitoring (May – September), residential wood smoke monitoring (September – March), and air toxics monitoring in selected communities statewide.

Data and Information Management and Other Useful Links

Barrow Arctic Science Consortium
http://www.arcticscience.org/aboutBASC.php

North Slope Borough, Department of Wildlife Management
http://www.co.north-slope.ak.us/departments/wildlife/

State of Alaska Department of Environmental Conservation
Air monitoring & Quality Assurance:
http://www.dec.state.ak.us/air/am/index.htm

Water Quality Assessment & Monitoring:
http://www.dec.state.ak.us/water/wqsar/index.htm

State of Alaska Department of Natural Resources Division of Oil and Gas:
http://www.dog.dnr.state.ak.us/oil/

Habitat management and planning:
http://www.dnr.state.ak.us/habitat/

Tundra travel:
http://www.dnr.state.ak.us/mlw/tundra/index.htm

State of Alaska Department of Transportation and Public Facilities Road Weather Information System:
http://www.dot.state.ak.us/iways/roadweather/forms/IndexForm.html

RWIS data can also be found at the following sites:

Alaska Ocean Observing System:
http://ak.aoos.org/op/data.php?region=AK&name=met_rwis)

US Department of Transportation Clarus:
http://clarus.mixonhill.com/observations/ClarusMap.html?lat=61.2&lon=-147.3&zoom=5

MADIS:
http://madis.noaa.gov/

Appendix 3: Volcano, Earthquake, and Geomagnetism Observing Activities

The Alaska Volcano Observatory (AVO) is a joint program of the USGS, the Geophysical Institute of the University of Alaska Fairbanks (GI/UAF) and the State of Alaska Division of Geological and Geophysical Surveys (ADGGS). AVO was created in 1988, and uses federal, state, and university resources to monitor and study Alaska's hazardous volcanoes, to predict and record eruptive activity, and to mitigate volcanic hazards to life and property. Alaska has just over 100 historically active volcanoes.

The backbone of the AVO volcano monitoring program consists of networks of continuously recording seismometers installed at more than 20 volcanoes. The seismometers provide a continuous data stream; consequently, the onset of explosive eruptions can be detected quickly in most cases and appropriate warnings issued.

Once a volcanic ash eruption has been detected, the NOAA NWS Alaska Aviation Weather Unit (AAWU) in Anchorage collaboratively serves as the Volcanic Ash Advisory Center (VAAC) and the Meteorological Watch Office (MWO). The role of the VAAC is to monitor all available satellite, radar, and other observational data (e.g. Pilot Reports) to determine the location, extent and movement of volcanic plumes. VAACs use this information to issue real-time text and graphical products about airborne volcanic ash to the aviation community. Volcanic ash dispersion model predictions are used to assist in making a forecast of these ash plumes out to 18 hours. The dispersion model predicts where the volcanic ash will spread over time and this information is then relayed to the user community. Information about the volcano, including a detailed forecast of the ash plume, is included in a Volcanic Ash Advisory (VAA). VAACs provide this information to international Meteorological Watch Offices (MWOs), which in turn issue Significant Meteorological Information (SIGMETs) to the aviation community. The SIGMET is the official warning product for airborne volcanic ash. The Anchorage VAAC is responsible for the Flight Information Region for Alaska which includes a portion of eastern Russia (north of 60°N latitude and east of 150°E longitude).

Satellite imagery provides information which complements seismic monitoring at those volcanoes with seismic networks. AVO analyzes available satellite data twice daily for thermal anomalies and ash plumes at about 80 volcanoes in the north Pacific. By analyzing satellite imagery and working with the NWS to predict where winds will carry the ash, AVO assists the FAA in warning aircraft of areas to avoid.

AVO also operates a network of telemetered GPS receivers at Augustine Volcano, in lower Cook Inlet, that provide a continuous record of ground deformation. AVO also conducts periodic field-based GPS surveys as well as measuring deformation with InSAR techniques. These techniques are providing important information about inflation and deflation of volcanoes, but are not yet evolved enough for routine real-time monitoring of many volcanoes.

As regards earthquakes, USGS works in cooperation with the State of Alaska, the Alaska Earthquake Information Center (AEIC), university partners to support State of Alaska, regional, national, and global seismic-monitoring network. The USGS and university and State geological survey partners have begun to install and operate the Advanced National Seismic System (ANSS), a national network of sophisticated shaking monitors placed both on the ground and in buildings in populated urban areas. The USGS will continue to improve on existing Arctic and global earthquake monitoring, assessment, and research activities, with the ultimate goal of providing new products that facilitate more effective mitigation and response.

The USGS Geomagnetism Program has, for over a century, monitored the geomagnetic field through a network of magnetic observatories located in the United States and its Territories. The Alaska observatories are located at Barrow, College (Fairbanks), Shumagin and Sitka. They support modern digital acquisition systems, designed to produce long time series of stable magnetometer data having high accuracy and resolution.

Data and Information Management and Other Useful Links

Alaska Volcano Observatory
http://www.avo.alaska.edu/

NOAA National Weather Service Alaska Aviation Weather Unit
http://aawu.arh.noaa.gov/

USGS Earthquake Hazards Program
http://earthquake.usgs.gov/

USGS National Geomagnetism Program
http://geomag.usgs.gov/

Appendix 4: List of Abbreviations and Acronyms

AAWU	Alaska Aviation Weather Unit
ACEX	Arctic Coring Expedition
ACIA	Arctic Climate Impact Assessment
ACRF	ARM Climate Research Facility
ADA	Arctic Domain Awareness
ADGGS	Alaska Division of Geological and Geophysical Surveys
AEIC	Alaska Earthquake Information Center
AFSC	Alaska Fisheries Science Center
AICC	Alaska Inter-agency Coordination Center
AMAP	Arctic Monitoring and Assessment Program
AMSA	Arctic Marine Shipping Assessment
AMSR-E	Advanced Microwave Scanning Radiometer-E
ANSS	Advanced National Seismic System
AON	Arctic Observing Network
AOOS	Alaska Ocean Observing System
AOSB	Arctic Ocean Science Board
APRFC	Alaska-Pacific River Forecast Center
ARCSS	Arctic System Science (NSF-OPP)
ARCUS	Arctic Research Consortium of the United States
ARM	Atmospheric Radiation Measurement
ASF	Alaska Satellite Facility
ASOS	Automated Surface Observing System
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVO	Alaska Volcano Observatory
BASC	Barrow Arctic Science Consortium
BASIS	Bering-Aleutian Salmon International Survey
BEO	Barrow Environmental Observatory
BEST	Bering Sea Ecosystem Study
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CADIS	Cooperative Arctic Data and Information Service
CAFF	Council Conservation of Arctic Flora and Fauna
CALM	Circumpolar Active Layer Monitoring
CARMA	Circumarctic Rangifer Monitoring & Assessment Network
CASTNet	Clean Air Status and Trends Networks
CBMP	Circumpolar Biodiversity Monitoring Program
CDC	Centers for Disease Control and Prevention
CEON	Circumarctic Environmental Observatories Network
CliC	Climate and Cryosphere
CLIVAR	Climate Variability and Predictability
C-MAN	Coastal Marine Automated Network
CO-OPS	Center for Operational Oceanographic Products and Services
CORE	Collaborative Observation and REsearch
CReSIS	Center for Remote Sensing of Ice Sheets
CRN	Climate Reference Network
CRREL	Cold Regions Research and Engineering Laboratory
DAAC	Distributed Active Archive Center
DAMOCLES	Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies
DEC	Department of Environmental Conservation, State of Alaska
DESDynI	Deformation Ecosystem Structure and Dynamics of Ice
DFG	Department of Fish and Game, State of Alaska
DGGS	Division of Geological and Geophysical Surveys, State of Alaska
DMSP	Defense Meteorological Satellite Program

DNR	Department of Natural Resources, State of Alaska
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOTPF	Department of Transportation and Public Facilities, State of Alaska
ELOKA	Exchange for Local Observations and Knowledge of the Arctic
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FMP	Fishery Management Plan
FOCI	Fisheries Oceanography Coordinated Investigations
GCM	Global Circulation Model
GC-Net	Greenland Climate Network
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GINA	Geographic Information Network of Alaska
GIS	Geographic Information System
GISP-2	Greenland Ice Sheet Project-2
GLAS	Geoscience Laser Altimeter Satellite
GLOBE	Global Learning and Observations to Benefit the Environment
GOOS	Global Ocean Observing System
GOSIC	Global Observing Systems Information Center
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GTN-P	Global Terrestrial Network-Permafrost
GTOS	Global Terrestrial Observing System
HHS	Health and Human Services
IABP	International Arctic Buoy Program
iAOOS	Integrated Arctic Ocean Observing System
IARC	International Arctic Research Center
IARPC	Interagency Arctic Research Policy Committee
IASC	International Arctic Science Committee
IASOA	International Arctic Systems for Observing the Atmosphere
ICARP II	Second International Conference on Arctic Research Planning
ICESat	Ice, Cloud and Land Elevation Satellite-II
ICOS-RMI	Interagency Committee on Ocean Science and Resource Management Integration
ICS	International Circumpolar Surveillance
IIP	International Ice Patrol
IMPROVE	Interagency Monitoring of Protected Visual Environments
InSAR	Interferometric Synthetic Aperture Radar
IODP	Integrated Ocean Drilling Program
IOOS	Integrated Ocean Observation System
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IPYDIS	International Polar Year Data and Information Service
ISAC	International Study of Arctic Change
ITEX	International Tundra Experiment
LTER	Long Term Ecological Research
MADIS	Meteorological Assimilation Data Ingest System
MDA	Maritime Domain Awareness
MMS	Minerals Management Service
MODIS	Moderate Resolution Imaging Spectroradiometer
NABOS	Nansen and Amundsen Basin Observational System
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NARS	National Aquatic Resource Survey
NASA	National Aeronautics and Space Administration
NASA DAAC	NASA Distributive Active Archive Centers

NASQAN	National Stream Quality Accounting Network
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Center for Environmental Prediction
NDBC	National Data Buoy Center
NDVI	Normalized Difference Vegetation Index
NEEM	North Eemian Ice Core Project
NEON	National Ecological Observatory Network
NGO	Non-Governmental Organization
NIC	National Ice Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Ocean Planning Partnership
NOS	National Ocean Service
NPMC	North Pacific Fishery Management Council
NPRB	North Pacific Research Board
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NPS	National Park Service
NRC	National Research Council
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSI	North Slope Science Initiative
NWLON	National Water Level Observation Network
NWS	National Weather Service
OASIS	Ocean-Atmosphere-Sea Ice-Snowpack
OCO	Orbiting Carbon Observatory
OMB	Office of Management and Budget
OMI	Ozone Monitoring Instrument
ONR	Office of Naval Research
OPP	Office of Polar Programs
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
OSTP	Office of Science and Technology Policy-White House
OSTM	Ocean Surface Topography Mission
PALE	Paleoclimates from Arctic Lakes and Estuaries
PAOOS	Passive Acoustics Ocean Observing System
PARCS	Paleoenvironmental Arctic Sciences
PMEL	Pacific Marine Environmental Laboratory
RAWS	Remote Automated Weather Station
RGPS	RADARSAT Geophysical Processing System
RUSALCA	Russian-American Long-term Census of the Arctic
RWIS	Road Weather Information System
S4D	SEARCH for DAMOCLES
SAON IG	Sustained Arctic Observing Networks Initiating Group
SAR	Synthetic Aperture Radar
SCICEX	Submarine Arctic Science Program
SEARCH	Study of Environmental Arctic Change
SEER	Surveillance, Epidemiology and End Results
SIGMET	Significant Meteorological Information
SIZONET	Seasonal Ice Zone Network
SMAP	Soil Moisture Active Passive
SNOTEL	SNOpack TELemetry
SSM/I	Special Sensor Microwave Imager
TES	Tropospheric Emission Spectrometer
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGEO	United States Group on Earth Observations
USGS	United States Geological Survey
USIABP	United States Interagency Arctic Buoy Program
USIEOS	US Integrated Earth Observation System
USNCDC	United States National Climate Data Center
UV-B	Ultraviolet-B radiation

VAAC	Volcanic Ash Advisory Center
VIIRS	Visible Infrared Imaging Radiometer Suite
WACAP	Western Airborne Contaminants Assessment Project
WFO	Weather Forecast Office
WMO	World Meteorological Organization

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