Study of Environmental Arctic Change:

Plans for Implementation During the International Polar Year and Beyond

SEARCH
Study of Environmental Arctic Change

Report of the SEARCH Implementation Workshop
May 23–25, 2005

Cover Photo: Coastal erosion due to thawing permafrost and increased wave action threatens several arctic communities, including Shishmaref, Alaska. Coastal dynamics, driven by a combination of natural and anthropogenic factors and occurring at the interface of land, ocean, and human activities, provides a salient example of the complexity of arctic change. Examples such as this underscore the need for a multi-disciplinary approach to understanding arctic change, as exemplified by SEARCH. Photo © Native Village of Shishmaref. Courtesy of Luci Eningowuk.

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Foreword

Development of the SEARCH program began in the late 1990s, in response to observations revealing changes in arctic ocean and atmospheric conditions. An open letter was circulated to the scientific community proposing a program to track and understand these seemingly widespread and rapid changes. By April 1997, 40 scientists from 25 institutions had signed the letter, which called for an international effort initially called the "Study of Arctic Change" to investigate those changes through measurement, data analysis, and modeling. A workshop in November 1997 gathered more than 70 scientists who reported on recent changes in the Arctic, supporting the premise of a related suite of changes that were occurring arctic-wide.

As the scientific effort developed to a broad initiative involving several federal agencies, its name changed to the Study of Environmental ARctic CHange (SEARCH). At a 1999 workshop, 39 researchers began to draft the SEARCH Science Plan. Published in 2001, the Science Plan summarizes observed changes; presents the SEARCH hypotheses, objectives, and strategies; and recommends a broad interdisciplinary program aimed at understanding the interrelated arctic changes and their implications. In 1999, the Interagency Arctic Research Policy Committee (IARPC) included SEARCH as "ready for immediate attention" in the U.S. Arctic Research Plan, and a SEARCH Interagency Working Group (IWG), now the Interagency Program Management Committee (IPMC), was established. The IPMC consists of the eight federal agencies responsible for scientific research in the Arctic that have agreed to work together on implementing SEARCH:

- National Science Foundation (NSF, current IPMC chair)
- National Oceanic and Atmospheric Administration (NOAA)
- National Aeronautics and Space Administration (NASA)
- U.S. Department of Defense (DOD)
- U.S. Department of Energy (DOE)
- U.S. Department of the Interior (DOI)
- Smithsonian Institution
- U.S. Department of Agriculture (USDA)

In close cooperation with the IPMC, the SEARCH Science Steering Committee developed an implementation strategy outlining activities for coordinated implementation to address the science questions posed in the Science Plan. Published in 2003, the Implementation Strategy clearly demonstrated that SEARCH activities transcend the intellectual, infrastructural, and fiscal resources of any single nation, strongly suggesting that an international program is needed to realize SEARCH goals.

The research community and agencies responded to this need during the SEARCH Open Science Meeting, held in October 2003 in Seattle, Washington. During this meeting over 440 researchers from around the world presented and discussed progress in understanding and new observations of the rapid environmental change in the Arctic. The OSM included over 280 oral and poster presentations, attesting to the significant interest of the research community to advance our understanding of arctic change. The scientific sessions were followed by an international implementation workshop during which participants requested that the International Arctic Science Committee (IASC) and Arctic Ocean Sciences Board (AOSB) start the formation of an international effort on arctic change. Both organizations responded positively and initiated the International Study of Arctic Change (ISAC)

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program, the international umbrella under which SEARCH will be a national component.

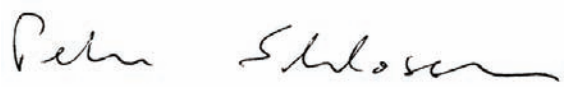
Initial SEARCH projects have been implemented with contributions from several U.S. funding agencies, including the NSF, NOAA, and NASA. In addition, SEARCH continues to develop cooperative relationships with many of the pertinent arctic science programs sponsored by other nations and international groups. Recent developments, including the creation of ISAC and the upcoming International Polar Year 2007–2008 (IPY), offer opportunities for accelerated implementation of SEARCH. In recognition of these opportunities, the SEARCH Science Steering Committee (SSC) organized a SEARCH Implementation Workshop to update the 2003 Implementation Strategy and to align the implementation priorities with the evolving thinking in the SEARCH and ISAC communities, as well as the arctic community-at-large.

The main goal of the workshop was to provide recommendations for prioritized implementation of SEARCH during the period of the upcoming IPY 2007–2008, with a view beyond this near-term time line. Held 23–25 May 2005 at the National Conference Center in Lansdowne, Virginia, the SEARCH Implementation Workshop was attended by over 80 scientists, including members of the SEARCH SSC, the three SEARCH Panels (Observing Change Panel, Understanding Change Panel, and Responding to Change Panel), the IPMC, and scientists from the wider research community. This report summarizes the results from deliberations held before, during, and after the SEARCH Implementation Workshop. The draft of this report was circulated for broad community review and has subsequently undergone several additional iterations of review by the three SEARCH implementation panels and the more than 80 scientists that participated in the workshop.

On behalf of the SEARCH Science Steering Committee, we would like to acknowledge the contributions from the arctic research community that have improved each successive draft of this report. We would also like to thank the SEARCH Implementation Panels and the Science Steering Committee for the insight and guidance they have provided, as well as the work of the members of the workshop organizing committee who led the development of this report.

The SEARCH Science Management Office at ARCUS was essential to the successful workshop process and the production of this report. We would like to thank Wendy Warnick and Helen Wiggins for their skillful guidance of the report's content development and editorial process, and Sarah Behr, Alison York, and Birte Horn-Hanssen for graphics, layout, and editorial contributions at various stages. The entire staff of ARCUS contributed to the success of the implementation workshop through excellent planning, organization, and hard work. Finally, on behalf of the arctic research community, we thank the National Science Foundation and the Interagency Program Management Committee for the opportunity provided to the arctic research community to participate in this planning and implementation process.

Peter Schlosser, SSC chair



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Executive Summary

The overall goal of the Study of Environmental Arctic Change (SEARCH) is to understand the nature, extent, and future development of the system-scale changes presently observed in the Arctic. These changes include, for example, increasing average annual surface air temperatures, decreasing summer sea ice extent and sea ice mass, changing ocean circulation, northward movement of tree lines and vegetation zones, thawing glacial ice masses and permafrost, and changing socioeconomic dynamics. The initial objectives of SEARCH have been documented in the SEARCH Science Plan (SEARCH, 2001) and Implementation Strategy (SEARCH, 2003) and include:

- Documenting the nature and extent of the present changes in the Arctic;
- Determining if such changes occurred in the past;
- Following the evolution of past and present changes;
- Understanding the forcing mechanisms and feedbacks that control system changes;
- Understanding the interaction between changes in the physical/chemical, biological, and human domains; and
- Illuminating system interactions between the Arctic and the lower latitudes.

Initial SEARCH projects have been implemented largely on an opportunistic basis with contributions from several U.S. funding agencies, including the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA), among others. Recent developments, including the creation of the International Study of Arctic Change (ISAC) as the international umbrella for SEARCH and the upcoming International Polar Year 2007–2008 (IPY), offer opportunities for accelerated implementation of SEARCH. In recognition of these opportunities, the SEARCH Science Steering Committee (SSC) organized a SEARCH Implementation Workshop to update the 2003 Implementation Strategy and to align the implementation priorities with the evolving thinking in the SEARCH and ISAC communities, as well as the arctic community-at-large. The main goal of the workshop was to provide recommendations for prioritized implementation of SEARCH during the period of the upcoming IPY 2007–2008, with a view beyond this near-term time line.

Held 23–25 May 2005 at the National Conference Center in Lansdowne, Virginia, the SEARCH Implementation Workshop was attended by over 80 scientists, including members of the SEARCH SSC, the three SEARCH Panels (Observing Change Panel, Understanding Change Panel, and Responding to Change Panel), the Interagency Program Management Committee (IPMC), and scientists from the wider research community.

Discussions at the workshop were facilitated by three position papers outlining implementation priorities for SEARCH Observing, Understanding, and Responding activities—the general categories of activities and related panel structure outlined in the SEARCH Implementation Strategy (2003). The three SEARCH panels—convened to work with the SEARCH SSC to plan and coordinate the broad spectrum of SEARCH activities—drafted the position papers that were distributed for community input before the workshop.

The workshop was organized to include a combination of plenary discussions and breakout sessions. Breakout sessions alternated between the panel-focused themes (Observing, Understanding, and Responding) and smaller working groups organized around several specific topical areas (e.g.,

terrestrial ecosystems, distributed marine observations, human dimensions, etc.) that were identified by the SSC as requiring specific attention.

This report summarizes the results from deliberations held before, during, and after the SEARCH Implementation Workshop. The draft of this report was posted for additional community input on the SEARCH website (http://www.arcus.org/SEARCH/index.php).

The priorities detailed in this report for the next steps of SEARCH are guided by the need to understand the complex of pan-arctic change. Workshop participants identified the following set of scientific questions that build on the hypotheses presented in the 2001 SEARCH Science Plan and lie at the heart of the 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 timescales)?
3. To what extent can recent and ongoing climate changes in the Arctic 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 (i.e., processes by which the environment produces resources that support human life) affected by environmental change and its interaction with human activities?
6. How do cultural and socioeconomic systems interact with arctic environmental change?
7. What are the most consequential links between the arctic and the earth systems?

Priority activities and major recommendations for implementation were developed to address the science questions and are summarized in tabular form (Table 1). The criteria used to prioritize activities included: importance to meeting SEARCH science objectives, fit with international activities, and readiness for implementation. Details of the scientific objectives and proposed activities are further described in Section 4 of this report (Meeting the SEARCH Objectives).

Under each science question listed in the table, SEARCH implementation activities are grouped by Observing, Understanding, and Responding activities, characterized in general terms as follows:

Observing Activities - Types of activities include: data rescue; improvement of observation density, co-location, and integration; improvement of coverage to close observation gaps; development of optimal observation and sampling strategies; observations of key processes and studies of feedbacks; acquisition of paleo-data over critical time periods; development of networks; development of data archival and distribution systems; and utilization of innovative and effective technology.

Understanding Activities - Types of activities include: model-based assimilation of available observations; improvement and expansion of model capabilities; model simulations for forecasting and for guiding observing system design; development and use of proxy records; paleo reconstructions; diagnostic analyses of synthesized observations and paleo reconstructions; and studies of interactions between arctic environmental, socioeconomic and cultural changes.

Responding Activities - Types of activities include: stakeholder-driven guidance of observations and identification of useful predictions; interpretation of modeling/analysis results in the context of local knowledge; assessment of the responsiveness and effectiveness of institutions in addressing social and economic concerns about climate change; and development of community-based networks and cooperatives to facilitate the above activities.

In addition to the grouping of activities according to the seven key science questions, the table contains two additional overarching groups of activities: Data Management Strategy and Education and Outreach.

Efficient progress within the SEARCH program requires continuous exchange of results and iterative development of the research activities outlined in the Observing, Understanding, and Responding categories. Activities within the three major categories must be closely coordinated, and activities from each simultaneously initiated.

Additionally, whereas the priorities outlined in this report generally focus on U.S. and Canadian sectors of the Arctic, predictive understanding of arctic change will require research throughout the pan-arctic system. Internationally coordinated and non-U.S. programs will lead activities in many regions of the Arctic; under the international umbrella of ISAC, SEARCH will coordinate U.S. participation in international programs and projects as appropriate.

With input from a broad representation of arctic researchers, the priorities and activities summarized in this report cut across disciplinary and geographic boundaries to guide the science community and agencies in SEARCH implementation, including that for the upcoming International Polar Year. Implementation of the SEARCH Observing, Understanding, and Responding activities will further our knowledge of the extent and future development of the system-scale change presently observed in the Arctic and the implications for the global community.

Table 1. Overview of SEARCH Priority Activities. *The first column, "Activity," lists the proposed activities organized by science question. The second column, "Priority/Phasing," rates the activity (1–3, with 1 representing highest priority) in terms of importance to SEARCH science objectives, fit with international activities, and readiness for implementation. The third column, "Additional Questions," references additional key science questions addressed by the activity, as described in Section 3 of the report. The fourth column lists the section(s) in the report that can be consulted for further information.*

Activity	Priority/ Phasing	Additional Questions	Section
1. Is the arctic system moving to a new state?			
Observing Activities (Page 9):			
(a) Construct a high-resolution (10^0–10^1 year) multiproxy spatial and temporal paleoclimate network extending back 2,000 years	1	2, 3, 5, 7	4.1.6
(b) Enhance and stabilize the distribution and continuity of the upper-air, surface climatology, and weather observation networks, including integration of cryospheric, hydrologic, and oceanic variables	1	2, 3, 4	4.1.1
(c) On land, initiate at least one intensive site for integrated time series measurements that include climate, surface energy balance, hydrology, glaciology, trace gases, permafrost/active layer, C/N/P budgets, species composition, vegetation structure, and contaminant compounds; apply new technology, numerical analyses, and remote sensing to extrapolate field measurements to high quality circumarctic gridded datasets	1	3, 4, 5, 7	4.1.4
(d) Develop an integrated observation network for identification and long-term monitoring of social and economic indicators of human subsystem changes that drive and/or feed back to arctic physical and biological system changes	1	2, 3, 4, 5, 6	4.1.5
(e) Implement automated monitoring in the ocean and for sea ice of key biological and chemical parameters coincident with physical observations (including key energy balance terms and fluxes) over annual cycles at critical representative locations	1	2, 4, 5	4.1.2
(f) Determine pan-arctic and regional mass budget parameters for sea ice and overlying snow (including key snow/ice properties) from remote sensing, surveys, and buoys, with adequate attention to both seasonal and perennial sea ice zones	1	2, 4, 5	4.1.2
(g) Determine water balance components in flagship research watersheds, key benchmark glaciers, and on the Greenland Ice Sheet through field measurements, remote sensing and modeling	1	2, 4, 7	4.1.3
(h) Determine the degree to which people across the Arctic are observing environmental change that exceeds the bounds of understood experience	2	2, 5, 6	4.1.5
Understanding Activities (Page 36):			
(i) Synthesize existing observations from the past several decades by an Integrative Data Assimilation for the Arctic System (IDAAS), producing a gridded database with maximum homogeneity for detection and attribution of arctic change	1	3, 4, 5	4.2.1
(j) Conduct observing system sensitivity experiments with models, drawing upon enhanced observations from the IPY, to design optimal observing networks and sampling strategies for monitoring the arctic system in the post-IPY period	1	5	4.2.1
(k) Synthesize human dimensions data on a pan-arctic scale, including data on resident socioeconomic changes, human perceptions (local, regional, and non-arctic) of arctic change, and on local and global-scale development and industrial activities	1	5, 6, 7	4.2.1

Responding Activities (Page 43):			
(l) Identify specific ways to improve knowledge of arctic environmental change such that people are enabled to make better-informed decisions	1	2, 3, 4, 5, 6, 7	4.3.1
(m) Determine and assess the ways in which stakeholder and residents' perceptions of an arctic state change affects responses to change	3	6	4.3.1
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 timescales)?			
Observing Activities (Page 9):			
(a) Repeat hydrographic sections across major frontal features of the Arctic Ocean; build on international programs and collaborations and use remote sensing to provide broader spatial coverage	1	1, 3, 4, 5, 7	4.1.2
(b) Determine spatial variation and temporal patterns of permafrost degradation, glacier ablation, and changing water resources	1	1, 4, 5, 6	4.1.3
Understanding Activities (Page 36):			
(c) Perform coordinated sets of model experiments targeted at understanding arctic change and reducing uncertainty in projections of future arctic change; include ensembles of simulations, process sensitivity studies, and downscaling to local information	2	1, 3, 4, 7	4.2.2
(d) Develop and conduct experiments with linked social-ecological models to assess the predictability of associated ecosystem changes and human adaptations	2	4, 5, 6	4.2.2
(e) Process climate datasets quickly enough to be useful for short-term forecasting, and calibrate and archive weather datasets for use in climate studies	3	6	4.2.2
Responding Activities (Page 43):			
(f) Identify predictions that will be most useful to stakeholder groups planning for and responding to change in areas such as fisheries, marine transportation and development, and renewable resource use/subsistence harvests	1	6	4.3.2
(g) Quantify and communicate the uncertainties in forecasts of changes in key variables in the arctic system	1	5, 6, 7	4.3.1
(h) Evaluate the effectiveness of different methods of expressing uncertainty in facilitating adaptive responses to change	3	6	4.3.1
3. To what extent can recent and ongoing climate changes in the Arctic be attributed to anthropogenic forcing, rather than to natural modes of variability?			
Observing Activities (Page 9):			
(a) Construct decadal-resolution multiproxy records from earlier warmer periods, particularly the early Holocene thermal maximum and Last Interglaciation	2	1, 3, 5, 7	4.1.6
(b) Coordinate atmosphere, ocean, and sea ice observation efforts to significantly enhance understanding of regional differences	2	1, 2	4.1.1, 4.1.2
(c) Improve quantification of essential paleo-proxies (sea ice, precipitation, temperature) through sampling and proxy measurements co-sited with terrestrial and marine instrumental observatories	3	1, 5	4.1.6
Understanding Activities (Page 36):			
(d) Conduct experiments and sensitivity tests with updated models to determine the portion of the recent changes in the Arctic attributable to increased greenhouse gas concentrations and aerosols relative to other large-scale drivers	1	1, 2, 4, 7	4.2.3

(e) Integrate observations of terrestrial, marine, and atmospheric variables from diverse sources into readily accessible databases suitable for integrated (across-variable) assessments of change, especially in the context of large-scale drivers such as the Arctic Oscillation, Pacific Decadal Oscillation, and greenhouse forcing	2	1, 4, 5, 6, 7	4.2.3
Responding Activities (Page 43):			
(f) Translate modeling results aimed at understanding the causes of climate change into a form useful to the many different groups of stakeholders	2	4	4.3.4
(g) Assess the effect of understanding the role of anthropogenic forcing on climate change in shaping responses to change	3	6	4.3.1
4. What is the direction and relative importance of system feedbacks?			
Observing Activities (Page 9):			
(a) Characterize permafrost and hydrological controls on vegetation change and quantify the resultant impact of ecosystem change on freshwater fluxes and biogeochemistry	2	2, 5, 6	4.1.3, 4.1.4
Understanding Activities (Page 36):			
(b) Improve and expand capabilities of models used for arctic simulations by enhancing formulations of key arctic processes (surface energy budget, clouds, vegetative effects, ocean/ice transports, and land and water use changes)	2	2, 3	4.2.4
Responding Activities (Page 43):			
(c) Assess the interaction of stakeholder responses to change with the direction and relative importance of system feedbacks	3	6	4.3.1
5. How are terrestrial and marine ecosystems and ecosystem services (i.e., processes by which the environment produces resources that support human life) affected by environmental change and its interaction with human activities?			
Observing Activities (Page 9):			
(a) Determine abundance and distribution of marine animals and pelagic/benthic communities, including measurements of key biophysical ocean and sea ice variables	2	6	4.1.2
(b) Work with stakeholders and resource managers to organize local ecological monitoring networks to collect and share data on regional ecological changes, including near-real time observations relevant to ecosystems and ecosystem services	2	1, 2, 6	4.1.5
(c) Integrate hydrology and glacier measurements with ecosystem dynamics	3	1, 2, 4, 6	4.1.3, 4.1.4
Understanding Activities (Page 36):			
(d) Synthesize information and modeling on ecosystem components and their interactions, assessment of freshwater flux, and marine ecosystem modeling, including the contribution of resource harvests and other human activities	2	6	4.2.5
(e) Develop an understanding of how to scale process and mechanistic knowledge in space and time, initially through focused studies on key variables and interactions (e.g., surface energy balance, trace gases, land vegetation cover); requires multi-scale observations, pan-arctic comparisons, modeling, and remote sensing	2	1, 2, 4, 6, 7	4.1.5

Responding Activities (Page 43):			
(f) Assess how human responses interact with changes in ecosystems and ecosystem services	3	6	4.3.1
6. How do cultural and socioeconomic systems interact with arctic environmental change?			
Observing Activities (Page 9):			
(a) Establish data outlets for near-real time observations relevant to stakeholder groups	1	1, 2, 4, 5, 7	4.1.5, 4.3.3
(b) Develop a pan-arctic database of key human dimensions indicators of population, employment, and subsistence	1	5	4.1.5
(c) Develop a coastal ocean-ice-atmosphere observation network providing data relevant to stakeholders (e.g., subsistence hunt safety, navigational hazards, storm surges, threats to coastal infrastructure, etc.)	2	5, 7	4.2.6
(d) Determine abundance and distribution of key commercial and subsistence species and integrate into database coupled with relevant environmental data	2	5	4.3.2
(e) Compile coastal dynamics and long-term tide and storm surge data	3	2, 5	4.1.2
Understanding Activities (Page 36):			
(f) Develop socioeconomic models incorporating ecosystem services; conduct qualitative and quantitative research on resilience of social-ecological systems	1	5	4.2.6
Responding Activities (Page 43):			
(g) Establish or identify community/industry networks and cooperatives, focusing on a variety of activities, including data gathering, identifying relevant predictions of change, and interpreting results in context of local and scientific knowledge	1	1, 2, 4, 5, 7	4.3.4
(h) Characterize the ongoing and potential effects on infrastructure resulting from permafrost degradation	2	5	4.1.3
(i) Assess the responsiveness and effectiveness of local, regional, and national institutions in addressing societal concerns about climate change in the context of other forces for change	3	5	4.3.2
7. What are the most consequential links between the arctic and the earth systems?			
Observing Activities (Page 9):			
(a) Enhance observations of heat, salt, and volume fluxes through straits connecting the Arctic with the north Pacific and Atlantic Oceans	2	1, 2, 3, 4, 5	4.1.2
(b) Monitor perceptions of temperate zone residents on arctic climate change and its consequences	2	6	4.1.5
(c) Integrate glacier and ice sheet mass balance measurements with observations of climate dynamics	2	1, 2, 4	4.1.3
Understanding Activities (Page 36):			
(d) Conduct controlled model experiments to understand global-arctic linkages focused on key physical linkages, effects of arctic warming on global sea level, and effects of hydrological changes on the North Atlantic	2	4	4.2.7
Responding Activities (Page 43):			
(e) Identify long-term effects of reduction in sea ice and sea level changes on arctic shipping, resource development and harvests, global markets, and international security	3	5	4.3.1

8. Data Management Strategy (Page 47)			
(a) Form a SEARCH Data Management Advisory Group:	1	All	5.3
Develop SEARCH Data Policy	1	All	5.3
Develop comprehensive SEARCH Data Management Plan	1	All	5.3
Develop SEARCH Data Inventory	1	All	5.3
Establish data management requirements for SEARCH investigators	1	All	5.3
Create a central SEARCH Data and Information Coordination Service	1	All	5.3
(b) Rescue and incorporate relevant historical data	2	All	5.3
9. Education and Outreach (Page 53)			
(a) Develop education and outreach sections and activities on SEARCH website, including K–12 and educational content, press links, and community-relevant content	1	All	6.4
(b) Develop comprehensive guide with information on ways in which individual SEARCH researchers and projects can participate in education and outreach efforts	1	All	6.4
(c) Implement a SEARCH-focused multi-agency Research Experience for Teachers program	2	All	6.4
(d) Initiate SEARCH-focused, student-centered informal science education programs integrated with community monitoring network activities, field research programs, and use of SEARCH datasets	2	All	6.4

1. Introduction and Motivation

The Study of Environmental Arctic Change (SEARCH, 2001) program was conceived as an integrated, interdisciplinary approach to study a complex of extensive, interrelated changes in the arctic system observed over the past few decades. After implementation of initial projects in response to the SEARCH Science Plan (SEARCH, 2001) and Implementation Strategy (SEARCH, 2003; see http://www.arcus.org/search/searchprojects for a listing of activities), SEARCH has now reached a critical juncture. While the origins and driving forces of system change are still not clear, accumulating evidence suggests that it is more than an ephemeral phenomenon. An increasing number of studies indicate that while the changes are part of the natural variability inherent to the arctic climate system, they also partly reflect and are amplified by the impact of human activity on the global environment. Arctic residents as well as governments and industry in circumarctic nations and beyond acknowledge these environmental changes and are beginning to take them into account in daily decisions and future plans.

In addition to initial SEARCH efforts, the International Study of Arctic Change (ISAC)—the international umbrella for SEARCH—has initiated discussions to coordinate research on environmental change on a pan-arctic scale among many interested nations. The International Polar Year 2007–08 (IPY; see http://www.ipy.org/) offers an opportunity to consolidate and expand existing studies and to implement observation networks or systems that are driven by the needs identified by the scientific community and stakeholders.

To provide guidance and open a channel for community and stakeholder input during this period of SEARCH evolution and implementation, the SEARCH Science Steering Committee (SSC) organized an implementation workshop held 23–25 May 2005 in Lansdowne, Virginia (see http://www.arcus.org/search/meetings/2005/siw/index.php).

Preparation for the workshop discussions was guided by position papers prepared by the three SEARCH panels:

- Observing Change Panel (OCP),
- Understanding Change Panel (UCP), and
- Responding to Change Panel (RCP).

The position papers were widely circulated to provide opportunity for the community-at-large to express their views on the next steps of SEARCH implementation. In many respects, the three position papers were intertwined; understanding change requires that the changes be observed, while observations and understanding of changes provide a context for scientific assessments and, most significantly, for planning mitigation and adaptation in response to the changes. Needs for understanding and responding to change can, in turn, guide the observational priorities.

This report builds upon the three panel position papers and is augmented by the community-wide planning discussions before, during, and after the SEARCH Implementation Workshop. It is meant to serve as a point of reference for immediate planning in preparation for the International Polar Year and for an Arctic Observing Network. It is also intended to provide a perspective on SEARCH beyond these immediate needs and priorities.

SEARCH Objectives

The overall goal of SEARCH is to understand the nature, extent, and future development of the system-scale change presently observed in the Arctic. This goal is described in detail in the SEARCH Science Plan (SEARCH, 2001) and Implementation Strategy (SEARCH, 2003).

The original observations that prompted initiation of the SEARCH program suggested that a majority of these changes, including increasing average annual surface air temperatures, decreasing sea ice extent and mass, changing ocean circulation and freshwater balance, and thawing permafrost, could be explained by a trend toward a more positive index in the Arctic Oscillation (AO)—a condition in the Northern Hemisphere atmospheric circulation cycle (i.e., Polar Vortex) characterized by relatively low pressure over the polar region and higher pressure at mid-latitudes.

The original science plan hypotheses focused in part on the roles of changes in the polar vortex and related indices such as the AO in affecting arctic climate and linking the Arctic to lower latitudes. Given the numerous documented relationships between the AO and recent climate variability, answering the SEARCH science questions is likely to require further consideration of the role of polar vortex variations, their relationships to global climate, and possible explanations for changes in the strength of correlation between the AO and arctic atmosphere, oceans, and land.

Recent observations of persistent change, however, such as further reductions in summer sea ice extent and sea ice mass, demonstrate the complexity of the relationship between system-scale changes and atmospheric circulation, as these changes have continued despite recent weakening in the positive AO index. It is clear that the linkages and patterns between atmospheric cycles and variability, observed environmental changes, and the contributions of human activities as drivers of change in the modern arctic environment require further clarification. Importantly, improved understanding of system drivers is needed for possible mitigation and adaptation strategies designed to minimize the impact of arctic change.

Thus, in the prioritization of SEARCH implementation activities summarized in this report, more emphasis is placed on secular change (i.e., long-term rather than quasi-cyclical variation) as well as a possible transition of the Arctic into a new state.

In order to meet its overall goal, the objectives of SEARCH are to:

- Document the nature and extent of the present changes in the Arctic;
- Determine if such changes occurred in the past;
- Follow the evolution of past and present changes;
- Understand the forcing mechanisms and feedbacks that control system changes;
- Understand the interaction between changes in the physical/chemical, biological, and human domains; and
- Illuminate system interactions between the Arctic and the lower latitudes.

The evolution of the SEARCH program from the hypotheses and science questions posed in the original Science Plan and Implementation Strategy is reflected in this report by a set of organizing science questions that build upon those in the original documents, but also reflect new lines of thought in the SEARCH and ISAC communities, as well as other arctic research

and stakeholder communities. As we learn more about the nature of arctic change, we can expect continued adjustments of the SEARCH program in the future.

The following chapters present the science questions and proposed activities required to meet the SEARCH objectives.

Key Science Questions

The arctic system encompasses physical, biogeochemical, ecological, and human domains. In combination, these domains govern atmospheric and ocean processes, terrestrial and marine ecosystem dynamics, and socioeconomic functions. Changes in these tightly linked system components may play out at local, regional, and global scales. Recent and ongoing changes in the arctic physical system appear to be large and, in some cases, unprecedented in the period of instrumental and satellite observations. The magnitude of these changes raises the possibility that the arctic system may be crossing a threshold or approaching a tipping point, especially if amplification or irreversibility of change is introduced through processes such as the ice-albedo-temperature feedback. Such considerations lead to the overarching question that is a main driver of the SEARCH program:

3.1. Is the arctic system moving to a new state?

Answering this question will require well-conceived observations and fundamental advances in our understanding of the arctic system as a whole. The answer also has profound implications for stakeholder responses to the presently observed changes.

Key questions that must be addressed in order to understand whether the Arctic is moving into a new state include the following:

3.2. 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 timescales?

An answer to the question about the Arctic's evolution toward a new state requires that at least some degree of predictability be inherent in the different components of the system. Ensemble simulations and diagnostic evaluations of changes in the recent and distant past, together with model experiments targeted at predictability within the system, must provide the basis for an assessment of the predictability of relevant variables over different timescales. Relevant sub questions include:

- To what extent can climate models and other environmental forecasting tools predict seasonal and interannual changes of arctic environmental variables?
- To what extent can linked social-ecological models predict ecosystem changes and human adaptations?
- What are the uncertainties in arctic predictions at various timescales, and what are the most useful ways to convey these uncertainties?

3.3. To what extent can recent and ongoing climate changes in the Arctic be attributed to anthropogenic forcing, rather than to natural modes of variability?

Changes in arctic climate over the past several decades have been large and rapid, and there are indications of similar rapid changes in the past. In contrast to today, however, these past changes did not occur in association with dramatic increases of greenhouse gases of anthropogenic origin. For example, the warming of the 1930s and 1940s is not fully understood, but the episode is hypothesized as a manifestation of natural variability. In order to include attribution in our understanding of future arctic climate change, it is necessary to determine the relative roles of anthropogenic forcing and natural variability in the recent changes. Anthropogenic

forcing includes not only the emission of greenhouse gases, aerosols, and stratospheric-ozone depleting substances, but also changes in land use and other impacts on terrestrial and marine ecosystems. Progress toward attribution requires consideration of several questions, some of which could include:

- How do clouds, aerosols, and their chemistry interact to force the pan-arctic surface energy balance and the albedo-temperature feedback?
- What is the relative role of tropospheric dynamics and stratospheric linkages in controlling arctic surface variability?
- How do intrinsic oscillations in the atmospheric circulation react to anthropogenic forcing?
- What portion of the recent change in the Arctic can be attributed to increased greenhouse gas concentrations and aerosols?

3.4. What is the direction and relative importance of system feedbacks?

Each component of the arctic system—the atmosphere (including clouds and aerosols), the ocean, sea ice, the terrestrial surface and subsurface, and humans—has the potential to trigger a complex web of feedbacks. Understanding these feedbacks, which are now known only qualitatively at best, and their roles in moving the Arctic to a new state will require answers to questions such as:

- What type and scale of human activities feed back to arctic environmental change and how do these feedbacks function?
- How do the interactions and feedbacks among climate, hydrology, cryosphere, biology, biogeochemistry, and human action determine the rate and trajectory of arctic change?
- What is the role of clouds, aerosols, and water vapor in the albedo-temperature feedback?

3.5. How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and its interaction with human activities?

Ecosystems and their services (i.e., processes by which the environment produces resources that support human life, such as water, food, and hydropower) are sensitive in a variety of ways to climate change and human-induced disturbances. Changes in the physical environment impact terrestrial and marine ecosystems and alter the biology and biogeochemistry inherent to ecosystem function. In marine ecosystems, physical changes may impact and result from fisheries and transportation activities. On land, terrestrial hydrology and soil state (e.g., permafrost) can serve as conduits between atmospheric change and ecosystem function. In order to place ecosystem change into a framework of arctic system change and the possible emergence of a new arctic state, relevant research questions include:

- What are the key variables and processes critical to ecosystem function and delivery of ecosystem services?
- How do physical changes in the arctic system, including change in the arctic sea ice cover, interact with biogeochemical cycles, changes in ecosystem structure, and human activities?
- What are the positive and negative feedbacks to environmental change that result from changes in ecosystem composition, structure, and function?
- How is the flux of freshwater from land areas changing and what are the causes?
- What are the constraints and thresholds that control arctic landscape change? Do these constraints and thresholds regulate the impact that terrestrial change has on the integrated atmosphere-ocean system?

3.6. How do cultural and socioeconomic systems interact with arctic environmental change?

Arctic societies are diverse, characterized by a variety of cultural, economic, and technological systems. The interactions among these systems

and with environmental change make it clear that multiple drivers of change must be considered in any assessment of societal responses and adaptations to broader system changes. Similarly, the arctic system, including the human component, is linked to non-arctic societies that also function as both receptors and agents of change. In order to assess the role of human systems in arctic system change, one must establish which variables and relationships are important for understanding human-environment dynamics. Relevant questions include:

- What are the consequences of environmental changes for people in the Arctic, subarctic, and beyond?
- How do multiple stressors combine to influence the adaptive responses and vulnerabilities of arctic social systems?
- What factors contribute to the resilience of social-ecological systems to environmental (and other forces) of change, and what determines the thresholds beyond which further stresses are likely to lead to rapid social change?

3.7. What are the most consequential links between the Arctic and the Earth systems?

The Arctic is part of the global system and as such responds to and influences changes elsewhere. Among the more obvious conduits of interaction are atmospheric and oceanic circulation systems and, increasingly, global socioeconomic systems. The potential for arctic system interaction with and influence on the global system points to the need to address questions such as:

- How are global climate and arctic environmental change coupled?
- How is the storage of water in ice sheets and glaciers changing, and what are the potential impacts (e.g., sea level rise) on regions outside the Arctic?
- What are the roles of the arctic system in the regional and global radiation balance, the carbon cycle, and sea level change?
- How will development related to climate warming (e.g., dams, expansion of forestry, and agriculture in the subarctic) affect the thermal and freshwater regimes of the Arctic?
- How does improved scientific information about the causes and consequences of arctic environmental change affect perceptions, attitudes, and decisions of temperate zone residents?

Meeting the SEARCH Objectives

A combination of observational (Section 4.1.), synthesis and modeling (Section 4.2.), and response-directed (Section 4.3.) activities will be required to answer the questions posed in Section 3. These categories of activities must be closely coordinated, as efficient progress requires continuous exchange of results between them. Thus, the success of SEARCH critically depends on simultaneous initiation of activities in all three categories rather than sequenced implementation.

4.1. Observing Change: Identified Needs, Existing Programs, and Priorities

Observations and measurements of a broad thematic and geographic scope will be required to address the SEARCH objectives including analysis, synthesis and modeling needs.

The following section details these observation and measurement requirements for SEARCH implementation and is organized into six sub-sections:

- Atmospheric Observations (Section 4.1.1.),
- Distributed Ocean and Sea Ice Observations (Section 4.1.2.),
- Terrestrial Hydrological and Cryospheric Observations (Section 4.1.3.),
- Terrestrial Ecosystem Observations (Section 4.1.4.),
- Human Dimensions (Section 4.1.5.), and
- Paleoclimate and Paleoenvironmental Observations (Section 4.1.6.).

This disciplinary structure follows the organization of component tasks outlined in the SEARCH Implementation Strategy (SEARCH, 2003) and the structure of the Implementation Workshop discussions in order to define a tractable scope for observational—and the concomitant methodological—needs and priorities. Each sub-section references relevant overarching science questions and provides specific comments on the links between disciplines and activity areas that are essential to a successful integrated SEARCH program. The geographic priorities referenced within the text and related maps (Figures 1–6) are intended as general guidance and will involve close coordination and collaboration with existing U.S. and international programs.

As SEARCH community science planning proceeds, further work will build on the workshop discussions to integrate and organize priority observing, understanding, and responding to change activities according to the key science questions.

4.1.1. Atmospheric Observations: Needs, Existing Programs, and Priorities

In recent years, there has been an attempt to relate much of the variability in the arctic atmosphere to the Arctic Oscillation (AO; Thompson and Wallace, 1998; Morison et al., 2000). The AO is defined to be in negative phase when there is anomalously high pressure over the Arctic relative to mid-latitudes, and in a positive phase when the pattern is reversed. It has been hypothesized that the positive phase of the AO results in storm tracks displaced to the North and warmer winters over North America, as well as other associations with mean changes in precipitation and temperature patterns. Although the AO has been in a generally positive phase since the 1970s, there is evidence of a decrease in the magnitude of this large-scale phenomenon, while many arctic parameters are still outside of the bounds typical of the last several thousand years. This suggests that more complex mechanisms may control parameters such as the overall warming that seems to affect almost all regions of the Arctic.

As variability in the AO does not provide a complete explanation for changes in the arctic atmosphere, a mechanistic understanding will almost certainly require ongoing direct measurements of the atmospheric parameters that affect change, including clouds, aerosols, upper air temperatures, ozone, upper atmospheric dynamics, greenhouse gases, atmospheric pollutants, and surface radiation budgets. At present, surface observations in the Arctic tend to be sparse and rudimentary and, for a number of important networks such as upper air measurements in Canada, are on the decline.

Satellite measurements have the ability to provide a pan-arctic view. Yet, while there has been progress, there are still a number of issues to be addressed due to arctic-specific problems introduced by the long polar night, highly reflective surfaces, and retrieval algorithms that were developed for the mid-latitudes. In addition, it cannot be assumed that high quality, calibrated, and continuously refined satellite products will be readily available, yet continuous satellite records with full understanding of the transitions created by changing sensors and algorithms is essential.

Similarly, while there are a number of arctic-specific reanalysis projects and regional models, the modeling community is still in a state of development with arctic modeling, especially in terms of integration into the coupled general circulation models (GCMs).

To understand the tangible results of changing climate in the Arctic (e.g., length of melt seasons, sea ice thickness, permafrost distribution, and coastal erosion), it will be necessary to determine the atmospheric forcing mechanisms through integration of surface and space-based observations with models. The key observations must be carefully chosen to provide information that may untangle natural variability from variability owing to anthropogenic forcing.

Important questions to direct arctic atmospheric observations and research activities for SEARCH include:

1. How do clouds, aerosols, and chemistry interact to force the pan-arctic surface energy balance and albedo-temperature feedback?
2. What is the relative role of tropospheric dynamics and stratospheric linkages in controlling the arctic surface variability?
3. What portion of the recent changes in the Arctic can be attributed to increased greenhouse gas concentrations?

Requirements of an atmospheric observing program. The Arctic will always be a challenging environment and an expensive region in which to make surface-based and airborne measurements. It cannot be treated as a single region, and there are significant variations to be expected between Alaska, the Canadian Archipelago, Greenland, Scandinavia, Siberia, and the Arctic Ocean. Therefore, the SEARCH Atmospheric Observing program should include several components (see Figure 1):

- Maintenance and enhancement of standardized, calibrated, uninterrupted, and long-term monitoring networks (e.g., temperature, precipitation, upper air measurements, surface radiation, ozone, UV, and albedo).

- Increased atmospheric measurements over the Arctic Ocean from ships, ice camps, and buoys. This would include surface meteorological, aerosol, radiation, flux, and precipitation measurements, as well as upper air measurements whenever and wherever possible.
- Strategically located, long-term, land-based atmospheric observatories with sophisticated, co-located instruments to make intensive measurements at the surface and through the depth of the atmosphere. Measured quantities should include, but are not limited to: solar radiation, aerosols, air chemistry, trace gases, cloud properties, water vapor, ozone, temperatures, winds, precipitation, boundary layer fluxes, spectral albedo, and stratospheric properties. The observatories should also include routine meteorological measurements and more densely distributed networks in addition to the intensive measurements.
- Regularly scheduled unmanned aerial vehicle (UAV) and aircraft campaigns that can collect data on horizontal variability, transitions between regions, and over the Arctic Ocean.
- Coordinated surface-satellite activities such as archiving of intensive satellite measurements over the observatory sites; balloon launches and UAV missions timed with satellite overpasses; and on-going comparisons between surface and satellite-derived atmospheric quantities, in particular, those likely to have direct effects on atmospheric radiation budgets.
- International coordination on standards for measuring practices, technologies, and data archiving.
- A mechanism whereby research and developmental observational technologies and practices can be transitioned to long-term operational programs.

Existing measurement programs and further needs. Existing upper-air and weather stations are most densely distributed in Alaska, Canada, and Scandinavia. Measurements are particularly sparse in Russia and in general have declined significantly over the last ten years. This trend is reflected in a number of surface network measurements programs for radiation, surface aerosols/gases, and measurements of the stratosphere/mesosphere, for instance the Baseline Surface Radiation Network (BSRN) Program and the Global Atmosphere Watch (GAW) program. The distribution and continuity of the network observations requires enhancement and stabilization.

At present, a number of uncoordinated programs are in varying stages of developing Intensive Atmospheric Observatories. Existing and proposed programs include activities in Barrow, Alaska; Alert and Eureka, Canada; Ny-Ålesund, Norway; Tiksi, Russia; the Greenland Summit Station; Pallas, Finland; and Kiruna, Sweden. Coordination of efforts between these atmospheric observatory programs will significantly enhance the potential for understanding regional differences in the Arctic. The atmospheric observatories should also integrate with other interdisciplinary activities. Of particular concern will be enhancing both network and observatory measurements in Russia where science activities have been in a general state of decline. Coordinated international support will be necessary to reinstate, enhance, and establish new atmospheric observations throughout Siberia north of the Arctic Circle.

An integrated program needs to be established to take advantage of any programs in the Arctic Ocean that can be expanded to include atmospheric measurements. For instance, existing environmental observatories and icebreaker cruise opportunities would be useful platforms for collecting upper air measurements**.** This would be part of an overall SEARCH objective of multi-tasking research locations with interdisciplinary measurements that would be logistically efficient and provide important interdisciplinary datasets to investigate the interactions between different components of the arctic system.

At present, researchers and operators interested in climate and weather studies often take very similar atmospheric measurements. To enhance the utility of these measurements for both communities, it is necessary for climate datasets to be processed quickly enough to be

useful for short-term forecasting and for weather datasets to be calibrated and archived to provide usable data for climate studies.

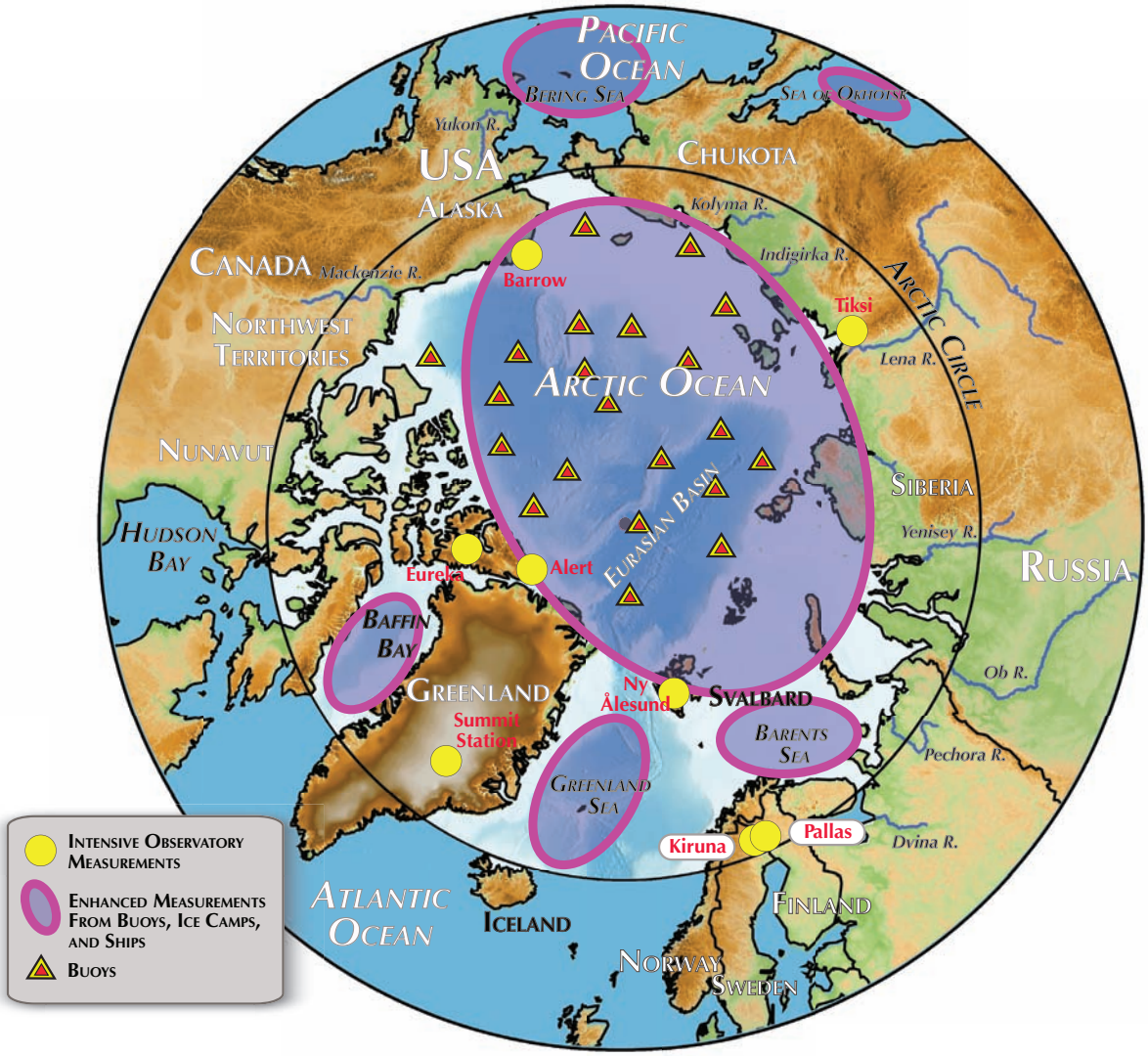

Figure 1. Priority areas for atmospheric observation activities. *A SEARCH atmospheric observing program should include coordinated intensive observatory measurements (yellow dots) in Barrow, Alaska; Alert and Eureka, Canada; Ny-Ålesund, Norway; Tiksi, Russia; the Greenland Summit Station; Pallas, Finland; and Kiruna, Sweden, as well as the inclusion of upper air measurements within existing ocean data collection activities (pink circles), including those from potential buoy deployment areas (see Figure 2). Weather station networks, unmanned aerial vehicles (UAV), and satellite data represent additional sources of atmospheric observations (not shown). Coordination of efforts between atmospheric observatory programs, integration with other interdisciplinary activities, and international support to reinstate, enhance, and establish new atmospheric observations throughout Siberia north of the Arctic Circle will significantly enhance the potential for understanding regional differences of atmospheric changes in the Arctic.*

4.1.2. Distributed Ocean and Sea Ice Observations: Needs, Existing Programs, and Priorities

The arctic seas have experienced major shifts in water mass properties, circulation, sea ice coverage and ecosystems over the past few decades. Successive pulses of warm, salty Atlantic water observed at depth within the Arctic Ocean, overlain by large lateral displacements of halocline and surface water fronts (Carmack et al., 1995; Morison et al., 1998; Steele and Boyd, 1998) were some of the first documented indications of a widespread, systematic change at high latitudes. Many of these changes have been tied to the climate trends and oscillations that are central to the hypotheses of SEARCH (SEARCH, 2001).

Changes in the physical ocean and sea ice environment modify ecosystem structure and function, ocean-atmosphere gas exchange, land-sea material transfer, and ultimately the living resources on which local human populations depend. They also influence global climate via albedo feedbacks and the meridional overturning circulation. Global Circulation Model (GCM) simulations indicate that the predicted high-latitude warming is dominated by sea ice thinning and retreat (Holland and Bitz, 2003; ACIA, 2004).

The arctic sea ice cover has declined substantially in thickness and extent over the past three decades (Comiso, 2002; Rothrock et al., 2003). In the Pacific Arctic sector, reductions in perennial ice extent may have reached a "point of no return." Ice-albedo feedback plays a key role in the responses of the ice cover to climate variations, and is one of two key feedbacks believed to underlie observed and projected arctic climate change (see also Section 4.2).

Changes in the arctic marine ecosystem are also underway. Dramatic shifts in the structure of the Bering Sea ecosystem have occurred (Brodeur et al., 1999; Hunt et al., 1999; Hunt et al. 2002; Grebmeier and Dunton, 2000; Grebmeier and Cooper, 2004; Overland and Stabeno, 2004). The ranges of species such as salmon, seabirds, and gray whales have extended north- and eastward into the Beaufort Sea (Moore et al., 2003). Changes in the timing of the northward migration of animals (e.g., walrus) associated with the timing of the retreat in the annual ice cover are impacting the hunting success of local human communities. Despite numerous observations that ecosystem change is ongoing, the extent and magnitude of these changes, the range of natural variability of many ecosystem characteristics, and the interactions between the biological, physical, and chemical components that shape ecosystem change are still poorly understood.

With respect to the ocean and its ice cover, six targeted questions are important to achieving an understanding of the overall SEARCH science questions (Section 3):

1. How is the ocean responding to and influencing changes in the arctic hydrologic cycle?
2. Is the sea ice/ocean system undergoing an irreversible and/or unprecedented transition into a different regime?
3. What is the impact of warming and reduced sea ice cover on the physical marine system, carbon pathways and trophic linkages, and stakeholders?
4. How do changes in the arctic marine system affect populations, community composition, biodiversity, key species, and living resources, and how do these changes feed back to the Arctic Ocean?
5. How do changes in the Arctic Ocean influence global climate via the thermohaline circulation, biological processes, and air-sea interactions?
6. What are the controls on near-shore sea ice, and how do changing ice conditions affect coastal settlements and infrastructure?

Requirements of an ocean and sea ice observation program and implementation priorities. Understanding marine change requires, where feasible, the deployment of interdisciplinary observation and sampling networks that are coincident in space and time. Integrated measurements of physical, chemical, and biological parameters of air, sea, and ice are the only way to truly observe the arctic marine system.

Distributed marine observatories can include highly instrumented installations; broadly distributed, less densely instrumented sites; and ship, aircraft, or drifting buoy surveys of key regions. Instrumented installations can include ice-based drifters, fixed bottom moorings, or a combination of both. Installations can be equipped with a range of multidisciplinary sensors to enable the coordinated measurement of physical, biological, chemical, atmospheric, and cryospheric parameters. Servicing of these sites typically includes hydrographic surveys from ship or aircraft, thereby leveraging logistics requirements with science goals. Such surveys provide an opportunity to measure variables difficult to measure autonomously (e.g., species and organic carbon composition, benthic abundance) and thus contribute to our understanding of important rate processes, such as ocean and sea ice primary production and trophic dynamics. Land-based cabled observatories for observing near-shore processes could also be a powerful tool for deployment of high-power and large data volume instruments and for year-round, real-time transmission of data back to scientists and the public. These instrumented observatories could include seawater access lines as have been discussed for the Bering Strait and Barrow environmental observatories.

Physical/chemical ocean observations should include (in order of decreasing priority):

- Repeat hydrographic/tracer sections across the major frontal features of the Arctic Ocean.
- Observations of fluxes (e.g., volume, heat, salt, and dissolved nutrients) through the straits that connect the Arctic Ocean with the North Pacific and Atlantic Oceans.
- Time series at key sites that monitor boundary currents and shelf-basin exchange.

Geophysical sea ice observations should include (in order of decreasing priority):

- Sea ice mass budget parameters: ice extent and concentration (daily, pan-arctic), ice thickness and roughness (survey profiles at annual to multi-annual intervals and time series at selected locations), ice age, ice velocity (buoys distributed throughout the Arctic providing at least hourly Global Positioning System (GPS) position and pan-arctic satellite coverage), ice production and melt (net annual cycle at selected points, freeze-up, and onset of melt), and landfast ice extent and duration.
- Snow depth distribution and density (surveys in selected regions on multi-annual basis).
- Energy balance of atmospheric and oceanic boundary layers: sea ice albedo (pan-arctic seasonal estimates from satellite remote sensing and daily observations at selected locations), surface net radiation and shortwave energy partitioning, turbulent atmospheric and oceanic heat fluxes to the ice, and heat and salt budget of ocean mixed layer and regional input by ice growth/melt (long-term seasonal measurements at selected sites).
- Paleo-sea ice distribution (extent and seasonality, ice conditions, and drift).
- Sea ice structural and thermal properties: density (including ridge porosity), salinity, temperature (vertical profiles at selected locations on seasonal basis), and melt pond coverage (aerial coverage at selected locations on annual or multi-annual basis).
- Sea ice in arctic reanalysis studies: improve representation of sea ice cover in reanalysis work and continue to extend time series.

Biological/chemical observations should include (in order of decreasing priority):

- Automated time series monitoring of key biological and chemical parameters coincident with physical observations over annual cycles at representative locations, including the use of drifting sensor systems (Chukchi/Beaufort Shelves, inflow/outflow regions, Arctic Basin, coastal ocean, and rivers). Variables measured in ocean and sea ice could include photosynthetically active radiation, organic carbon, major nutrients, alkalinity, standing stock, primary production, and suspended particulate matter.
- Ship- and shore-based measurements of pelagic, benthic and sea ice community composition and abundance, including upper trophic level animals.

- Key process studies (e.g., bacterial/primary production and trophic transfer rates).

Local stakeholder-relevant observations should include (in order of decreasing priority):

- Ocean, ice, and atmosphere properties relevant to navigation, resource development, and coastal erosion as identified and prioritized by stakeholders (see Section 4.3). Relevant observations could include wind, fetch, coastal/landfast ice morphology, stability and drift, spatial patterns of ice growth and decay, coastal currents and tides, sea level, sea surface temperature, and coastal bathymetry. The general importance of the coastal environment in the context of SEARCH and more detailed measurement needs are outlined in a community document on Land-Shelf Interactions (Cooper, 2003).
- Abundance and distribution of commercial and subsistence marine animals (e.g., fish, mammals, and birds) relative to the ocean environment, including sea ice, and to the distribution and abundance of pelagic and benthic prey.

Assuming that Eurasian programs will, at least in the near-term, take the lead in studying Arctic-Atlantic linkages (e.g., Fram Strait), key regions for activities should include (no priority order; see Figure 2):

- Beaufort Gyre, North Pole, Bering Strait, Canadian Archipelago, Eurasian Basin slopes and shelves (physical/chemical/biological)
- Bering/Chukchi/Beaufort near-shore (stakeholders)
- Chukchi/Beaufort Shelf-Slope (biological/chemical)

In the event that Eurasian programs would not provide key SEARCH-related measurements in areas such as the Siberian Arctic or the Kara, Barents, or Greenland Seas, consideration should be given to U.S. involvement in studies of these regions.

Prioritization of these observations reflects the overarching goals of the SEARCH effort; observation efforts should be guided towards improving forecasting, downscaling, and real-time data distribution capabilities. The SEARCH Implementation Strategy and, in particular, two relevant workshops on large-scale atmosphere-cryosphere observations (Overland et al., 2002) and sea ice mass balance of the Arctic (Hutchings and Bitz, 2005) provide further guidance. Wherever possible, geophysical variables should be combined with biological and other observations (including atmospheric measurements) resulting in co-located, integrated datasets.

The location, spatial coverage, density, and frequency of observations may vary substantially for the different overarching SEARCH questions and aims. This problem can, in part, be addressed by a nested, distributed network of observation sites, with stakeholder groups involved in the planning and operation of such a network to ensure sufficient coverage in at least one region of prime interest. Nesting of observations in time and space implies the need for a combination of high-resolution ground-based measurements (i.e., buoys and moorings, many of which are already in place) and remote sensing approaches. The latter should be augmented by methods that provide observations of processes (typically requiring long-duration flights) and should function as part of a long-term observing program. Utility and accuracy of remotely-sensed satellite products, in turn, benefit from small-scale surface-based field measurements. All these observations should be coordinated with atmosphere and hydrologic measurements.

Existing measurement programs and further needs. For the International Polar Year in the near term, we envision a strategy to take the first steps in the implementation of the broader vision as outlined above. We encourage innovative measurement strategies that would help explain and monitor oceanic variability using a variety of sensors and measurement platforms. In particular, it is important to:

- Use satellite observations to provide broader spatial coverage and ensure continuity of climatological satellite-derived datasets. Currently, satellite-borne instruments provide a wealth of key sea ice and ocean datasets, including many, but not all, identified as high-priority items. The need

for datasets of higher spatio-temporal resolution requires continued access to Synthetic Aperture Radar (SAR) data through negotiations with foreign space agencies currently flying SAR instruments. At a time of restructuring and reorientation of national agencies, ensuring continuity of climatological satellite-derived datasets is critical and of particular importance for arctic sea ice data. The commitment of agencies to support production of climate-relevant data is critical, especially in light of shifts in agency priorities such as has occurred at NASA that may jeopardize the agency's mission to advance the capabilities of earth observations from space (Robinson et al., 2004). Furthermore, remote sensing approaches to measuring ice thickness need to be developed. Such work (e.g., with laser or radar altimetry) can play an important role in SEARCH efforts. IPY could provide a major venue for concerted thickness-measurement validation efforts involving different platforms (e.g., satellite, upward-looking sonars, airborne, and on-ice) and field observations and could also initiate a series of survey-type observations with at least one basin-wide transect of snow/ice thickness and ice properties. A community workshop (Hutchings and Bitz, 2005) identified ice-mass budget measurements as critical at the pan-arctic scale, while at the 10-km scale, albedo and ice thickness redistribution processes need to be examined in more detail.

- Maintain and expand existing time-series measurements at key locations. Existing programs such as the North Pole Environmental Observatory (NPEO), Beaufort Gyre Exploration Project (BGEP), and Nansen and Amundsen Basins Observational System (NABOS) focus on the large-scale circulation of the central Arctic Ocean. Each consists of bottom moorings, ice-tethered buoys, and large-scale surveys by ship or aircraft. These programs represent a resource that could be used research community as a base for further exploration of large-scale marine climate change, for sensor development/deployment, and for opportunistic process studies. When augmented by ship, aircraft, and/or remote sensing, they provide the means to relate larger-scale observations to extensive and detailed local measurements. Other installations exist or are planned for several target locations, including the Bering Strait and the Beaufort Shelf/Slope. The highly successful International Arctic Buoy Program (IABP) could be expanded to include more sophisticated sensor systems (e.g., measurements of snow/ice mass-balance and biogeochemically relevant variables) and extend coverage into the increasing area of the seasonal ice zone. Moored upward-looking sonars (ULS) at a few strategic locations (five, with measurements planned for North Pole, Fram Strait, and the Western Arctic as part of ongoing programs such as NPEO or BGEP [cf. Lindsay and Zhang, 2005]) can provide information on ice thickness and mass flux, although the placement of point-based measurement systems most likely will have to adapt to changing environmental conditions and needs to be augmented by drifting sensor and remote sensing observations.
- Augment existing and new observing systems with an increased diversity of sensors (chemical, physical, biological) and sampling strategies (e.g., autonomous profiling and autonomous underwater vehicle [AUV]/autonomous air vehicle [AAV] deployments) to enable the coordinated measurement of physical, biological, chemical, atmospheric, and sea ice parameters over a range of space and time scales.
- Encourage the development and use of new, innovative technologies such as profiling systems, air-dropped sensors, miniaturized and integrated drifting sensor systems, autonomous air/sea vehicles, and new biogeochemical sensors (with IPY providing an ideal context for exploration of a multitude of approaches) to achieve observations of key variables and processes at reduced cost and in undersampled

locations such as the seasonal ice zone. For ice-tethered systems, a recent workshop report provides further guidance (Proshutinsky et al., 2004).

- Use modeling to tie contemporary measurements into the framework of recent and more distant paleo-oceanographic change and to forecast future scenarios (see Section 4.2). The importance of modeling arises through the need for improved short-term and long-term forecasts (including local weather, marine, and ice forecasts as well as climate predictions), but also through the ability of models to assimilate observations, extrapolate them in time and space, and provide information on conditions and processes that are difficult or impossible to observe directly. Reanalysis tools are critical for understanding the mechanisms of change and require improved modeling of sea ice and improved ability to assimilate ice-related observations and remotely-sensed data. Examples of reanalysis activities are: model-data comparisons performed by the Arctic Ocean Model Intercomparison Project, simulations of past and future change by the Community Climate System Model at the National Center for Atmospheric Research (NCAR), regional modeling to relate large-scale conditions to regional and local processes, and several data assimilation efforts through NASA's Cryospheric Sciences Branch.
- Build on international collaborations and international observing programs (see Appendix A) to provide a pan-arctic perspective, in particular for work in the Arctic/Atlantic and the undersampled Siberian domain. Programs such as Arctic/Subarctic Ocean Fluxes (ASOF) and Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) have explicit roles for U.S. projects such as ASOF-West, Nansen and Amundsen Basins Observational System (NABOS), and seagliders in order to complete their overall objectives. Such collaborations leverage modest U.S. funding by participation in larger, non-U.S. funded programs.

Consideration should be given to developing a network that takes advantage of human observations of ice and ocean conditions and ice-ocean-atmosphere-land interactions. A community-based observation network that includes both traditional indigenous and western scientific observation methods would provide a holistic, system-oriented view of local conditions (i.e., interactions of ice, ocean, atmosphere, and ecosystems) and offer the potential for a long-term observations program at locations of most significance to arctic residents (see Section 4.3).

Strong collaboration should also be established and maintained with programs focused on the subarctic seas (e.g., Bering Ecosystem Study, [BEST]), which provide the connection between the Arctic and the global ocean. Finally, the continuation of other programs not directly funded by NSF, such as U.S. Navy submarine transects of the Arctic Ocean and various international cruises within the arctic seas, is endorsed.

Figure 2. SEARCH priority areas for distributed ocean and sea ice observations. *The highest priority for SEARCH is long-term and large-scale observations of environmental change. Observation requirements include those related to physical/chemical ocean, geophysical sea ice, biological/chemical, and stakeholder-relevant variables; sensors and measurements should be co-located to the extent possible. Key regions include: Beaufort Gyre, North Pole, Bering Strait, Canadian Archipelago, and Eurasian Basin slopes and shelves; Alaska near-shore observations in the Bering, Chukchi and Beaufort Seas (stakeholder priority areas, purple shading); and the Chukchi/Beaufort shelf-slope area. Priority observation activities include: repeat hydrographic/tracer surveys across frontal features (yellow dotted lines) and sea ice and ocean sampling along transects (blue line) via ship, aircraft, AUVs, and submarine; boundary flux sections (red dotted lines, additional boundary flux moorings denoted by purple squares); drifting buoys for marine and sea ice measurements (yellow/red triangles); sea ice and ocean observations via land-based platforms (orange polygons) and upward-looking sonar (ULS) on moorings (white stars); and long-term observing stations (green dots). Eurasian observations (gray shaded areas) will focus on Arctic/Atlantic linkages, with some explicit U.S. collaborations assumed. The locations of all SEARCH sections, buoys, and moorings in this figure are meant only as general suggestions of deployment schemes.*

4.1.3. Terrestrial Hydrologic and Cryospheric Observations: Needs, Existing Programs, and Priorities

The recognized importance of the arctic freshwater balance to the broader climate system has motivated a wide range of climate modeling and other studies. The mechanistic understanding of feedbacks and threshold changes in hydrologic regimes and their relation to changes in terrestrial permafrost, however, remains limited, hampering reliable predictions of arctic system response to natural climatic variations or long-term change. Changes in terrestrial hydrology and permafrost will impact the physical climate system, oceanic circulation patterns, and ecosystems of both the terrestrial and marine domains and society throughout the Arctic, Subarctic, and more temperate latitudes. Prediction of such changes, or even diagnosis of changes that have already occurred, will require a new generation of coupled dynamic hydrologic, climatologic, geophysical, and ecosystem models. It may be that such models must be applied in a global context, but this capability must be developed through process studies on local scales across a range of physiographic landscapes. An observational network is needed to advance the capability to predict the nature and implications of hydrologic and cryospheric changes on the coupled climate, biogeochemical, and biological systems of the region and the consequent impacts on society.

Specifically, the following questions should be addressed:

1. How are the stocks and fluxes of terrestrial freshwater changing over time and space in response to natural variability and global change?
2. How do feedbacks among permafrost and hydrological processes interact with the ecosystem, atmosphere, and ocean, and how will these processes change in response to a changing climate?
3. How is the storage of water in glaciers and ice sheets changing in relation to climate dynamics, and what are the potential impacts to arctic and global processes?
4. How do changes in permafrost and the arctic hydrologic cycle affect human systems, including infrastructure, transportation, economies, and subsistence?

Requirements of a hydrology-cryosphere observation program and implementation priorities. Owing to budget limitations, it is not possible to create an optimal network of geophysical and water balance measurements in the pan-arctic domain to confidently resolve these questions. Therefore, it is critically important to establish a minimal network of key observations coupled with concurrent process studies enabling regional extrapolation of understanding (see Figure 3). It is recommended that a network of complementary research watersheds and permafrost observatories be instituted, each collecting integrated time series data enabling process studies, intercomparison, and extrapolation. The watersheds could be nested in size, with some approximately equivalent to the size of a grid cell in regional climate models. It is important to obtain simultaneous measurements of fluxes of water, energy, and biogeochemical constituents to elucidate ecosystem responses to climatic variations. Many of the observed changes in the arctic system are occurring over extended regions with highly variable responses and interactions. Some changes, such as increases in shrubbiness and degradation of permafrost, will interact with complex and variable influence on hydrologic parameters such as soil moisture, evapotranspiration, and runoff. Adequately characterizing these system level changes and effects will require integrated analyses, sophisticated modeling studies, and remote sensing to permit prediction of system level changes.

The contribution of freshwater from glaciers to the ocean is likely to increase, as the largest and coldest ice caps in the Canadian and Russian arctic archipelagos and Svalbard may have accelerated wastage in the past few decades. The mass balance of the Greenland Ice Sheet as a whole has not yet been accurately defined, but its coastal parts with large outlet glaciers have experienced substantial thinning.

Global acceleration of glacier volume losses has affected the freshwater cycle at many scales, from global to local. It is critically important to continue existing observations on benchmark glaciers in the Canadian Arctic, Svalbard, Alaska, Scandinavia, and Iceland. It is also very important to add to the existing network several large subarctic glaciers in Alaska (Columbia, Bering, or Malaspina), to resume observations in the Russian Arctic (Cupol Vavilova, Severnaya Zemlya, and small glaciers in the Polar Ural), and on the coastal ice caps around the Greenland Ice Sheet. Additionally, it is important to repeat laser altimetry on Alaskan glaciers in order to estimate aggregate changes in volume. Process studies must be conducted to understand the dynamics of ice sheet and glacier behavior and response to changing climate.

Permafrost in arctic regions exerts a significant influence on the surface energy balance through controls on soil temperature, moisture, and vegetation. Permafrost also exerts strong controls on local and regional hydrology through short-term active layer dynamics and longer-term geomorphological processes. The primary control on local hydrological processes in northern regions is dictated by the presence or absence of permafrost but is also influenced by the thickness of the active layer and the total thickness of the underlying permafrost. As permafrost becomes thinner or decreases in areal extent, the interaction of surface and sub-permafrost ground water processes becomes more important (Woo, 1986). The inability of soil moisture to infiltrate to deeper groundwater zones due to ice-rich permafrost maintains very wet soils in arctic regions. However, in the slightly warmer regions of the subarctic, the permafrost is thinner or discontinuous. In permafrost-free areas, surface soils can be quite dry as infiltration is not restricted, thus impacting ecosystem dynamics, fire frequency, and latent and sensible heat fluxes. Projecting future climate and ecosystem processes correctly is completely dependent upon first obtaining accurate predictions of permafrost thermal state and dynamics.

Needs for terrestrial hydrologic and cryospheric observations include:

Geophysical observations (in order of decreasing priority):

- Establish flagship research watersheds (IPY activity). Requires monitoring of all water balance components and the thermal state of permafrost.
- Augment a precipitation, energy flux, active layer, and permafrost thermal state monitoring network (IPY activity).
- Establish permafrost observatories with comprehensive meteorological, soil moisture, and permafrost temperature measurements.
- Repeat mass balance measurement of key benchmark glaciers and the Greenland Ice Sheet (IPY activity). Requires annual assessment of mass balance and glacier movements.
- Develop annual maps of seasonal snow cover water content. Requires extensive measurements of snow cover depth and water content.
- Characterize the response of glaciers and the Greenland Ice Sheet to climate dynamics. Requires mass balance and surface deformation measurements in concert with surface energy and water balance.
- Initiate observations of glacier and ice sheet hydrology. Requires monitoring of glacier ablation and melt runoff.
- Develop an observational/modeling strategy for ungauged basins. Requires combination of remote sensing and operational modeling.
- Establish satellite remote sensing capabilities for systematic repeat observations of key glaciers, ice sheets, snow cover, and precipitation fields.

Stakeholder-relevant observations (in order of decreasing priority):

- Characterize the ongoing and potential effects on infrastructure resulting from permafrost degradation. Requires monitoring network of permafrost temperatures in disturbed and undisturbed sites.
- Designate a global network of high priority arctic river stations (monitored by specific agencies in circumarctic nations). Requires continuous measurements of discharge and water temperature in strategic locations.

- Document the extent and processes driving changes in lake surface areas. Requires surveys of lake area changes combined with field studies of causes of change.
- Determine the interdependence of the changing hydrologic regime and the changing fire regime. Requires distributed measurements of unburned and burned sites of various ages.
- Establish high-resolution (on the order of 5 m) digital terrain data for entire pan-arctic domain (total area of arctic drainage basin).
- Characterize the relationship and potential timing associated with sea level rise and coastal erosion. Requires measurements of erosion rates complemented with storm surge and tidal records.

Biological observations (in order of decreasing priority):

- Quantify the impact of ecosystem change on freshwater fluxes. Requires distributed energy, water balance, and permafrost thermal state measurements in various ecosystem types.
- Characterize the controls imposed by permafrost dynamics and hydrology on vegetation change. Requires distributed measurements of ecosystem parameters with permafrost thermal state and active layer measurements.
- Characterize the effects of changing hydrology and glaciers on aquatic systems. Requires monitoring of river flows, sediment and nutrient transport, and ecosystem health.

Existing measurement programs and further needs. A variety of hydrological and geophysical measurements are currently collected as part of several active research programs funded by the U.S. National Science Foundation, U.S. Department of Energy, U.S. National Oceanic and Atmospheric Administration, U.S. National Aeronautics and Space Administration, Environment Canada, Norwegian Polar Research Institute, Russian Hydrometeorology Committee, Japanese National Polar Research Institute, and other federal and state agencies. These could be characterized as an assortment of critically important observations collected in support of unrelated research programs rather than consistent, integrated measurements of a monitoring program. Investment in maintaining some ongoing key observations, complemented with additional observations to fill gaps previously discussed, would provide SEARCH with the tools needed to document and understand the changing arctic hydrosphere and cryosphere.

The network of hydrological gauging stations maintained by the arctic nations has been seriously reduced in the past two decades (Shiklomanov et al., 2002); the small network of rivers gauged in Alaska, Canada, Iceland, Russia, and Svalbard by local governments must be maintained as core measurements. A similarly sparse network of meteorological observations is supported by these arctic nations to enable weather forecasting. These stations are inadequate for climate research in that they seldom provide measurements of atmospheric or surface radiation, soil moisture, or soil temperature.

A program to initiate Long-Term Hydrologic Observatories (LTHO) has been proposed to the National Science Foundation (http://www.cuahsi.org/programs/hos.html) by the Consortium for the Advancement of Hydrologic Sciences, Inc. The main objective of these observatories is to improve the predictive understanding of the flow paths, fluxes, and residence times of water, sediment, nutrients, and other contaminants across a range of spatial and temporal scales.

In 1997, the Global Climate Observing System (GCOS) and the Global Terrestrial Observation System (GTOS) identified the active layer and permafrost thermal state as two key cryospheric variables for monitoring in permafrost regions (WMO, 1997). In 1999, the Global Terrestrial Network for Permafrost (GTN-P) was established under the GCOS/GTOS with the assistance of the International Permafrost Association (IPA). Some 370 boreholes from 16 countries have been identified as candidate sites for inclusion in the GTN-P borehole thermal monitoring system. The majority of the boreholes are between 10 and 125 m deep and are in the Northern Hemisphere. The inventory

of candidate boreholes, site metadata, and background material on the GTN-P are available on the GTN-P website (http://www.gtnp.org). The Circumpolar Active Layer Monitoring (CALM, http://www.udel.edu/Geography/calm/) program is a long-term, international research and observational effort involving 15 investigating countries at over 100 sites in both hemispheres.

Several other programs can provide some ancillary data. The International Tundra Experiment (ITEX, http://nsidc.org/arcss/projects/itex.html) is the first global change experiment to be replicated at the biome level. The purpose of ITEX is to monitor and simulate impacts of climate change on tundra vegetation. The U.S. Long Term Ecological Research program (LTER, http://www.lternet.edu/) operates a research program in the headwaters of the Kuparuk River near Toolik Lake, Alaska. This program can supplement studies on hydrology and cryosphere interactions with ecology.

The U.S. Department of Energy supports an Atmospheric Radiation Monitoring program (ARM, http://www.arm.gov/) in Barrow and Atkasuk, Alaska. These are critically important data for climate monitoring and model simulations.

The Earth Observing System (EOS) is the centerpiece of NASA's Earth Science Enterprise (ESE). It is composed of a series of satellites, a science component, and a data system supporting a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) was started in 2002 and will converge existing polar-orbiting satellite systems under a single program. NASA's Global Precipitation Measurement (GPM, http://gpm.gsfc.nasa.gov/) mission is presently in the formulation phase. Ensuring broad-scale precipitation monitoring in the Arctic is critically important to understanding current responses and projecting future changes. Generally, there is a critical need for maintaining continuous, high-quality remotely-sensed datasets that are suitable for climate investigations.

The Greenland Ice Sheet is monitored through an ongoing program at NASA (Program in Arctic Regional Climate Assessment; PARCA, http://nsidc.org/data/parca). The Polar Radar for Ice Sheet Measurements (PRISM) program at the University of Kansas is developing tools to measure ice sheet thickness (http://ku-prism.org/). In Alaska, the U.S. Geological Survey has maintained a long-term program to study two small glaciers, Gulkana and Wolverine; the Juneau Ice Field Project monitors Taku and Lemon Creek Glaciers (http://www.juneauicefield.org); and the U.S. Bureau of Land Management is monitoring the Bering Glacier. Many other glaciers are monitored intermittently as part of NSF-funded research activities. Data from all glaciers in the Arctic and Subarctic are being archived by the World Glacier Monitoring Service (http://www.geo.unizh.ch/wgms). Repeat laser altimetry surveys conducted as a research activity have proven useful in monitoring changes over several years to decades.

Figure 3. SEARCH priority areas for terrestrial hydrologic and cryospheric observation activities. *SEARCH implementation will require a minimal network of key observations, including a network of research watersheds coupled with process studies enabling regional understanding. Key research basins for hydrology and permafrost study sites are indicated by red stars. Permafrost/ecological transects are marked by triangles; blue triangles represent a North American transect, green triangles represent a West Siberian transect, and purple triangles represent an East Siberian transect. Key glaciology study sites are indicated by yellow dots.*

4.1.4. Terrestrial Ecosystem Observations: Needs, Existing Programs, and Priorities

The terrestrial ecosystem observation priorities relate specifically to the overarching science questions developed from the SEARCH Science and Implementation Plans. Key within the SEARCH Observing Change component is understanding and predicting shifts in terrestrial and freshwater ecosystem structure and function. Such efforts require an integrative perspective on dynamics and interactions among organisms and the abiotic environment at a broad range of spatial and temporal scales. Of particular importance will be efforts to understand the large-scale biogeochemical consequences of changes in species composition of arctic communities and potential feedbacks to the atmosphere. These efforts will best be served through regular monitoring of soil and atmospheric fluxes of elements such as carbon and nitrogen, periodic assessments of abundance of key species at broadly-distributed sites, and development of remote sensing and modeling techniques to facilitate scaling to ecosystems of the pan-arctic region. These ecosystems span the current spatial extent of permafrost and include the biomes of arctic tundra and boreal forest.

Additionally, the terrestrial activities should make observations of the hydrosphere/cryosphere, which represents an interdependent system where large threshold changes occurring annually manifest dramatically in the surface water and energy budgets. Subtle changes in the timing of thawing and freezing, snow vs. rain, and open water vs. ice can impart substantial differences in mass and energy transfers that can cascade through the ecosystem and climate system. These sets of observations in terrestrial ecosystems are critical both to characterizing the changes that are occurring in the Arctic and to developing an understanding of how the land-water-ice-atmosphere components interact as a system. Such interactions are what ultimately lead to social and economic impacts on local residents as well as on communities and nation-states outside the Arctic.

Specifically, the following questions should be addressed:

1. How do the interactions and feedbacks among climate, hydrology, cryosphere, biogeochemistry, species composition and vegetation structure, and human forcings determine the rate and trajectory of arctic change?
2. How are the surface properties of the arctic landscape (including permafrost, fires, and other disturbance) determined as a function of climate, hydrology, cryosphere, biogeochemistry, and biology?
3. What are the constraints and thresholds that control arctic landscape change in relation to climatic forcing oscillations such as the North Atlantic Oscillation (NAO)/Arctic Oscillation (AO) and the Pacific Decadal Oscillation (PDO)? Do these constraints and thresholds apply to regulate the impact that terrestrial change has on the integrated atmosphere-ocean system?
4. What are the roles of arctic ecosystems in the regional and global radiation balance, carbon cycle, and sea level change?

Requirements of a measurement/observation program. The implementation strategy of a terrestrial observation program has components grouped into three categories: (1) physical (climate, water, permafrost, and energy), (2) chemical (trace gases, nutrients, and soils/sediments), and (3) biological (primary productivity, plant and animal dynamics, species composition and distribution). Because of the interrelatedness of these components, the most critical need is to establish sites where integrating, time series measurements can be made. Since SEARCH is defined by detecting multi-year to multi-decade changes, the priority for observations in these categories should be on annual scales or on scales that are required to integrate measurements into annual values. The second critical need is to develop a framework and methods to scale to the pan-arctic region the mechanistic knowledge gained by making integrated, intensive measurements. Measurements focused on the catchment scale will be most useful in developing a hierarchy of catchments and the modeling and remote sensing

tools needed for scaling. The overall spatial scale of measurements will be initially defined by the existing monitoring sites and should be refined by observed anomalous trends and by representative terrestrial characteristics. For example, opposite trends in air temperature or thaw depth in different parts of the Arctic would warrant more detailed or at least continued investigations at those locations. Deficiencies in spatial cover or resolution of sampling sites may, to some extent, be compensated for by focusing efforts on communities or species with cosmopolitan distribution throughout the Arctic. In addition, the pan-arctic terrestrial landscape can be divided into provinces with consistent characteristics (such as climate zones or soil chemistry defined by geological age or by loess inputs) that affect an array of ecosystem properties. Thus the minimum spatial positioning of monitoring sites should represent these characteristic provinces in order to facilitate arctic-wide extrapolations to unmonitored areas. A primary goal in selection of study sites should be to capitalize on existing measurement programs and on the spatial autocorrelation of landscape features and community characteristics across the Arctic (see Figure 4). In addition, the use of transects across the full climate gradient should be employed where possible. Finally, priorities on a minimum or expanded set of measurements should be defined by variables that (1) have demonstrated trends of change in the last 50 years, (2) have the most direct and obvious linkages or feedbacks between different components of the arctic system, and (3) are most critical for other activities in the SEARCH program.

State of the art and existing networks, sites, and programs on pan-arctic scale. A recent National Science Foundation (NSF)-International Arctic Science Committee (IASC) workshop on "Flagship Arctic Observatories and Networks" (Webber et al., in prep.) concluded that although there are currently no terrestrial sites or networks that meet the "flagship" criterion of integrated, multi-variable, multi-process monitoring and research, there are several sites that approach this status (e.g., Zackenberg in Greenland, Svalbard, Long Term Ecological Research [LTER] sites in Alaska), and several well-integrated research networks that exist or are under development (e.g., Circumarctic Environmental Observatories Network [CEON], Scandinavian/North European Network of Terrestrial Field Bases [SCANNET], National Ecological Observatory Network [NEON], and Arctic Observing Network [AON]). Recent funding of SEARCH-related projects (e.g., Community-wide Hydrologic Analysis and Monitoring Program [CHAMP] freshwater projects, see SEARCH projects at: http://www.arcus.org/search/searchprojects) have already contributed a great deal of hydrological and hydrology-related information to distributed terrestrial observatories. The International Tundra Experiment (ITEX) network and other less intensively studied sites represent candidates for intermediate or extensive sites within the distributed terrestrial observatories network, and developing Conservation of Arctic Flora and Fauna (CAFF) efforts designed to monitor biodiversity across the Arctic will contribute to SEARCH goals. Overall, however, there have been few syntheses beyond the recent Arctic Climate Impact Assessment report (ACIA, 2004), and the terrestrial and freshwater research results related to SEARCH goals and activities are scattered to the point that clear assessments of the strength and impacts of arctic change on terrestrial ecosystems are difficult.

Needs beyond existing programs. The SEARCH Implementation Strategy (SEARCH, 2003) identified the maintenance of the current time series of terrestrial observations as a high priority as SEARCH plans develop. These observations included the international ITEX network, the Kuparuk River watershed climate monitoring network in Alaska, and key hydrologic monitoring stations, such as the station at the mouth of the Yukon River. SEARCH-related funding has addressed some of these priorities (e.g., the SEARCH freshwater projects), although major deficiencies in existing terrestrial observations still exist. There are still very few, if any, sites that collect coincident data on surface energy balance, hydrological fluxes, biogeochemical fluxes (trace gases,

nutrients), and the plant and animal responses to these physical and chemical fluxes. The lack of such sites is the most critical issue facing the terrestrial component of SEARCH. Integrated, long-term observations are needed to understand the full scope of arctic change in the context of the terrestrial components of the arctic system, the linkages between elements of the arctic system, and linkages to Northern Hemisphere atmospheric circulation and global climate. There are several sites that are close to fulfilling these needs (Zackenberg, Svalbard, Toolik, Barrow), and the initial U.S. sites should be on a transect from the arctic coast south to interior Alaska. Finally, a focused synthesis (e.g., through funded workshops) of the available but scattered terrestrial observations that relate directly to arctic change is needed to guide implementation of further observation projects.

Terrestrial ecosystem sites and projects should follow a framework that will allow extrapolation and scaling of results to the pan-arctic region. The use of catchment scale, integrated observations will facilitate this scaling through nested catchments of increasing size, as will the development of modeling and remote sensing methods and capabilities. The terrestrial programs also need to work directly with the Understanding Change activities to build terrestrial observations and processes into the modeling efforts. Such observations initially should include first-order interactions between terrestrial and atmospheric systems, such as surface energy fluxes and trace gas exchange with the atmosphere, both of which require observations on vegetation and freshwater extent and dynamics. Specific interfacing with human dimensions activities may be accomplished first in the areas of permafrost and transportation, inland fisheries, and changes in freeze-up and break-up of rivers.

In summary, there are *two essential needs*. The *first need* is a monitoring system combining a few intensively monitored sites with a more extensive network where fewer variables are monitored. The *second need* is a program of research focused on scaling of process and mechanistic knowledge in space and time (a modeling program). This program should first focus on the catchment scale to facilitate integrated, mass balance approaches to answering the scientific questions. Catchments can be nested in hierarchies to develop scaling methodologies.

It is desirable but not necessary to implement fully developed programs to meet these needs all at once. If an incremental approach must be adopted, the following are the highest-priority needs:

- Initiate at least one intensive site that makes integrated, time series measurements that include climate, surface energy balance, hydrology, trace gases, permafrost/active layer, C/N/P budgets, species composition, vegetation structure, and contaminant compounds. Implicit in such intensive site measurements are linkages to the processes or characteristics important at the pan-arctic scale. Candidate sites include those with existing long-term and extensive measurement records (e.g., Zackenberg, Svalbard, Toolik, Barrow). The initial U.S. sites should be in northern Alaska along a transect from the arctic coast to interior Alaska. Eventually, only a few intensive sites will be needed (<10 throughout the Arctic).
- Continue long-term monitoring of key systems such as glaciers, permafrost, and ecosystems representative of pan-arctic variation, including development of remote sensing capabilities. A wide range of monitoring networks could be developed — built first on the CEON model or structured around major ecosystem and climate types.
- Develop an understanding of how to scale process and mechanistic knowledge in both space and time, initially through focused studies on key variables and interactions (e.g., surface energy balance, trace gases, and vegetation cover). This will require multi-scale observations, pan-arctic comparisons, modeling, and remote sensing.

Figure 4. Potential sites for SEARCH terrestrial ecosystem observation activities*. Observatories range from intensive, integrated "flagship" observatories to intermediate or extensive sites where only a few variables are observed. The initial SEARCH implementation activities should include at least one intensive, "flagship" site in U.S. territory that makes integrated time series measurements. In addition, circumarctic long-term monitoring of key measurements that build on existing and planned observation platforms, sites, and transects (such as shown for Alaska in Figure 3) should be continued. Note that all potential sites are not shown, and full development of this network and choice of sites will require international collaboration to develop non-U.S. sites.*

4.1.5. Human Dimensions: Needs, Existing Programs, and Priorities

Human activities in the Arctic are central to several of the SEARCH science questions. Arctic residents are affected directly by environmental and ecosystem change, and their activities (along with those of more distant societies) can feed back to drive further change. Understanding the relationships among arctic system changes involving humans requires direct examination of system variables on common spatial and temporal scales.

Rapid and significant changes already confront all arctic societies. Some societal changes are driven by environmental change; others result from broader cultural and socioeconomic forces, or from complex interactions between environment and society (AHDR, 2004; ACIA, 2004). SEARCH-relevant environmental changes likely to have important human dimensions include those affecting the extent and nature of sea ice, storminess and erosion, marine and terrestrial ecosystems (especially fish and mammal populations), permafrost, and vegetation. Arctic environments and ecosystems are affected by human activities originating both within and outside of the Arctic, such as mining, energy or industrial development; contaminants; transportation; water use; and fisheries or other renewable-resource consumption. The impacts of physical environment changes will likely be felt through interactions with human activities and resource use (Watson et al., 2001; ACIA, 2004; AHDR, 2004). Human interactions with arctic subsystems occur at local, regional, and global scales.

To address the human-dimensions (HD) aspects of the SEARCH science questions therefore requires well-designed, rigorous, and thoughtful analyses that integrate data across different social and natural science domains. Multivariate, time-indexed HD data for such research could be supplied through a network analogous to SEARCH plans for the physical sciences and integrated with other observation networks from the design phase. An HD network is essential to understanding common patterns and local variations in the flow of arctic social change, testing hypotheses and developing models about their causes, and constructing credible, evidence-based future scenarios and policy analyses to support decision making under conditions of escalating environmental and social change (HARC SSC, 2005).

Requirements of a human dimensions measurements/observations program. The analogy with a physical network of weather stations or ocean buoys is not an exact one. An HD arctic observing network need not take physical form. It could instead consist of a network of social scientists, citizens, and other observers to help make available and accessible high-resolution arctic HD data already being collected, and to organize this information into common structures compatible with other SEARCH data. Data to be compiled, at annual/community or annual/region resolution, should include the following:

- Vital statistics and demographic measures including in- and out-migration, births, deaths, and population structure.
- Livelihood and economic data including subsistence activities, employment by sector, transfer payments, business activity, infrastructure, and community/regional government.
- Health, education, and other indicators reflecting well-being and quality of life.
- Local observations concerning environmental or ecosystem changes, especially where these affect daily life.
- Trends related to transportation, tourism, fisheries, and mining, energy, or other natural resource development.

National variations in the availability and definitions of data complicate efforts to harmonize all measurements or achieve an ideal degree of completeness. The HD observing network should, however, be able to construct roughly comparable databases covering much of the Arctic (see Figure 5) at annual/community or annual/region resolution and make these available to explore a wide range of analytical questions—notably, on the interactions between environmental and social change.

Other types of information will supplement this framework. Qualitative data such as

historical accounts, interviews, or individual life histories can be integrated with the timelines of quantitative measures and contribute to detecting and understanding patterns. Case studies drawing on diverse data to understand change in particular regions comprise a first, well-established route to integrated analysis. Larger-scale information on topics such as shipping, food webs and the populations of key marine and terrestrial species, national government actions, and even the perceptions held by non-arctic publics provide important context for the impacts felt in arctic communities.

Establishing a formal network to integrate data from existing but widely scattered sources will be a first priority for the HD component of SEARCH. This network will also help to identify critical gaps where new data are needed.

State of the art and existing networks, sites, programs on pan-arctic scale. Circumpolar human dimensions data is collected in a variety of formats at a range of geographic and organizational scales. Federal and state agencies collect HD data (often yielding time series at community or regional levels) via many different mechanisms such as the census; fisheries and harvest monitoring; economic records; or social services, local government, educational and other reports. These data presently tend to be scattered, in various formats and the province of various agencies, even within one country. It should be quite feasible—and a high-payoff SEARCH undertaking—to bring these together. Human dimensions data relevant to SEARCH are also collected through a series of regional programs (e.g., Arctic Borderlands Ecological Knowledge Co-op, http://www.taiga.net/coop/, the Survey of Arctic Living Conditions http://www.arcticlivingconditions.org/, and dozens of individual projects that are situated locally in communities across the Arctic [e.g., Krupnik and Jolly, 2002]). These efforts have been largely independent and uncoordinated, but many of them generate information potentially valuable to SEARCH goals.

Coordination of data collection (including physical and biological data), analysis, and synthesis across programs deserves immediate attention (see for example AHDR, 2004).

Figure 5. Proposed extent for SEARCH human dimensions observations*. A SEARCH human dimensions observing network will collect and organize multivariate, time-indexed human dimensions data into a pan-arctic database. Data to be compiled should include: vital statistics and demographic measures; livelihood and economic data; health, education, and other indicators of well-being; and trends related to transportation, tourism, fisheries, mining, energy, or other natural resource development. The measurements—new observations as well as compilation of existing data—should be circumarctic in extent (yellow boundary, generally follows Arctic Monitoring and Assessment Programme [AMAP] boundary).*

4.1.6. Paleoclimate and Paleoenvironmental Observations: Needs, Existing Programs, and Priorities

The principal objective of SEARCH is to understand the suite of recent changes taking place in the arctic system and predict future changes and impacts. Several questions will be critical to this effort, including:

1. Is the recent state of the arctic system (e.g., climate, ecosystem, Greenland, sea ice, and humans) unprecedented with respect to the range of natural background variability?
2. What are the forcing mechanisms (natural versus anthropogenic, plus intrinsic oscillations and feedbacks) responsible for observed arctic variability, and what are the links to global system variability (e.g., Pacific Decadal Oscillation, monsoons, El Niño-Southern Oscillation)?

Accurate knowledge of past behavior of the arctic system that can only be gained through paleoclimate and paleoenvironmental data is crucial for assessing whether recent conditions and rates of change are unique. Records extending back over previous warm periods are needed to identify the range of natural variability and role of long-term changes in external forcing, such as solar radiation or volcanic activity, on 20th and 21st century climate variability (e.g., Overpeck et al., 1997). High-resolution paleoclimate networks showing the spatial and temporal patterns of arctic change can resolve the behavior of complex intrinsic oscillations such as the Arctic Oscillation (Hughen et al., 2004). Such networks, together with instrumental, reanalysis, and modeling data, are thus central to identifying the fingerprints of anthropogenic and natural forcing on the changing arctic system. Within the period of instrumental data, paleoclimate records can also play an important role in filling regional observational gaps (e.g., Jones and Moberg, 2003) and providing constraints on the selection of key observation sites for SEARCH monitoring studies. Detailed proxy environmental and archeological observations from different climate states are important for determining the relationship between climate variability and ecosystem and human responses.

Requirements of a measurement/observation program. To fulfill SEARCH objectives, the program must develop a dense spatial network of proxy records that span at least 2,000 years and extend through the 20th century (see Figure 6). The focus should be on high-resolution (10^0-10^1 year) archives from lake and marine sediment cores, tree rings, and ice cores wherever possible, but multi-decadal resolution records are integral to this effort as well. In addition, longer terrestrial and marine paleoclimate records are needed to investigate periods of warmer past climate (e.g., early Holocene thermal maximum [Kaufman et al., 2004], Last Interglaciation [CAPE Last Interglacial Project Members, in revision]), to identify abrupt climate shifts, and to provide insight into possible threshold conditions that may trigger rapid climate jumps. For sequences of all lengths, multiple proxies are required to document shifts representative of the whole arctic system (e.g., temperature, sea ice extent, precipitation, freshwater runoff, Greenland ice volume, ecosystem composition, etc.), and are essential for proper interpretation and a full understanding of more complex integrated arctic system changes such as the Arctic Oscillation.

Another critical focus will be the development and quantitative calibration of specific climatic and environmental proxies by sampling at key terrestrial and marine observatory locations. This effort is important not only for improving the robustness of temporal and spatial interpretations of climatic variability, but also for expanding our understanding from paleoclimate to paleoenvironmental and ecological patterns and variability. This will allow for measurements made at terrestrial and marine observatories to be linked more strongly to the record of past changes, providing insight for understanding change. The strategy of developing quantitative records of paleoecological and human change, for example collecting data on shell middens, faunal remains, and chemical signatures (e.g., oxygen isotope levels in shells, bones, and otoliths) at coastal and inland archeological sites, is also required to link to the responding to change activities and

aspects of the human dimension of arctic change.

State of the art and existing networks, sites, and programs. Figure 2 of the SEARCH Implementation Strategy (SEARCH, 2003) shows locations of annual to sub-decadal resolution paleotemperature records used for investigations of modes of variability in arctic climate. The current sampling network can resolve arctic-wide average temperature, as well as AO variability—a critical variable for SEARCH—from proxy temperature records (Hughen et al., 2004). However, this synthesis only extends back 600 years and does not provide insight into the warmer conditions of the previous millennium. A synthesis of longer paleotemperature records investigated the timing of warming following the last deglaciation through the early Holocene thermal maximum (Kaufman et al., 2004), but had limited spatial resolution confined to the North American Arctic. A compilation of temperature reconstructions and model simulations of the Last Interglaciation provides evidence for melting of the Greenland Ice Sheet under conditions warmer than today (Overpeck et al., submitted; Otto-Bliesner et al., submitted).

The program that most directly addressed many paleoclimate issues related to SEARCH was Paleoenvironmental Arctic Sciences (PARCS). PARCS, now sun-setted, was a program initiated to understand the range of natural climate variability in the Arctic, evaluate the impacts and causes of rapid changes, determine the sensitivity of the Arctic to altered forcing, document the history and controlling mechanisms of biogeochemical cycling, and evaluate state-of-the-art numerical climate models (PARCS, 1999). A final PARCS effort is underway to synthesize decadal-resolution lake sediment records of the past 2,000 years into existing proxy networks, seeking to maximize the number of new records produced with relatively little effort (re-measuring existing cores at higher resolution, constructing records using rapidly measured, inexpensive proxies, etc.). The PARCS goals are coincident with many SEARCH objectives, and these current synthesis results can provide a foundation from which to guide SEARCH-relevant paleoclimate and paleoenvironmental research.

Needs beyond existing programs. To fulfill SEARCH objectives, arctic paleoclimate research should be prioritized around three general activities:

A high-resolution (10^0–10^1 year) multiproxy spatial and temporal paleoclimate network should be constructed extending back 2,000 years. Paleorecords covering the past 600 years (Hughen et al., 2004) allow us to identify low-frequency (multi-decadal to centennial) variability that cannot be reconstructed from instrumental records, but this time window does not extend through the Little Ice Age, hence fails to capture natural variability when arctic temperatures were closer to those of the 20th Century. Paleorecords that cover the past 2,000 years will allow us to resolve important modes of arctic system variability (including trends in mean summer temperature, summer Arctic Oscillation, and relationships between them) during the most recent warm period. Comparing detailed paleoclimate reconstructions to modeling and dynamical studies of arctic climate will help identify natural versus anthropogenic forcing mechanisms and predict future changes. Current NSF Arctic System Science (ARCSS) Program funding is starting to address this need, but the thrust of that research is at slightly lower resolution (10^1–10^2 year).

Decadal-resolution multiproxy records should be constructed from earlier warmer times (particularly the early Holocene thermal maximum and Last Interglaciation). Long paleorecords are needed in order to describe arctic system boundary conditions (e.g., summer temperature, sea ice extent, Greenland ice mass, species composition and range) and system variability during periods warmer than present. Long paleoclimate records from terrestrial and marginal marine environments, especially in Pacific (e.g., Bering Strait) and Atlantic gateways, should also be used to identify abrupt climate shifts and provide insight into possible threshold conditions that may trigger rapid future climate changes.

Observing: Paleoenvironment

Improved quantification of proxies essential to SEARCH objectives (sea ice, precipitation, temperature) should be pursued through sampling and proxy measurements co-sited with SEARCH-sponsored terrestrial and marine instrumental observatories. To meet SEARCH goals, it is necessary to quantify specific proxies for variables such as sea ice, precipitation and temperature. This should be accomplished by linking between paleoclimate and marine/terrestrial observations and utilizing intensive monitoring sites located near suitable archives (e.g., lake and marine sediments, ice cores, tree line, archeological sites).

As an integral part of this program, SEARCH researchers must continue to coordinate data sharing and collaboration with international groups currently working to recover and construct arctic paleoclimate records (e.g., International Partnerships for Ice Core Science [IPICS]). Broad international efforts will be necessary to enable synthesis and to achieve the spatial and temporal coverage required to understand arctic change. Long-term goals include the development and application of specific new proxies to create networks recording changes in precipitation, sea ice extent, ecosystem composition, etc. The creation of new high-resolution spatial networks and longer records synthesizing changes in components other than summer temperature will be critically important for fully documenting and understanding the range of arctic system variability, as well as predicting the magnitude of future change.

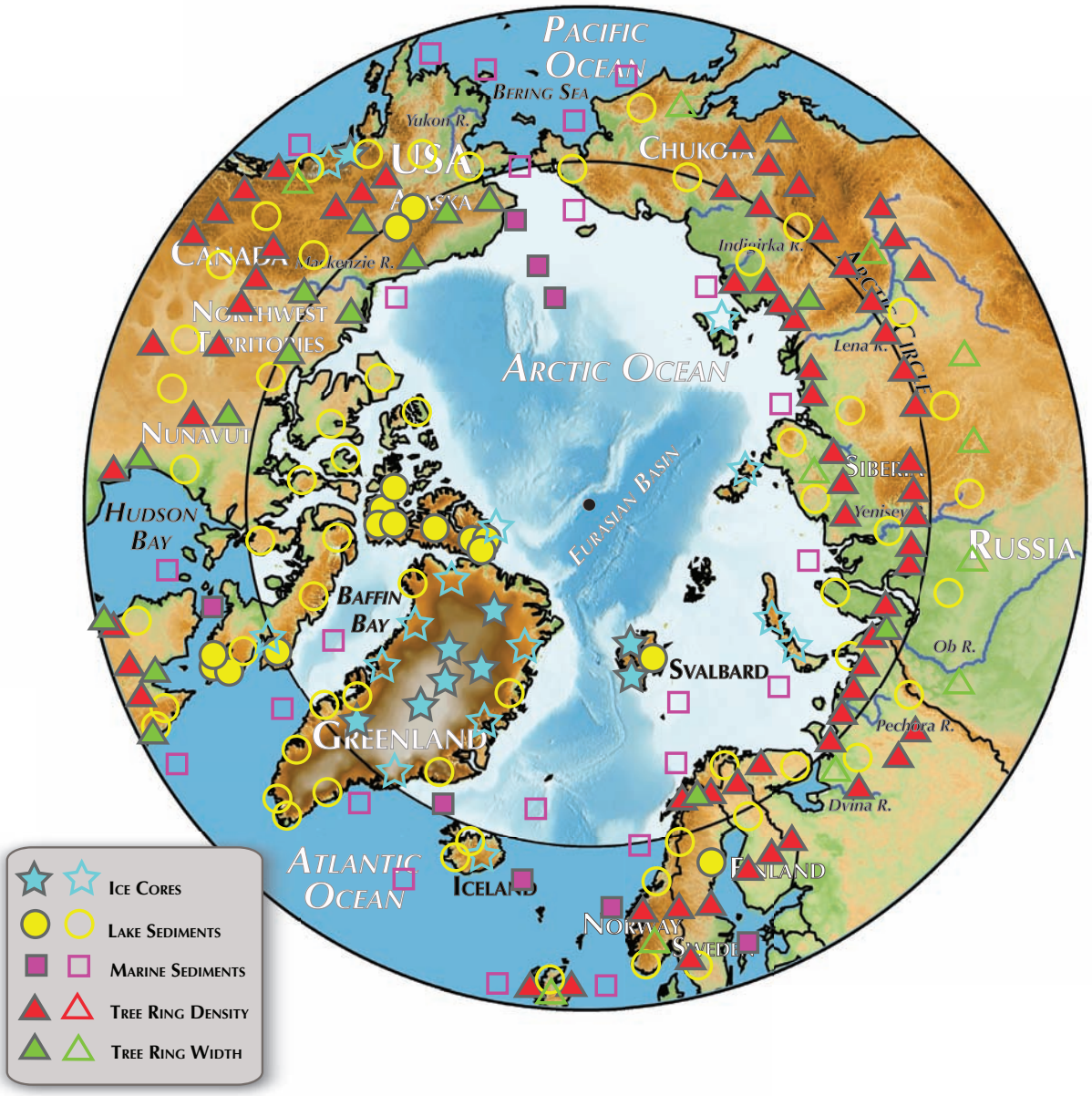

Figure 6. Types and density of SEARCH high-resolution proxy array. *Existing records are shown with filled symbols according to the type of proxy archive. Proposed additional records showing idealized proxy distributions and spatial densities are indicated with open symbols, showing the spatial density and overlap (not specific location) necessary for confident multi-proxy assessment of past natural climate variability. Figure adapted from Figure 2 in the SEARCH Implementation Strategy (2003).*

4.2. Understanding Change: Analysis, Synthesis, and Modeling

Section 4.2. identifies analysis, synthesis, and modeling activities pertinent to each of the key science questions identified in Section 3. These activities, in turn, point to the observational needs and response-directed activities addressed in Sections 4.1. and 4.3., respectively.

4.2.1. Is the arctic system moving to a new state?

A prerequisite to answer this question is a comprehensive depiction of the present state of the Arctic and of its ongoing evolution. Importantly, paleoenvironmental depictions of past states and variability will provide the needed historical context for understanding and responding to ongoing changes.

The Arctic is a coupled system that includes the physical, biological, and human components. Therefore, a depiction of the arctic state must involve a synthesis of information not only about the system components, but also about their interactions. While the observational gaps in component observations are addressed in Section 4.1., here we highlight several activities that will facilitate the required syntheses:

A model-based assimilation of available observations into a regional atmospheric system reanalysis can provide a viable approach to capturing the system evolution during recent decades as well as the interactions among the system components. Reanalysis of atmospheric data has a long history of development in numerical weather prediction as well as application in a wide variety of environmental research activities.

The products are created by assimilating atmospheric observations into a numerical weather prediction model by comparing measurements to modeled values. Differences between observations and calculated fields are minimized by adjusting the fields. The final result is a gridded dataset that is physically consistent and constrained to the observations. It also includes many variables that are not directly measured, but that are calculated from observed quantities using well known physical relationships. Because it is gridded and includes a complete set of atmospheric and surface variables, the reanalysis dataset constitutes a powerful tool both for diagnostic studies and for evaluations of change.

An Integrative Data Assimilation for the Arctic System (IDAAS) would follow this general plan, but with a focus on the arctic region (north of 45° N) and a particular emphasis on assimilating observations that are important for arctic change processes and impacts. While existing reanalyses assimilate only atmospheric measurements, an IDAAS activity would include additional (non-atmospheric) oceanic and terrestrial geophysical and biogeochemical parameters as well as human dimensions data. In addition, it would include non-standard atmospheric measurements such as satellite-derived atmospheric profiles of temperature and moisture, as well as cloud parameters. Since the assimilated data are primarily instrumental (*in situ* or remotely sensed) measurements, the viable time frame for a system reanalysis is the past several decades. With resolutions of several hours in time and several tens of kilometers in space, the product would provide a wealth of opportunities for identifying and diagnosing system-level changes in the arctic environment. Recent global reanalyses of the atmosphere have received sufficiently widespread usage by the research community that they are regarded as one of the major success stories of the past decade in atmospheric research.

Data assimilation experiments also serve as vehicles for designing optimal observing systems. By determining the sensitivities of reconstructed system states to particular types, densities, and locations of measurements, minimal requirements of observing systems can be established.

In this respect, the enhanced observational suites of the International Polar Year will permit experiments that will contribute to the development of a legacy observing network that meets monitoring and scientific needs in the most cost-effective way.

Paleoenvironmental reconstructions for the Arctic synthesizing information from tree-rings, lake and marine sediments, ice cores, archaeological deposits, and other sources will provide the longer-term (centuries to millennia) perspective required for placement of recent (i.e., decadal) changes of the Arctic into a longer temporal perspective. While efforts to synthesize paleo data have been made for some regions, a coordinated pan-arctic effort in SEARCH, targeted at the identification of changes in system state on the pan-arctic scale, would complement the more intensive decadal-scale focus of the data assimilation activity described above.

Several types of human dimensions synthesis activities are necessary for modeling the state and evolution of the human dimensions component of the arctic system, including:

- Synthesis of arctic residents' observations of local scale changes, which is necessary for assessing small-scale human impacts and feedbacks to the system (anthropogenic or otherwise);
- Synthesis of data on human perceptions (local, regional, and non-arctic) of arctic change, which is necessary for development of effective responses to change;
- Circumarctic synthesis of development and industrial activities, which is necessary for understanding and modeling human impacts and feedbacks at the regional scale; and
- Synthesis of relevant global-scale development and industrial activities.

4.2.2. 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 timescales?

"Predictability" includes not only prediction of equilibrium states but of trajectories of change, especially those changes that occur over decadal to century scales. While all parts of the system are ultimately linked to each other, not all parts of the system will change at the same rate. Examples include the slow equilibration of permafrost temperature profiles relative to air temperature changes and differences in the rates of change in animal populations, vegetation composition, and soil organic matter stocks.

There are several frameworks for predictability assessments, including statistical measures of correspondence between forecasts and measurements as well as measures focused on perceptions of the variables most important to humans and ecosystems (e.g., fish abundance, viability of travel). If the Arctic is indeed moving to a new state, predictions of the new state are essential to the planning of responses to the change.

Key SEARCH activities pertaining to the predictability of arctic change include the following:

Through interaction with the user community, determine the characteristics (i.e., variables, timescales, spatial scales, locations) of predictions that are most useful to increase the relevance of modeling activities. This activity will require collaborative efforts between researchers and stakeholders.

Through a combination of (a) model experiments and (b) application of understanding variability in the arctic system, establish the seasonal, interannual and decadal-scale predictability of arctic environmental variables. Included in (a) are hindcast experiments addressing the accuracy of the initial state, boundary conditions, and external forcing—issues that affect predictability in areas outside the Arctic. Assessments of the predictability of large-scale circulation modes (e.g., the Arctic Oscillation [AO], the Pacific Decadal Oscillation [PDO]) are also essential to a determination of the predictability of the Arctic.

Assessments of arctic predictability over seasonal to decadal scales will also need to draw upon an understanding of feedbacks within the arctic system and of the role of human-driven changes; both these issues are topics of the discussion below.

Develop linked ecological and sociological models to provide the vehicles for assessing the extent to which ecosystem changes and human activities and adaptations can be predicted. Experiments with such models are essential to

the identification and subsequent determination of the predictability of key variables affecting and effecting change in the ecological and human systems and in the arctic system more broadly.

Establish, quantify, and effectively communicate uncertainties in predictions of the arctic system. Uncertainties arise from the unknown evolution of external forcing mechanisms (e.g., greenhouse gas concentrations and volcanic eruptions), deficiencies of models that are used to generate predictions, our incomplete understanding of the arctic system, and from inherent natural variability ("noise") in the arctic and global climate systems. Rigorous assessments of uncertainties require ensemble experiments with climate models in collaboration with major modeling centers addressing uncertainties in global predictions. Collaboration is also required with social scientists whose expertise extends to the methods of communication of uncertainty to diverse user groups.

Undertake quantitative and qualitative studies to determine the predictability of change in arctic social systems. Such studies are needed to understand the uncertainties of responses to ongoing changes. How people in the Arctic will adapt to the cumulative effects of local resource development, the increasing globalization of markets and ideas, and political changes—all in the context of climate change—is uncertain. Yet such predictions guide SEARCH Responding to Change activities and could help to structure broader policy concerns.

4.2.3. To what extent can recent and ongoing climate changes in the Arctic be attributed to anthropogenic forcing, rather than to natural modes of variability?

Conclusive answers to this question require a combination of analyses of historical changes and controlled experiments with model simulations of climate. Key activities include:

Provision of context for the recent variations by historical analyses, drawing upon paleo records as well as syntheses of recent instrumental observations. In particular, paleo information that provides measures of arctic variability in the absence of anthropogenic forcing must be synthesized into a framework suitable for comparison with recent evidence of decadal-scale variability.

Contributions of the major modes of variability of atmosphere/ocean circulation (e.g., Arctic Oscillation, Pacific Decadal Oscillation) to arctic changes over the past century or two need to be quantified through diagnostic analyses. While such analyses have been performed for primary climate variables such as temperature and precipitation, assessments of the consequences of these modal variations for ecosystem and socioeconomic variations over the past century have not been established.

A key issue in the attribution of change is the extent to which the major oscillations (modes of variability) of the atmospheric circulation are related to anthropogenic forcing. If the alterations of atmospheric heating patterns indeed arise from anthropogenic factors (e.g., greenhouse gas and aerosol inputs, land use changes), then the anthropogenic fingerprint can extend to systematic shifts of the atmospheric circulation and associated impacts. Controlled model experiments are required to identify the direct and indirect consequences of anthropogenic forcing. Supporting experiments and diagnostic studies must consider possibilities such as stratospheric linkages to tropospheric climate, possibly attributable to effects of increased greenhouse gases and ozone-depleting chemicals on stratospheric temperatures and their variations. Similarly, there is a need to determine the role of aerosols and chemistry in variations of arctic cloud properties; such determinations will require a combination of field measurements and enhancements of cloud-aerosol-radiative parameterizations in models.

4.2.4. What is the direction and relative importance of system feedbacks?

The complexity of possible feedbacks in the arctic system pose a major challenge to the diagnosis and attribution of recent changes as well as to the projection of future changes in the Arctic. While controlled model experiments can serve as tools for assessing the magnitudes, directions, and relative importance of feedbacks, interlinkages among the feedbacks require careful and coordinated approaches. Moreover, some of the factors associated with possible feedbacks are not yet well quantified (e.g., human effects on the surface properties of the arctic landscape). Nevertheless, the following activities can lead to progress toward achieving the SEARCH objectives:

A determination of the types and scales of human feedbacks to arctic environmental change will require quantification of landscape changes, including effects on surface fluxes of heat, moisture, aerosols (e.g., particulates and dust), and carbon. The alteration of surface albedo through vegetative changes is a particular human impact in need of quantification. In addition, process studies and model experiments to assess the first-order impacts of these changes, and hence their roles in triggering feedbacks, should be a priority of SEARCH.

More generally, there is a need to determine the controls of the arctic landscape. While humans are direct contributors in some areas, other controls include fires, insects, and permafrost, all of which interact with climate, hydrology, biogeochemistry, and biology. The ways in which these influences interact and feed back to each other needs to be addressed by synthesizing available information from field measurements and process studies and by using this information to develop and calibrate terrestrial modules that enhance the utility of broader system models.

The role of clouds, aerosols, and water vapor calls for special attention in the context of the albedo-temperature feedback, which has been shown to shape the pattern of high-latitude greenhouse warming in global models. The large uncertainties in model parameterizations of arctic clouds, aerosols, and their chemistry calls for a synthesis of observational findings from field programs (e.g., Surface Heat Budget of the Arctic Ocean [SHEBA], Atmospheric Radiation Monitoring [ARM]) augmented by measurements from intensive observatories elsewhere in the Arctic and the use of the findings to assess the role of changing cloud/aerosol characteristics in arctic change.

The rates and trajectories of arctic system change will be altered by feedbacks. A hierarchy of model experiments, ranging from ones with simplified geometries and idealized formulations to fully coupled global system models, are needed to determine the sensitivities of projected changes to the inclusion of feedback processes. These experiments can, in turn, point to parameters for which there is the greatest need to establish bounds or narrow uncertainties through observations and process studies.

Changing conditions in the Arctic are also of interest to the large number of people who live in temperate zones. Their perceptions about the causes of these changes matter. If early signs of global change in the Arctic are attributed in a substantial way to anthropogenic forcing, we can expect residents in temperate zones to support a different set of policy choices than if the changes appear to be primarily the result of natural climate variability. Such actions represent a significant potential feedback to anthropogenic forcing of climate change, hence the rationale for monitoring such perceptions. Over the long term, we recommend that research be undertaken to assess the role of arctic climate change information in the formation of attitudes and responses of non-arctic residents regarding climate change.

4.2.5. How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and its interaction with human activities?

In order to address the effects of environmental change on ecosystems and their services, it is necessary to identify the ecosystem variables and processes that are most critical to ecosystem function and delivery of services. Ecological assessments require the synthesis of information on different ecosystem components. Such

activities are essential for SEARCH in order to link physical environmental change to impacts. Particular activities for which there is a need and readiness for SEARCH include:

Evaluations of the direct effects of changes of sea ice (e.g., thickness, age, and extent) and snow (e.g., seasonal timing, depth, and moisture content) on ecosystems and on humans. Direct effects would include changes in migration routes and local habitat shifts of key species along with weather-related transportation changes that might affect harvest success. This evaluation will require the synthesis of indigenous knowledge and disparate observational datasets, integrative assessments on a regional basis, and the incorporation of the findings into ecosystem models that can be coupled with models of future climate change.

Assessments of the variations of fluxes of freshwater from arctic land areas are needed to determine associations with terrestrial and marine ecosystems and their services. Such assessments will require homogenization of river discharge data, maintenance of a baseline network, and estimation of fluxes that are not directly measured. Interfaces with the NSF-supported Arctic Community-Wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) are essential to this activity.

The constraints and thresholds that control arctic landscape changes need to be evaluated in the context of climate forcing variations such as the AO and the PDO. This activity will require the evaluation of landscape changes in a format compatible with the available data on the major components, or modes, of atmospheric forcing. The relevant landscape characteristics include vegetative characteristics, as well as biophysical, hydrologic, and cryospheric (permafrost) variables. Credible model frameworks developed for simulating system component interactions can lead to evaluations of the roles of these thresholds in regulating terrestrial feedbacks to the broader climate.

Another possible focus could be the development of marine ecosystem models capable of predicting changes in community structure and function in response to human-induced and physical forcing, which may affect population processes at very different spatial and temporal scales. In most cases, the relevant scales are still poorly understood for upper-trophic level predators. Traditionally, population models have focused on the dynamics of single species in response to the effects of fishing. More recently, model development has advanced on several fronts. Ecosystem models such as Ecopath and multi-species models such as Multi Species Virtual Population Analysis (MSVPA) simultaneously examine variability among many interacting species. Models that incorporate environmental variability, for example in predicting recruitment or affecting vulnerability to fishing gear, are becoming increasingly common. These models show promise in helping to predict population responses to harvesting in the presence of environmental forcing, on seasonal to decadal time scales.

4.2.6. How do cultural and socioeconomic systems interact with arctic environmental change?

Multiple stressors acting in the Arctic—often arising in other parts of the globe—combine to increase the vulnerabilities and shape adaptive responses of arctic social systems. These stressors include climate change, resource development, contaminants, population migration, new technologies, changing markets, and other aspects of globalization. A goal of SEARCH is to identify the cumulative effect of arctic environmental changes while considering the combination of other stresses affecting peoples of the Arctic and elsewhere. To date, the interplay among these stressors has been mainly addressed with qualitative studies. Models of social-ecological systems require further development to evaluate the impacts of arctic change and understand the consequences of response strategies.

Activities to increase the capability of addressing the interaction of cultural and socioeconomic systems with arctic environmental changes include:

Comparative statistical analysis: Integrative time series and cross-section comparisons of

community and regional change can advance understanding of the relative importance of climate change on various aspects of society. Lack of broadly generalizable data currently limit the scope and sophistication of comparative statistical studies, however. Enhanced data on socioeconomic and cultural change, including data on human health, is required to support these analyses.

Dynamic modeling: Simulation models can be utilized to predict impacts of combined socioeconomic and environmental change, to investigate resilience of social-ecological systems, and to test environmental and social effects of response strategies. Understanding arctic change will require development of models that combine interacting elements of environmental, economic and social change. In addition, continued development is needed of region-specific models and/or generalized models that can be applied to regions across the Arctic.

Target research topics that are likely to have clear connections to the physical and biological systems studied under SEARCH include fisheries, reindeer husbandry, subsistence and personal-use wildlife harvests, and transportation and development. Coastal regions in particular provide an opportunity to focus research on the interaction of socioeconomic systems with a changing environment, as coastal environments of the Arctic are (and/or likely will be) locations of changing subsistence hunting/fishing practices, transportation, resource development, coastal erosion, and marine and terrestrial ecosystem change.

4.2.7. What are the most consequential links between the Arctic and the earth systems?

The Arctic is linked to the rest of the globe physically (via atmospheric and oceanic connections), biogeochemically (via carbon exchanges), and socioeconomically. Consequently, changes in the arctic system and global system are related. These linkages are among the motivations for the SEARCH program. Activities that will enhance understanding of these linkages include:

Evaluations and improved understanding of the coupling between arctic and global environmental change can be enabled by controlled model experiments that focus on the key physical linkages, for example, the effect of cryospheric (ice sheet, glaciers) change and arctic warming on global sea level and the effects of arctic hydrologic changes on the deep ventilation of the ocean in the subarctic seas of the North Atlantic.

Observational evidence of changes in glacier/ice sheet mass balances, ocean stratification, and oceanic overturning rates would permit model validation tests that would improve the credibility of models as diagnostic and predictive tools with respect to arctic-global linkages. A key focus of these observations is the storage of water in glaciers and ice sheets of the north.

Since the effects of arctic change on the global radiation balance and the carbon cycle are central to the Arctic's role in the broader earth system, improved measurements of the radiation balance are needed, especially at the snow/ice surface and in areas of changing cloud characteristics. Surface albedo emerges as a priority for measurement on the non-local scale, particularly over areas comparable in size to global climate model grid cells. Changes in surface-atmosphere carbon exchanges in the Arctic is another priority for measurements, provided that the measurements permit meaningful conclusions about flux variations on the regional to pan-arctic scale.

External (non-arctic) forces contribute to arctic developments such as river damming, expansion of forestry and agriculture, and ecosystem disturbance in areas of mineral extraction. Effects of these activities on albedo and the freshwater fluxes into the Arctic Ocean need to be evaluated. Observational strategies for monitoring these quantities must be considered a priority in the context of arctic-global connections.

Policy choices of national governments related to greenhouse gas emissions and other anthropogenic drivers depend on what decision-makers know about the causes and consequences of arctic environmental change, along with pressure exerted by various stakeholder groups.

Understanding

Improved understanding of the role of arctic research in formulation of national climate policy requires modeling not only the role of science in policy development, but also the relationship of scientific information to public perceptions and attitudes. To support such modeling, we recommend that research be undertaken to monitor perceptions and understanding of temperate zone residents related to arctic climate change and its global consequences.

4.3. Responding to Change: Developing Adaptive Responses

The Responding to Change component of SEARCH should directly address the question, "How can understanding of arctic system changes be used to develop adaptive responses?" Such responses should consider all components of the arctic system, from physical to biological to social, although emphasis may focus on the latter as it is through various elements of the human component that responses to system change will be identified, implemented, monitored, and adjusted as SEARCH implementation moves ahead.

It is possible to envision that responding to change can take several forms, depending upon which element of the system is considered. For example, the human component has been responding to environmental change for millennia at multiple scales (i.e., individual, community, and regional). Recently, new subsets of the human component are anticipating and planning for future environmental changes at larger scales. On the one hand, various industries (e.g., oil/gas and shipping) are considering new developments in light of a potentially ice-free summer Arctic Ocean, while at the same time fisheries managers are trying to account for changes in variables (e.g., ocean temperature) that impact stock viability in quota sets and harvest limits. At individual and local scales, people must make decisions about the safety of travel, the safety of certain subsistence pursuits, and the placement of homes and other infrastructure in the face of seemingly unprecedented changes in nearshore ice, permafrost, weather patterns, and erosion cycles.

A key goal then of the Responding to Change component of SEARCH is to identify the specific knowledge necessary to make informed decisions about adaptive and mitigative strategies at the level of the individual, the community, the region, and outside of the Arctic. Wherever possible, scientific activity should be undertaken with appropriate stakeholder groups. These groups may include local communities, resource managers, local, regional, and national governments, commercial interests, scientists, and non-arctic communities, as well as others yet to be identified but still affected by arctic change.

4.3.1. Key Science Questions

Effective response to change requires a clear understanding of arctic system change and of stakeholder options. Responding to Change issues and activities related to the key science questions identified in Section 3 include:

Is the arctic system moving to a new state?

This overarching SEARCH question, which has profound implications for stakeholders, can be addressed through activities targeting the other key science questions, as discussed below.

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 timescales?

Arctic residents and other stakeholders are keenly interested in predictions that are relevant to their daily lives. Key questions include:

- To what extent are seasonal and interannual changes of arctic environmental variables predictable by climate models and other environmental forecasting tools?
- What predictive information and products are most useful to various groups of stakeholders?
- What are the uncertainties in arctic predictions at various timescales, and what are the most useful ways to convey these uncertainties?

If predictions are developed without the involvement of the people for whom they are intended, they are likely to be flawed or irrelevant to potential users. A priority SEARCH/IPY activity is to work with stakeholders to identify useful predictions (see Section 4.3.2).

To what extent can recent and ongoing climate changes in the Arctic be attributed to anthropogenic forcing, rather than to natural modes of variability?

People in the Arctic are accustomed to adapting to highly variable conditions. Yet a common observation of arctic residents is that the types of short-term predictions on which they depend are no longer working. Weather changes appear to be more frequent. It makes a difference to the people who live and work in the Arctic and

to decision makers in government and industry whether these changes in the arctic environment are the result of short-term variations in climate, long-term change, or anthropogenic forcing. In the context of decision-making at all levels, from individual and local to national and international, short-term predictions are particularly important. The Responding to Change component of SEARCH must work with the Understanding Change component to translate modeling results aimed at understanding the causes of climate change into a form useful to the many different groups of stakeholders. This research task is a long-term priority in SEARCH.

What is the direction and relative importance of system feedbacks?

Synthesis and modeling activities described in Section 4.2 include the contribution of human activities in the Arctic to system feedbacks such as surface albedo, freshwater containment, and greenhouse gas emissions. Such relationships are relevant to both the responding and understanding components of SEARCH to the extent that they involve specific stakeholder groups.

How are terrestrial and marine ecosystems and ecosystem services affected by environmental change and its interaction with human activities?

Ecosystem services are the processes by which the environment produces resources that support human life (e.g., water, food, hydropower). Particularly relevant to arctic and subarctic residents are habitats for fisheries, marine mammals, and terrestrial wildlife. Also relevant are stable shorelines and soils for community infrastructure. Three areas of human activity are highlighted for early attention in the SEARCH Implementation Strategy and by SEARCH Implementation Workshop participants: (1) arctic and subarctic fisheries; (2) marine transportation and associated resource development; and (3) subsistence harvests. A SEARCH/IPY responding priority is to work with stakeholders to provide them with near-real time observation data related to the above topics; these data could be used:

- by managers, who must account for changes when managing renewable resources;
- by industry to facilitate consideration of the environmental effects of development activities; and
- by subsistence and traditional commercial (e.g., reindeer) harvesters in planning their activities.

How do cultural and socioeconomic systems interact with arctic environmental change?

The responding to change component of SEARCH focuses on the two-way communication of research needs and priorities between stakeholders and researchers. The responding to change research component of SEARCH will complement, but not replace, the Education and Outreach component of SEARCH. As discussed in Section 6, the Education and Outreach component will focus on broad population groups both inside and outside the Arctic and its activities will involve scientists from all components of SEARCH. The Responding to Change science component of SEARCH will focus on specific user groups; information from stakeholders will help guide climate research in the near-term to aid business and policy decisions. Over the long-term, the application component will also foster inter-community links to share learning about adaptations to change.

What are the most consequential links between the arctic and the earth systems?

Environmental changes such as decreasing sea ice extent may foster increased development of petroleum, mineral, and fisheries resources for the global markets. Similarly, globalization and easier access may lead to an increased presence of tourists in remote communities. Such processes can have local, regional, system, and global scale effects and are relevant to the responding component of SEARCH to the extent that they involve specific stakeholder groups both in the Arctic and elsewhere.

4.3.2. Research activity: Identification of useful predictions

The predictions that are most useful to climatologists may not be the predictions that are most useful to people responding to change. This makes sense when one considers

the difference in use of observations and predictions. Climatologists focus on system-level changes using observations and predictions that integrate over large geographic regions. People responding to changes often focus on a broader suite of changes (e.g., climate, vegetation, fish and wildlife populations/migrations, wildfire, ice, etc.) in a local region and are interested in observations and predictions at this local scale, specific to resources or impacts of interest. For example, predicting changes in the ice mass balance of the Arctic Ocean is not equivalent to predicting changes in nearshore ice in coastal areas of the Bering Sea. The integration of SEARCH can best be achieved in the long run by an early consideration of the system variables most useful as predictors at both geographic scales. Early consideration will likely open up opportunities in the observation and modeling stages to find innovative ways of meeting multiple objectives. In fact, our understanding of the arctic system depends upon coupling system-level changes with local-scale changes.

The aspects of system change, or anticipated aspects of change, to which people are responding varies by region and even by community. Changes need to be explicitly identified, or else the idea of responding to change is too abstract to be useful. It is therefore valuable to start with clusters of closely related changes, recognizing that it will take time to build a comprehensive view. For example, some arctic communities are dependent primarily on migratory species; others are dependent on resident species. Some depend primarily on ocean or river ice for transportation; others do not. Some are vulnerable to erosion; others are not. It could be useful to facilitate connections between groups of people in similar situations who are disconnected by geographic or political boundaries. One approach would be to identify a physical change relevant to one or more clusters of related changes, with a focus on decisions of a group of people dealing with one of these clusters (e.g., decisions of commercial fishers). Another approach would be to identify a region, or a group of communities in several regions that face similar decisions, and then scale up by adding more regions or communities.

Given the high level of uncertainty about physical-biological-human environment relationships, concerns raised by people responding to change is of considerable importance. The three areas of concern targeted in the Implementation Strategy – fisheries, transportation and development, and subsistence harvests – have the advantage of involving largely (but certainly not wholly) different groups of people, including arctic residents (subsistence harvests), arctic and subarctic residents and industry (fisheries), and multinational industries (marine transportation and resource extraction).

A high priority research activity for SEARCH is the identification of predictions that people would find most useful, focusing on stakeholder groups associated with arctic or subarctic fisheries, marine transportation and associated development, or subsistence, personal use, or commercial harvests (e.g., reindeer) of renewable resources.

A near term priority research activity is to work with the understanding change component to make relevant predictions available.

A long term priority research activity is to assess the responsiveness and effectiveness of local, regional, and national institutions in addressing social and economic concerns.

4.3.3. Research activity: Establishing near-real time data outlets

Recognizing that people are already responding to change and that observation and modeling tasks will precede even initial attempts at prediction, the next most useful output of SEARCH is relevant near-real time data such as sea ice conditions and caribou locations.

A high priority research activity for SEARCH is research that identifies and makes available near-real time observations relevant to stakeholder groups, focusing in particular on stakeholder groups associated with arctic or subarctic fisheries, marine transportation and associated development, or subsistence harvests.

A near term priority research activity is to monitor responses to environmental change and to fill gaps in data needs.

A long term priority research activity is to assess the utility of near-real time observations.

4.3.4. Research activity: Identifying or establishing community/industry networks and ecological knowledge cooperatives

The intent of both community/industry networks and ecological knowledge cooperatives is the same: to support the involvement of groups of people responding to change in SEARCH. The difference relates to the heritage of the terms, with community/industry networks most commonly associated with commercial fisheries and ecological knowledge cooperatives most commonly associated with subsistence harvest systems (for related website examples, see http://www.beringsea.com and http://www.taiga.net/coop/index.html).

The Implementation Strategy discussion of networks and cooperatives focuses primarily on data gathering and the contribution of local and traditional knowledge. The list of research activities dependent on the establishment of networks or cooperatives includes, among many other activities listed in the Implementation Strategy: (1) identification of clusters of related changes in the physical, biological, and human systems; (2) identification of the most relevant predictions; (3) compilations of historical data; (4) designing and implementing observation systems; (5) establishing near-real time data outlets; (6) interpretation of modeling results in the context of local knowledge; (7) outreach to users; and (8) dissemination and assessment of SEARCH results. These activities involve the observing and understanding as well as the responding components of SEARCH. Cooperatives and networks can assist in data gathering and environmental monitoring (i.e., observing); share local and traditional knowledge about processes and feedbacks and identify needed research (i.e., understanding); and identify needs for useful predictions relevant to local decisions and foster exchange of information (i.e., responding).

A high priority research activity for SEARCH/IPY is the identification or establishment of community/industry networks or ecological knowledge cooperatives to facilitate involvement of stakeholder groups in SEARCH.

A near term priority research activity is to foster exchange of adaptive responses among stakeholders.

A long term priority research activity is to work through the community/industry networks and ecological cooperatives to assess the utility of SEARCH research products.

5. SEARCH Data Management Strategy

5.1. The Role of Data Management in SEARCH

Data management activities in SEARCH must be designed and implemented so that they effectively and efficiently support the key scientific activities of SEARCH, which include change detection, attribution, and prediction. SEARCH data management activities also need to effectively support education and outreach. It is important that a comprehensive data management plan be developed for SEARCH that will effectively support the science of the program, achieve broad impacts relevant to stakeholders, and assure secure and available data archives that have been collected at great expense. Because the interdisciplinary nature of SEARCH will involve data that is heterogeneous, a comprehensive data management plan must integrate across the various disciplines while building upon disciplinary expertise in data management. Data management methods must be flexible and extensible so that SEARCH researchers can easily contribute data and information at appropriate levels of sophistication. Thus, an efficient and effective SEARCH data management plan must provide: (1) data discovery across disciplines and the entire program; (2) open data distribution to the greatest possible extent; and (3) data archival and stewardship for long-term data preservation.

As SEARCH is a highly interactive and collaborative science program, data management strategies to reinforce SEARCH must be flexible and optimized to the diverse communities that comprise SEARCH, yet at the same time provide interoperability among researchers. The best way to provide such interoperability is to build data systems around recognized and accepted community standards and common "best practices." The earth science data management community is evolving towards common standards. Several recently produced documents enumerate standards and practices applicable to SEARCH (CCSDS, 2002; ICSU, 2004; NSB, 2005). These published reports should be considered in the development of a SEARCH data management plan that identifies relevant standards, guidelines, and practices for SEARCH.

The Long-Lived Digital Data Collections report (NSB, 2005), which outlines data issues for NSF-wide consideration, may be particularly useful in providing guidance for the inter-agency and international nature of SEARCH data management. This report provides useful definitions for data system terminology, as well as roles and responsibilities for data systems, data managers, data providers, and data users. Of particular relevance to SEARCH is the definition of data collections that fall into one of three functional categories depending on their use and applications: (1) research, (2) community, and (3) reference data collections. Research data collections are traditionally those data collected by individual Principal Investigator projects, which are often not made available to the wider scientific community for a year after collection. In contrast, community data collections are those data collected as part of a scientific network of observations, and are made public a short time after collection once the data have been checked for quality (verified). Community data collections are especially important for a program like SEARCH, which must provide such data quickly to facilitate change detection, attribution, and prediction activities. Reference data collections are data that are generally collected by an operational agency, such as the National Weather Service. While SEARCH

management activities need to deal with all three of these data collection types, the success of SEARCH clearly hinges on the effective management of community data. Because of the heterogeneous nature of community data collections in SEARCH, the implementation of effective and efficient data management will require a coordinated distributed data management system. Below, we first elaborate on the design issues and options of a coordinated distributed data management system. We then provide a set of recommendations relevant to developing and implementing the data management plan for SEARCH. Finally, we identify some high priority recommendations that should receive immediate attention.

5.2. Design Issues and Options

The need for a distributed data management system. Because complex systems are coupled systems by nature, scientific data management systems share a common need for rapid change as the science and understanding changes. The SEARCH community should implement a Distributed Data System (DDS) to build on disciplinary expertise in data management. In practice, a DDS capitalizes on local expertise and community-wide interoperability standards to enhance the ability for the local data management system to adapt quickly as understanding of the scientific process naturally evolves. Such a system allows for rapid change in functionality as methods change over time. A DDS is essential for the effective development of a scientific computing environment to support information management, data synthesis, and modeling activities involving heterogeneous data. Each discipline within the overall SEARCH program will have special requirements that will be difficult to communicate to a centrally operated data center. The primary generators of data are the scientists that best understand their data and in principle know how to represent the data in a way that leads to effective communication of findings and scientific publications. The understanding of the primary data is essential for capturing, extracting and understanding the information content of data and results. Assuming that each major SEARCH component adheres to a working set of standards for interoperability among the components, such a system would support a higher form of analysis, or synthesis across datasets. This would enhance the ability of a broader scientific community and policy makers to exploit the encompassing richness of research results generated by the SEARCH program.

The need for a data and information coordination service. Although the SEARCH data system should be distributed, there is a need for a data management focal point to act as an overall data management consultant and coordinator and as a central data portal. The Data and Information Coordination Service would establish close partnerships with data centers and organizations to build on existing systems in creating the overall SEARCH data system. The service should work closely with the SEARCH IPMC and SSC and a SEARCH data management advisory group (SDMAG, see Recommendation 1 below) to implement the SEARCH data management plan and the SEARCH data policy and to facilitate cross-disciplinary data integration. The service should also collect and catalog metadata from SEARCH projects and provide a web-based portal to *all* SEARCH data.

The need to plan for integration. The SEARCH science goals, many of which will involve multidisciplinary synthesis, will require scientists to be able to integrate highly heterogeneous data, including atmospheric, oceanographic, hydrological, geological, biological, chemical, ecological, and social sciences datasets. To that end, SEARCH data systems must be able to provide the needed integration capabilities. Such a service will require fusion of myriad data on widely ranging spatial and temporal scales, from in-situ and remote sensing observations, model-generated data, and integration of new data with historical data in repositories. It is important to recognize that integration is most appropriate for those systems that are amenable to integration, but may not be appropriate or practical in all instances. Also, the integration component of the SEARCH data system should be designed in a modular fashion so as to be flexible, scalable,

and extensible. It is worth underscoring that integration is not a yes or no proposition. It can be full or partial, and it can be implemented gradually, based on the needs of the program, the resources available, and the presentation of new opportunities. The key to successful integration is achieving interoperability, or seamless linkages at the interfaces, and adherence to widely used standards. A successful data integration effort will also require effective coordination among data and information management systems, as well as between data providers and data managers.

The need to define activities for the generation of data products. The SEARCH data and information coordination service should be designed around the data products and functionality that SEARCH investigators will need. In some cases customized data products may be required in advance of SEARCH field data collection to facilitate the design of data collection. For these reasons, there is a need to survey data requirements as soon as possible. Two broad categories of data will need definition early in the program. *Community data* will be shared with the scientific community in near real time. A data and information coordination service should facilitate access to and archival of these data. Examples are data produced during field experiments (e.g., atmospheric profiles or meteorological observations), satellite remote sensing data, data from observational networks, forecast products, and data from operational sources such as the National Ice Center or National Weather Service. *Retrospective data products* are constructed after data are collected. These data products will include the datasets of individual SEARCH investigators but are also likely to include compilations designed to multiply the value of individual datasets by combining them in synthesis data products. Other types of retrospective data products are environmental data atlases and climatologies, which may be tailored for a region in order to facilitate planning for field studies. The acquisition and documentation of "rescued" data is often an especially labor intensive data management activity that is important for filling gaps in datasets of interest to the SEARCH community. Other relevant historical data may not require rescue but may need updating or processing. Activities involving data rescue and historical data processing should be identified so that the scope and costs of such activities can be ascertained.

The need for a central data portal. A central data portal is required as a point of entry for access to the datasets across the entire SEARCH program in order to promote integration and synthesis. In general, data portals can provide data and information over a wide range of capabilities and disciplines. In its simplest form, a data portal enables data discovery that subsequently transfers users to participating data serving systems. More complex portals can provide functionality that enhances integration and synthesis. Commitment to portal technologies at the minimum means that data contributors provide standardized metadata. While the entry-level metadata requirements can be easily achieved, it is important to recognize that increased functionality of data portals for integration and synthesis requires more metadata detail that places additional requirements and burdens on SEARCH scientists. Also, advanced portals are able to communicate with other portals by automatically sharing metadata. Such extensibility of the SEARCH data portal would be an asset for the International Polar Year.

The need to coordinate with other data management activities. The scientific success of SEARCH and related international efforts such as the IPY, the International Study of Arctic Change (ISAC), and the Climate and the Cryosphere (CliC) Project will depend in some part on a data management strategy that enhances international access to and exchange of the datasets that result from each of these efforts. SEARCH data management policies and practices should be coordinated with these activities and other relevant organizations such as the International Arctic Science Committee (IASC), the International Council for Science (ICSU), and the Arctic Ocean Science Board (AOSB).

The need for free and open access. Free and open access to global data from all countries is encouraged through the World Meteorological Organization (WMO) Resolutions 25 (hydrometeorological data) and 40 (meteorological and related data). In addition, the acceptance and implementation of international standards for geographical metadata (e.g., ISO 19115) and related standards for other data types by SEARCH will facilitate access by a broad international science community. SEARCH data management should make use of existing regional and global data centers in providing access to and archival of data. Improved approaches for data access and retrieval, including use of metadata standards, advanced data search capabilities using web data portal technology, and emerging technologies of data display and integration, should facilitate data access and support of SEARCH science as well as education and outreach objectives.

The unique needs of social data. Social data, including quantitative and qualitative individual and household interviews, community-based observations, and local and cultural knowledge, have unique data management needs. It is important to understand that issues involving social data are related to, but somewhat different from, the overall data management issues. Furthermore, there are many existing community-based datasets, studies, and networks that might be included within the SEARCH effort. It may be appropriate to have a specific group of social scientists, community representatives, and data managers work together to address the issues below and relationships with other networks. In particular, the SEARCH data management plan needs to address the following fundamental issues regarding social data:

- Data transfer methods including interfaces and agreements that lay out the rights and responsibilities of data archives, data providers, and data users. The agreements should explicitly address issues of data proprietorship, fair use, and privacy.
- Appropriate data access by the local community and world at large in a manner that maintains the original context of the data while maintaining appropriate levels of privacy.
- Appropriate data attribution. Communities and individuals need to maintain ownership of their knowledge and be recognized for their contributions.
- Data description, especially metadata to facilitate data discovery and integration.
- Data preservation for myriad data types and formats, including text, maps, video, audio, imagery, databases, and narrative documents.
- Compliance with relevant policies for research using human subjects, including the Alaska Federation of Natives Guidelines for Research, the *Federal Policy for the Protection of Human Subjects,* and corresponding regulations in other countries.

The need to support education and outreach. The credibility and success of SEARCH will in part be judged by how effectively the program communicates the results of this effort to the public and policy makers. The opportunity and challenge is to provide an "end-to-end" service that permits all participants to tap into the data stream for real time "classroom in the field" opportunities, data sub-setting for real time observational (e.g., small communities), multi-dimensional modeling efforts, as well as the preparation and distribution of science education products. Not all scientific datasets may be suitable for use in K–12 or undergraduate educational contexts, and therefore some data will need to be processed before being used in educational materials. The need for data processing and perhaps reduction has been recognized by the Digital Library for Earth Science Education (DLESE) in its Data Services activity, which is working toward the goal of facilitating the use of data in education.

5.3. Recommendations

1. The SEARCH IPMC and SSC should form a SEARCH Data Management Advisory Group (SDMAG) to develop the comprehensive SEARCH data management plan and a SEARCH data policy and to advise the data coordination service on data access requirements and product

development. The advisory group should include members from each of the SEARCH Panels, the SEARCH IPMC, the SEARCH SSC, and three to four data managers. It is important that this advisory group be characterized by membership that represents breadth across disciplines involved in SEARCH.

2. The SDMAG should develop a SEARCH data policy addressing issues of data accessibility, timeliness, attribution, and security. The SDMAG should consider existing international, national, and agency level policies in developing the SEARCH data policy.

3. SEARCH should create a central Data and Information Coordination Service to develop the central data portal, ensure consistent and responsible data management across the program, and implementation of the SEARCH data management plan and the SEARCH data policy.

4. Data, metadata, interfaces, and tools should adhere to existing community standards. Where possible, open source technologies should be encouraged.

5. SEARCH should encourage the rescue and incorporation of relevant historical data.

6. Agencies supporting SEARCH must provide support for the long-term stewardship of SEARCH data in accordance with relevant standards and recommendations such as the OAIS Reference Model (CCSDS 2002) and the *Global Change Science Requirements for Long-Term Archiving* (Hunolt, 1999).

7. To facilitate data discovery and integration, any SEARCH announcements of opportunity (AO) and grants should include the following data management requirements for investigators:

- Data authors (investigators who produce data under SEARCH funding) shall provide, within the first 3 months, a metadata inventory description (a high level summary of the data they plan to collect) to the data coordination service and relevant archive.
- Investigators must specify, in their proposal, where their data will be archived. At a minimum, the proposal should include a letter of support from the specified data center or data manager contact.
- Investigators must specify, in their proposal, a person who will be the data management point of contact responsible for submitting the data and documentation.
- Investigators must specify, in their proposal, which data that they will collect are destined to be community data. All community data must be made available through the SEARCH data management system as soon as data are collected and verified.
- Every project must submit complete documentation and quality-controlled data to the appropriate archive in accordance with the SEARCH data policy.
- Investigators submitting proposals to this solicitation must agree to adhere to the general data policy of the agency to which they are proposing and to the specific terms of the SEARCH data policy.

5.4. Issues Requiring Immediate Attention

The following steps should be taken as soon as reasonably possible to begin development and implementation of a SEARCH data management plan:

- Announcements of Opportunity should incorporate Recommendation 7 above regarding data management requirements for investigators.
- The SDMAG should be formed according to Recommendation 1 above. Initial activities of the SDMAG should be to develop the SEARCH data policy and begin development of the comprehensive SEARCH data management plan based on scientific, measurement, and support requirements of the science panels.
- The SEARCH Data Policy recommended by the SDMAG should incorporate details of data submission, attribution, sharing and collaborative research, security, and handling of special datasets (e.g., social science and human dimensions).
- The SDMAG should immediately facilitate the development of a SEARCH data inventory, based on the needs of the SEARCH panels. This will permit early recognition of data gaps and other possible

inconsistencies in the proposed measurement strategy.

- The SDMAG should work with the SEARCH IPMC and SSC in fostering cooperation with international projects and organizations, especially with regard to developing a consistent data management strategy for the IPY.

6. Education and Outreach

6.1. Goals

The SEARCH Education and Outreach component should serve as the public face of SEARCH. The goals of education and outreach activities are to:

- Broaden the awareness of the importance of the Arctic in the global system;
- Highlight the human dimensions of arctic change;
- Excite and engage the public in arctic science by increasing a general understanding of arctic processes and research;
- Foster the development of the next generation of arctic scientists, engineers, scholars, leaders, and citizens that are literate in science issues; and
- Become an integral part of the International Polar Year education and outreach efforts.

6.2. Message and Audience

The public awareness message of SEARCH is that the Arctic is changing, and that as a consequence of global climate interactions and feedbacks, these changes have wide-ranging implications not only for the Arctic but also for the global environment and population. In short, the Arctic matters. SEARCH education and outreach activities will effectively communicate the SEARCH goals of documenting, understanding, and responding to environmental arctic change. SEARCH education and outreach activities will also convey the inter- and multi-disciplinary, scientifically integrated, and geographically diverse nature of SEARCH research to illustrate the concept of science as a process.

SEARCH education and outreach activities should aim to reach the broadest possible audience. In geographic terms, this audience would include members from local, regional/state, national, and international populations. The audience would include the general public, K–12 educators and students, college students, policy makers, and stakeholders (e.g., northern residents and communities, business and industry, etc.).

6.3. Approaches

A SEARCH Education and Outreach program would be most effective through the combined efforts of individual investigators and a centrally coordinated SEARCH Education and Outreach Office. The SEARCH Education and Outreach Office would assist investigators or projects to develop and implement education and outreach efforts, thus leveraging the efforts of individual projects into effective, far-reaching, collaborative, and integrated campaigns. Through such coordinated efforts, the SEARCH Education and Outreach Office would promote a uniform message, communicate with a broad audience, and connect SEARCH outreach activities with IPY education and outreach efforts.

Efforts critical to accomplish the education and outreach goals described above include:

- Develop a detailed education and outreach plan that clearly addresses elements for each target audience and includes methods for evaluating their effectiveness.
- Develop education and outreach content on the SEARCH website directed to each target audience.
- Develop course materials to which individual investigators and projects can contribute.
- Implement an annual college student competition for SEARCH-related research papers.
- Implement a multi-agency SEARCH Research Experience for Teachers (RET) program.

- Initiate planning of informal education programs that are SEARCH-focused, student-centered, and integrated with community monitoring networks, field research programs, and SEARCH datasets.

6.4. Activities and Materials

SEARCH education and outreach can be accomplished through the development and use of a wide range of activities and materials.

Elements that support effective education and outreach infrastructure might include:

- An Education and Outreach Coordinator.
- A web portal that (1) describes SEARCH goals, activities, recent results, and key findings; (2) includes links to SEARCH investigators' websites; (3) provides biographies and background stories (e.g., path to current involvement with arctic science) of SEARCH scientists, northern residents, and others involved in arctic science; (4) provides maps, diagrams, graphs, illustrations, and other resources for educators and SEARCH investigators to use in their education and outreach activities; (5) provides K–12 education materials, including curriculum and activities that address national education standards and are culturally responsive; and (6) includes SEARCH datasets that have been appropriately designed for use in K–16 classrooms.

Elements that support outreach efforts to the general public might include:

- Communication between scientists, science support personnel, and students from the field, office, and classroom (e.g., via e-mail, webcasts/webchats, telephone calls, and distance learning courses).
- Elder Hostel/Life-long Learning Programs, including guided trips and cruises.
- The Arctic Visiting Speakers' Bureau.
- An Arctic Writers and Artists program (including creation of books for K–12 use).
- Local, national, and international media reports and interviews.
- Exhibits for museums, aquariums, and/or science centers.
- Exhibits for government visitor centers (e.g., Public Lands Information Centers, National Park Service Visitor Centers, and Bureau of Land Management Science Centers).

Activities that engage community stakeholders might include:

- Community/citizen observation networks and research projects.
- Presentations to the general public, community groups and civic organizations (e.g., Girl Scouts, Boy Scouts, Rotary, Lions, Elks, school boards, etc.).

Activities directed to K–12 educators and students might include:

- School-based research programs for K–12 and beyond (e.g., the GLOBE Program, an international school-based education and science program; Alaska Lake Ice and Snow Observatory Network [ALISON]; Observing Locally, Connecting Globally [OLCG]; Schoolyard Long Term Ecological Research [SLTER]; and the Alaska Rural Research Partnership [ARRP]).
- Research experiences for educators (e.g., Teachers and Researchers Exploring and Collaborating [TREC]; Teachers Experiencing Antarctic and the Arctic [TEA]).
- Individual student (K–12) research experiences/internships.
- Scientist "adopts" a K–12 student, class, or school.
- K–12 student, class, or school "adopts" a scientist and/or scientific project.
- Classroom visits by scientists, community experts (e.g., Native Elders), students (e.g., college-level), and science support personnel to share knowledge.
- Development of science and mathematics curriculum and educational activities for K–12 classrooms that address national education standards, are culturally responsive, and include both traditional ecological knowledge and SEARCH observations, measurements and model results.

Elements that target college students might include:

- Individual student research experiences/ internships—including ones that target non-science majors.
- An annual research paper competition relating to SEARCH activities.
- Online supplements to course material.

6.5. Summary

Science education and outreach has expanded greatly in recent years, with an expanding group of learners benefiting from increased collaborations within and among the research and education communities. SEARCH offers numerous opportunities to include a wide range of research topics, participants, collaborations, and audiences to broaden awareness and understanding of arctic science. SEARCH education and outreach activities should target a broad audience and utilize web-technologies to create connections that otherwise would not exist. While many compelling suggestions are presented here, this list is by no means comprehensive and will adapt over time, especially with regard to increased outreach and education opportunities catalyzed by the International Polar Year.

Summary

This report, *Study of Environmental Arctic Change: Plans for Implementation During the International Polar Year and Beyond*, summarizes key unresolved science questions and related priority activities within Observing Change, Understanding Change, and Responding to Change categories of SEARCH implementation.

Community discussions before, during, and after the SEARCH Implementation Workshop were guided by the need to understand the complex of pan-arctic change; prioritization of activities focused on advancing SEARCH from a pilot program toward full implementation. Building on the SEARCH Science Plan (SEARCH, 2001) and Implementation Strategy (SEARCH, 2003), an interdisciplinary group of experts identified a set of scientific questions and activities for prioritized implementation of SEARCH with emphasis on the period of the upcoming International Polar Year 2007–2008. The plans outlined in this document, however, reach beyond the IPY time frame.

It is envisioned that the priorities and activities outlined in this report will evolve and be revised to reflect scientific advances, emerging priorities and activities, and increased international coordination of SEARCH as a national program under the International Study of Arctic Change (ISAC).

With input from and collaboration with a broad range of arctic researchers, stakeholders, agencies, and programs, we expect significant advances in our understanding of the nature, extent, and future development of the system-scale changes presently observed in the Arctic.

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Appendix A:
Research Programs Relevant to SEARCH

Alaska Ocean Observing System (AOOS)
A regional component of the developing National Oceanographic Partnership Program, AOOS plans to support moorings and other observing systems as part of a long-term monitoring effort in Alaskan waters.
http://www.aoos.org/

Arctic Borderlands Ecological Co-op
An ecological monitoring program for the northern Yukon region, northeastern Alaska, northern Yukon and northwestern Northwest Territories that brings together science and local and traditional knowledge to focus on the issues of climate change, contaminants and regional development. Since 1994, the co-op has worked with communities to monitor and assess change in the range of the Porcupine Caribou Herd and extending to the Mackenzie Delta. Funding and support come from Canadian, territorial and U.S. government agencies, co-management boards, and Inuvialuit and First Nation councils.
http://www.taiga.net/coop

Arctic Climate Impact Assessment (ACIA)
An international project of the Arctic Council and the International Arctic Science Committee (IASC) to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The aim is to provide useful and reliable information to the governments, organizations and peoples of the Arctic on policy options to meet such changes. An overview of the findings was released in 2004, and a detailed scientific report is expected in 2005.
http://www.acia.uaf.edu/

Arctic Climate System Study (ACSYS)
The scientific goal of this core World Climate Research Programme (WCRP) project was to ascertain the role of the Arctic in global climate by attempting to find answers to the following related questions:
- What are the global consequences of natural or human-induced change in the arctic climate system?
- Is the arctic climate system as sensitive to increased greenhouse gas concentrations as climate models suggest?

The ACSYS Initial Implementation Plan was published in 1994 and revised in 1999. ACSYS ended in 2003, and many of its efforts now fall under the WCRP Climate and Cryosphere (CliC) project.
http://acsys.npolar.no/

Arctic Coastal Dynamics (ACD)
A multi-disciplinary, multi-national forum to exchange ideas and information to improve understanding of circumarctic coastal dynamics as a function of environmental forcing, coastal geology and cryology, and morphodynamic behavior.
http://www.awi-potsdam.de/www-pot/geo/acd.html

Arctic Community-Wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP)
Funded by the NSF Office of Polar Programs (OPP), Arctic-CHAMP is an interdisciplinary effort to construct a holistic understanding of arctic hydrology. Arctic-CHAMP consists of three interacting components:
- Compilation and evaluation of long-term monitoring of the hydrologic cycle;
- Field observations and focused process studies; and
- Simulation modeling operating over multiple time and space domains.

The Arctic-CHAMP synthesis strategy contributed to the development of the NSF Arctic System Science (ARCSS) Program Freshwater projects.
http://arcticchamp.sr.unh.edu

Arctic Environmental Observatory in the Bering Strait (AEO)
An NSF-funded cooperative research project involving studies of marine mammals and benthic communities on the shallow Bering and Chukchi shelves, community outreach activities at Little Diomede Island, the development of a seawater environmental system at Diomede Village, and community outreach activities at Little Diomede Island. Data collection began in 2000.
http://arctic.bio.utk.edu/AEO/

Arctic Human Development Report (AHDR)
Published in November 2004, the first comprehensive assessment of human well-being covering the entire arctic region was mandated under the Arctic Council's 2002 Ministerial Declaration to provide a comprehensive knowledge base for the work of the Council's Sustainable Development Programme. Based on contributions from some 90 scientists, the report offers a wide-ranging scientific assessment of achievements and challenges relating to human development in the Arctic.
http://www.svs.is/AHDR

Arctic Monitoring and Assessment Programme (AMAP)
Established in 1991, the Arctic Monitoring and Assessment Programme is one of five Working Groups of the Arctic Council. The primary function of AMAP is to advise the governments of the eight arctic countries on matters relating to threats to the arctic region from pollution, and associated issues. AMAP has produced a series of high quality scientifically-based assessments of the pollution status of the Arctic.
http://www.amap.no

Arctic Observing Network (AON)
A focused study of the Polar Research Board (PRB) to provide guidance on the design of an arctic land, atmosphere, and ocean observing network. The project is sponsored by the NSF Office of Polar Programs (OPP).
http://dels.nas.edu/prb/aon/about.shtml

Arctic Ocean Model Intercomparison Project (AOMIP)
An international effort to identify systematic errors in Arctic Ocean models under realistic forcing. This multi-institutional project is supported by the International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF) and the NSF Office of Polar Programs (OPP). The project is an official activity of the Arctic Climate System Study/Climate and Cryosphere Numerical Experimentation Group (ACSYS/CliC NEG).
http://fish.cims.nyu.edu/project_aomip/overview.html

Arctic Paleoclimate and its Extremes (APEX)
Proposed for IPY 2007–2008, APEX would form an umbrella program for European arctic activities related to paleoclimate studies during IPY. The project would continue beyond IPY as a European Science Foundation initiative committed to the promotion of international research in polar regions, using the model previously advocated by the Polar North Atlantic Margins (PONAM) and Quaternary Environments of the Eurasian North (QUEEN) programs.
IPY # 183: http://www.ipy.org/development/eoi/details.php?id=183

Arctic / Subarctic Ocean Fluxes (ASOF)
An international program that aims to measure and model the variability of fluxes between the Arctic Ocean and the Atlantic Ocean with a view to implementing a longer-term system of critical measurements needed to understand the high-latitude ocean's steering role in decadal climate variability. Begun in 2000, ASOF is a subprogram of the International Study of Arctic Change (ISAC) and an endorsed project of Climate Variability and Predictability Study (CLIVAR) and Climate and Cryosphere (CliC).
http://asof.npolar.no

Arctic System Science (ARCSS) Program
The NSF Arctic System Science (ARCSS) Program supports research aimed at achieving a system level understanding of the Arctic. Begun in 1989, ARCSS is one of NSF's contributions to the U.S. Global Change Research Program (USGCRP). The program supports most of its research through special targeted announcements developed in close cooperation among NSF, the ARCSS research community, and the ARCSS committee.
http://www.arcus.org/ARCSS

Atmospheric Radiation Monitoring (ARM)
A U.S. Department of Energy (DOE) program created to help resolve scientific uncertainties related to global climate change, with a specific focus on the crucial role of clouds and their influence on radiative feedback processes in the atmosphere. This program is the largest global change research program supported by the DOE. One of its three primary cloud and radiation testbeds is on the North Slope of Alaska (NSA), where heavily instrumented sites gather massive amounts of climate data.
http://www.arm.gov/

Baseline Surface Radiation Network Program (BSRN)
Designed to provide frequent, state-of-the-art measurements of surface radiation fluxes according to internationally agreed standard operational and instrument calibration procedures. These measurements are needed to assess theoretical treatments of radiative transfer in the atmosphere, to verify climate model computations, and for monitoring regional trends in surface radiation. The Solar and Thermal Atmospheric Radiation (STAR) group, a subdivision of the NOAA Climate Monitoring and Diagnostics Laboratory, provides management oversight for BSRN.
http://www.cmdl.noaa.gov/star/bsrn.html

Beaufort Gyre Exploration Project (BGEP)
Supported by the NSF Office of Polar Programs (OPP) and the Woods Hole Oceanographic Institution (WHOI) Ocean and Climate Change Institute, this program has been continuously monitoring freshwater and heat content in this climatically sensitive region of the Arctic Ocean since 2002. Current observations will be maintained through at least 2008.
http://www.whoi.edu/beaufortgyre/index.html

Bering Ecosystem Study (BEST)
A planned ten-year research program (2007–2017) focused on the marine ecosystems of the eastern Bering Sea and the people dependent on its resources. To improve understanding of the variables and processes shaping all aspects of the Bering Sea, from physical forcing (atmosphere and ocean) to food web responses including fish, seabirds, marine mammals, and humans, fundamental research in the physical, biological, and social sciences, appropriate for funding by NSF, will be linked to more applied studies funded by other agencies with interests in the region. BEST is a component of SEARCH. The BEST science plan was published in 2004, and an Implementation Plan was published online in fall 2005.
http://www.arcus.org/Bering/index.html

Bipolar Climate Machinery (BIPOMAC)
Proposed for IPY 2007–2008, BIPOMAC is an international study of the interplay of northern and southern polar processes in driving and amplifying global climate variability as recorded in high-resolution (Pleistocene-Holocene) marine, terrestrial and ice core records. Building on several proposed IPY expeditions, the project will include (i) process studies based on an iron fertilization experiment to test the effect on CO_2 sequestration and to better understand resulting sedimentary proxies, (ii) ground truthing based on well synchronized polar ice volume/extent records, and (iii) numerical modeling of ice-atmosphere-ocean processes.
IPY # 62: http://www.ipy.org/development/eoi/details.php?id=62

Boreal Ecosystem-Atmosphere Study (BOREAS)
A large-scale international interdisciplinary experiment in the northern boreal forests of Canada focused on improving understanding of the exchanges of radiative energy, sensible heat, water, CO_2 and trace gases between the boreal forest and the lower atmosphere. A primary objective of BOREAS is to collect data at multiple spatial scales to improve computer simulation models of the processes controlling these exchanges. BOREAS was funded by both Canadian and U.S. agencies. The field campaign ended in 1996.
http://www-eosdis.ornl.gov/BOREAS/bhs/BOREAS_Home.html

Census of Marine Life (COML)
A global network of researchers in more than 70 nations engaged in a ten-year initiative (2000–2010) to assess and explain the diversity, distribution, and abundance of marine life in the oceans. COML is funded by participating government agencies and is affiliated with several intergovernmental international organizations. COML includes a program on Arctic Ocean Diversity.
http://www.coml.org/

Circumarctic Environmental Observatories Network (CEON)
CEON is a developing network of terrestrial and freshwater observation platforms, science experts and network partners promoting the collection of environmental data from the Arctic. CEON observation platforms include, but are not limited to, land and freshwater observatories, research infrastructures, former research sites, data and image archive centers, and localized community monitoring programs. Sponsors include NSF, the Royal Swedish Academy of Sciences' Abisko Scientific Research Station, and the Scandinavian-North European Network of Terrestrial Field Bases (SCANNET).
http://www.ceoninfo.org/about/index.htm

Circumpolar Active Layer Monitoring (CALM)
Funded by NSF and administered by the University of Cincinnati, this program is designed to monitor and model changes in the thickness of the active layer above permafrost. It currently consists of 81 research sites, where researchers from ten nations collect data using a standard protocol. The CALM network began as a voluntary effort in 1991.
http://www.geography.uc.edu/~kenhinke/CALM/

Climate and Cryosphere (CliC)
The principal goal of this international project is to assess and quantify the impacts that climate variability and change have on components of the cryosphere, and the consequences of these impacts for the climate system. An additional goal is to determine the stability of the global cryosphere. To support these goals, CliC seeks to enhance and coordinate efforts to monitor the cryosphere, to study climate-related processes involving the cryosphere, to model and understand the cryosphere's role in the climate system, and to assess changes in the cryosphere as indicators of global climate change. CliC was established by the World Climate Research Programme (WCRP) in 2000; the CliC science and coordination plan was published in 2001. In 2004, the Scientific Committee on Antarctic Research (SCAR) became a cosponsor of the project.
http://clic.npolar.no/

Climate Variability and Predictability (CLIVAR)
Started in 1995, CLIVAR is an international research program to describe and understand climate variability and predictability on seasonal to centennial time-scales, identify the physical processes responsible, including anthropogenic effects, and develop modeling and predictive capabilities where practicable. CLIVAR is part of the wider World Climate Research Programme (WCRP). The primary focus of CLIVAR is on the atmosphere and the ocean and their interactions.
http://www.clivar.org/index.htm

Conservation of Arctic Flora and Fauna (CAFF)
One of the Working Groups of the Arctic Council, CAFF's primary role is to advise the arctic governments on conservation matters and sustainable use issues of international significance and common concern. Since its inaugural meeting in 1992, the CAFF Working Group has sponsored a variety of projects, including circumpolar conservation strategies for murres (guillemots) and eiders, a circumpolar network of protected areas, documentation of traditional ecological knowledge, circumpolar expert networks for monitoring key species, an atlas of rare endemic vascular plants of the Arctic, an assessment of the conservation status of arctic migratory birds, and development of integrated ecosystem management strategies in the Russian Arctic.
http://www.caff.is/

Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES)
A new project funded by the European Community (EC) Framework Programme that will seek international collaboration to support investigations of three core themes: sea ice changes, atmosphere and air-ice interactions, and oceans.
IPY Full Proposal: http://www.ipy.org/development/eoi/proposal-details.php?id=40

Digital Library for Earth System Education (DLESE)
A geoscience community resource that supports teaching and learning about the Earth system, DLESE is funded by NSF and is being built by a community of educators, students, and scientists to support earth system education at all levels and in both formal and informal settings.
http://www.dlese.org/dds/index.jsp

Earth Observing System (EOS)
The centerpiece of NASA's Earth Science Enterprise, EOS is the first observing system to offer integrated measurements of the Earth's processes. It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.
http://eospso.gsfc.nasa.gov/index.php

Ecosystem Studies of Sub-Arctic Seas (ESSAS)
A new regional Global Ecosystem Dynamics (GLOBEC) program, which addresses and compares the effects of changing climate on subarctic seas. The Bering Ecosystem Study (BEST) is the U.S. component of ESSAS. The ESSAS science plan was published in 2005, and an implementation plan is under development.
http://www.pml.ac.uk/globec/structure/regional/essas/essas.htm

Freshwater Cycle Projects
Funded in 2002 by the ARCSS program, these projects bring together atmospheric, terrestrial, and marine researchers to study the sources, fates, and variations in the pan-arctic freshwater cycle. These projects represent an ARCSS contribution to SEARCH that will:

- explore decade to century variability of the arctic water cycle, and
- link land dynamics to ocean water mass and circulation through the stocks and fluxes of fluxes of freshwater.

http://arcticchamp.sr.unh.edu/

Global Atmosphere Watch (GAW) Program
Established in 1989, GAW is a major World Meteorological Organization (WMO) program. Its mission is to:

- make reliable, comprehensive observations of the chemical composition and selected physical characteristics of the atmosphere on global and regional scales;
- provide the scientific community with the means to predict future atmospheric states; and
- organize assessments in support of formulating environmental policy.

GAW is considered the atmospheric chemistry component of the Global Climate Observing System (GCOS).
http://www.wmo.ch/web/arep/gaw/gaw_home.html

Global Observing Systems
Three sister observing systems: the Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS), and Global Terrestrial Observing System (GTOS), co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU). Each system is part of a larger plan to provide comprehensive, global data on the biophysical environment, ecosystem processes and the socioeconomic forces that influence them.

Global Climate Observing System (GCOS)
Established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. GCOS is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for monitoring the climate system, for detecting and attributing climate change, for assessing the impacts of climate variability and change, and for supporting research toward improved understanding, modeling, and prediction of the climate system. GCOS does not itself directly make observations nor generate data products, but it facilitates observing by national or international organizations in support of their own requirements as well as of common goals.
http://www.wmo.ch/web/gcos/gcoshome.html

Global Ocean Observing System (GOOS)
Established in 1992, GOOS is a permanent global system for observations, modeling, and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS will provide accurate descriptions of the present state of the oceans, including living resources, continuous forecasts of the future conditions of the sea for as far ahead as possible, and the basis for forecasts of climate change.
http://ioc.unesco.org/goos/

Global Terrestrial Observing System (GTOS)
Established in 1996, GTOS is a program for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change.
http://www.fao.org/gtos/

Global Precipitation Measurement (GPM)
Currently in the formulation phase, this NASA mission aims to improve ongoing efforts to predict climate, improve the accuracy of weather and precipitation forecasts, and provide more frequent and complete sampling of the Earth's precipitation. Carrying both a dual frequency radar instrument and a passive microwave radiometer, the mission's core spacecraft will serve as a calibration standard for an international constellation of NASA and contributed spacecraft, which will provide frequent precipitation measurements on a global basis. The spacecraft observations will be complemented with calibration/validation sites and a Global Precipitation Data Center. The core spacecraft's instrumentation and design are currently in development.
http://gpm.gsfc.nasa.gov/

Global Terrestrial Network for Permafrost (GTN-P)
Initiated by the International Permafrost Association (IPA) to organize and manage a global network of permafrost observatories for detecting, monitoring, and predicting climate change. The network, authorized under the Global Climate Observing System (GCOS) and its associated organizations, consists of two observational components: the active layer (the surface layer that freezes and thaws annually) and the thermal state of the underlying permafrost.
http://www.gtnp.org/

Holocene Climate Variability (HOLIVAR)
A European Science Foundation program, this project seeks to bring together European scientists interested in climate variability of the last 6,000 years. The over-arching research questions concern how and why climate has varied naturally on different time-scales (annual to centennial) over this period and how an understanding of past variability can improve the predictability of climate models.
http://www.holivar2006.org/
http://www.esf.org/esf_article.php?language=0&article=99&domain=3&activity=1

Human Dimensions of the Arctic System (HARC)
HARC was created in 1997 as a component of the ARCSS program. The aim of HARC is to better understand the role of humans in the functioning of and interactions among the various physical, biological, and social components of the arctic system and the significance of changes in the arctic system for people in the Arctic and across the globe. HARC also provides a way to examine the policy implications of ARCSS research through stakeholder collaborations that examine decision-making in light of environmental change. HARC seeks to identify the needs of decision makers and to improve the ability of ARCSS researchers to communicate their findings effectively.
http://www.arcus.org/harc/index.html

Integrated Arctic Ocean Observing System (iAOOS)
Proposed for IPY 2007–2008, iAOOS would assemble a comprehensive observing system devoted to the northern ocean-ice-atmosphere system and provide a pan-arctic perspective by bringing together investigators coordinated by the science steering groups of the Study of Environmental Arctic Change (SEARCH) and Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) and their Arctic/ Subarctic Ocean Fluxes (ASOF) subgroups, with oversight by the international Arctic Ocean Sciences Board (AOSB) and Climate and Cryosphere (CliC) Committees.
http://www.aosb.org/Dickson_IPY_EoI.doc

International Arctic Buoy Program (IABP)
Established in 1978 as the Arctic Ocean Buoy Program, IABP maintains a network of drifting buoys throughout the central Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes, including support to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) Programme. A cooperative effort, the IABP is funded and managed by its participants who provide equipment, services, and program coordination, as well as funding.
http://iabp.apl.washington.edu/

International Conference on Arctic Research Planning (ICARP)
The goal of ICARP is to prepare arctic research plans to guide international cooperation over the next 10–15 years. The first ICARP was held in 1995, and the resulting projects contributed significantly to arctic research and knowledge. The second ICARP is planned for November 10–12, 2005. In preparation, more than 140 scientists are reviewing 13 draft research plans. The outcome of ICARP will complement ongoing national and international programs and planned major initiatives, such as the International Polar Year (IPY), in order to guide international cooperation over the next decade of change in the Arctic. Sponsors include Alfred Wegener Institute for Polar and Marine Research (AWI), Arctic Ocean Sciences Board (AOSB), Danish Polar Center (DPC), International Arctic Science Committee (IASC), National Oceanic and Atmospheric Administration (NOAA), NSF, and the U.S. Arctic Research Commission (USARC).
http://www.icarp.dk

International Geosphere-Biosphere Programme (IGBP)
Established by the International Council for Science (ICSU) in 1986, IGBP is one of four international global environmental change research programs. IGBP works to describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth System, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. IGBP collaborates closely with the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP), and DIVERSITAS, an international program of biodiversity science.
http://www.igbp.kva.se

International Partnerships in Ice Core Sciences (IPICS)
The National Ice Core Laboratory Science Management Office organized an International Partnerships in Ice Core Sciences (IPICS) workshop, supported by NSF. Fifty-five scientists, engineers, and funding agency representatives from Australia, Canada, China, Denmark, France, Germany, Italy, Japan, Russia, Switzerland, the U.K. and the U.S. attended the March 2004 workshop. A workshop report is available, and a follow up workshop is planned for fall 2005.
http://www.nicl-smo.unh.edu/IPICS/index.html

International Polar Year 2007–2008 (IPY)
An internationally coordinated campaign of polar observations, research, and analysis designed to further understanding of physical and social processes in the polar regions, examine their globally-connected role in the climate system, and establish research infrastructure for the future. The IPY will run from March 2007 through March 2009 to allow observations during all seasons and two summer field seasons in both polar regions. The International Council for Science (ICSU) is leading the planning for IPY.
http://www.ipy.org/

International Study of Arctic Change (ISAC)
A developing international counterpart to the Study of Environmental Arctic Change (SEARCH), jointly sponsored by the Arctic Ocean Sciences Board (AOSB) and International Arctic Science Committee (IASC). ISAC builds on the SEARCH science plan and is being developed as a long-term, cross-disciplinary program that will document changes in the Arctic.
http://www.aosb.org/isac.html

International Tundra Experiment (ITEX)
A network of experiments focusing on the impact of climate change on selected plant species in tundra and alpine vegetation. ITEX is a collaborative effort begun in 1992 involving more than eleven countries, including all the arctic nations. Researchers carry out similar, multi-year plant manipulation experiments that allow them to compare annual variation in plant performance with respect to phenological response to climate conditions.
http://www.itex-science.net/

Land-Shelf Interactions Initiative (LSI)
An outgrowth of the Russian-American Initiative for Shelf-Land Environments in the Arctic (RAISE) that has a goal of developing new research opportunities in the arctic coastal zone. The 2003 LSI Science Plan contributed to the development of the Study of the Northern Alaska Coastal System (SNACS) announcement of opportunity in 2004.
http://arctic.bio.utk.edu/screen_LSI_science_plan.pdf

Long-Term Ecological Research (LTER) Network
A collaborative effort involving more than 1800 scientists and students investigating ecological processes over long temporal and broad spatial scales. The U.S. network of 26 sites promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs. NSF established the U.S. LTER program in 1980. Related efforts are the International LTER and Schoolyard LTER networks.
http://www.lternet.edu/

Long-Term Hydrologic Observatories (LTHO)
With guidance from the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI), NSF expects to develop an enhanced hydrologic research program focusing upon the development of a series of experimental observatories. An Arctic Long-term Hydrological Observatory (LTHO) has been proposed for IPY 2007–2008.
http://www.cuahsi.org/
IPY # 201: http://www.ipy.org/development/eoi/details.php?id=201

Mooring-Based Arctic Ocean Observational System (MAOOS)
Proposed for IPY 2007–2008, MAOOS is a coordinated large-scale mooring-based observational program of the Eurasian and Canadian basins of the Arctic Ocean that would provide a quantitative, observationally based assessment of circulation, water mass transformations, biogeochemical fluxes, key mechanisms of variability in the Arctic Ocean, and links to the lower-latitude processes. Linked with North Atlantic and Canadian Archipelago observations provided by other international programs like Arctic/Subarctic Ocean Fluxes (ASOF), the large-scale oceanographic survey will coordinate long-term measurements over a vast polar/sub-polar region.
http://www.frontier.iarc.uaf.edu/NABOS/connections.php
IPY # 915: http://www.ipy.org/development/eoi/details.php?id=915

Nansen and Amundsen Basins Observational System (NABOS)
The overall purpose of this international observational program is to provide a quantitative, observationally based assessment of circulation, water mass transformation, and their mechanisms in the Arctic Ocean via a set of moorings deployed along the shelf slope of the basins, where major transports of water, heat, and salt occur. The NABOS field program began in 2002. CABOS is a parallel effort in the Canadian Basin.
http://www.frontier.iarc.uaf.edu/NABOS

National Ecological Observatory Network (NEON)
NSF has proposed that Major Research Equipment and Facilities Construction (NSF-MREFC) funds be used to implement a National Ecological Observatory Network (NEON).
http://www.neoninc.org/

National Science Foundation Office of Polar Program (NSF-OPP)
The Office of Polar Programs (OPP) manages and initiates NSF funding for basic research and its operational support in the Arctic and the Antarctic. OPP has two science sections—one each for the Arctic and the Antarctic. The Arctic Sciences Section includes programs in

- Arctic Cyberinfrastructure and Sensors
- Arctic Natural Sciences
- Arctic Research and Education
- Arctic Research Support and Logistics
- Arctic Social Sciences
- Arctic System Science

A number of other NSF programs also fund arctic research.
http://www.nsf.gov/div/index.jsp?div=ARC

North Pacific Research Board (NPRB)
The mission of the NPRB is to develop a comprehensive science program of the highest caliber to enhance understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems and fisheries. Its new science plan emphasizes the development of integrated ecosystem research programs. The NPRB approved about $2.2 million in research funding in 2002, $7 million in 2003, $3.6 million in 2004, and $5.9 million in 2005.
http://www.nprb.org/

North Pole Environmental Observatory (NPEO)
First established in 2000, the purpose of the observatory is to help track and understand ongoing changes in the arctic environment, and to increase the availability of long-term environmental data in the Arctic by providing a data and infrastructure resource for other polar science and climate investigations. Supported by NSF, the NPEO includes an automated drifting station of buoys fixed to the sea ice, an ocean mooring, and airborne hydrographic surveys. NPEO data are permanently archived at the ARCSS Data Coordination Center.
http://psc.apl.washington.edu/northpole/index.html

Northern High Latitude Climate Variability During the Last Millennium (NORCLIM)
Proposed for IPY 2007–2008, NORCLIM is an international program investigating northern high latitude climate variability during the past 2,000 years, with implications for human settlement. The project emphasizes permafrost and sea ice and the contrasting climatic trends (south)west of Greenland when compared with the northeast Atlantic region.
IPY # 207: http://www.ipy.org/development/eoi/details.php?id=207

Ocean-Atmosphere-Sea Ice-Snowpack (OASIS)
OASIS is an international multi-disciplinary effort to study Ocean-Atmosphere-Sea Ice-Snowpack Interactions in polar regions. The specific focus is on the study of the impact of Air-Surface Interactions and chemical exchange between the title reservoirs in polar regions.
http://www.oasishome.net

Paleoenvironmental Arctic Sciences (PARCS)
Arctic paleoclimate research straddles the NSF Arctic System Science (ARCSS) and Earth Systems History (ESH) Programs. Paleoenvironmental research activities in the Arctic have been coordinated through a PARCS office and Science Steering Committee (SSC) funded by ARCSS; this funding expired 31 October 2005.
http://www.ncdc.noaa.gov/paleo/parcs/

Pan-arctic Cycles, Transitions, and Sustainability (PACTS)
A research program proposed for the Arctic System Science (ARCSS) Program, focused on transitions and changes in arctic biophysical, biogeochemical, and social systems. The 2003 PACTS science plan contributed to the development of the 2004 SNACS announcement of opportunity.
http://www.arcus.org/arcss/snacs/files/PACTS_Plan_screen.pdf

Past Global Changes (IGBP-PAGES) Circumpolar Arctic Paleoenvironments (CAPE)
One of eight International Geosphere-Biosphere Programme (IGBP) projects, PAGES is designed to provide a longer time context for the dynamics of the Earth System and to document past variability toward understanding present and predicting future change. One PAGES project, Circumpolar Arctic Paleoenvironments (CAPE) facilitates integration of arctic paleoenvironmental research on terrestrial and adjacent margins covering over the last few glacial cycles.
http://www.pages-igbp.org/
http://www.ncdc.noaa.gov/paleo/cape/cape.html

Polar Radar for Ice Sheet Measurements (PRISM)
Through grants from NSF and NASA, scientists and engineers at the University of Kansas are developing and utilizing innovative radar and robotic rovers to measure ice thickness and determine bedrock conditions below the ice sheets in Greenland and Antarctica.
http://ku-prism.org/index.html

Program in Arctic Regional Climate Assessment (PARCA)
PARCA is a NASA project formally initiated in 1995 by combining into one coordinated program various efforts, started in 1991, to assess whether airborne laser altimetry could be applied to measure ice-sheet thickness changes. It has the prime goal of measuring and understanding the mass balance of the Greenland ice sheet. PARCA is a program at the Cooperative Institute for Research in Environmental Sciences (CIRES).
http://cires.colorado.edu/science/pro/parca/

Russian-American Initiative for Shelf-Land Environments in the Arctic (RAISE)
A multidisciplinary, multi-investigator research initiative supported by the ARCSS program and the Russian Foundation for Basic Research. It supported U.S. and Russian research on the land-shelf system of the Russian Arctic over prehistoric, historic and current time intervals. The ultimate objective is to integrate scientific knowledge on the biogeochemical processes affecting global change at the land-shelf boundary in the Eurasian Arctic.
http://arctic.bio.utk.edu/RAISE/index.html

Scandinavian / North European Network of Terrestrial Field Bases (SCANNET)
A network of field site leaders, research station managers and user groups in northern Scandinavia and Europe that are collaborating to improve comparative observations and access to information on environmental change in the North. SCANNET is establishing a scientifically strategic network of field bases covering many of the environmental and land use conditions found in northern Europe. SCANNET will facilitate comparative, regional science activities seeking to identify, record and understand environmental changes.
http://www.envicat.com/scannet/Scannet

Sea Ice Mass Budget of the Arctic (SIMBA)
A 2005 workshop sponsored by NSF to discuss current knowledge of arctic wide sea ice mass balance and variability, and to determine where new observation and/or modelling campaigns are required to improve understanding of the variability and mechanisms of the sea ice thickness distribution. Participants considered the sea ice component of pan-arctic observing system, and discussed how to monitor the Northern Hemisphere sea ice mass budget.
http://www.iarc.uaf.edu/workshops/SIMBA_2005/index.php

Shelf-Basin Exchange (SBE)
The Shelf-Basin Exchange (SBE) project is one of five elements of the ocean program of the proposed international Arctic Ocean Observing System (iAOOS). The SBE project envisions a coordinated research effort through a framework of time series moorings situated on radial circumarctic SBE transect lines, with process studies and paleoceanographic coring that can be coordinated internationally.
http://sbi.utk.edu/InternationalPolarYear.htm
http://www.joss.ucar.edu/aosb/SBE.html

Study of Northern Alaska Coastal System (SNACS)
In early 2004, NSF released an announcement of opportunity for the Study of the Northern Alaska Coastal System (SNACS). The solicitation drew on two science plans from the ARCSS research community: Land-Shelf Interactions (LSI) and Pan-Arctic Cycles, Transitions, and Sustainability (PACTS). The announcement defined the coastal system very broadly, from the Brooks Range to the ice edge. In response, NSF received 43 proposals for 23 projects requesting a total of $24 million, not including logistics costs. NSF was able to fund six projects for a total of $7.27 million in FY 2005 and 2006.
http://www.arcus.org/arcss/snacs/index.php

Surface Heat Budget of the Arctic Ocean (SHEBA)
An eight-year project (1995–2002) that acquired data on the canopy of pack ice that covers the surface of the Arctic Ocean. Researchers at the ice station studied the atmosphere, ocean, sea ice, and snow cover, to determine how these interact through the surface heat budget and how the interactions affect climate. SHEBA is an element of the U.S. Global Change Research Program and the ARCSS program. The primary sponsor of SHEBA was NSF (Office of Polar Programs, Division of Ocean Sciences, and Division of Atmospheric Sciences), with significant direct funding provided by the Office of Naval Research.
http://sheba.apl.washington.edu/

Survey of Arctic Living Conditions (SLiCA)
Funded by NSF, the goal of this international study is to develop an integrated set of individual, household, community, and regional databases for use in comparative analyses of living conditions among arctic populations. SLiCA is part of the Sustainable Development Program of the Arctic Council and will ultimately contribute new data on living conditions to the Sustainable Development Program.
http://www.arcticlivingconditions.org/

Western Arctic Shelf-Basin Interactions (SBI)
Funded through the Arctic System Science (ARCSS) Program and the Office of Naval Research, this multi-investigator project investigates the production, transformation, and fate of carbon at the shelf-slope interface in the Chukchi and Beaufort seas. The field program was completed in 2004, and investigators are synthesizing data through 2006. Phase III (2007–09) will focus on modeling potential impacts of change on the physical and biological linkages between these shelves and adjacent basins.
http://sbi.utk.edu/

World Glacier Monitoring Service (WGMS)
Collects standardized observations on changes in mass, volume, area and length of glaciers with time, as well as statistical information on the distribution of perennial surface ice in space (glacier inventories). The WGMS receives financial and logistic support from the University of Zurich and the Swiss Federal Institute of Technology, Zurich.
http://www.geo.unizh.ch/wgms/index.html

Appendix B: Science Planning Documents Relevant to SEARCH

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Arctic Climate Impact Assessment (ACIA). 2004. *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge: Cambridge University Press. 139 pp.

Arctic Human Development Report (AHDR). 2004. Akureyri, Iceland: Stefansson Arctic Institute. 242 pp.

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Bering Ecosystem Study (BEST) Science Plan. 2004. Fairbanks, Alaska: Arctic Research Consortium of the U.S. 82 pp.

Census of Marine Life (COML) Research Plan. 2005. Washington, DC: Census of Marine Life Secretariat. 57 pp.

CLIVAR—A Research Programme on Climate Variability and Predictability for the 21st Century. 1997. Southampton, UK: International CLIVAR Project Office. 47 pp.

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Appendix C: Workshop Agenda

23–25 May 2005

The National Conference Center
Lansdowne, VA

Day 1 - Monday, 23 May 2005

9:00 a.m.	Welcome and Overview SEARCH Status and Implementation International Study of Arctic Change (ISAC)	Peter Schlosser Chair, SEARCH SSC Lamont-Doherty Earth Observatory
9:40 a.m.	Remarks from the National Science Foundation	Karl Erb Director, NSF Office of Polar Programs
10:00 a.m.	Remarks from the Interagency Program Management Committee (IPMC)	Neil Swanberg Chair, IPMC National Science Foundation
10:20 a.m.	**BREAK**	
10:45 a.m.	Priorities for Observing Arctic Change: Implementation of SEARCH observations	Hajo Eicken Chair, Observing Change Panel University of Alaska Fairbanks
11:10 a.m.	Priorities for Understanding Arctic Change: Priorities for data analysis, synthesis, assimilation, and modeling	John Walsh Chair, Understanding Change Panel University of Alaska Fairbanks
11:35 a.m.	Priorities for Responding to Arctic Change: Priorities for adaptive response to change	Jack Kruse Chair, Responding to Change Panel University of Massachusetts
12:00 p.m.	**LUNCH** *(Organizing Committee meets during lunch)*	
1:00 p.m.	Charge to Breakout Groups	Peter Schlosser
1:30 p.m.	Breakout Session: Panel Groups *All participants will break into three groups to discuss panel white papers. The three breakout groups will be composed of corresponding panel members (Observing, Understanding, Responding to Change), with additional participants assigned to breakout groups according to expertise and interest.* Observing Change Understanding Change Responding to Change	

3:00 p.m.	**BREAK**

3:30 p.m. Breakout Session: Working Groups

The SEARCH SSC has identified several areas within the SEARCH Implementation Strategy that require specific attention in order to set SEARCH priorities and draft a detailed implementation plan. Workshop participants will break into the following working groups to address these specific areas of SEARCH activities, using the Observing, Understanding, and Responding to Change white papers as a guiding framework:

- Terrestrial Ecosystems
- Distributed Marine Observations (DMO): Physical Observations
- Distributed Marine Observations (DMO): Ecosystems
- Distributed Atmospheric Observations
- Terrestrial Hydrology and Cryosphere
- Human Dimensions
- Paleo/Long-term Observations
- Data and Data Products
- Outreach and Education

5:30 p.m. Brief plenary: Review progress and Tuesday's plan

6:00 p.m. Adjourn for day

6:15 p.m.	**DINNER**
	(Organizing Committee and working group representatives meet during dinner)

Day 2 - Tuesday, 24 May 2005

8:30 a.m.	Plenary Session: SEARCH relevant programs	
	EU Damocles	Craig Lee
	USGS Carbon Cycles Science Program	Richard Alley
	Brief syntheses by panel chairs of progress in working groups	
		Jack Kruse, Responding to Change
		Matthew Berman, Understanding Change
10:00 a.m.	**BREAK**	
10:30 a.m.	Brief syntheses of progress in working groups continued	Hajo Eicken, Observing Change
11:00 a.m.	Plenary Session: Discussion	Peter Schlosser
12:00 p.m.	**LUNCH**	
1:00 p.m.	Breakout Session: Working Groups *Working Groups will continue to work on specific areas of SEARCH implementation, guided by the morning plenary session presentations and discussion.*	
2:45 p.m.	Plenary Session: Working Group Presentations	
3:30 p.m.	**BREAK**	
4:00 p.m.	Breakout Session: Panel Groups *Participants will break into the three panel groups to review working group progress and discuss integration into panel white papers.*	
6:00 p.m.	Adjourn for day	
6:15 p.m.	**DINNER** *(Organizing Committee meets during dinner)*	

DAY 3 – WEDNESDAY, 25 MAY 2005

8:00 a.m.	Putting it all together: Workshop report and today's goals	Peter Schlosser
8:30 a.m.	Plenary Session: Panel Presentations *Panel chairs or representatives will present progress of panel group and discuss integration of working group discussions into panel white papers.*	
10:00 a.m.	**BREAK**	
10:30 a.m.	Breakout Session: Panel Groups *Participants will break into panel groups to finalize priorities for Observing, Understanding, and Responding to Change activity areas.*	
12:00 p.m.	**LUNCH**	
1:00 p.m.	Plenary Session: Panel reports to plenary *Final plenary reports and discussion on development of SEARCH priorities.*	
2:30 p.m.	Next steps, writing tasks, assignments, deadlines, closing comments	
3:00 p.m.	Meeting adjourns (except for panel chairs and SSC)	
3:30 p.m.	Panel chairs and SSC meet as one group to discuss final workshop report	
4:30 p.m.	Meeting adjourns for panel chairs and SSC	

Appendix D: Workshop Participant List

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