SEARCH Observing Change Panel (OCP) Position Paper

Preparation for SEARCH Implementation Workshop,
Lansdowne, Va., 23-25 May 2005
05/16/05 DRAFT

1. INTRODUCTION

Conceived as an integrated, interdisciplinary approach to the study of a complex of sweeping, interrelated changes in the arctic environment observed over the past few decades, the Study of Environmental Arctic Change (SEARCH SSC, 2001) initiative is now at a critical juncture. While the origins and driving forces of change are still not clear, evidence is accumulating that it is more than an ephemeral phenomenon, and not necessarily part of natural variability inherent to the arctic climate system (UCP, 2005). Arctic residents as well as government and industry in circum-Arctic nations and beyond have acknowledged these environmental changes and are beginning to integrate them into their daily lives and future plans.

Research activities motivated by or related to SEARCH have received both formal and informal support through various funding agencies (see http://www.arcus.org/search/searchprojects for listing of activities). On a pan-Arctic scale, in addition to initial SEARCH efforts, an international component to SEARCH--the International Study of Arctic Change (ISAC)--has led to first discussions of coordination of research efforts. The International Polar Year 2007/08 (IPY) offers an opportunity to consolidate and expand existing, often opportunistic studies and to implement a network or system of measurements that is driven by the needs identified within the scientific community as well as by stakeholders and planners. In order to provide guidance from different perspectives and open a channel for community and stakeholder input during this period of SEARCH evolution and implementation, the SEARCH Science Steering Committee (SSC) has established three panels: Observing Change (OCP), Understanding Change (UCP), and Responding to Change (RCP).

2. AIMS OF OCP POSITION PAPER

The aims of the OCP as spelled out in the SEARCH Implementation Strategy (SEARCH SSC and IWG, 2003) are to provide advice on the observation component of SEARCH implementation, communicate with the SEARCH SSC, UCP and RCP to ensure integration of planning, modeling and observation efforts, and to track and oversee the observation program. The SEARCH Implementation Workshop in May 2005 will result in a report assessing the status of SEARCH science and identifying priorities for implementation at a level of detail that goes beyond the SEARCH Implementation Strategy.

The goals of this OCP position paper are to engage the scientific community, stakeholders and planners in an exchange that includes the following goals: (1) review the scientific motivation for observations within the different disciplinary components of

SEARCH, (2) provide an overview of existing observation programs, (3) prioritize existing measurements, as well as those required to meet the SEARCH science objectives, and (4) discuss strategies of integrating different sets of observations and reconciling measurement demands by the scientific and stakeholder community. The OCP envisages that through continued incorporation of community input, the position paper will become a living document that provides guidance to funding agencies seeking to implement components to SEARCH as well as researchers and stakeholders interested in the measurement strategy. In order to achieve this goal, we propose to implement a web-based information and discussion site that integrates the input from the three SEARCH panels and serves as a portal and input channel.

3. GENERAL REMARKS ON IMPLEMENTING A SEARCH OBSERVATION SYSTEM

A well-designed pan-Arctic SEARCH observation system needs to address a number of challenges. A "bottom-up" approach to observation network design, aimed to further scientific understanding of arctic system variability and feedbacks, needs to be tempered by the needs of stakeholders and planners. The latter may require both long-term prediction and modeling (as outlined in UCP, 2005) as well as near-real time observations that are of immediate value in decision-making (see RCP, 2005). From the perspective of circum-Arctic native populations as well as other stakeholders, SEARCH has a long way to go at this point. Scenarios addressed by the Arctic Climate Impact Assessment (ACIA, 2004) are still hampered by significant uncertainties and provide little information at time and spatial scales relevant to planners. On the observation side, traditional environmental knowledge and observations have arguably provided as much impetus to the SEARCH enterprise as have other scientific activities. In order to make progress in this regard, guidance provided to the OCP by both UCP and RCP in arriving at an observation system is critical and informs this position paper and the implementation workshop. Identifying exemplary programs that manage to integrate such different demands may provide further direction.

A particular problem in reconciling science and stakeholder demands are the differences in spatial and temporal sampling rates required; much of SEARCH is focusing on interannual variability at the pan-Arctic scale, whereas stakeholders often require information on sub-daily timescales at very specific locations. Here, nested observations networks (see Section 6 below) and the identification of a few intensive observation areas (see also RCP, 2005) may help address this issue.

Identifying priorities and implementation sequences in as broad a context as that of SEARCH is inherently difficult. Again, the UCP can provide some insight, but ultimately a SEARCH measurement network needs to conform to the integrated needs of the community. Up to this point, the scope of SEARCH in a planning context has increased steadily, and has reached truly challenging proportions from the perspective of an operational measurement system. The position papers and follow-up discussions are important steps in identifying the scope and nature of a leaner observation system with maximum benefits. IPY provides a platform for exploring different options and approaches to an observing system that can subsequently be implemented in operational fashion.

Choices of specific measurement sites, sampling rates and design of a nested observation network should be informed by Observation System Design Theory and disciplinary scientific studies. Given the limited resources and vast potential scope of SEARCH, such considerations should be of a more than informal nature and include funding support for, for example, research projects or a workshop.

4. IMPLEMENTATION OF DISCIPLINARY/TOPICAL SEARCH MEASUREMENT PROGRAMS AND OBSERVATION NETWORKS

4.1. Atmospheric Observations

Relevance of observations in the context of SEARCH

In recent years, there has been an attempt to relate much of the variability in the arctic atmosphere to the Arctic Oscillation (AO). The AO is defined to be in negative phase when there is 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 temperatures 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, suggestive of more complex mechanisms may control the overall warming that seems to affect almost all regions of the Arctic.

As variability in the AO may not be a completely encompassing explanation for changes in the arctic atmosphere, a mechanistic understanding will almost certainly require ongoing, direct measurements of the atmospheric parameters that affect change, such as clouds, aerosols, upper air temperatures, ozone 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 because of arctic-specific problems introduced by the long Polar night, highly reflective surfaces, and retrieval algorithms that were developed for the mid-latitudes. 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 in to the (coupled) general circulation models (GCMs).

To understand the tangible results of changing climate in the Arctic such as changing melt seasons, sea-ice thickness, permafrost redistribution, 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 also be carefully chosen to provide information that may untangle natural variability from the variability resulting from anthropogenic forcing.

Requirements of an Atmospheric Observing Program

The Arctic will always be a challenging environment and an expensive region in which to make surface-based 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, an Arctic Atmospheric Observing program should include several components:

- Calibrated, uninterrupted and long-term monitoring networks (for instance temperature, precipitation, upper air measurements, surface radiation, ozone, UV and albedo).
- Strategically located, long-term Atmospheric Observatories with sophisticated, co-located instruments capable o make intensive measurements at the surface and through the depth of the atmosphere. Measured quantities can include (but are not limited to) solar radiation, aerosols, air chemistry, trace gases, cloud properties, water vapor, ozone, temperatures, winds, surface albedo and stratospheric properties. The Observatories will be designed to also include the routine measurements made at meteorological stations and more densely distributed networks in addition to the intensive measurements.
- Regularly scheduled uninhabited aerial vehicle (UAV) and aircraft campaigns that can collect data to provide information on horizontal variability and transitions between regions. The airborne programs will also be key in developing data sets over the Arctic Ocean.
- Coordinated surface-satellite activities such as archiving of intensive satellite measurements over the Observatory sites and on-going comparison between surface and satellite based 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 10 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 Alesund, Norway, Tiksi, Russia, the Greenland Summit Station, and Pallas, Finland. **Coordination of efforts between these**

Atmospheric Observatory programs will significantly enhance the potential of these difficult operations for understanding regional differences in the Arctic.

While a number of satellite programs are developing Arctic-specific atmospheric retrievals, these are typically lagging several years behind present and are mostly supported by episodic, grant-based funding and have not been transitioned into operational climate products. It is noteworthy that the recent Arctic Climate Impact Assessment did not utilize satellite observations of the atmosphere in drawing conclusions. **To remedy this situation, the mission-based agencies must have a method for interfacing with the research agencies to facilitate the transition.**

4.2. Distributed Marine Observatories (water-column component only)

The arctic seas have experienced major shifts in water mass properties and circulation over the past few decades. A dramatic example has been the 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. These were some of the first documented indications of a wider-spread, systematic change at high latitudes (e.g., Carmack et al., 1995; Morison et al., 1998; Steele and Boyd, 1998). Changes in the physical ocean environment modify ecosystem structure and function, ocean-atmosphere gas exchange, land-sea material transfer, and ultimately the living resources on which the local populations depend. They also influence global distributions of oceanic heat and freshwater via the meridional overturning circulation. These shifts have been tied to the climate trends and oscillations (SEARCH SSC, 2001). However, as yet the mechanisms of change are not well understood, and the impact of change on biological systems and stakeholders has not been made clear. A real understanding of arctic change cannot be achieved without long-term observations of all aspects of the oceanic system.

A true Arctic Change system synthesis likely will involve a series of modeling efforts focusing on a range of interactions including those between atmosphere and ocean, ocean and land, physical and biological systems, and humans and the environment. To a great extent, such modeling efforts can only be as good as the information that is available to describe the important processes. This information in turn is derived from focused, observational programs and systems that monitor both changes in key variables and interactions between the different components of the system. Hence, because of the key role of the oceans to many aspects of Arctic Change, observations of the ocean are critical to our understanding of the Arctic system.

Observing large-scale change in the marine environment demands the measurement of key variables such as temperature; salinity; ocean currents; inorganic tracers such as dissolved nutrients, barium, oxygen isotopes, and trace gasses; and biological parameters such as measures of abundance (e.g., fluorescence, acoustic backscatter, passive acoustic monitoring of marine mammals). To capture the large-scale shifts in major current systems of the central Arctic Ocean, temporal/spatial measurement scales should be large (10’s of years / 1000’s of kilometers), and temporal/spatial resolution can be relatively low (annual observations / 100’s of kilometers). However, understanding the *causes* of these changes probably requires finer scale observations at key locations, e.g., over continental slopes, deep ocean ridges, and on the shelves.

Observation strategies
At a minimum, observing change in the Arctic Ocean marine system requires two strategies: (1) measuring fluxes at the lateral boundaries and (2) measuring change within the basin. Lateral fluxes in Nares and Davis Straits are currently monitored as part of the NSF Arctic System Science Program's (ARCSS) Freshwater projects, with funding through 2007. The other major Canadian strait, Parry Channel, is monitored by the Bedford Institute of Oceanography. Bering Strait fluxes have been measured since 1990, but funding is presently not secure for future work. Fram Strait and Barents Sea fluxes are monitored by European efforts. Measurements within the Arctic Ocean should attempt to resolve change in the Beaufort Gyre, the Transpolar Drift Stream, the boundary currents, and shelf-basin fluxes. Results from a variety of recent projects (SCICEX, Laptev shelf moorings, NABOS, Switchyard, Shelf-Basin Interactions (SBI), and modeling) indicate the presence of strong cyclonic slope/ridge currents that swiftly carry pulses of Atlantic and Pacific water masses into the Arctic Ocean. Results from the SBI project indicate that biogeochemical inputs from the Chukchi Sea into the Arctic Ocean occur with high interannual variations along the shelf break, from Barrow to Herald Canyon and probably westward to the Russian coast.

Thus for the IPY intensive and coordinated observation phase, we encourage innovative measurement strategies that would help explain and monitor this variability, using a variety of sensors and measurement platforms. In particular, we encourage proposals that (1) continue measurements at key locations, and (2) augment existing observing systems with an increased diversity of sensors (chemical, physical, biological) and sampling strategies (autonomous profiling, air-dropped instrumentation, AUV/AAV). Specific areas of interest include:

- <u>Inputs/outputs</u>: Continued monitoring of Bering Strait, the Chukchi Sea, and the Canadian Archipelago, with close Russian and Canadian collaboration. Collaboration with European monitoring of Atlantic-Arctic exchanges is probably of secondary importance, although this is also encouraged, especially where gaps in the Eurasian efforts can be identified.

- <u>Deep basins</u>: The existing North Pole Environmental Observatory (NPEO, funding through 2009) and Beaufort Gyre Exploration Project (BGEP, funding through 2008) 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. We encourage use of these two stations as a base for sensor development and for further exploration of large-scale marine climate change.

- <u>Boundary currents</u>: These have been measured by moorings supported by ship surveys (e.g., SBI, NABOS). For IPY, we encourage continued monitoring of the Eurasian Basin slope current by NABOS or similar programs, and also of the North American and Makarov Basin slope currents. New thrusts might include water column profiling through the surface mixed layer, innovative methods to measure cross-slope variations, and addition of chemical/biological sensors.

We also encourage strong collaboration with programs focused on the Bering Sea, which provides important source waters for the western Arctic Ocean. Finally, we endorse 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.

4.3. Sea Ice Observations

Relevance of observations in the context of SEARCH

The response of the arctic sea-ice cover to climate variability and change is one of two key feedbacks that are believed to underlie observed and projected Arctic climate change (UCP, 2005). GCM simulations indicate that the predicted high-latitude warming is dominated by sea-ice thinning and retreat (Holland and Bitz, 2003, ACIA, 2004). At this point, it is not clear whether observed sea-ice changes, in particular in the Pacific Arctic sector (Comiso, 2002), have reached a "point of no return." Attribution of observed sea-ice variations and prediction of future change is hampered by lack of key data such as summer ice albedo believed to dominate feedback processes.

A complex of interconnected changes driven by thinning and shrinking ice has emerged over the past two decades (Serreze et al., 2000, ACIA, 2004). Native observers have reported these changes (reduced length of ice season, less predictable and more dynamic ice conditions, reductions in landfast ice stability, etc.) and felt their impact on transportation and subsistence hunting in various regions throughout the Arctic (Huntington, 2000). Arctic marine ecosystems as well as fisheries and subsistence activities appear to be responding in dramatic fashion to changes in the ice cover (Tynan and DeMaster, 1997, Huntington, 2000, Hunt et al., 2002).

A shortened and less severe ice season has favored ship traffic along the Northern Sea Route and the Northwest Passage and projections are for substantially less severe ice conditions by mid-century (ACIA, 2004). In the post-Cold War era, predictions for a much more trafficable and accessible Arctic by the end of the century are of substantial geopolitical importance and are driving renewal or revisions of territorial claims by circum-Arctic nations.

Requirements of a sea-ice observation program

Most of the requirements articulated by UCP and RCP could be addressed by observations of quantities that influence the sea-ice mass budget and sea-ice biophysics (see below for more details). 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 (SIMBA, Hutchings and Bitz, 2005) provide further guidance. The location, spatial coverage and density as well as frequency of observations may vary substantially for the different aims identified in the UCP and RCP position papers. As will be argued below, this problem can in part be addressed by a nested, distributed network of observation sites, with stakeholder groups affected by a cluster of changes involved in the planning of such a network to ensure sufficient coverage in at least one region of prime interest.

Observations required for assessment and attribution of arctic environmental change include:

- Sea ice mass budget parameters: ice extent and concentration (daily, pan-Arctic), ice thickness and roughness (survey profiles at annual to multi-annual intervals; time series at selected locations (sub-daily time scales), ice velocity (at selected locations from buoys and pan-Arctic from satellite remote sensing at sub-daily timescales), ice production and melt (net annual cycle at selected points, freeze-up, onset of melt), landfast ice extent;
- Snow depth distribution and density (surveys in selected regions on multi-annual basis);
- Sea ice properties: density, salinity, temperature (vertical profiles at selected locations on seasonal basis), melt pond coverage (aerial coverage at selected locations on annual or multiannual basis);
- Sea ice albedo (pan-Arctic seasonal estimates from satellite remote sensing, at selected locations at daily timescales);
- Sea ice biophysical variables: photosynthetically active radiation, organic carbon, major nutrients and alkalinity, algal standing stock (at selected locations on seasonal basis), primary production, impurities; and
- Near-real time ice observations: identified by stakeholder (RCP, 2005), may include measurements of coastal/landfast ice morphology, stability and drift, spatial patterns of ice growth and decay, coastal currents/tides/sea level and under-ice bathymetry.

Existing measurement programs and further needs

The suite of instruments that are part of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) currently provide a wealth of key sea-ice data sets, including ice concentration, extent, drift, and albedo. At a time of restructuring and reorientation of national agencies, ensuring continuity of climatological satellite-derived data sets is critical and of particular importance for arctic sea-ice data. In addition, development and validation of remote-sensing approaches to measuring ice thickness, e.g., with laser or radar altimetry need to play an important role in future efforts. Here, the IPY could provide a major venue for concerted thickness-measurement validation efforts involving different platforms (satellite, upward-looking sonars, airborne, on-ice) and field observations in an international context. IPY could also start off a series of survey-type observations, both from above (icebreaker, aircraft) and below (submarine) with at least one basinwide transect of snow/ice thickness and ice properties.

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; cf. Lindsay and Zhang, 2005) can provide information on ice thickness and mass flux. Such point-based measurements need to be augmented by drifting sensor observations. Here, the highly successful International Arctic Ocean Buoy Program (IABP) needs to be expanded to (i) include more sophisticated sensor systems, including measurements of snow/ice mass-balance and properties and biogeochemically relevant variables, and (ii) extend coverage into the increasing area of the seasonal ice zone. A workshop report by Proshutinsky et al. (2004) summarizes the relevant issues. As outlined in a community workshop report by Hutchings and Bitz (2005), ice mass budget measurements are 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. Finally, stakeholder input indicates a need for observations of the ice regime at high spatial and temporal resolution in critical sectors of the coastal and shallow shelf seas (see also RCP, 2005). Regionally, the western Arctic has seen some of the most significant ice changes, but is also disproportionately important from an impacts perspective. At the same time, the vast Siberian Arctic sector is critically undersampled.

4.4. Terrestrial Ecosystem Observations

Relevance of observations in the context of SEARCH

The terrestrial ecosystem observations relate specifically to several science questions developed from the 2001 Science Plan and put forth in the 2003 Implementation Strategy (p. 2-4, also available at: http://www.arcus.org/search/searchscience/sciencequestions.php). Specifically, the relevance of terrestrial observations is strongest in Questions 3 (parts d,f,g), 4 (b,c,g,h), 5 (all), 6 (all), 7 (all), and 10 (a-d). Of the eight (8) overarching areas of activity within SEARCH, the terrestrial observations relate most strongly to DTO (Distributed Terrestrial Observatories) and ASR (Arctic System Reanalysis), and will be important for developing the DQU (Detecting and Quantifying Unaami) and LGC (Linkages and Global Coupling) activities. The ASR, DQU, and LGC activities represent the main links between the Observing Change panel and the Understanding Change panel within SEARCH. Finally, the terrestrial observations also will provide data for the activities guided by the third panel, Responding to Change (SEI, Social and Economic Interactions and SOR, Social Response activities).

Key among the SEARCH Observing Changes initiatives are understanding and predicting shifts in terrestrial 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 of such changes to the atmosphere. These efforts might best be served through regular monitoring of soil and atmospheric fluxes of elements such as carbon and nitrogen, and periodic assessments of abundance of key species at broadly distributed sites.

Additionally, the DTO activity will make atmospheric, hydrological, glaciological, and ecosystem observations in terrestrial environments (Note that separate sections in this position paper provide more detail on the atmospheric, hydrological, and glaciological observations). Each of these sets of observations is critical to both 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. These interactions are what ultimately lead to social and economic impacts on local residents as well as on communities and nation-states outside the Arctic.

Requirements of a measurement/observation program

The SEARCH Implementation Strategy document identified 10 major components of a terrestrial observation program (p. 24-27). These components can be grouped into 3 categories: (1) physical (climate, water, permafrost, energy), (2) chemical (trace gases, nutrients, soils/sediments), and (3) biological (primary productivity, plant and animal dynamics, species composition and distribution). Because 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 spatial scale of measurements will be initially defined by the existing monitoring sites (maps, p. 17, 23), 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. However, deficiencies in spatial cover or resolution of sampling sites may to some extent be accommodated 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 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 maximize information acquisition while minimizing effort and resources by capitalizing on existing spatial autocorrelation of landscape features and community characteristics across the Arctic. 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 project.

State of the art and existing networks, sites, programs on pan-Arctic scale

A recent NSF-IASC workshop on “Flagship Arctic Observatories and Networks” (draft report) 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, LTER sites in Alaska), and several well-integrated research networks that exist or are under development (e.g., SCANNET, CEON, AON). Recent funding of SEARCH-related projects (e.g., CHAMP-FWI, see SEARCH Activities Spreadsheet) have already contributed a great deal of hydrological and hydrology-related information to DTO. The ITEX network and other less intensively studied sites represent candidates for intermediate or extensive sites within the DTO network, and developing CAFF efforts designed to monitor biodiversity across the Arctic will contribute to SEARCH goals. Overall, however, there have been few syntheses (beyond the recent ACIA report) 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 Unaami on terrestrial ecosystems are difficult.

Needs beyond existing programs

The SEARCH Implementation Strategy (2003) identified as a high priority to maintain the current time series of terrestrial observations as SEARCH plans develop. Time series at risk 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 reduced some of these risks (e.g., the SEARCH Freshwater Initiative support of hydrological studies), 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. Long-term observations of this kind are needed to understand the full scope of Unaami 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.

In addition, a next priority is to continue working with the UCP and specifically the ASR activity 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.

4.5. Observing Change in the Hydrosphere and Terrestrial Cryosphere

Relevance of observations in the context of SEARCH

The hydrosphere/cryosphere represents an interdependent system where large threshold changes occurring annually manifest dramatic changes in the surface water and energy budgets. Subtle changes in the timing of thawing and freezing, snow vs. rain, open water vs. ice, can impart substantial differences in mass and energy transfers that can cascade through the ecosystem and climate system. Changes are occurring over two distinct time scales, corresponding to climate (long term) and weather (short term). Over the long term, the most critical change that is taking place is the warming and thawing of permafrost along with the corresponding thickening of the active layer and reduction of the area of continuous permafrost. We absolutely need to understand how fast this transition is taking place and its geographic patterns. Over the short term, the critical issue is how the variance in the set of hydrological/cryological variables is changing: Is break-up continuing to occur earlier in most years? Is the soil drying? Is the peak discharge decreasing while the base flow increases? These long and short-term effects interact in a myriad of ways, and each small change has the potential to initiate a large system response. We need to not only observe single component changes, but also monitor how the interactions are changing as well.

Requirements of a measurement/observation program

The critical missing element in the cryosphere/hydrosphere is a unifying observing and analysis network akin to the Arctic Buoy program. Individual networks, such as NWS precipitation stations, exist, but the records are not coupled with measurements of energy or surface water flux, and a "state of the cryosphere" report is never issued. Secondly, there is complacency in the existing observation networks bred from long years of inadequate measurements of key parameters like evaporation, sublimation, and winter precipitation. Until methods of improving these fundamental hydrologic measurements are available, we will not be in position to understand how the hydrosphere/cyrosphere is changing. What needs to be done?

Needs beyond existing programs

Permafrost, the basement foundation

The broadest impacts to the terrestrial arctic regions will result through consequent effects of changing permafrost structure and extent, and we must develop a comprehensive pan-Arctic picture of how this is taking place. As the climate differentially warms in summer and winter, the permafrost will become warmer and the active layer (the layer of soil above the permafrost that annually experiences freeze and thaw) will become thicker. These simple structural changes will affect every aspect of the surface water and energy balances, as well as biogeochemical processes and fluxes. As the active layer thickens, there is greater storage capacity for soil moisture and greater lags and decays are introduced into the hydrologic response times to precipitation or snowmelt events. Changes in active layer also impact the formation and drainage of lakes, which can comprise 50% of the land surface and act as capacitors in the hydrologic response system. When the frozen ground is very close to the surface, the stream and river discharge peaks are higher and the base flow is lower. As the active layer becomes thicker, the moisture storage capacity becomes greater and the lag time of runoff increases. This has significant impacts on large and small scales. The timing of stream runoff will change, reducing the percentage of continental runoff released during the summer and increasing the proportion of winter runoff. This is already becoming evident in Siberian Rivers. As permafrost becomes thinner and is reduced in spatial extent, the proportions of groundwater in stream runoff will increase as the proportion of surface runoff decreases, increasing river alkalinity and altering element and nutrient chemistry. This could impact mixing of fresh and saline waters, formation of the halocline, seawater chemistry, and coastal productivity. Additionally, changes in surface soil moisture, lake area, and lake ice cover will impact local and regional climate by affecting sensible and latent heat fluxes, and trace gas fluxes. Changing permafrost extent and active layer thickness also affect local ecology, impacting dominant vegetative species (through changes in soil moisture) and faunal distribution (through changes in surface water bodies).

Needed: Measurements of active layer and permafrost temperatures and moisture must be coordinated with climate and hydrological stations enabling full characterization of the changing surface energy and water balances.

Phase, amount, and timing of precipitation: "The Holy Grail"

Projecting the response of the arctic ecosystem to a warming climate is completely intertwined with predicting changes in magnitudes and timing of rain and snowfall. It is still difficult to partition the mass balance of precipitation across an annual cycle at a single station, let alone do it across wide (and topographically diverse) landscapes. Yet, we must or we will never understand the fundamental drivers behind both the cryosphere and hydrosphere dynamics. In the summer, approximately 80% of the precipitation is recycled from evapotranspiration. In the winter, approximately 80% of the precipitation is due to long distance advection. As soils dry or as season lengths change, these proportions will change, yielding markedly changed climatic, hydrologic and ecosystem responses.

Needed: A variety of measurements across spatial and temporal scales. Glacier mass balance networks provide good, conservative long-term trends. We also need a reliable network of stations to provide real-time measurements of solid and liquid precipitation across the full range of topographic features. Additionally, we need to develop new methods to reliably and consistently measure sublimation and evapotranspiration across a range of spatial scales.

Run-off and storage

The link to ecosystems and oceans: River discharge is the integrated response of energy-hydrology coupling in a terrestrial catchment. However, the processes affecting discharge are so numerous and so complex that there is no good way to invert the river discharge back to the key hydrologic processes. Although we need more gauging stations to understand global water balance, we will not learn much more about hydrologic linkages or feedbacks among land, air and oceans by adding more river gauging stations to the existing network.

Needed: A coordinated set of research basins, all monitoring snow distribution, glacial dynamics, snow melt, energy balance, soil moisture and surface water dynamics, runoff, evaporation, transpiration and sublimation with complementary techniques is essential to enable process level studies and circumpolar assessment of climate change and response. This approach is necessary to develop an understanding of key drivers and changes in interactions among hydrological, biological and climatological processes. Changes in climate initiate a cascade of changes in interdependent processes that are integrated at the catchment scale. We need to characterize how the integrated response of river discharge and sediment yields will vary with permafrost degradation, increased glacier ablation, and climatic drivers. This characterization is required to understand how these changes in the hydrosphere/cryosphere link terrestrial and marine processes by impacting estuarine processes and ultimately oceanic circulation.

Interconnections

The first order effects of a warming climate in the arctic regions are already becoming apparent; some second order or subsequent impacts to the ecological and hydrologic systems are also becoming evident. The pressing research need for the coming decade is to quantify the interactions and feedbacks among related processes. It is essential that we quantify how changes in one component of the climate system will affect and be affected by changes in other components of the system. For example, we anticipate that precipitation will increase with warming air temperatures and degradation of sea ice, but we also assume that soils will become drier with degradation of permafrost. How will drying of tundra soils affect recycling of moisture and feedback to influence precipitation patterns? Observing these changes and quantifying such complicated interactions is the essential key to predicting future climate dynamics.

4.6. Human Dimensions

Relevance of observations in the context of SEARCH

Rapid and significant changes confront arctic societies. Some of these 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). Some system changes which have important human dimensions implications include decreases in the extent and nature of sea ice, marine and terrestrial ecosystem change, permafrost degradation, increased development of oil and gas resources, mineral exploration, mining, marine fisheries, waste dumping, shipping and tourism (UNEP 2001; ACIA 2004, AHDR 2004). Humans are both recipients of and contributors to this suite of changes and human interactions with the Arctic subsystems can be modeled as a series of impact and feedback processes occurring at local, regional, and global scales.

Understanding how social systems interact with natural systems (both physical and biological) involves qualitative analyses and quantitative studies that rely on forms of hypothesis testing and analysis familiar to fields such as atmospheric science, terrestrial ecology, glaciology, or ocean biogeochemistry. A human dimensions (HD) network that is analogous to that planned for the physical sciences should be a component of IPY activities and should be 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 developing credible, evidence-based future scenarios and policies useful for supporting decision making under conditions of escalating environmental and social change (HARC SSC, 2005).

Requirements of human dimensions measurements/observations program

The Arctic System Science Program (ARCSS) Human Dimensions of the Arctic System (HARC) Science Steering Committee has drafted a pamphlet on the possible nature and structure of a proposed human dimensions (HD) observing network (HARC SSC, 2005). At a minimum a network of social scientists, citizens and other observers is required to help make available and accessible data already being collected. This network could also function to identify data gaps and collect data as appropriate to fill those gaps. Existing and new data might include:

- The size, composition, well-being and livelihoods of arctic communities;
- Demographic vital statistics, such as births, deaths, migration, and population age-sex structure;
- Health and economic statistics;

- Qualitative data;
- Global economic and institutional trends; and
- Ecological indicators of change.

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. At the broadest level federal and state agencies collect HD data via mechanisms like the census and harvest monitoring. Human dimensions data relevant to SEARCH are also collected through a series of regional programs like the 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 (see for example Krupnik and Jolly, 2002). These efforts are generally un-coordinated and while each generates information relevant to SEARCH goals, coordinated data collection, analysis and synthesis among programs, including those of the physical and biological sciences, needs immediate attention (see for example AHDR, 2004), especially in the context of SEARCH implementation.

Needs beyond existing programs

A primary need is to develop the infrastructure to make existing HD datasets compatible with each other, and to establish common protocols for the collection of new data. Human dimensions monitoring includes both social and ecological indicators and requires co-ordination in data collection efforts. HD data should be integrated from the outset with data derived from other monitoring efforts (i.e. climate stations, remote sensing etc.).

In contrast to the physical and biological sciences, HD monitoring efforts are largely non-institutionalized. The appropriate infrastructure is also necessary to ensure that the collection of data continues over the long-term and to ensure that there is comparability across programs and in assessments of trends. A key element is the development of a venue to enable the kinds of analyses needed to disseminate the data in formats that are accessible, useful, usable, relevant and timely to the needs of researchers, policy makers and the public through a single web portal with multiple links (HARC SSC, 2005).

4.7. Paleo-Observations

Relevance of observations in the context of SEARCH

Paleo studies and observations are important for determining (1) whether Unaami has occurred in the past, (2) the forcing mechanisms of Unaami and its interactions with climate oscillations (e.g., AO, NAO), and (3) the relationship between climate variability and ecosystem responses. These observations will provide SEARCH with important insights and critical reference points about climate change at temporal scales that extend the instrumental records back 100s to 1000s of years with high resolution (annual), and back through several glacial cycles with lower resolution. In the recent past, proxy environmental data for periods of comparative Arctic warmth such as during the 1940s can help put the current observations of changing sea-ice cover, permafrost warming, and shifting treelines into perspective. Looking further back in time, paleo-data can be crucial in identifying the 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). A further important role for paleo-data is in filling regional observational gaps and providing constraints on the selection of key observation sites.

Requirements of a measurement/observation program
The program must develop a dense spatial network of sites that include records from ice cores, tree rings, and lake and marine sediment cores that span at least 2000 years and extend through the 20th century. The focus should be on annual-resolution archives wherever possible (e.g., varved lake and marine sediments, tree rings, annual ice layers), but sub-decadal to decadal resolution records from high deposition-rate sediments and ice cores are integral to this effort as well. Longer terrestrial and marine paleo records with decadal-to-centennial resolution from key arctic and subarctic regions, but at lower spatial resolution than the annual proxy network, are also required. Long records cover periods of much warmer and colder past climate and can identify abrupt climate shifts, and provide insight into possible threshold conditions that may trigger rapid climate jumps. For sequences of all lengths, multiple proxies are required to document shifts in temperature as well as precipitation, and are essential for proper interpretation of more complex or integrated arctic system changes such as the AO, as well as decreased sea ice extent, increased discharge of freshwater into arctic seas, and responses of marine and terrestrial biota to climate change.

State of the art and existing networks, sites, and programs
The SEARCH Implementation Strategy (2003; Figure 2) shows locations of proxy records used for investigations of annual and decadal-resolution modes of variability in arctic climate. This sampling network is the most dense and highly evolved of all SEARCH components, in part because of past NSF and other agency funding. Two programs that address the paleoscience issues related to SEARCH are the International Geosphere-Biosphere Program's Core Project titled "Past Global Changes" (IGBP-PAGES) and Paleoenvironmental Arctic Sciences (PARCS). PAGES pursues a broad range of paleoscience studies and has several synthesis efforts underway, and SEARCH needs to link to this initiative. PARCS (now ended) was a program 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. These goals are coincident with many goals of SEARCH, and PARCS synthesis results should provide a foundation from which we can identify SEARCH-relevant research questions and likely avenues for answering them successfully. For example, initial efforts suggest the potential to reconstruct Arctic-wide average temperature, as well as AO variability–a critical variable for SEARCH–from proxy temperature records. Together these programs should provide a paleoscience perspective on the changes in arctic systems that SEARCH uncovers.

Needs beyond existing programs

As detailed in the Program Requirements above, a network of paleoclimate records with high spatial and temporal resolution will be required to accurately reconstruct the range of past climate variability. The greatest need is to extend such a spatial network further back in time in order to identify climate system behavior, including AO variability, during periods of different background climate, particularly previous warm and cold intervals.

In addition, another critical step will be to establish intensive study sites at key locations for quantitative calibration and inter-comparison of different climate proxies (e.g., tree rings, varved lake and marine sediments, ice cores). Locations should be selected to maximize the number of proxy records available. This effort is important not only for improving the robustness of temporal and especially spatial interpretations of variability in climatic changes, but for starting the process of expanding our understanding from paleo-'climate' to paleo-environmental and ecological patterns and variability. It is through this effort that the measurements made at terrestrial and marine observatories can be better linked to the UCP and especially the ASR and LGC activities within SEARCH. This strategy of developing paleo-environmental and ecological interpretations is also required to link to the RCP and aspects of the human dimension of arctic change. For example, using coastal and inland archeological sites and collecting data on shell middens, faunal remains, and chemical signatures (e.g., oxygen isotope levels in shells, bones, and otoliths) will be critical for integrating the main activities and overarching goals of SEARCH.

5. DATA ARCHIVAL, ACCESS AND DISTRIBUTION

As a study of a complex of environmental changes over timescales extending well beyond a decade, the archival and ensured broad access to SEARCH-generated data is critical. The actual SEARCH-specific needs for data archiving and dissemination will have to be identified over the course of the next few years, with the IPY as an important testbed for different concepts. At present, Data Centers are distributed across a number of agencies, including NOAA, NASA, NSF and DOE. Different models are available for coordinating, linking and subsuming the existing resources, e.g., through the creation of Virtual Data Center. The details of this process will be determined by the different agencies involved, ideally in communication with the SEARCH community involved in data generation and use.

6. ON THE IMPORTANCE OF OBSERVATION NETWORKS

The integration of various measurement programs in SEARCH with related programs or pan-arctic networks will be guided and constrained by (1) the organizational philosophy of SEARCH, (2) the scientific needs of the different programs, and (3) the level of standardization of measurements and methods required or possible. Although SEARCH is more interdisciplinary than most other programs and networks, the philosophy of organization is to retain a narrow, vertical structure rather than allowing a horizontal spread of new programs with independent planning processes. Organizational plans and guidance for the program are carried out above the level of project activities (see Section 4), although individuals or groups working on the same activity must assume some responsibility for coordination across sites and integration across activities.

There are good examples of how network or large-program research can operate both *without* specific, forced protocols and standardized methods (e.g., IBP, LTER), and *with* such protocols (e.g., SeaWIFS, NOAA-Flask). In the former case, observations on defined sets of variables (e.g., productivity, biodiversity) are required by the funding agency, and the appropriate and comparable standards and methods are developed mainly through the peer-review process of publications and workshops. Standardization is an appropriate project or network goal, but SEARCH should avoid the imposition of detailed and inflexible designs for various measurement programs. Furthermore, the effort spent on increasing the number of observation sites relative to an expansion of the number of measurements made at each site should be gauged relative to the SEARCH goals of first uncovering temporal changes in arctic systems, and second understanding their spatial extent. Thus the program needs a progression of making complete (i.e., useful) measurements at single sites and then expanding the observations spatially. Finally, the prioritization and importance of very different sets of variables needs to be carefully weighed. For example, which is more important to measure - sea ice extent, treeline movement, or atmosphere-biosphere gas exchange? Here, community and stakeholder input are as important as guidance from a theoretical, systems-oriented approach.

What is needed now is a consensus on levels of network organization within SEARCH and between other networks. The entry level is communication of research plans and sharing of data sets and results (part 5 of this paper) - even a group of independently conceived and randomly placed measurement sites can become a network through communication. The next levels of organization in a network include (a) coordination of measurements including temporal scaling, (b) planned locations of sites and spatial scaling, (c) promotion of coordinated sampling and measurement on the same sites (including major experiments), (d) standardization of approaches and methods, and (e) integration of results and organized synthesis activities. At this stage, SEARCH is committed in some way to levels (a) and (b), although the Implementation Strategy (SEARCH SSC & IWG, 2003) mostly focuses on distributed observatories. The next step is to focus on improving level (c), the coordination of observations within a site. One example of an operating network is the hydrological monitoring in SEARCH, sending data from all sites routinely (automatically) to the Water Research Center at the University of New Hampshire. The OCP believes that this level of networking (data sharing with an active repository, research planning and coordination of sites and measurements) is essential, and may be sufficient for many questions. SEARCH must continue to evaluate and coordinate with other arctic networks, through both a clearinghouse of all network activities and data repositories (maintained by the SEARCH Science Management Office) and recognition of related efforts in arctic network integration such as the recent NSF-IASC workshop on "Flagship Observatories" (NSF-IASC 2005).

7. INTEGRATION OF SEARCH EFFORTS WITH OTHER PROGRAMS

SEARCH activities can be facilitated by a number of coordination efforts both within the U.S. and with a number of International programs.

7.1 U.S. Activities

SEARCH was originally conceived as an interagency program by the Interagency Arctic Research Policy Committee (IARPC), which includes representation from 13 federal agencies and offices. The SEARCH Interagency Program Management Committee (IPMC; formerly Interagency Working Group) is composed of representatives from eight (8) of the IARPC agencies as well as the U.S. Arctic Research Commission, and is tasked with working closely with the SEARCH Science Steering Committee to identify cross-agency activities that can support the SEARCH program. An important part of the process will be the development of multi-agency coordinated budget initiatives to implement the SEARCH program. At present, NOAA has a limited within-agency SEARCH program and NASA and NOAA have released research announcements including SEARCH-specific language. Continued coordination on the interagency level through the SEARCH IPMC will be vital to the success of SEARCH.

7.2 International Activities

Because the arctic region crosses international boundaries, and has far-reaching global environmental impacts on non-Arctic Nations, effective arctic research activities require a high level of international coordination. The period March 2007 to March 2009 has been designated as an International Polar Year (IPY). The IPY International committee collected over 870 Expressions of Intent (EoI) in January 2005 from researchers around the world with interests in Arctic and Antarctic science issues. These EoIs have been organized into "Topic Clusters" around which coordinated efforts can be organized. The IPY process provides a significant tool for the U.S. SEARCH program to coordinate activities internationally. SEARCH, along with ISAC will play a leading role in defining the integrated environmental change and arctic observing components of IPY.

References

ACIA, Impacts of a warming Arctic: Arctic Climate Impact Assessment, Cambridge University Press, Cambridge, 2004.

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

Carmack, E., R. Macdonald, R. Perkin, F. McLaughlin, and R. Pearson, Evidence for Warming of Atlantic Water in the Southern Canadian Basin of the Arctic Ocean: Evidence from the Larsen-93 Expedition. Geophysical Research Letters, 22: 1061-1065, 1995.

Comiso, J.C. 2002. A rapidly declining perennial sea ice cover in the Arctic. *Geophys. Res. Lett.*, **29**, 1956, doi:10.1029/2002GL015650.

HARC SSC (2005 in prep). *A Human Dimensions Observing Network for the Arctic System*.

Holland, M.M. and C.M. Bitz. 2003. Polar amplification of climate change in coupled models. *Climate Dyn.*, **21**, 221-232.

Hunt, G.L.Jr.S.P., G. Walters, E. Sinclair, R.D. Brodeur, J.M. Napp and N.A. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. *Deep-Sea Res. II*, **49**, 5821-5853.

Huntington, H. 2000. Native observations capture impacts of sea ice changes. *Witness the Arctic*, **8** , 1-2.

Hutchings, J., and C. Bitz (2005, in prep.) Sea Ice Mass Budget of the Arctic (SIMBA) Workshop Report, www.iarc.uaf.edu/workshops/SIMBA_2005/

Krupnik, I. And D. Jolly (eds.). 2002. *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change*. Fairbanks, Arctic Research Consortium of the United States/Arctic Studies Center, Smithsonian Institution

Lindsay, R. W. and J. Zhang, 2004: Arctic Ocean ice thickness: modes of variability and the best locations from which to monitor them, *J. Physical Oceanogr*.

Morison, J. H., M. Steele, and R. Andersen, Hydrography of the upper Arctic Ocean measured from the nuclear submarine USS Pargo, *Deep Sea Res. I, 45*, 15-38, 1998.

NSF-IASC, 2005 (Draft Report). Flagship observatories for arctic environmental research and monitoring. Report of a workshop held November 18-20, 2004 at The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts, USA.

Overland, J., F. Fetterer, D. McGuire, J. Richter-Menge, and J. Walsh, SEARCH Workshop on Large-Scale Atmosphere/Cryosphere Observations, NOAA OAR Special Report, Pacific Marine Environmental Laboratory, Seattle, 2002.

Overpeck, J. and 17 others (1997) Arctic Environmental Change of the Last Four Centuries, Science, 278 (5341), 1251-1256.

Proshutinsky, A., , A. Plueddemann, J. Toole and R. Krishfield. Ice-Based Observatories: A strategy for improved understanding of the Arctic atmosphere-ice-ocean environment within the context of an Integrated Arctic Observing System. Woods Hole Oceanographic Institution, June 28-30 2004, Woods Hole MA USA. Nov. 2004.

Responding to Change Panel (RCP) (2005) RCP Position Paper.

SEARCH SSC, SEARCH: Study of Environmental Arctic Change, science plan, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle,

2001.
SEARCH SSC & IWG: SEARCH Implementation Strategy, xxx
Serreze, M.C., J.E. Walsh, F.S. Chapin III, T. Osterkamp, M. Dyurgerov, V. Romanovsky, W.C. Oechel, J. Morison, T. Zhang and R.G. Barry. 2000. Observational evidence of recent change in the northern high-latitude environment. *Climatic Change*, **46**, 159-207.
Steele, M. and T. Boyd, Retreat of the cold halocline layer in the Arctic Ocean, *J. Geophys. Res., 103*, 10,419-10,435, 1998.
Tynan, C.T. and D.P. DeMaster. 1997. Observations and predictions of Arctic climatic change: Potential effects on marine mammals. *Arctic*, **50**, 308-322.
Understanding Change Panel (UCP) (2005) UCP Position Paper.
UNEP 2005. Vital Arctic Grapics : People and global heritage on our last wild shores. UNEP/GRID-Arendal

Appendix: Observing Change Panel Members

Hajo Eicken, *Panel Chair*
Geophysical Institute (GI)
University of Alaska Fairbanks
PO Box 757320
903 Koyokuk Drive
Fairbanks, AK
Phone: 907-474-7280
Fax: 907-474-7290
hajo.eicken@gi.alaska.edu

Carin J. Ashjian
Department of Biology
Woods Hole Oceanographic Institution
Redfield 246 MS #33
266 Woods Hole Road
Woods Hole, MA
Phone: 508-289-3457
Fax: 508-457-2134
cashjian@whoi.edu

Larry D. Hinzman
Water and Environmental Research Center
University of Alaska Fairbanks
PO Box 755860
437 Duckering Building
Fairbanks, AK
Phone: 907-474-7331
Fax: 907-474-7979
ffldh@uaf.edu

George Kling
Department of Biology
University of Michigan
Natural Sciences Building
Ann Arbor, MI
Phone: 734-647-0894
Fax: 734-647-0884
gwk@umich.edu

Eric Post
Department of Biology
Pennsylvania State University
325 Mueller
University Park, PA
Phone: 814-865-1556
Fax: 814-865-9131
esp10@psu.edu

Michael Steele
Polar Science Center - Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Box 355640 Henderson Hall
Seattle, WA
Phone: 206-543-6586
Fax: 206-616-3142
mas@apl.washington.edu

Taneil Uttal
Environmental Research Laboratory
National Oceanic and Atmospheric Administration (NOAA)
325 South Broadway - R/E/ET6
Boulder, CO
Phone: 303-497-6409
Fax: 303-497-6181
taneil.uttal@noaa.gov