SEARCH

Study of Environmental Arctic Change

Implementation Strategy

Revision 1.0

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by the SEARCH Science Steering Committee* and the SEARCH Interagency Working Group

Based on the SEARCH *Science Plan* and SEARCH Implementation Framework
including input from the Arctic Hydrology Workshop 2001, the ACCA Workshop 2001, the Arctic Ocean Measurements and Modeling Workshop 2002, The SEARCH Terrestrial and Marine Ecosystem Workshop, and the SEARCH Human Dimensions Workshop

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Shishmaref, Alaska beach erosion, courtesy Native Village of Shishmaref

M/V *Arctic*, Canadian Coast Guard, courtesy Lawson Brigham

Polar bears, courtesy James Morison

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1. BACKGROUND

The Study of Environmental Arctic Change (SEARCH) is conceived as a broad, interdisciplinary, multiscale program with a core aim of understanding the complex of significant, interrelated, atmospheric, oceanic, and terrestrial changes that have occurred in the Arctic in recent decades. These changes are affecting every part of the arctic environment and are having repercussions on society. There is evidence that these changes are connected with the positive trend in the Arctic Oscillation (AO), a mode of variability that involves the strength of the circumpolar vortex. The AO is potentially active over a broad range of time scales, including climatic time scales. Modeling studies indicate that the recent positive trend in the AO might be forced in part by greenhouse warming. It is unclear what feedback processes on climate or ecosystems may be involved in the recent changes, or what the long-term impacts may be. However, observations suggest that the impact at high latitudes is substantial and that the impact at mid latitudes is significant. Because the observed changes have made it more difficult for those who live in the north to predict what the future may bring, we have given the name Unaami (the Yup'ik word for "tomorrow") to the complex of intertwined, pan-arctic changes.

A core aim of SEARCH is to understand Unaami. To gain this understanding we will need to determine the full scope of Unaami. As a working definition based on present knowledge, **we define Unaami as the recent and ongoing, decadal (e.g., 3–50 year), complex of interrelated pan-arctic changes.** These changes include, among others, a decline in sea level atmospheric pressure, an increase in surface air temperature, cyclonic ocean circulation, and a decrease in sea-ice cover. The physical changes are affecting ecosystems, living resources, and the human population. Furthermore, they are impacting local and hemispheric economic activities such as shipping and fisheries that are collectively worth billions of dollars. These biological and societal consequences may be considered part of Unaami. Although the dynamics are different, the situation is similar to the El Niño-Southern Oscillation (ENSO) phenomenon. A continuation, or even acceleration, of the changes comprising Unaami is a possibility.

The research community, working with the SEARCH Science Steering Committee (SSC), has developed the SEARCH Science Plan, which describes the observed changes and advances four key hypotheses, (1) Unaami is related to the strength of the atmospheric polar vortex (e.g., AO), (2) Unaami is a component of climate change, (3) feedbacks among the ocean, land, and atmosphere are critical to Unaami, and (4) the physical changes of Unaami have large impacts on the arctic ecosystems and society. The plan lays out the objectives and general strategy for investigating these hypotheses. The SEARCH Interagency Working Group (IWG) has developed the SEARCH Funding Implementation Framework for FY 2001, 2002, and 2003. **This document, the *Science Implementation Strategy*, describes how SEARCH will be implemented.** It is based on the *Science Plan* (SEARCH SCC, *Search: Study of Environmental Arctic Change, Science Plan*, 2001, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, 91 pp.) and the *FY 2003 Funding Implementation Framework*, and input from the Arctic Hydrology Workshop 2001, the ACCA Workshop 2001, the Arctic Ocean Measurements and Modeling Workshop 2002, The SEARCH Terrestrial and Marine Ecosystem Workshop, and the SEARCH Human Dimensions Workshop. It includes description of science questions arising from the key SEARCH hypotheses, an organization plan, priorities, readiness, and an expanded outline of the scientific tasks that will be required to address the SEARCH goals. The document will evolve with SEARCH. Subsequent drafts and supporting documents will include more detailed descriptions of the science activities such as measurement types and locations, analysis activities, and modeling.

2. SEARCH QUESTIONS

The *FY2003 SEARCH Funding Implementation Framework* describes recent changes in the Arctic as dramatic, and forecasts that the changes will continue into the future with consequences throughout the Northern Hemisphere. SEARCH is focused on understanding the reasons for the documented changes, extrapolating the course of change into the future, and helping to prepare society to adjust to future changes. Key SEARCH questions are enumerated here to serve as concrete and specific guides to implementation. It should be recognized at the outset that the list of questions will not remain fixed throughout SEARCH research efforts. As questions are answered, new ones will arise. It will be the responsibility of the SEARCH participants and leadership to evaluate repeatedly the list of questions and modify it as needed. The SSC recognizes fundamental science questions and application-oriented questions.

2.1 Science Questions

Question 1: *How can we best characterize the composition, scales, and persistence of the recent complex of changes in the arctic system termed Unaami in the* Science Plan?

As described in the *Science Plan*, a fundamental idea behind SEARCH is that a complex of interrelated changes has occurred in the Arctic in recent decades. We have given the name Unaami to this complex and used it in our working hypotheses. However, the definition of Unaami is not complete in terms of key variables, space scales, time scales, and persistence. Unaami includes such changes as a drop in surface atmospheric pressure, cyclonic shifts in ocean circulation, and rising air temperature in certain regions, but other variables in the physical environment and ecosystem have also changed recently and may be part of Unaami as well. The *Science Plan* considers Unaami a decadal time-scale event. Based on timing of events and physical arguments, it maintains in Hypothesis 1 that Unaami is related to the AO, the dominant pattern of change in sea level atmospheric pressure over the Northern Hemisphere. However, the AO is energetic at many time scales and its rising trend, which is synchronous with the recent rise of Unaami, is a topic of ongoing research. Thus, regardless of the validity of Hypothesis 1, it is possible that Unaami varies in subtle ways over a range of space and time scales, and it is unknown whether Unaami will oscillate, decline, remain in its present state, or gradually increase. Question 1 aims to improve the definition of Unaami. It may be considered in two parts.

a) What are the key characteristics of Unaami in space, time, and persistence (e.g., oscillation vs. secular change)?

b) Which variables of the Arctic system, beyond those already recognized, are key elements of Unaami?

Question 2: *Are the climatic components of Unaami consistent with natural variability, or are they anthropogenic*?

This is addressed at least indirectly by *Science Plan* Hypothesis 2; “Unaami is a component of climate change.” The AO is a fundamental mode of atmospheric variability. Its rising trend characterizes several model scenarios of greenhouse warming. We suggest that in this way Unaami may be tied to anthropogenic climate change through the AO. Even accepting Hypothesis 2, it remains for SEARCH to determine whether Unaami is largely produced by greenhouse gas increases or is mostly the result of natural variation. Specifically we must answer:

a) How unusual is Unaami in the context of modern, paleo, or model-based results?

b) What is the association between increased greenhouse gases and Unaami?

Question 3: *What are the critical interactions among ocean, ice, land, and atmosphere as they relate to Unaami*?

This is addressed by *Science Plan* Hypothesis 3, “Feedbacks between the ocean, the land, and the atmosphere are critical to Unaami.” This topic recognizes that Unaami is not merely a passive response to a changing atmosphere, but involves feedbacks that dampen or reinforce the response. Specific questions that illustrate critical interactions are:

a) Do stratospheric processes drive AO variability? (*Science Plan*, p. 38)

b) Do albedo feedbacks from snow and sea ice extend the duration of melt season anomalies? (*Science Plan*, p. 37)

c) How much of the AO trend is driven by processes outside the Arctic?

d) What impact do changes in terrestrial runoff have on Arctic Ocean circulation? (*Science Plan*, p. 38)

e) Do changes in ocean circulation such as the diminution of the cold halocline and changing freshwater pathways contribute to maintaining Unaami?

f) How do land surface changes dampen or reinforce Unaami through changes to energy balance, hydrologic balance, hydrologic cycles, trace gas fluxes, and ecosystem function?

g) What will be the role of changes in precipitation and soil moisture on runoff, ecosystem function, and ocean circulation?

h) How do changes in marine biota provide feedback?

i) How do changes in shelf circulation influence the availability of nutrients to phytoplankton in the Arctic?

Question 4: *How are global climate and Unaami coupled?*

This is a fundamental prerequisite to answering Question 2 and is an important special case of Question 3. To really learn if Unaami is a manifestation of anthropogenic climate change (Question 2), we must learn how Unaami and global climate are coupled, and clearly this involves interaction amongst the atmosphere, ocean, ice, and land (Question 3). Specific candidates for coupling are posed by the following questions:

a) Is the Arctic capable of causing rapid climate change on hemispheric scales? (*Science Plan*, p. 37)

b) What are the effects of changes in freshwater and ice fluxes on Unaami? (*Science Plan*, p. 37)

c) What is the role of arctic and sub-arctic ice and freshwater fluxes in modulating global thermohaline circulation and meridional overturning circulation? (*Science Plan*, p. 37)

d) How does warming associated with Unaami affect sea ice and can it initiate ice-albedo feedback?

e) How do atmospheric and oceanic circulation changes associated with Unaami affect sea ice and do they initiate ice-albedo feedback?

f) What is the association of Unaami with storm tracks and meridional heat transport? (*Science Plan*, p. 39)

g) What is the effect of Unaami on radiatively active trace gas exchange of arctic and sub-arctic ecosystems with the atmosphere?

h) How do changes in heat and moisture contrast between land and ocean in arctic and sub-arctic regions influence atmospheric circulation, such as the location of the arctic and subarctic fronts?

Question 5: *How does Unaami interact with biogeochemical cycles?*

This question is important for two reasons. First, it represents a specific aspect of Questions 3 and 4 because some of the biogeochemical cycles may affect the physical feedbacks within Unaami and between Unaami and global climate. Therefore addressing this question is a necessary activity when addressing *Science Plan* Hypotheses 2 and 3. Second, because this question concerns the relation of the biosphere to the physical changes in the arctic system, it is crucial to testing *Science Plan* Hypothesis 4, “The physical changes of Unaami have large impacts on the arctic ecosystems and society.” Examples of more specific questions include:

a) How are the key biogeochemical (e.g., C, N, P, S, greenhouse gases, and contaminants) cycles coupled with Unaami?

b) How are biogeochemical cycles of terrestrial ecosystems affected by Unaami-associated changes in precipitation?

c) Is Unaami affecting fluxes of dissolved and particulate matter from land to sea (e.g., coastal erosion) that, in turn, influence ecosystem dynamics?

d) How will Unaami influence the mobilization of constituents such as marine clathrates and permafrost carbon that are legacies of past environments?

e) How might Unaami affect the transport and deposition of airborne and waterborne contaminants (pollutants)?

Question 6: *What changes in populations, biodiversity, key species, and living resources are associated with Unaami?*

This question is addressed by *Science Plan* Hypothesis 4, "The physical changes of Unaami have large impacts on the arctic ecosystems and society." Examples of more specific questions include:

a) What impact does Unaami have on living resources (biomass, diversity, distribution, health, physiological status, and annual biological phenomena [phenology])?

b) How does Unaami, as reflected in populations, biodiversity, key species, and ecosystems, interact with driving forces such as harvesting and cumulative impacts of regional development?

c) How do changes in species composition and trophic dynamics associated with Unaami affect ecosystem structure and function, including biogeochemical cycles?

d) What are the most sensitive biotic indicators of Unaami (e.g., indicator species, genetic change, demography, and recruitment, abundance.)? (*Science Plan*, p. 70)

Question 7: *What are likely effects of Unaami on the health and well being of arctic residents?*

This question is also raised by *Science Plan* Hypothesis 4, "The physical changes of Unaami have large impacts on arctic ecosystems and society." Specific examples include:

a) How might Unaami affect marine and terrestrial subsistence and commercial harvests and associated ways of life in the Arctic?

b) How does Unaami interact with other changes (technology, markets) and social change?

c) How might Unaami interact with other changes to affect arctic human settlements, transportation systems, and economic development?

d) How might Unaami interact with other changes to affect the spread of diseases, health of resources and people, and quality of life?

Question 8: *How can we characterize the adaptive responses of arctic communities?*

a) How have arctic people adapted to past environmental change?

b) How do social factors (institutions, social structure, information flows, empowerment, social capital, human capital, infrastructure) affect the contemporary adaptive responses of arctic communities to Unaami and other coupled changes?

Question 9: *How might Unaami affect people outside the Arctic?*

This question is also raised by *Science Plan* Hypothesis 4 in the context of society beyond the Arctic. Specific examples include:

a) How might Unaami affect arctic and subarctic fisheries?

b) How might Unaami affect species and habitats of special concern? (e.g., arctic migratory species, endangered species)

c) How might Unaami affect transportation, resource development, and other economic activities?

d) How might Unaami affect international relations and national security?

e) How might Unaami affect energy use and cost?

2.2 Application Questions

SEARCH will strive to predict Unaami and its effect on ecosystems and society. This raises key application questions for SEARCH:

Question 10: *Can we ultimately predict Unaami and its effects?*

This is the future corollary of Question 1. To answer in the affirmative we will, at a minimum, have to understand Unaami and answer most of the other questions. In addition we must ask specifically:

a) How well do models reproduce the observed Unaami?

b) What are the lags between physical changes in the Arctic and changes in ecosystems and other regions?

c) What is the sensitivity of predictions to initial state?

d) What is the level of process detail needed in models to actually predict Unaami?

e) What is the possibility that Unaami will trigger a major step change in the Arctic (i.e., an ice-free Arctic Ocean?)

Question 11: *How can understanding of Unaami be used to develop adaptive responses?*

a) How do we communicate scientific understanding of Unaami?

b) How do we communicate community needs?

c) How effective or adequate are contemporary responses?

d) What responses would be most effective?

2.3 Implementation Priorities and Readiness

The implementation priority and readiness for action to pursue science questions have to be considered in the priority and timing of SEARCH activities (see Sections 5 and 6). All questions have a high priority in SEARCH, but in light of research costs and funding availability, some questions have a higher implementation priority than others. Also, although all questions must ultimately be addressed, for reasons of readiness and natural progression, some questions will have to be addressed before others. Generally speaking, the questions that aim to define and track the character and scales of Unaami (e.g., Questions 1, 2, and parts of 3–6) tend to rank high in priority and readiness. Those that explore more specific interactions (e.g., many parts of 3–8) rank slightly lower. Questions aimed at application (e.g., parts of 7–8 and most of 9–11) may be high priority, but they may be impossible to address until we know more about Unaami. However, even with these questions there may be important initial action required in order to lay the groundwork for ultimate resolution. As with the questions themselves, the priority and readiness of the questions will obviously change as we learn more. It will be the responsibility of the SEARCH leadership, based on research community input, to repeatedly ask how well SEARCH is answering the science questions and evaluate their implementation priority and readiness for action.

3. Organization

The organization of SEARCH is special because, though SEARCH will have many facets, it should remain focused on understanding Unaami and its impacts. While many disciplines are involved, SEARCH does not intend to spawn a host of new programs with their own independent planning processes. The solution is to maintain a fairly narrow, vertical structure. Potentially problematic, SEARCH activities will likely be a mix of new efforts, programs already in the planning process, and existing programs. For this reason, and in order to keep an appropriate mix of disciplinary and interdisciplinary coordination, organizational plans for guidance of the program and program activities should remain distinct. Thus no separate and complete organizational structure for each area of activity is required. This plan also allows some independence for existing programs, and lets the guidance elements concentrate on the overall picture.

A good example of the type of focused, vertically structured organization needed to guide SEARCH is that of the Tropical Ocean Global Atmosphere (TOGA) program. TOGA was developed to understand the ENSO phenomenon. The problem parallels the SEARCH problem in fundamental ways. Just as TOGA's aim was to understand a decadal, large-scale, atmosphere-ocean phenomenon, El Niño, SEARCH seeks to understand a decadal, pan-arctic, atmosphere-ice-ocean-land phenomenon, Unaami. In both El Niño and Unaami, the physical environmental changes have important impacts on ecosystems and society. Like TOGA, SEARCH requires long-term observations, modeling, process studies, and application. Finally, like TOGA, SEARCH will be an interagency program in the U.S. with critical international aspects. Therefore, it is natural for us to look at the TOGA organization as a possible model for SEARCH.

The TOGA organization was fairly simple, and this simplicity seems to have contributed greatly to maintaining the focus of the program. International TOGA included a TOGA Scientific Steering Group roughly analogous to the SEARCH SSC. Under that, TOGA implemented a TOGA Numerical Experimentation Group for modeling and theoretical work, a TAO (Tropical Atmosphere Ocean) Implementation Group that devised the TAO observation system, and a Coupled Ocean Atmosphere Response Experiment (COARE) Panel that designed TOGA’s main process study (U.S. TOGA had a NRC panel for scientific advice, U.S. TOGA Project Office at NOAA for administration, and an interagency agreement under the U.S. Global Change Research Program for funding). To achieve the required breadth in the program, the TOGA Numerical Experimentation Group, the TAO Implementation Group, and COARE Panel each employed working groups of experts to develop detailed observation and modeling activities and to solve problems as the program progressed. Generally the scope and focus of these working groups was fairly narrow. Using this structure, TOGA avoided having a proliferation of new groups writing individual science plans and going off in new directions. SEARCH will benefit from the same general organizational philosophy.

3.1 SEARCH Organization Diagram

The SEARCH guidance organization will be headed by a SEARCH Steering Committee similar to the present SEARCH SSC (Figure 1). SEARCH will ask for review of its activities by an *ad hoc* advisory group, composed of disinterested experts empanelled every 5 years. This group, perhaps under the National Academy of Sciences, will provide review and advice on the direction of SEARCH. Under the SEARCH SSC will be three panels, a Detecting Change Panel (DCP), an Understanding Change Panel (UCP), and a Responding to Change Panel (RCP). The panels’ top priority and most timely activities are continuing and initiating critical long-term observations, and analyzing and modeling data to answer key questions. The DCP and UCP will develop and oversee the research implementation plans for these two types of activities. The DCP will design the SEARCH observing system. The UCP will plan the use of data and models in developing data assimilation methods and modeling Unaami with the ultimate aim of understanding the causes of variability at these large space-time scales and predicting their impact on ecosystems and society. The panels will coordinate the activities in the SEARCH action areas and core functions and assess their activity in terms of the SEARCH goals, *Science Plan*, and *Implementation Strategy*. With the perspective provided by panel input, the SSC and IPMC establish the SEARCH action areas and core functions and working groups to implement them. The working groups could be established by discipline, environment, or specific problems, but they will work on problems laid out by the SEARCH leadership.

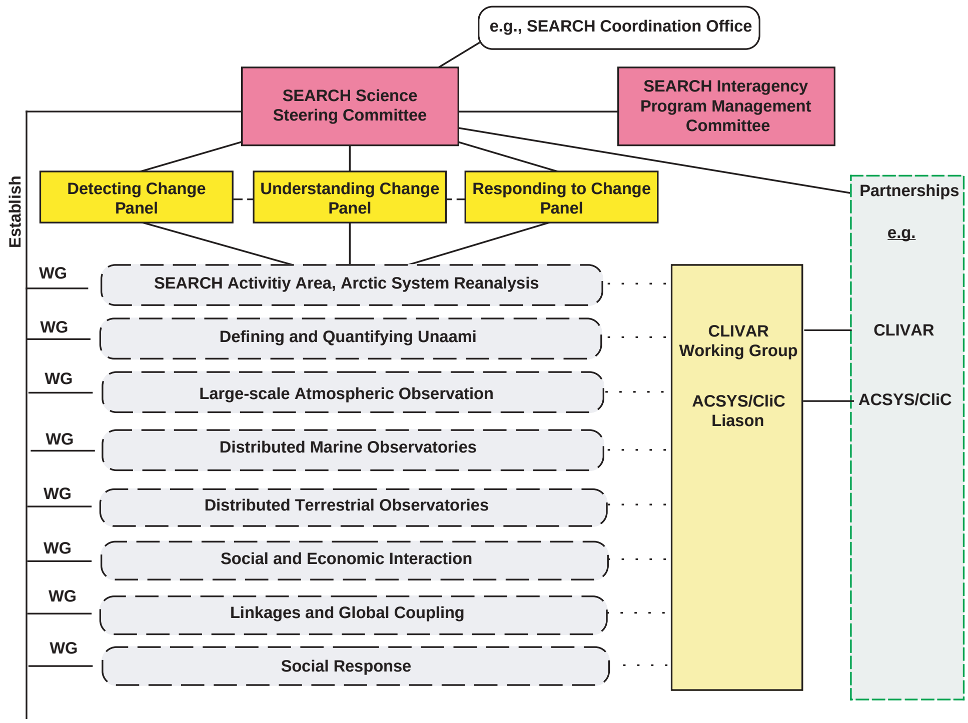

Figure 1. Organization of SEARCH guidance. The SSC and IPMC guide the Detecting, Understanding, and Responding to Change panels. The panels coordinate the activities in the SEARCH action areas and core functions and assess their activity in terms of the SEARCH goals, Science Plan, *and* Implementation Strategy. *With the perspective provided by panel input, the SSC and IPMC establish the SEARCH action areas and core functions.*

SEARCH organization will be interdisciplinary at every level. For example, the paleo science, biology, and social science activities will be represented along with the physical sciences on the SSC, DCP, UCP, and RCP. Observations will include historical and paleo observations as well as new instrumental observations. The observation and modeling-prediction activities for the ecosystem and societal issues would be taken up by the DCP and UCP right along with the physical modeling. This does not mean necessarily that all observations or modeling will be phased in at the same time in all areas. Phasing will be decided by the panels consistent with SEARCH implementation priorities and the readiness of the various activities. Sub-elements of SEARCH already in existence, for example, the study of Arctic and Sub-arctic Ocean Flux (ASOF), or at least major parts of them, will have a place in the activity areas under guidance by the panels. Where appropriate SEARCH will take advantage of existing national and international programs (e.g., IABP, ASOF), and SEARCH may tie in with these in ways that will be slightly different from its *ab initio* activities.

Because SEARCH addresses pan-arctic issues, SEARCH must have international representation. SEARCH has cultivated high-level international partnerships through the International Program on Climate Variability (CLIVAR) and Arctic Climate System Study/Climate in Cryosphere (ACSYS/CliC). This will continue. There will also be participants at the PI level from countries outside the U.S. However, to ensure that the science program has the proper level of international cooperation, some non-U.S. members should be included on the SSC and each of the key panels. The non-U.S. members of these committees must be capable of representing to some extent the opportunities for international collaboration on SEARCH activities. They must be knowledgeable about SEARCH-relevant activities in other countries and recognized as people who can influence other non-U.S. colleagues to seek connections with SEARCH.

A separate panel has not been established for process studies. The DCP and UCP will recognize when process studies are needed. These will be taken up under SEARCH and involve finite-life dedicated planning activities, or the process studies may be carried out independently. An example is SBI, which already exists, but will help answer SEARCH questions. Process studies under SEARCH should address the long-term goals of SEARCH, documenting, understanding, and ultimately predicting Unaami.

Plans for the SEARCH Responding to Change Panel will follow the general scheme of the DCP and UCP. It is sensible to have this panel work from the very beginning to incorporate and test application of what is learned to predicting the impact of Unaami on the ecosystem and society. The vision of how the RCP will function will have to evolve during the early stages of SEARCH.

As suggested by the descriptions above, the terms of reference for the committees and panels of SEARCH are as follows.

3.2 Terms of Reference

SEARCH Activities are observational, analytical, and modeling activities that respond to science plans and priorities established by the SEARCH SSC and are endorsed by the SEARCH IPMC, or those that respond to science plans and priorities established by other groups and acknowledged by the SEARCH SSC and endorsed by the SEARCH IPMC. It is expected that results of SEARCH activities will be made available for inclusion in SEARCH synthesis and reporting activities.

SEARCH Activity Areas are groups of activities aimed at answering specific questions or groups of questions in specific regions and/or requiring especially close scientific or operational cooperation.

SEARCH Overarching Functions are those whose work integrates the various sub-elements of SEARCH.

3.2.1 SEARCH Steering Committee (SSC)

1. Takes overall responsibility for planning and implementation of SEARCH science activities.
2. Provides scientific advice to and consults with the SEARCH Interagency Program Management Committee (IPMC) to promote SEARCH and to ensure SEARCH science implementation is consistent with the funding plans.
3. Nominates candidates for membership on the DCP, UCP, and RCP panels for approval by the IPMC.
4. Works to ensure the integration of the observation, modeling, and application elements of SEARCH to produce an efficient, productive, and appropriately interdisciplinary program.
5. Seeks and help coordinate the international cooperation necessary to conduct a pan-arctic program.
6. Takes responsibility for liaison with other programs that share SEARCH objectives.

The SSC membership will include expert representatives from the fields of atmospheric science, physical oceanography, chemical oceanography, geochemistry, biological oceanography, terrestrial biology, climate studies, paleo studies, hydrology, sea ice, terrestrial ice, and human dimension. There will be at least one non-U.S. member. The chairs of the DCP, UCP, and RCP will attend the SSC meetings. (Three SSC members will also be appointed by the SSC to attend the meetings of the three panels, one to each of the DCP, UCP, and RCP.)

The term of office will be three years with one third of the positions up for nomination every year. With nominations from the SSC, the IPMC will appoint the SSC members and the chair. The chair and the members will serve three years from the date of the election, with the possibility of a further three-year term. Start dates will be staggered among the members to ensure continuity.

3.2.2 SEARCH Interagency Program Management Committee (IPMC)

1. Approves terms of reference for the SSC and panels. Appoints SSC members with nominations from the existing SSC. Approves appointments to the three main SEARCH panels.
2. Reviews and approves science and science implementation plans prepared by the SSC and its subsidiary bodies.
3. Solicits science advice from the SSC and develops responsive programs and plans.

4. Discusses and coordinates agency plans for out-year budget requests to support activities related to SEARCH and provides appropriate interagency assistance.
5. Discloses and reviews agency activities that address SEARCH hypotheses and science questions.
6. Facilitates international efforts needed to address the SEARCH science questions (e.g., ASOF).
7. With the SSC facilitates international efforts needed to undertake the SEARCH program, reviews SEARCH accomplishments, plan integration, synthesis, and outreach activities.

The IPMC will include a representative of each agency supporting SEARCH. The selection and terms of office will be decided by each agency.

3.2.3 Detecting Change Panel (DCP)

1. Advises and aids the SSC in development of the observation component of the implementation plan. Plan revisions will be ongoing, and the panel will be involved with these as well.
2. Communicates with the SSC and particularly the UCP to ensure that the modeling efforts are integrated with the observation efforts. Specifically some of the panel members will sit with members of the modeling panel to develop the Arctic System Reanalysis (ASR), which as described by the SEARCH *Science Plan*, will be a program of data assimilation and modeling to develop optimum estimates of difficult or impossible to observe critical parameters of the arctic system.
3. Works with the RCP to ensure observations provide the data needed for application.
4. Has oversight of the details of the observation program. This will involve using the SEARCH project office to track the observation program and to disseminate information about activities and progress.

This will be a working panel and should be small enough to be intensely active. The panel should include six or seven members with at least one expert on observations in the marine environment, terrestrial environment, the atmosphere, paleo science, and the human dimension. Disciplines not represented on a panel directly will be represented through use of specialized working groups. Joint membership on more than one panel (DCP, UCP, and RCP) will be permitted and may be advisable to maintain close ties between the panels. At least one member of each panel should be appointed by the panel to attend meetings of the other panels on an *ex-officio* basis. One SSC member will be appointed by the SSC to attend *ex officio* the meetings of the DCP. (The chair of the DCP will also attend the SSC meetings *ex officio*.)

The chair and members will be appointed by the SSC with the approval of the IPMC. They will serve for three years with the possibility of one additional three-year term. Start dates will be staggered among the members.

3.2.3 Understanding Change Panel (UCP)

1. Advises and aids the SSC in development of the modeling component of the implementation plan. Plans revisions will be ongoing, and the panel will be involved with these as well.
2. Ensures timely access to new observational information for analysis activities and model comparisons.
3. Communicates with the SSC and particularly the DCP to ensure that the modeling efforts are integrated with the observation efforts. Specifically some of the panel members will sit with members of the DCP to develop the ASR.
4. Works with the RCP to ensure modeling provides the type of predictions needed for application.
5. Has oversight of the details of the modeling program. This may involve using the SEARCH project office to track the modeling program and to disseminate information about activities and progress.
6. Fosters collaborations with the major international climate modeling centers to catalyze their efforts in Arctic modeling in general.

This will be a working panel and should be small enough to be intensely active. The panel should include six or seven members with at least one expert on modeling in the marine environment, terrestrial environment, and the atmosphere. They should also include modelers who understand how to work with paleo data and the human dimension information. Disciplines not represented directly will be represented through use of specialized working groups. Joint membership on more than one panel (DCP, UCP, and RCP) will be permitted and may be advisable to maintain close ties between the panels. At least one member of each panel should be appointed by the panel to attend meetings of the other panels on an *ex-officio* basis. One SSC members will be appointed by the SSC to attend *ex officio* the meetings of the UCP. (The chairs of the UCP will also attend the SSC meetings *ex officio*.)

The chair and members will be appointed by the SSC with the approval of the IPMC. They will serve for three years with the possibility of one additional three-year term. Start dates will be staggered among the members.

3.2.4 Responding to Change Panel (RCP)

1. Advises and aids the SSC in development of the application component of the implementation plan. In this area especially the initial plan will not be well developed so that revisions will be critical and the panel's activity will probably increase with time.
2. Works with the DCP and UCP to ensure planned observations and modeling provide the data needed for application.
3. Has oversight of the details of the application program.

This will be a working panel and should be small enough to be intensely active. The panel should include six or seven members with at least one expert on the marine environment, terrestrial environment, and the atmosphere. Several members should be expert in the human dimension. Disciplines not represented directly will be represented through use of specialized working groups. Joint membership on more than one panel (DCP, UCP, and RCP) will be permitted and may be advisable to maintain close ties between the panels. At least one member of each panel should be appointed by the panel to attend meetings of the other panels on an *ex-officio* basis. One SSC members will be appointed by the SSC to attend *ex officio* the meetings of the RCP. (The chairs of the RCP will also attend the SSC meetings *ex officio*.)

The chair and members will be appointed by the SSC with the approval of the IPMC. They will serve for three years with the possibility of one additional three-year term. Start dates will be staggered among the members.

3.3 SEARCH Working Groups

These working groups will carry out the individual SEARCH action areas. They will advise the DCP, UCP, and RCP on their activity and see that their results are communicated to the core functions and other action areas. At the discretion of the panels, the working groups may be disciplinary.

Membership will be a small (3–7) group of experts in various areas. Selection and terms of office will be made by the responsible panel (DCP, UCP, or RCP).

3.3.1 SEARCH/CLIVAR Working Group

This is an example of the kind of working groups that may be set up jointly with other programs that form partnerships with SEARCH (Figure 1).

1. Identifies the processes that are important for the coupling of the high latitude climate to the mid and low latitudes.
2. Develops and advises the CLIVAR and SEARCH SSCs on field, empirical, and model studies in the regions that influence the coupling between high latitudes and the mid and low latitudes to achieve the goals of CLIVAR and SEARCH.
3. Suggests mechanisms for implementation of such studies.

4. Advises the CLIVAR and SEARCH SSCs on the relevance and priority of specific projects in the context of the overall scientific objectives of such studies.
5. Coordinates U.S. activities with international studies to effectively use the combined resources of the international community working on the problem of linking the high latitudes to lower latitudes. This includes keeping track of, assessing, and advising the CLIVAR and SEARCH SSCs of plans for climate observations, including operational observations by U.S. agencies, GCOS, GTOS, and GOOS, in the regions important for linking the high latitudes to lower latitudes.

The membership will include three members chosen by each the SEARCH SSC and the CLIVAR SSC.

Selection of the SEARCH members will be made by the SSC and the IPMC. The term of office will be three years with possible nomination for repeat terms. The SEARCH SSC and CLIVAR SSC will choose the rotation sequence.

4. SEARCH IMPLEMENTATION ACTIVITIES AND ACTIVITY AREAS

SEARCH takes as its goals an understanding of Unaami, its relationship to ecosystems and social change, and an ability to track Unaami into the future. Given these, the effort early in SEARCH must be to learn the full scope of Unaami and how to observe it with an observing system of practical size. This is consistent with the priority and readiness of the SEARCH questions (Section 2). The highest priority and most timely question is: "How can we best characterize the composition, scales, and persistence of the recent complex of dramatic environmental changes in the arctic system (termed Unaami in the *Science Plan*)?" Closely related questions of high priority and readiness for action are: "Is Unaami consistent with natural variability, or are the climate changes it involves anthropogenic?" and "How are global climate and Unaami coupled?"

The initial stages of SEARCH, emphasizing the observation and modeling-analysis efforts, are aimed at (1) establishing the dominant modes of variation of the arctic system, especially as part of Unaami, (2) understanding the interaction of these modes, and (3) a prototype modeling and observation system based on (1) and (2) that allows tracking and prediction of the behavior of Unaami. Establishing and understanding the modes of variability of many parts of the arctic system will be useful for the relevant components of the ASR. As SEARCH proceeds, increasing emphasis will be given to applying, testing and improving this prototype system and applying its products to prediction of impacts on the ecosystem and society. Such a sequence will not be absolute. Ecosystem and societal factors must be considered part of Unaami during the early stages of SEARCH. Conversely, understanding of the system will improve and physical models will change as SEARCH proceeds. This approach is meant to be roughly consistent with the priority-readiness rankings of the SEARCH science questions; first we will find out what is going on in the arctic system, and then we will seek both the larger and more specific implications.

Early efforts at detecting change will be characterized by a strong interest in historical and paleoclimatic data that will provide higher quality, pan-arctic time series. At the same time, fieldwork will focus on new time-series observations at high priority locations. These will be needed to track Unaami until more optimal measurement locations are chosen.

Early efforts at understanding change will emphasize objective characterization of Unaami using the covariability of observations of the atmosphere, marine and terrestrial environments, and social and economic systems, and the development of explanations for this covariability. This will also involve comparing and reconciling the modes of variability found in models with those observed in historical data records.

The connections between physical modes of variability and ecosystem variability will prove complex. Although there are areas of similarity in marine and terrestrial ecosystems, there are also important differences. One difference that may have a major impact on the responses of these ecosystems to physical forcing is the life histories of the primary producers. In the pelagic marine system, most primary producers are microscopic and have generation times of hours to days; in the terrestrial environment, most primary producers have annual or longer generation times. This difference will provide an opportunity to examine how different modes of change in physical variables impact biological systems.

The early components of SEARCH aimed at responding to change will emphasize application of research on Unaami to fisheries, subsistence hunting, transportation, and other related social and economic issues of interest to industry and government decision-makers. It will also develop a systematic method of connecting SEARCH science with northern communities and society in general.

This section discusses the SEARCH activities broken down first by the *Detecting*, *Understanding*, and *Responding* paradigms and then in subsections by activity area. Operationally the activities of SEARCH fall naturally into eight interdisciplinary activity areas that closely interact with each other. These SEARCH operational activity areas take advantage of common science infrastructure and logistics. Most of them fall largely under *Detecting, Understanding,* or *Responding* to change, but several fall under two such categories. They are:

1. *DQU—Detecting and Quantifying Unaami and Other Modes of Variability*
   Detecting and Understanding Change

2. *LAO—Large-scale Atmospheric Observatories*
   Detecting Change

3. *DMO—Distributed Marine Observatories*
   Detecting Change

4. *DTO—Distributed Terrestrial Observatories*
   Detecting Change

5. *SEI—Social and Economic Interactions*
   Detecting and Understanding Change

6. *ASR—Arctic System Reanalysis*
   Understanding Change

7. *LGC—Linkages and Global Coupling*
   Understanding Change

8. *SOR—Social Response*
   Responding to Change

For DMO and DTO, distributed is used to indicate a number of observation stations at various locations in the terrestrial or marine domains. There will also be regionally-oriented SEARCH operational elements such as the Arctic and Sub-arctic Ocean Flux (ASOF) and Bering Sea (BSP) programs that will combine activities in one or more activity areas. Beyond the *Detecting*, *Understanding*, and *Responding* themes, activities are broken down according to activity area (see Section 5). In the following section the activity areas are summarized and the initial SEARCH priorities are recommended.

4.1 Detecting Change

4.1.1 *DQU* - Detecting and Quantifying Unaami and Other Modes of Variability

These studies will examine historical data and undertake paleoclimatic studies to determine the dominant modes of variability of the Arctic. They will determine whether the current suite of dominant modes has persisted through time, and if not, how they have changed. High-resolution records will investigate changes in high-frequency modes (e.g., AO) over several centuries, whereas longer, lower resolution records will identify centennial-scale modes of variability (e.g., are periods and amplitudes of AO variability stable? Did shifts to an increased AO positive phase occur in the past? Can a link be found between an increased AO positive phase and increased radiative forcing?) (Also see DQU, section a.) These studies will also examine whether dominant modes change so as to produce fundamental regime shifts (including possible surprise system behavior), and whether small changes in one part of the environment can produce a dramatic, non-linear change in another (e.g., ocean circulation affecting marine species composition). (Also see DMO, section a.)

a. Develop multiple lines of evidence (physical, biological, and human) for large-scale spatial covariability and change in the Arctic.

b. Develop a protocol for detection of arctic change.

c. Support standards for time series and metadata to permit timely sharing of information and enhance multidisciplinary analyses. This includes quality control of historical data sets. An example concerns streamflow, where measurement methods for discharge under ice cover may have changed over time, and records may be affected by upstream water management. It will be critical to adopt agreed upon standards for sampling (e.g., Joint Global Ocean Flux Study/ World Ocean Circulation Experiment methodologies) and to inter-calibrate old and new times series. These issues are important not only for physical and chemical measurements (e.g., nutrients, chlorophyll), but also for biological sampling (e.g., standardization of zooplankton sampling gear and fish population assessment methodologies). It will be important to support the development and application of tools for visualization and analyses of multi-disciplinary data and communication of results.

d. Develop a dense spatial network of high-resolution (annual to sub-decadal) terrestrial and marine paleoclimate records from throughout the Arctic. Figure 2 shows locations of proxy records used for investigations of annual and decadal-resolution modes of variability in arctic climate. Current research is investigating spatial and temporal patterns of change, including shifts in average temperature and the Arctic Oscillation, using annual records for the past 600 years, and decadal records over the past 1000–2000 years. Future work will focus on increasing the spatial density of the array, for better precision in capturing the AO and other modes of variability, as well as extending these high-resolution reconstructions further back in time. Additional work with lower-resolution records will include documenting past extreme states and threshold conditions leading to rapid change. The proxy network will 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. We will focus 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 will be integral to this effort as well, particularly for coverage in regions typically lacking laminated sediments such as Beringia and Siberia. Multiple proxies will be used to reconstruct primarily summer season temperature, an important climate parameter in the Arctic, with a subset of records documenting mean annual temperature and/or precipitation. The network will be used to address questions such as the impact, periodicity and persistence of oscillations inherent to the arctic and global climate system. Patterns of climatic change will be reconstructed at a variety of temporal scales and will be compared to the known patterns of historically documented oscillations (e.g., AO, NAO) to elucidate possible driving mechanisms and longer-term behavior of the arctic climate system. Long-term comparisons of AO indices with mean background climate state will facilitate identification of forcing mechanisms during the pre-anthropogenic period, including the potential influence of average arctic surface temperature on AO behavior.

e. Obtain a network of long (Holocene+) terrestrial and marine paleoclimate records with decadal-centennial resolution from key arctic and subarctic regions, but at lower spatial resolution than the annual proxy network. Long records covering periods of warmer and colder past climate will be used to identify abrupt climate shifts and quantify regional and arctic-wide climatic conditions at those times. Such records will provide insight into possible threshold conditions that may trigger rapid climate jumps. The identification and precise determination of such threshold states will be critical in the face of continued future arctic change.

f. 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 will be selected to maximize the number of proxy records available. In limited instances, all proxy archives may be represented within a small geographic location (e.g., southeast Alaska).

g. Collect and analyze data from coastal and inland archeological sites such as shell middens and faunal remains; analyze chemical signatures (e.g., oxygen isotope levels in shells, bones, and otoliths) for evidence of climate variation. (Note: remains at marine sites are better preserved than at terrestrial sites so continuous historical records are more easily obtained.) At inland sites ascertain occupation: presence/absence in an area and intensity of use. Artifacts signal what animals people are using and size of human population. Archeological evidence from sites at diverse locations across the arctic and subarctic will be compared to determine arctic-wide changes contained in patterns of regional or local changes. Here there could be a tie with the Census of Marine Life History of Marine Animal Populations and Future of Marine Animal Populations.

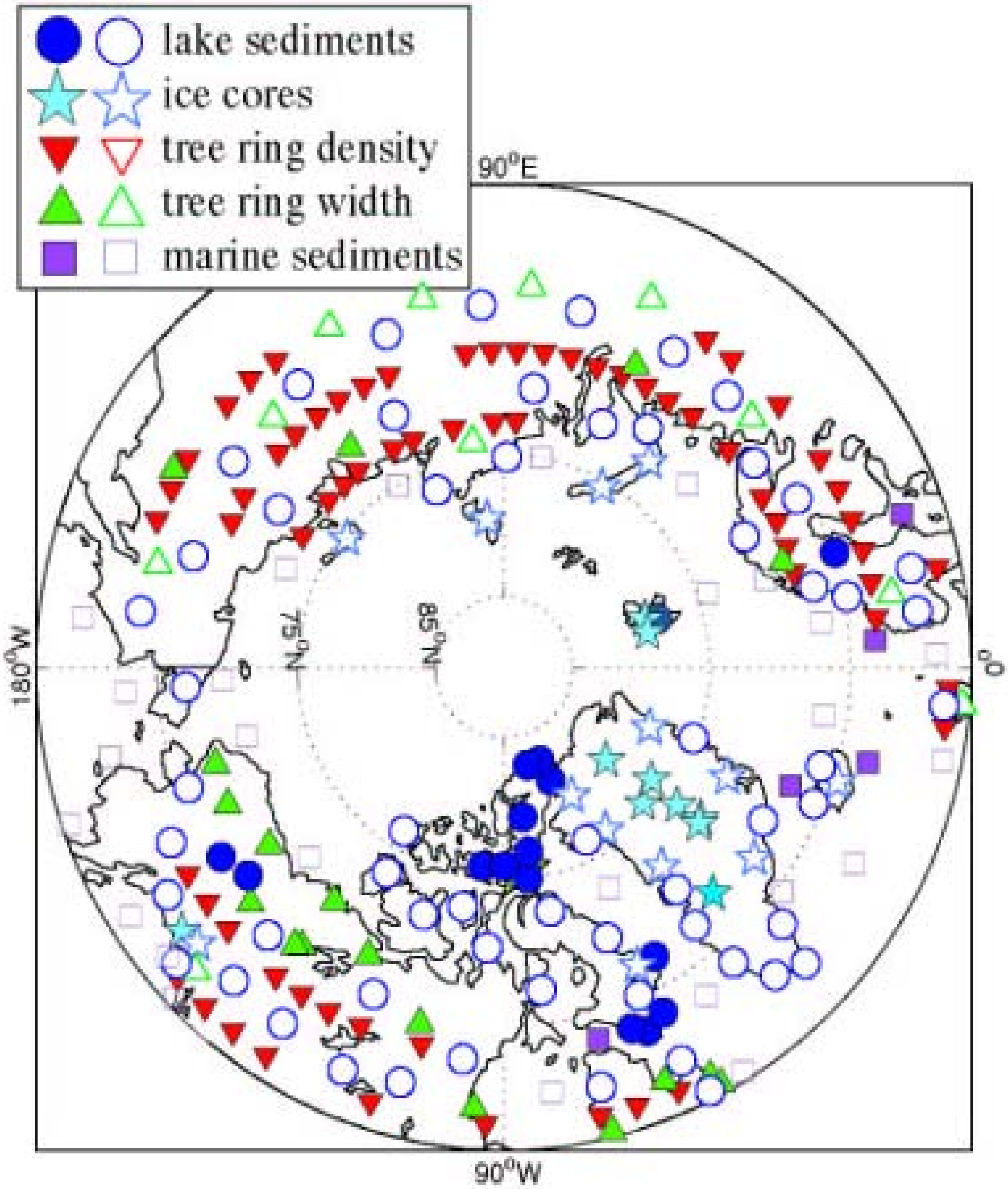

Figure 2. SEARCH High-Resolution Proxy Array. Existing records are shown with filled symbols according to the type of proxy archive (tree rings, lake sediments, ice cores, marine sediments, etc.). Proposed additional records showing idealized proxy distributions and spatial densities are indicated with lighter, open symbols. Note that these proposed future records are not intended to convey specific locations or specific proxy types, but are shown instead to represent the spatial density and proxy overlap necessary for confident multi-proxy assessment of past natural climate variability.

h. Compile historical data on stock abundance and distribution, and migration routes for key species across places and time. Key industrial fisheries with potential biophysical relationships to polar vortex/AO in the North Atlantic include Atlantic cod, herring, shrimp, and capelin; in the North Pacific, pollock, Pacific cod, herring, and several crab species are important. Marine mammals as well as Arctic cod, and some salmon runs are important species for subsistence use. Terrestrial species of greatest interest are rangifer (caribou and reindeer), and moose.

i. Collect and document evidence of variation in local and regional resource use over time. Use archeological data, historical accounts, oral histories, and contemporary harvest data to record amount and quality of important food sources, trends in total harvest effort, changes in seasonal effort, shifts to alternative food types, and changes in processing and preservation methods.

j. Find long-term records of human activity [e.g., shipping, development, fishing, subsistence, transportation (air, boat, overland)] to analyze for variability and social and/or environmental changes.

k. Interview arctic residents and others with long experience and knowledge of oral history in the region to identify the timing and types of change for further investigation; compare oral history to evidence from paleoclimatic data.

4.1.2 *LAO* - Large-scale Atmospheric Observatories

a. *Major Weather Stations* - Establish or incorporate several complete weather stations on land (e.g., Barrow, Alert, Svalbard, and Tiksi). Much of the infrastructure is already in place at these sites. Barrow for example has a very complete set of observations at the DOE ARM site. Developing this array of major stations will require all the stations have the same minimum set of observation. We should consider the addition of an inland site, e.g., away from the coast on the North Slope of Alaska (possibly as part of DTO below).

b. *Satellite Sounding* - Construct a framework recalibrating and updating the satellite-derived temperature and water vapor sounding data from systems such as VTPR, TOVS, ATOVS and AIRS (see the acronym list for definitions of the remote sensing system acronyms), and integrate these into the ASR. Required activities include data assembly, recalibration, and instrument error characterization. Satellites provide the only source of upper-air information on temperature and water vapor over the central Arctic Ocean. Other satellite data that are routinely assimilated into atmospheric reanalyses and would be useful to LAO. For open water conditions of the marginal and sub-arctic seas these include winds from SSM/I and scatterometers (NSCAT, Quicksat). Upper air or cloud-top winds can now be derived from imaging data; ECMWF has recently started using MODIS-derived (tracked) water vapor winds over the Arctic and seen a significant improvement in their forecasts. Ozone retrievals from TOMS or TOVS (HIRS) are another important input for ASR.

Beyond data that are naturally going to be assimilated into ASR, there are many other large-scale atmospheric observations from satellite that are useful for validation of models (including the ASR) and for process studies critical to SEARCH. Major contributions would likely include:

i. clouds and cloud properties measured with AVHRR, ATSR, TOVS, MODIS, AIRS, IceSat, CloudSat, MISR, ASTER ,
ii. radiation using for example AVHRR Extended Pathfinder (APP-X), TOVS-derived fluxes, ISCCP, and CERES,
iii. upper air atmospheric chemistry including gases and aerosols. There is a wealth of instruments contributing to this area [e.g., TOMS, TOVS, SAGE, as well as a variety of instruments on UARS, ERS 1 and 2 (GOME) and Envisat (GOMOS)].

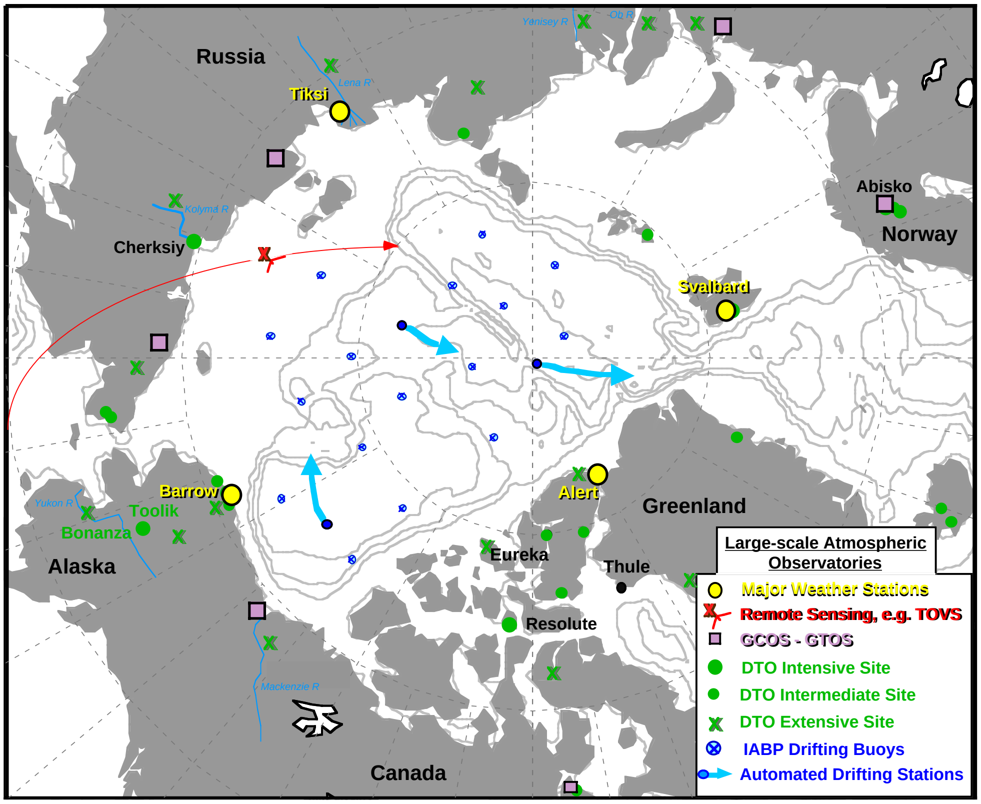

Figure 3. SEARCH Large-scale Atmospheric Observatories. Major weather stations would be established or enhanced with the latest instrumentation at four locations around the Arctic. GCOS sites would add to the large-scale observations and would be augmented by surface atmospheric observations at components of the Distributed Marine and Terrestrial observatories shown here in blue (marine) and green (terrestrial) and in Figures 4 and 5. Stations in the Bering Sea region would also be used but are not shown here. Remote sensing (TOVS) will be critical for large-scale coverage.

c. *Global Climate Observing System (GCOS)* - Working with the GCOS and GTOS (global terrestrial observing) programs, establish quality controlled long time series available in near real time. Key issues include the rescue of existing data on precipitation, temperature, snow depth and water equivalent, and other hydrological variables, especially over the former Soviet Union where large amounts of data may remain undigitized. We also need to examine how much data is being made available in near-real time through the Global Telecommunication System and, to the extent possible, enhance data delivery. In general the GCOS coverage in the Arctic is inadequate for the needs of SEARCH and will be augmented by observations at DMO sites (IABP and Automated Drifting Stations in gray in Figure 3 and in color in Figure 4) and DTO sites (ITEX and Borehole sites in gray in Figure 3 and in color in Figure 5) and additional World Meteorological Organization (WMO) sites not included in the GCOS.

4.1.3 *DMO* - Distributed Marine Observatories

a. *International Arctic Buoy Program (IABP)*. Enhance the IABP to improve coverage of atmospheric pressure and temperature measurements, particularly for the Eurasian Basin (Figure 4).

b. *Automated Drifting Stations*. Maintain two or three complete drifting automated stations in the Arctic Ocean measuring atmospheric conditions including radiative conditions, ice mass balance, upper ocean conditions, and ocean surface heat flux in the Arctic Ocean (e.g., Beaufort Sea, North Pole, and Makarov Basin regions; see Figure 4). These stations provide critical atmospheric data and detailed upper ocean hydrographic and velocity measurements that cannot be obtained by other means. By measuring seasonal changes in the upper ocean, ice, and atmosphere, we can track the net influence of the changing ocean and atmosphere on sea ice. By measuring the ice mass balance and ice-ocean-atmospheric fluxes in key regions, we can evaluate the thermodynamic forcing of the ice thickness distribution equations. This, along with the ice kinematics from the IABP and remote sensing techniques, can be used to validate ice models, enhance the sea-ice part of the ASR, and evaluate the importance of thermodynamic forces in changing ice conditions. Russian partnership will be critical in establishing an automated drifting station in the Makarov Basin area.

The International Arctic Buoy Program buoys will provide atmospheric pressure and temperature and ice motion data at about ten to twelve locations in the basin. The automated drifting stations will contribute to the IABP.

c. *Arctic Ocean Moorings*. Deploy moored, instrument arrays to assess the means by which water and ice are redistributed and mixed interior to the Arctic Ocean. These should be located along key water and sea-ice pathways in the Arctic Ocean (e.g., Eurasian continental slope, Lomonosov Ridge, Northwind Rise, Canada/Alaska continental slope). For example, mooring locations could include the end points of the hydro-repeat surveys of the CliC Implementation Plan (Figure 4). The moorings of the Nansen and Amundsen Basins Observing System (NABOS) being established by the International Arctic Research Center on the Russian continental slope will contribute to this effort. The shelf-basin exchange should be monitored at critical points (e.g., St. Anna Trough, Herald Canyon, Barrow Canyon, Mackenzie Canyon). Some of these moorings or nearby moorings may also satisfy the requirement for monitoring along-slope pathways.

d. *Arctic Ocean Hydrographic Surveys*. Periodically conduct hydrographic surveys (including water sampling for nutrients, oxygen, tracers, etc.) across key regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea-Pole, and Lincoln Sea-Pole). Optimally, the surveys would be repeated annually and at a minimum once per 5 years. Sections may be done by surface ship, aircraft, or submarine. Ultimately, when under-ice navigation problems are solved, surveys may be done with autonomous devices such as the new automated gliders or autonomous underwater vehicles. In planning the sections, there should be coordination with CliC Implementation Plan sections as illustrated in Figure 3. The ongoing North Pole Environmental Observatory (NPEO) sections cover the CliC Alert-North Pole section and the northernmost part of the CliC Alaska-North Pole section. They also include a

section into the important but relatively inaccessible Makarov Basin. A special effort should be made to enlist the cooperation of Russia to conduct hydrographic surveys in that region. The Japan-Canada Joint Western Arctic Climate Studies (JWACS) section will complement the Alaska-North Pole section by crossing the Beaufort Sea from east to west. Some thought should also be given to filling a perceived hydrographic data gap in the eastern Beaufort Sea, Alpha Ridge region (Figure 4).

An effort should be made where appropriate to extend survey lines across the Siberian shelves. Areas such as the Barents, Kara, Laptev, East Siberian, and Chukchi seas are important to ice and water mass formation and should be monitored.

Some of the hydrographic section lines or portions of them should be surveyed in both the spring (representing the end of winter condition) and the fall (representing the end of summer condition). For reanalysis activities and data assimilation, hydrographic surveys are needed in both seasons. For example, in the past the Arctic and Antarctic Research Institute compared open water surveys of the Barents, Kara, Laptev, East Siberian, and Chukchi seas (we should add the Beaufort Sea) in early autumn with springtime surveys to evaluate heat accumulated in the ocean during summer. These data were used to predict sea-ice conditions for the following winter. Also, the difference in total upper ocean salt content between the spring and the previous summer is an indication of total winter ice production. The seasonal measurements should be made at locations that analysis and modeling indicate are sensitive to climate variability and have long historical records.

e. *Moorings at Arctic Ocean Gateways*. Establish mooring arrays to monitor the Arctic Ocean exchanges (including sea ice) through Fram Strait, Barents Inflow Region, Bering Strait, and the Canadian

Archipelago. These are described largely in the *SEARCH-ASOF Implementation Plan*. A region that is particularly difficult from a permitting standpoint is the western half of Bering Strait. Governmental agreement with Russia on the desirability of such monitoring could help here. Another challenging area is the Canadian Archipelago. The proper means to monitor this complex region is a key issue for SEARCH-ASOF.

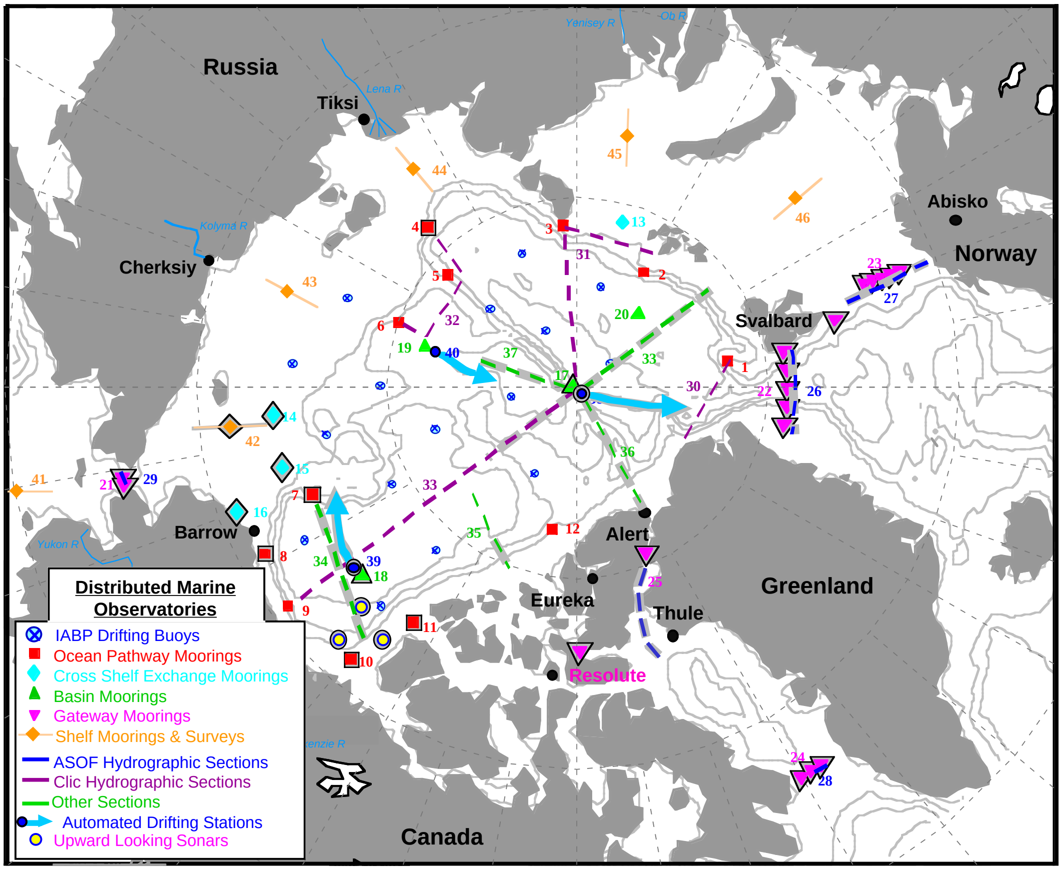

Figure 4. SEARCH Distributed Marine Observatories. The DMO includes moorings on key Arctic Ocean pathways, in the interior of major basins, and in the major gateways between the Arctic Ocean and subarctic seas. For clarity, the exact number and location of the gateway moorings are not shown here but are described in the SEARCH-ASOF Implementation Plan. The CliC Implementation Plan hydrographic sections are shown and are components of the SEARCH hydrographic sections. NPEO sections cover some of the CliC sections and provide stations in the northern Makarov Basin. The JWACS section crosses the Beaufort Sea in an east-west direction. Automated stations in the Arctic Ocean measure atmospheric conditions including radiative conditions, ice mass balance, upper ocean conditions, and ocean surface heat flux. The IABP buoys provide ice drift data as well as atmospheric pressure and temperature. Not all the existing buoys are shown, but the distribution is more uniform than is usual, SEARCH should strive to fill the deep basin gaps that sometimes develop. Installations that are in place or partial in place as part of SEARCH or other programs as of Fall, 2003 are indicated by a gray and black "halo" around the measurement symbol.

f. *Sea level and Ocean Bottom Pressure*. Measure sea level and ocean bottom pressure variation in the Arctic Ocean and subarctic seas. Sea level variation is a key indicator of ocean circulation. Measured rising trends in coastal region sea level relative to modeled sea level decreases in the central basin are fundamental signs of enhanced cyclonic circulation. Sea level has been and should continue to be measured by direct observation and with tide gauges at the coasts. Deep-sea pressure gauges, combined with hydrography and associated with moorings (e.g., c and e above and Figure 4) should be used at key sites along the continental slope and in the central basins. A variety of remote sensing tools (e.g., Gravity Recovery and Climate Experiment or GRACE) should be used to extend the point measurements over most of the Arctic Ocean.

g. *Ice Thickness*. Implement a coordinated sea-ice thickness monitoring program. Use upward looking sonar on all moorings (c and e above and Figure 4) to measure thickness in various regions of the Arctic Ocean and in key straits. Measure profiles of ice thickness with satellite remote sensing tools such as the Geoscience Laser Altimeter (GLAS) on ICESat and the CryoSat and ENVISat (see the acronym list for definitions) radar altimeters (satellite and aircraft), and when possible with submarines. Combine these measurements plus *in situ* measurements of key thermodynamic factors such as atmosphere and ocean heat flux with current-generation sea ice models (see Understanding Change section) to make optimum estimates of the ice thickness distribution.

h. *Hydrographic Surveys in the Sub-Arctic Seas*. Periodically conduct hydrographic surveys (including water sampling for nutrients, oxygen, tracers etc.) in the regions of the sub-arctic seas adjacent to the critical straits (see the *SEARCH-ASOF Implementation Plan*).

i. *Repeated Census of Key Marine Species*. Begin or continue periodic censuses of key species in specific regions of the marine environment. These should include key components of the sea ice communities, phytoplankton, zooplankton, key benthic communities (e.g., amphipods, bivalves), and a selection of benthic- and pelagic-feeding marine birds and mammals. Some groups will require use of remote sensing techniques, such as satellite telemetry of marine mammals and video surveys of gelatinous zooplankton and under-ice fauna and flora. Advantage should be taken of hydrographic surveys to sample biota so that changes in species composition, abundance, and distribution can be related to physical forcing factors in representative regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea, and Lincoln Sea-Pole, Barents Sea, Bering Sea) (see b and d above and Figure 4.)

   In the sub-arctic seas, such as the Bering Sea, it will be important to continue and expand time series on fish populations and other biota. In the Bering Sea, it would be useful to extend fisheries surveys to the north, to detect northward shifts in fish populations and their effects on the pelagic and benthic ecosystems.

   Dedicated surveys of marine biota should be concentrated on the marginal shelves of the Arctic and in the subarctic seas where we might expect the greatest impacts on biota from changing ice cover, light availability, and water temperature. This will be a major activity of the SEARCH Bering Sea Program (BSP).

j. *Automated Sampling of Biological Parameters on Moorings and from Shore-based Stations*. Establish automated sampling of biologically relevant parameters at moorings in the key ice and ocean pathways (see a and c above). For example, fluxes through Bering Strait and the Barents Sea involve nutrients and particulate carbon in the form of phytoplankton and zooplankton that are the result of processes that have taken place in the Bering and Barents Seas. Carbon and nutrients advected through Bering Strait support the rich benthic communities of the Chukchi Sea and are carried as far as the Arctic Basin. Changes in the abundance of this organic material could affect upper trophic-level organisms including benthic-foraging seals, walrus, and gray and bowhead whales. Thus, it is important that we add biological and biogeochemical tracers to mooring observations in key pathways. Moorings in addition to those deployed for detecting change in physical and chemical characteristics of the system may be required at locations of exceptional importance for tracking biological responses. Currently existing instruments that might be added to moorings include:

   i. Chlorophyll sensors

   ii. PAR sensors

   iii. Nutrient sensors (we now possess *in situ* ammonium, nitrate, nitrite, phosphate, and silicate sensors that can telemeter data)

   iv. Dissolved oxygen

v. pCO_2 sensors (G. Friederich at Monterey Bay Aquarium and Research Institute has one that works on moorings)

vi. Water samplers/sediment traps for other tracers and indicators that would detect change

vii. Acoustic and video-based fish and zooplankton sensors, and passive acoustic detectors of marine mammals, which have been deployed in other regions

viii. Primary productivity sensors, two different types of which have been tested at lower latitudes

At appropriate and feasible locations install shore-based observation stations that sample seawater by pumping water from offshore. This water can then be sampled for critical biogeochemical and biological parameters without the constraints of volume and battery life imposed by sampling at moorings (e.g., present efforts in Bering Strait). Activities of this type will be critical to the SEARCH BSP.

k. *Automated Sampling of Biological Parameters on Drifting Stations*. Establish automated sampling of biologically relevant parameters (including primary production) at automated drifting stations (see above e and h). The availability of carbon in the Arctic Ocean will also be affected by *in situ* production. Particulate carbon in the Arctic Ocean may go through a variety of food webs, some end in the benthos and others support pelagic systems. At present, it is not known whether global change will favor one of these pathways over another. Repeated use of automated drifting stations offers a unique opportunity to measure long-term changes in sea-ice ecosystems while resolving differences due to very significant seasonal variation. To examine *in situ* changes, parameters such as i–viii above should be added to automated drifting stations in the basin. Further, because the timing of snow melt and the surface water temperature and salinity greatly affect the sea ice and upper ocean ecosystems, sensing devices should be added to the systems for monitoring the thickness and extent of sea ice and its biota. Specific examples of research activities might include:

i. Routine monitoring of the snow cover on arctic sea ice, because the snow cover has an enormous impact on light penetration relative to ice thickness

ii. Routine monitoring of melt ponds is needed for the same reason

iii. Routine monitoring of chlorophyll in and under the ice

iv. Measuring the effects of changing ice algae populations on albedo and the spectrum of re-radiated light

l. *Monitoring Runoff for Biogeochemical Parameters*. Monitor biologically and biogeochemically important parameters (such as in i and j above) in river outflows. River inflows impact the Arctic Ocean by contributing fresh water, nutrients, silt, and organic material that may impact the near-shore environment. This may overlap with DTO efforts described below.

m. *Pollutant Sampling.* Pollutants will reach the Arctic Ocean through riverine inflow and atmospheric deposition. The content of major riverine inflows to the Arctic as well as sample snow and ice for evidence of pollutant deposition must be monitored. Because there is considerable biological magnification of organic pollutants in the food chains leading to human consumption of higher trophic level carnivores, collections of fat samples from the harvests of subsistence hunters would provide a direct measure of the level of contaminants to which people dependent on these resources are exposed. The Arctic Monitoring and Assessment Program (AMAP) may undertake this requirement.

n. *Nearshore Fluxes*. Monitor the effect of nearshore processes on flux and fate of carbon and nutrients. For example, coastal erosion introduces large amounts of very old carbon in the form of peat into the coastal waters. This erosion has impacts on the terrestrial as well as the marine environment. This may overlap with DTO efforts described below.

o. *New Technologies.* Generally encourage the development and use of new technologies such as profiling mooring instruments, gliders, tomography, new tracer techniques, and new biological and biogeochemical sensors. In some cases these are essential to measuring the proper parameters on moorings, drifters, and hydrographic surveys.

Extensive arrays (e.g., ARGO) of profiling drifters are planned to monitor temperate oceans. There are a number of technical obstacles to deploying such systems in the Arctic, chief among them being navigation and data transmission from an ice covered sea. However, it may be possible to develop an optimum combination of surface drifters, moorings, and profiling floats or autonomous vehicles that allow measurements from multiple reference frames and transmission of subsurface float data.

Tomography and other acoustic techniques have already shown promise for measuring the temperature distribution and even ice properties. Large-scale measurements of roundtrip acoustic travel time with multiple sensors may show promise for estimating ocean circulation velocity.

Certainly remote sensing tools such as CryoSat and ICESat will be important, especially with regard to sea-ice thickness, sea-ice concentration, sea level, snow cover, and biological parameters. Quantification of the size, distribution, and geometry of leads may be important for determining the mechanisms responsible for biological responses, as may be changes in the type, thickness and roughness of ice. Thus detection of change in these parameters may be essential to understand change. Aircraft remote sensing instruments may be developed to allow optical sensing below the prevalent cloud layers. Instrument packages deployed on free-ranging marine mammals can collect data from hard-to-survey areas (e.g., sea temperature under ice) and then relay this information via satellite to shore stations. In ice- and cloud-free conditions that may be found in the marginal and sub-arctic seas, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) instrument measures ocean color/chlorophyll and provides data on ocean bio-optical properties that signify various types and quantities of marine phytoplankton.

p. *Sea Bottom Topography*. Although it is not a climate variable in itself, improved knowledge of ocean depth may be important for meeting the objectives of SEARCH. Understanding and modeling ocean circulation requires accurate knowledge of the bottom topography. Improved knowledge of bottom topography is also needed to find potential sediment core sites that are likely to provide improved paleoclimate records. Despite the strides made by the IBCAO project, and the data acquired by U.S. Navy submarines, the Scientific Ice Expeditions program, and the joint *Healy/Polarstern* activity in 2001, the observational database of sea floor depths in the Arctic remains one of the sparsest of any ocean. In particular, there are essentially no observations within 200 miles of shore in the Kara, Laptev, or East Siberian Seas. SEARCH should take every opportunity to acquire improved bathymetric data. In addition to pushing for bathymetry measurements on cruises, we should develop portable precision depth sounders so that depth can be measured at every airborne hydrographic survey point.

q. *Trace Gases* - Measure trace gas exchange at the surface in conjunction with observation sites in the marine environment. These might include automated measurements from buoys and periodic aircraft sampling. Automated techniques for trace gas observation are becoming available. For example, technology exists to measure CO_2 in surface water and the adjacent atmosphere. SEARCH is an appropriate activity for using these methods and developing them further.

r. *Ecological Knowledge Cooperatives* - Utilize ecological knowledge cooperatives to bring local and traditional knowledge of marine climate and ecosystem variability as described under SEI below.

s. *Community/Industry Data Networks I* - Establish community and industry (e.g., fisheries, shipping) data gathering networks that provide marine data as described for SEI below.

4.1.4 *DTO* - Distributed Terrestrial Observatories

The key need is for a network of field stations or sites, chosen as representative of the major arctic ecosystem types and environmental gradients (Figure 5). At each site of the network, the focus of SEARCH activities should be on collecting an integrated multivariable time series of key measurements. The purpose of collecting such a time series is to illuminate interactions and possible chains of cause and effect among components (states and processes) of terrestrial and aquatic ecosystems and their responses to changes in climate. Such a time series will be key to understanding interactions among ecosystem components with different time constants of response to climate change; this will require time series that extend for at least a decade, ideally several decades. Spatial interactions will also be revealed, for example, by tracing the response to a climatic or biogeochemical signal between neighboring patches of arctic landscapes.

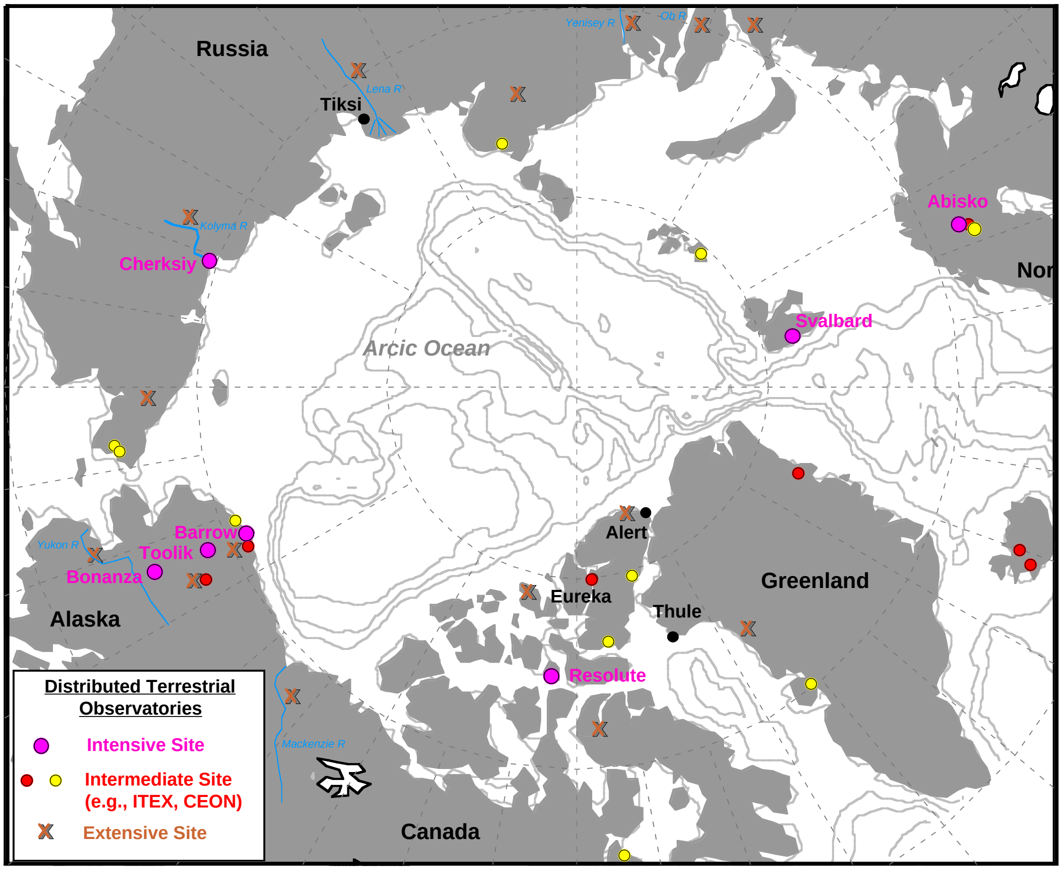

Figure 5. The Intensive sites will be core elements of DTO and include multiple types of measurements in regions typifying several ecosystem types. Some Intensive sites may be augmented by existing LTER or CEON sites and at the sites of major weather stations (Figure 3). Intermediate sites may be existing ITEX or CEON sites. Extensive sites will feature subsets of the DTO observable. Existing borehole sites may provide some of these.

The reason for placing DTO observatories in contrasting ecosystem types and along environmental gradients is to develop an understanding of how the interactions of key ecosystem states, processes, populations, and environmental drivers change among ecosystems such as wet, moist, and dry tundras, polar deserts and semi deserts, and boreal forests. The network of observatories should eventually consist of a few (6–10) *intensive* sites where the full suite of observations (described below) is made, and a larger number of sites where fewer variables are measured. Among the less intensive sites, *intermediate* sites would serve to test the generality of key relationships developed at intensive sites and to extrapolate predictions over large areas. *Extensive* sites will be focused on regional understanding of changes in individual states, processes, or populations.

Several candidate observatories already exist, such as the Barrow Environmental Observatory, the Toolik Lake Long-term Ecological Research (LTER) site, and Bonanza Creek Experimental Forest in Alaska, the Abisko Station in Sweden, Alexandra Fiord in Canada, and Zackenberg in Greenland. Each of these sites maintains a large existing research program, and most have a long history of research and monitoring. Although there is already considerable overlap in the time series being collected at these sites, eventually a standard set of variables should be defined for measurement at all intensive sites. The International Tundra Experiment (ITEX) network, and other less intensively studies sites, represent existing candidates for intermediate or extensive sites within the DTO. The proposed Circumarctic Environmental Observatory Network (CEON) may provide the foundation for various DTO sites. The CEON concept was first raised by the Forum of Arctic Research Operators (FARO) as a cooperative effort to share existing data (often gathered by government stations and logistics providers).

DTO may have much in common with projects recently funded under the Arctic Community-wide Hydrological Analysis and Monitoring Program (CHAMP). CHAMP aims to understand the arctic freshwater cycle and projects focus on a variety of hydrology related activities throughout the Arctic with at least a partial emphasis on long-term observations.

A high priority for the immediate future is to maintain the current time series of observations without interruption as SEARCH plans develop. These time series are valuable not only for themselves but also as the foundation for implementation of DTO. Examples of time series at risk include the 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. A deficiency in existing terrestrial observations in the Arctic is the relatively small number of gauged watersheds suitable for water balance studies at which coincident measurements of surface energy fluxes (radiative and turbulent) are collected. SEARCH will work with the hydrologic reference site program of WCRP CEOP (Coordinated Enhanced Observing Period) to identify a small number of index sites across the pan-arctic domain at which hydrologic and surface flux information is collected, suitable for development and testing of high latitude land-atmosphere transfer schemes.

a. *Climate, Weather, Snow, and Permafrost*. Climate and surface weather should be monitored at all intensive, intermediate, and extensive DTO sites, integrating data from existing extensive terrestrial field networks [e.g., ITEX and Circumpolar Active Layer Monitoring (CALM)], augmenting where large spatial gaps exist, and coordinating and collating output in a way that facilitates cross-comparisons and synthetic use. Projected CHAMP activities may also make new contributions in this area. Because snow cover and permafrost play such a critical role in terrestrial biological processes, it is important to monitor these in a way that captures short- and long-term trends, as well as critical spatial gradients in these changes.

   Traditional measurement programs do not adequately resolve some of the key aspects of the snow-active layer-permafrost system. Aspects of snow cover that need to be measured include: (a) winter precipitation and sublimation, both difficult to measure; (b) snow depth on the ground along snow courses of length suitable to provide robust averages; (c) snow water equivalent or density to establish depth-snow water equivalent relationships; and (d) snow phenology and extent.

   Permafrost temperature and active layer thickness measurements are needed and must be integrated closely with snow measurements. One aspect of snow not typically measured, but essential to understanding, is drifting of snow and the winter flux of transported/sublimated snow. Snow depth, density, extent, permafrost temperature, active layer depth, and snow phenology are currently being monitored in several networks (CALM, ITEX, USDA-NRCS Wyoming gauges, AVHRR satellite instruments), but data are of limited usefulness because the measurements are not well-coordinated, or co-located, across networks. Efforts are needed to better integrate data sets. In addition, current networks do not delineate critical latitudinal gradients in snow cover and permafrost. Careful expansion of these networks to include critical areas is needed.

   Where intensive biological measurements are being made, coordinated complementary snow and permafrost measurements are needed. Separate but related measurements that allow computation of the year-round surface energy balance are needed. Shifts in this balance in response to the physical changes in arctic environmental conditions are intimately related to changes in soil moisture, snow cover, permafrost temperatures, and biological activity.

   These measurements underpin modeling efforts related to understanding arctic environmental change. Air temperature, precipitation, wind speed and direction, soil temperature, and soil radiation and albedo are the main measurements needed to compute the balance. Of these, winter measurements of precipitation and radiation remain problematic. Efforts to establish and maintain snow and permafrost monitoring stations should be coordinated with efforts to monitor terrestrial climate and surface weather. (See 4.1.2 *LAO* - Large-scale Atmospheric Observatories, and Figures 2 and 4.)

b. *Surface Energy and Soil State*. Surface vegetation in the Arctic responds to the soil state and surface energy balance. The plant community composition responds to these, but more slowly than the weather or the climate. Essentially, the surface vegetation integrates the soil state and energy balance on a multi-year to decadal time scale. To understand and anticipate changes in land surface vegetation, monitoring the surface energy balance and the state of the soil is necessary. The soil and surface energy balance are closely coupled, so the monitoring must be coordinated. Recent work also makes it clear that they need to be monitored over the full annual cycle, not just during the growing season. In addition to full monitoring of all energy and soil state components at key sites (including radiation, soil moisture, and snow cover as well as temperature and other customary parameters), more easily measured index parameters (like the snow-soil interface temperature) must be monitored more widely.

c. *Trace Gases*. Measure trace gas exchange at the surface in conjunction with observation sites in the terrestrial environment. Measure trace gas exchange at the surface in conjunction with observation sites in the marine environment. These might include (a) automated measurements from towers, (b) periodic aircraft sampling of vertical structure at strategic points for a large region, (c) and continental-scale aircraft sampling of trace gases. Automated techniques are becoming available, and SEARCH is an appropriate activity for using these methods and developing them further.

d. *Runoff and Runoff Chemistry*. Maintain and enhance systematic long-term gauging of major rivers. Measure the concentrations of constituents in runoff from the major river basins. River discharge and constituent concentrations are key integrative measures of the function of the arctic landscape. Quantitative measurements of water flow and chemical concentrations allow us to close the water and element budgets for large segments of the arctic land mass. Changes in discharge can signal changes in precipitation, permafrost, and evapotranspiration in watersheds. Changes in constituents can indicate human impacts, permafrost thaw, erosion, or mobilization of nutrients and organic matter. Impacts of altered river discharge and constituent fluxes on the marine environment are covered in Section 4.1.3 *DMO – Monitoring Runoff for Biogeochemical Parameters*.

Maintain a dense network of gauging stations to measure the spatial distribution of runoff from the arctic watershed and temporal trends in runoff. Current databases contain more than 4000 stations but many have been discontinued in the past 10 years or so. We must determine how many stations are needed to map runoff changes. We must develop an infrastructure to ensure timely reporting and analysis of stream discharge.

Maintain a network of river monitoring stations to detect changes in constituent fluxes in rivers. These stations must be allocated to carefully chosen intensive and extensive sites to address issues at different scales. Sites should be coordinated with other ecosystem studies to maximize use of the information. A number of activities under CHAMP should contribute to runoff and runoff chemistry measurements.

e. *Phenology and Vegetation Structure, Composition, Production, and Associated Measurements.* One of the objectives of the DTO intensive sites is to provide a core data set of vegetation structure, composition, phenology, and production that is regionally representative and on an annual time step. An objective of the extensive sites would be to extend intensive site data to a broad region and to provide replication for intensive studies (i.e., are patterns of variability and change regional or local?). Sites located near communities would develop regional data on variability in key vegetation and phenology parameters that may affect subsistence resource use and lifestyles, either directly or indirectly. At intensive sites, there should be development and maintenance of annual point-framing on 1-km grids according to ITEX protocols, which would be used to monitor phenology, growth, and reproduction of 5–20 key plant species at permanent locations. Automated photographic recording and archiving stations should be established that will measure green up and green down on intermediate-sized areas (via web cams or similar digital systems). As vegetation changes are often associated with changes in nutrient cycling, measurements that indicate changes in nutrient cycling (e.g., isotope ratios, plant nutrient concentrations, nitrogen mineralization rates) should be coordinated with vegetation monitoring at intensive sites.

The same techniques for monitoring vegetation would be used at extensive sites, but at a less frequent measurement internal (3–5 years) and with few samples (5–20 1-m^2 samples). Phenology measured at extensive sites would require automated systems and should be installed where power is available. Phenology and vegetation measurements are currently being monitored across the Arctic by the existing ITEX network, which provides an ongoing intermediate-scale set of integrated measurements. SEARCH should continue to support and encourage development of ITEX sites and measurements, ensure continuation of existing data series, and consider enhancing ITEX in underrepresented regions (such as in Russia). SEARCH should also coordinate closely with developing Conservation of Arctic Flora and Fauna (CAFF) efforts that are designed to monitor biodiversity across the Arctic.

f. *Species Census and Demography of Key Animal Populations and Associated Measurements.* Initiate/continue integrated annual censuses of key species that span taxonomic diversity (i.e., from microbes to vertebrates) in specific regions of the terrestrial environment with the goal of a) determining the causes of changes in the number and abundance of species, and b) understanding changes in their distribution, demography, recruitment, and production, and their interactions with other species and processes (e.g., biogeochemical cycles and indigenous subsistence). For key species, determine reproductive success and the phenology of annual cycles (e.g., reproduction, migration, and hibernation), and develop indices of body condition, health, and physiological stress. Because important indicators of changes in health, stress, disease, and function, including expression of genes, may not be currently known or economically discoverable, archives of tissues, organisms, and soil cores shall periodically be collected and stored appropriately for future analyses.

g. *Lakes: Changes in Spatial Dynamics Such as Distribution and Area, Changes in Characteristics Such as Color and Chemistry, and Changes in Phenology Such as Duration of Ice Cover.* Lakes are both important parts of the landscape, covering more than 50% of the land surface in some regions, and habitats for freshwater fish, which are an important resource for humans. Lakes will form or disappear when permafrost thaws and shorelines slump, temperatures warm, and ice cover diminishes. The biology will be altered as the changes in vegetation in a drainage basin add more dissolved organic carbon (DOC) to lake waters. Fish species may change as the waters warm and increasing primary productivity adds organic carbon and depletes the oxygen of deep waters. At large scales of whole river basins, the presence and area of lakes should be measured by remote sensing in late summer each year to identify natural variability. At extensive sites, lake color (a proxy for DOC), lake primary productivity, and water chemistry should be measured twice each summer in a series of lakes across a gradient of climate and surrounding vegetation. The species present in these lakes should be determined at ten-year intervals.

h. *Soil, Stream, and Lake Chemistry, and Aquatic Productivity.* The cycling of nutrients and organic matter in soils is clearly linked by transfer via water to streams and lakes. When vegetation, growing season, and water movements change, changes in soil water chemistry (nutrients, inorganic ions, organic matter), stream water chemistry, and lake chemistry must be documented. Intensive sites must be measured every two weeks, extensive sites once per year. One integrating measure of the impact of changes in nutrient cycling and transfers is primary productivity in streams and lakes. Stream productivity can be measured every two weeks by ultra-sensitive oxygen electrode measurements. Lake productivity can be measured by radioisotope techniques (incorporation of $^{14}CO_2$) every two weeks.

i. *Remote Sensing of Changes in Snow, Vegetation, and Disturbance Regimes.* While current satellite technology can be used to monitor changes in snow extent (e.g., AVHRR imagery) and to measure snow water equivalent (e.g., SSM/I and soon ASMR-E), algorithms are not completely reliable. Scatterometer data from NASA's Quikscat and Japan's Midori 2 satellites can be used to determine exactly when and where spring thaw occurs. Coordinated field validation of snow cover and snow water equivalent measurements derived from remote sensing should be conducted to increase confidence in these measurements. Key issues of land cover change in high latitude regions relevant to the arctic system include expansion of treeline at the expense of tundra, expansion of shrub tundra at the expense of sedge tundra, changes in vegetation leaf area and growing season length, and changes in extent and severity of disturbances, such as fire.

Field validation of satellite-derived changes in land cover should be verified and validated at intensive, intermediate, and extensive sites. In particular, extensive field validation should be conducted at selected ITEX sites and sites along the high latitude International Geosphere-Biosphere Program (IGBP) transects. Remote sensing protocols to monitor vegetation and habitat changes across the circumpolar north should make optimal use of imagery that is available at different spatial resolutions (e.g., IKONOS, Landsat, AVHRR, MODIS). For example, IKONOS and LandSat imagery (hectare resolution) may be more appropriate for detecting changes in shrub cover at decadal to century time scales, while AVHRR and MODIS imagery may be more appropriate for detecting changes in the timing of snow melt and green-up and changes in the extent of fire disturbance/vegetation succession at inter-annual to decadal time scales.

j. *Ecological Knowledge Cooperatives.* Utilize ecological knowledge cooperatives to bring local and traditional knowledge of terrestrial climate and ecosystem variability as described under SEI below.

4.1.5 *SEI* - Social and Economic Interactions

a. *Harvests.* Monitor trends in total harvest effort, changes in seasonal effort, shifts to alternative food types, and changes in processing and preservation methods. Also monitor evidence of changes in condition of harvested resources including factors affecting human health and nutrition and culturally significant indicators of quality (e.g., blubber thickness, caribou hide quality, fish health).

b. *Erosion and Flooding.* Monitor erosion and coastal flooding due to storm surges, river flooding, changes in sea, river, and lake ice conditions, changes in timing of freezeup and breakup, and ice road construction.

c. *Resource Use.* Monitor changes in seasonal resource use, relocation of camps, structures, or entire communities as a result of environmental changes. Monitor spread of urbanization and resource development and tourism activities in the Arctic and associated environmental impacts.

d. *Transportation.* Monitor changes in transportation strategies (water vs. snow), changes in gasoline and heating oil or other fuel demands and costs. Monitor changes in commercial shipping by water, air, or other means, as well as diffusion of new technologies for transportation for household use and for commercial and industrial activities. Monitor changes in safety of transportation by all modes. Record number of structures lost by region due to coastal erosion/storm surge, riparian erosion and flooding, wildfire, and permafrost melting.

e. *Commercial Fishing.* Monitor commercial fisheries harvests by species, change in location of fish harvests, and change in health and quality of harvested fish. Compile data on location and intensity of oil and gas development onshore and offshore in the Arctic, changes in patterns of tourism and recreation, and changes in technology used in commercial activities as it may be related to Unaami.

f. *Livelihood Strategies.* Establish data collection programs for data on livelihood strategies not routinely collected through established censuses and other government statistical programs to monitor changes in demographic characteristics of arctic communities, changes in employment in established communities and development enclaves, changes in types of jobs located in the Arctic and in seasonal patterns of employment, and migration by demographic characteristics.

g. *Quality of Life.* Establish data collection programs for quality of life indicators not routinely collected through established censuses and other government statistical programs to monitor changing social structure, changing time spent on the land, changes in sharing and other risk-coping strategies, and community events related to resource harvests. Monitor loss of traditional knowledge and activities, and loss of aboriginal languages related to changes in the land. Monitor birth and death rates and indicators of social pathologies such as crime, substance abuse, and injury deaths.

h. *Community/Industry Data Networks II.* Establish community and industry data gathering networks that provide data on terrestrial ecological change that are important to the communities and industries. The community-industry data network concept overlaps with knowledge co-ops, and should include state and federal agency data. Coordination with co-ops is needed. Planning data collection throughout SEARCH should be sensitive to local community concerns. Working with co-ops, SEARCH data collection can build on existing programs such as CAFF, a biodiversity monitoring initiative that is species oriented (e.g., reindeer and caribou, polar bears, and sea birds).

4.2 Understanding Change

4.2.1 *DQU* - Detecting and Quantifying Unaami and Other Modes of Variability

a. *Pattern Analysis of Unaami*. Perform statistical/pattern analyses of multivariate data sets to characterize Unaami. For example, start with a matrix of time-series data sets hypothetically related to Unaami and define an appropriate Unaami index and Unaami (multivariate) pattern. Investigators could then search for correlations (including lagged correlations) between this index and other independent parameters (e.g., the AO index, precipitation, poleward heat flux, indicators of ecosystem change, and social and economic factors). For linking changes in the biological components of marine ecosystems to changes in the physical and chemical environment, a series of conceptual models would be an appropriate first step.

b. *Model Characterization of Unaami*. Use models to simulate the multivariate spatial patterns and statistics of Unaami. GCM sensitivity studies can help identify the components of the model earth system that must be allowed to interact freely to simulate Unaami.

c. *Record Linking*. Link historical records and archeological data with paleoclimate records (e.g., sediment cores) to establish thresholds of change, and links between parts of the system. Examples include shifts in subsistence patterns as a potential reflection of changing environmental conditions, and perhaps the correspondence or lack thereof between changes in marine and terrestrial environments (see 4.1.1b).

d. *Collaborate with Arctic Residents*. In ecological knowledge co-ops review model predictions for ecosystem change and obtain suggestions for new hypotheses or directions for research.

4.2.2 *ASR* - Arctic System Reanalysis

Understanding the scope of Unaami is well suited to an ASR. The *Science Plan* emphasizes the importance of an ASR as a central element of SEARCH. It will be a program of data assimilation and modeling to develop optimum estimates of difficult or impossible to observe critical parameters of the arctic system.

One component of the ASR will be an arctic atmospheric reanalysis. An atmospheric reanalysis system blends a numerical weather prediction model and observations in an optimal way, with the recognition that both have shortcomings. The ASR's Arctic Atmosphere Reanalysis will be improved with better representation of arctic processes, which will provide improved estimates of such variables as evaporation minus precipitation.

The ASR will expand the reanalysis philosophy to other parts of the physical environment, ecosystem, and social system. This will be done by considering the system in modules (Figure 6). For example, a reanalysis-like approach will involve measurements of ice motion and surface atmospheric temperature measurements combined with a few measurements of ice draft and a sea-ice model to make optimum estimates of sea-ice thickness distribution. Experimentation with the elements of the ASR will also help to determine the optimum mix of measurement types and locations.

Reanalysis or data assimilation for systems with sparse samples, such as the ocean, requires knowledge of the fundamental modes of variation of the system. In such cases reanalysis often requires having a model of how these modes interact and respond to changing forcing. With such a model, limited observations can be used in an optimum way to infer the actual behavior of the system and from these the value of parameters that may be hard or impossible to measure directly.

As exemplified by the discussion of 4.1.2b the ASR will benefit greatly from new remote sensing tools and new ways of looking at old remote sensing data.

Because the ASR is critically dependent on observational data and provides optimal estimates of critical parameters, it is at the heart of SEARCH data management. Consequently we discuss implementation of data management in the context of ASR.

a. *Diagnostic Modeling*. Data assimilation studies that make use of long-term observations are needed to confirm, refute, and modify the list and sequence of events that constitute the provisional definition of Unaami.

b. *Arctic Atmospheric Reanalysis.* Perform atmospheric reanalysis, but with models with improved polar physics to produce more accurate reanalysis products for the Arctic. A good approach might be to examine the North American Regional Reanalysis (NARR) as a prototype for the ASR. A key element of this activity is to evaluate the performance of the NARR and determine the appropriateness of land surface treatments to arctic conditions. This could be accomplished through a model inter-comparison project using a series of different land surface models. These activities will benefit from efforts under Sections 4.1.1 – 4.1.3 to enhance available data networks.

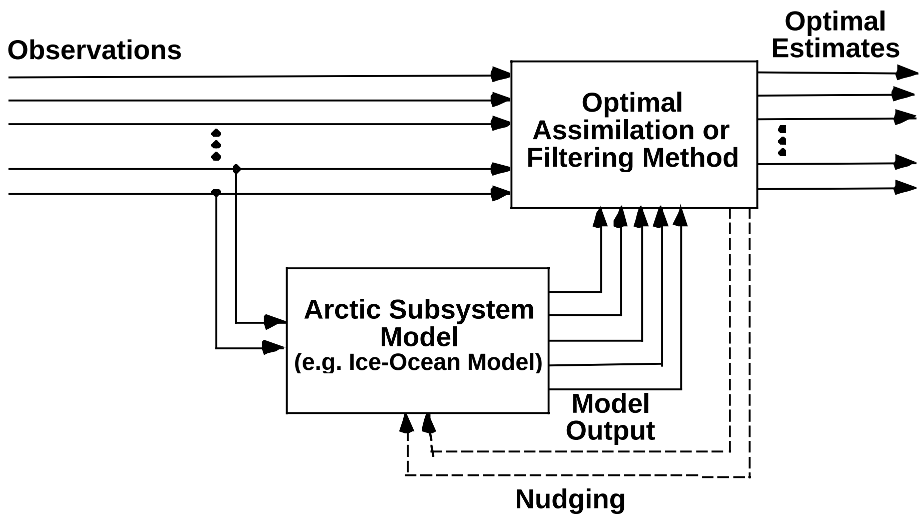

Figure 6. An idealized and generalized schematic of an Arctic System Reanalysis module. Observations are combined in an optimal way with model output to produce improved estimates of critical parameters. Depending on the method, the model may be "nudged" in an amount related to the difference between observations and model output.

c. *Expand to Other Parts of the Arctic System*. Expand the reanalysis concept to develop the ASR. This is to estimate hard-to-measure variables that pertain to all parts of the Arctic system. Various data assimilation or reanalysis philosophies may be necessary to include variables in the atmospheric, oceanic, terrestrial, ecological, and social parts of the system. The geographic limits of the arctic system may be extended (e.g., recent observations that the Arctic hydrologic cycle may be affecting Atlantic Ocean salinities as far south as 30°N). Useful models already exist for the physical and ecological parts of the system. Social models only exist for small regions of the Arctic. System reanalysis is likely to require use of simple social models or models extrapolated from small regions pending significant improvement in these areas.

Perhaps the greatest challenge facing the expansion of the ASR to the non-atmospheric environment is the sparseness of data relative to the scales of variability. This is also potentially the source of greatest benefit. Sparse data is probably best used to validate and/or tune a model by adjusting model parameters to remove model bias. This might be called zero order data assimilation, since the variability in the model is not forced by periodic assimilation events. Model parameters are most eloquently estimated with an adjoint model (four-dimensional variational analysis; 4DVAR), but adjoint models for sea ice are not yet available. Less eloquent is a Green's Function approach, which is essentially a systematized method of parameter selection using sensitivity studies.

The next level of data assimilation is climate nudging, where the mean of all observations are used to modify model results. True data assimilation comes into play where an optimal mix of observations and model output is used to determine the best estimate of various fields. Optimal interpolation, Kalman filters of various flavors, and adjoint models are used. Data assimilation using Kalman filtering for the ocean, where data may be very sparse, may consider the modes of variability as characterized by empirical orthogonal functions to reduce the degrees of freedom of the system. Keys to all of these methods are estimates of the errors in both the model estimates and the observations. Much needs to be done to determine adequately the error covariances of both systems (the model and the data).

Variables that are currently assimilated into coupled ice/ocean models are ice velocity from drifting buoys and remote sensing (SSMI, AVHRR, RGPS) and ice extent (SSMI, ice charts). In the future this list should include sea surface temperature in the liquid oceans, sea surface height, ice thickness from submarines and moorings, and direct measurements of ocean-ice-atmosphere heat fluxes from drifting instruments.

The Arctic Ocean Model Intercomparison project (AOMIP) is an example of how the ASR might be extended to marine parameters. AOMIP is performing coordinated model runs to reconstruct Arctic Ocean conditions including sea-ice parameters from 1948 to the present and plans to extend the runs back to 1870. The runs are based on all available and reconstructed forcing parameters. The first phase is to improve the models and estimate their accuracy. The second phase will involve running the improved models using all available data for model validation. The third phase will utilize the models with data assimilation for ocean reanalysis. Finally, AOMIP will build an Arctic Ocean ecosystem model that will incorporate biochemical processes and interactions with terrestrial and other ocean systems.

d. *Linkages with Ecosystems and Society*. Model links will be made between social and environmental change by integrating analyses of paleo, historical, and contemporary observation data to understand (1) how social and economic factors have filtered or moderated the observed effects of historical and recent climate change, and (2) how climate change effects have interacted with ecosystem and human system dynamics. Using archeological techniques, historical methods, and oral histories, compare past responses to environmental to contemporary responses such as shifts in subsistence patterns, technological change, and migration to identify similarities and differences.

e *Test Model Responses to Past Altered Forcing.* Test models developed for SEARCH against the paleo-environmental record. This will be tied to Section 4.2.1 Understanding Change–DQU.

f. *Data Management and the ASR.* Data from the SEARCH observational programs will follow two paths (Figure 5). The more traditional path will lead to an immediate, informal repository for first-look data to be used by the SEARCH community. After quality control and further scientific validation, the original data will be archived. The second path will send the quality-controlled data to the ASR for assimilation with models and the derivation of optimum estimates of key variables. These optimum estimates will then be passed on to the data archive. One of the benefits of the ASR will be the quantification of measurement errors that is a necessary part of data assimilation. This will be helpful to control the quality of the original data. In this way the two data streams are coupled. Of course the data assimilation process also reveals problems with the subsystem models and the understanding they represent. Therefore, the models and data assimilation schemes in which they are used must themselves be archived.

We envision the first-look repository and the archive as taking advantage of existing data management facilities. However the SEARCH Project Office should maintain a data directory to a wide range of data pertinent to SEARCH. The directory may only provide internet links to data Web sites or, if necessary, maintain data at least temporarily in its own database.

We envision that initially there will be one central facility to assemble the Arctic Atmospheric Reanalysis and various institutions will contribute to the development of it. Numerous institutions will also be working to expand the reanalysis philosophy to other parts of the arctic system. Ultimately, and depending on the discretion of the Understanding Change Panel, SSC, and IPMC, there may be one central ASR facility or several, each devoted to a different part of the system. In any event these central ASR facilities will take responsibility for feeding data from their assimilation process to the data archive.

4.2.2 *LGC* - Linkages and Global Coupling

a. *Model the Connection Between the Strength of the Polar Vortex and Unaami*. Force a variety of ice, ocean, and terrestrial models with the boundary conditions observed over the past few decades or other periods of significant polar vortex or AO variability.

b. *Global Climate Connection of AO and Unaami: AO as Stochastic Variation or Fundamental Mode.* Address whether the variation of the AO (or other indicators of the strength of the polar vortex) is a simple stochastic variation of a fundamental circulation mode, is a result of only atmospheric processes, or involves feedbacks with the arctic system.

c. *Global Climate Connection of AO and Unaami: Radiative Forcing.* Exercise GCMs to determine if altered radiative forcing due to greenhouse gases, sulfates, volcanic dust, or solar properties drive the AO variability and trends.

d. *Global Climate Connection of AO and Unaami: Effect on Thermohaline Circulation.* Model the effect of the meteoric freshwater, ice formation, and mixing on the stratification of the Arctic Ocean, the outflow to the subarctic seas, and global thermohaline circulation.

e. *Global Climate Connection of AO and Unaami: Heat and Salt.* Model the effect of variable inflow of heat and salt into the Arctic Ocean on the Arctic Ocean stratification and its subsequent effect on sea ice.

f. *Global Climate Connection of AO and Unaami: Albedo Feedback.* Model the effect of Unaami on large-scale albedo and ultimately on large-scale atmospheric circulation.

g. *Global Climate Connection of AO and Unaami: Ecological Effects.* Model links between North Atlantic/Arctic and North Pacific/Bering Sea/Arctic marine ecosystem changes associated with changes in thermohaline circulation in subarctic and adjacent arctic seas to understand connection between ENSO/AO/NAO and their interrelated ecological effects.

h. *Feedbacks Within the Arctic System: Sea Ice.* Improve our understanding of how wind driven and thermodynamically driven variability in sea-ice extent and concentration affect atmosphere-ocean heat and moisture exchanges over large scales. Isolate consequent feedbacks on synoptic-scale circulations of the atmosphere (e.g., through alterations in coastal baroclinicity) and the surface energy budget through alterations in arctic cloud cover and surface albedo. Within this scope, attention must be given to improved understanding of the magnitude and direction of cloud radiative forcing over both ocean and land areas.

i. *Feedbacks Within the Arctic System: Land Surface-Atmosphere.* Assess feedbacks to the atmosphere related to terrestrial changes in precipitation, surface temperature, active layer depth, and permafrost extent. Changes in arctic precipitation and temperature will produce both local and distant feedbacks to the atmosphere. Local feedbacks will initially be related to changes in soil moisture, thaw depth and permafrost and will include changes in summer evapotranspiration. During winter higher temperatures will increase rates of sublimation of snow and ice. These immediate feedbacks will change over time as surface vegetation and associated properties are altered by long-term trends in precipitation and temperature. More remote feedbacks to the atmosphere are due to the horizontal transport of runoff to the ocean. Increases in precipitation in a warmer climate may stimulate increases in runoff. Freshwater runoff to the coastal seas allows a near surface density stratification that facilitates sea-ice formation. Sea ice covering the coastal seas changes the albedo of the surface and inhibits the exchange of heat with the atmosphere. A freshening of the surface layers of the Arctic Ocean will cause a decline in salinity in the Nordic and Labrador seas where North Atlantic Deep Water (NADW) is formed. If the salinity decline continues and is not offset by a compensating salinity rise in northward flowing waters, there is the possibility of a slowing of NADW formation. As deepwater formation declines, less warm tropical water will be advected northward into the North Atlantic region with a net cooling effect on the atmosphere of the North Atlantic region.

j. *Feedbacks Within the Arctic System: Snow on Land.* Assess how changes in the timing of snow melt and spring snow depth over terrestrial regions may have feedbacks to the atmosphere through (a) effects on coastal baroclinicity, and (b) effects on soil moisture as they influence the summer convective regime.

k. *Feedbacks Within the Arctic System: Vegetation.* Analyze and model processes responsible for temporal and spatial dynamics of vegetation responses to environmental change in the Arctic and conversely how change in vegetation drives changes in surface energy, water, and carbon feedbacks. Of particular concern is identification of fast vs. slow dynamics in vegetation and restricted vs. extensive changes in vegetation distribution. It may turn out that the rate of change in surface properties is constrained more by limitations on how fast the vegetation can change than anything else. Understanding how biology causes lags in the response of surface energy/water/carbon balance is a key modeling issue.

l. *Feedbacks Within the Arctic System: Radiatively Active Gases.* Analyze and model how environmental changes alter the exchange of radiatively active gases (i.e., carbon dioxide and methane) between terrestrial ecosystems and the atmosphere. Of particular relevance is to understand how interactions among soil thermal changes, hydrologic changes, disturbance regimes, and vegetation dynamics influence trace gas exchange via effects on plant and soil processes.

m. *Feedbacks Within the Arctic System: Particulate Emissions.* Analyze and model (a) the effects of changes in particulate emissions on radiation balance of the atmosphere, and (b) the effects of the deposition of particulates on snow in changing the albedo of snow.

n. *Feedbacks Within the Arctic System: Ecosystem and Social Feedbacks.* Develop, validate, and refine multi-scale models of the coupled response of humans and key populations of animals, freshwater vertebrates, plants, and microbes to Unaami. Focus on (a) the dynamic linkages (energetic pathways) to reproductive and socio-economic strategies and performance, and on (b) the feedbacks among trophic levels (e.g., decomposers, primary producers, and herbivores and their natural and human consumers). For example, model the implications of temporal (days to decades) and spatial (local to continental) variability in snowmelt, green-up, summer warming, and winter warming and associated icing on (a) the performance (distribution and demography) of wide-ranging migrants such as caribou and reindeer and their important forage species, (b) the interactions of caribou and reindeer and their forage species with biogeochemical cycles within ecosystems, and (c) the accessibility and influence of reindeer and caribou on indigenous subsistence cultures.

o. *Feedbacks Within the Arctic System: Marine Production Feedbacks.* Model the marine response to Unaami and feedbacks through population cycles of key marine species (for example, impacts of sea ice ecosystem changes on ice optical and mechanical properties). Examine how changes in the timing and location of sea ice extent, the types of ice present, stratification, nutrient and property gradients, and material fluxes and transport (including benthic processes and cross-shelf fluxes to the basins) would be expected to influence marine ecosystems. Model the energetic pathways of a few key marine species, including lower and upper trophic levels, to explore the links between life history characteristics of organisms (e.g., life span, reproductive strategies) and modes of ocean variability.

p. *Feedbacks Within the Arctic System: Marine Harvest Practices and Thermohaline Changes.* Model changes in marine food webs as fish harvesting and aquaculture activities combine with thermohaline changes and biogeochemical cycling to change the ecosystem.

q. *Feedbacks Within the Arctic System: Feedbacks from Society at Large.* Model interactions between global and arctic social and environmental change. Model how arctic environmental changes affect environments and societies "downstream" at lower latitudes. Model how lower-latitude environmental, economic and social changes affect arctic ecosystems and societies.

4.2.4 *SEI* - Social and Economic Interaction

a. *Subsistence Harvest Impact*. Analyze subsistence harvest data in relation to other environmental and social variables to determine:

   i. the relationship between changes in resource abundance and distribution and changes in harvest

   ii. the variability of the response of communities to Unaami

   iii. the exceptionality of Unaami compared to paleo evidence

   iv. the variation in community response (alternative resources, institutions)

   v. the thresholds of change (i.e., in use areas, species), and what determines the thresholds

b. *Resource Use Adaptation to Unaami*. Analyze data on resource harvests, demographics, and the cash economy to ascertain how modes of subsistence (mixed economic systems) may be shifting in response to Unaami. Undertake comparative case-study analyses to develop understanding of key relationships between changes in resource use and indicators of health and well being. This includes examining how systems of resource exchange and risk-coping mechanisms are able to accommodate Unaami and/or may be changing in response to Unaami. Develop models on a variety of relevant temporal and spatial scales to simulate changes in resource use and associated indicators of well being, including perceptions of change as viewed by arctic residents.

c. *Access and Transportation*. Analyze data on changing seasons for river freezeup and breakup, sea-ice conditions, snow cover, and ice road construction to asses how Unaami may change local and regional access to resources. Assess the consequences for commercial and subsistence activities if ice-based transportation modes become unavailable at key times. Where new modes of access may be required, assess the effect of changing access modes on local economies. Examine the costs and risks involved in changing from permafrost to non-permafrost soils for remote rural communities and resource development enclaves.

d. *Identify linkages amongst global systems, prices, and production of arctic resources.* Sub-Antarctic fisheries may be targeted by displaced harvesters of subarctic fisheries; Atlantic cod declines may cause prices to rise for Pacific pollock and cod, increasing harvest pressure on these and other species.

e. *Examine links between changing air and water temperatures and changes in the abundance and distribution of invasive species, parasites, disease vectors, and other species that may affect health of humans and subsistence resources*. In general, terrestrial and marine ecosystem research should place sufficient emphasis on modeling Unaami in upper trophic levels to analyze ecosystem effects relevant to people, who primarily consume resources at upper levels.

f. *Examine the association between Unaami and social indicators of human health, well being, and cultural activities that reflect on the quality of life in arctic communities.* Examine non-arctic residents' perceptions of the Arctic, arctic people and ecosystems, and climate change, and how Unaami may change these perceptions.

g. *Evaluate the comparative role of institutional factors, social structure, information flow, social, human, and physical capital, technology, and political empowerment in enhancing or inhibiting the capacity of arctic communities to adapt to Unaami*. Identify interactions from changes in markets, technology, and resource management resulting from Unaami. Examine variations in responses and outcomes to Unaami-like change across different circumpolar locations and different time periods (e.g., changes in patterns of resource use, population movements, technological changes, demographic change, and other economic responses). Examine effectiveness and effects of opportunistic and change-buffering adaptations to Unaami such as sharing, migration, resource management, and government policies. Identify differential vulnerabilities, and the winners and losers from adaptations.

4.3 Responding to Change

4.3.1 *SOR* - Social Response

a. *Apply research on Unaami to fisheries, subsistence hunting, transportation, and other related social and economic issues of interest to industry and government decision-makers.*

   i. Make pilot application of the prototype ASR to ecosystem and social variables important to communities and industries. Review reanalysis products, the changes they reveal, and their relation to the variables and changes observed by and which are of greatest concern to arctic residents (see c below).

   ii. Establish pan-arctic virtual repositories or meta-database to provide access to relevant real-time and historical data from industry, scientific studies (past and ongoing), agencies, and communities. For example, a circumpolar database showing local variations in soil temperature, soil characteristics, aspect, and vegetative insulation, and other factors could help predict areas where permafrost is likely to become unstable if regional climate warms.

b. *Establish SEARCH related communication with social and economic entities concerned with conditions in the Arctic*.

  i. Conduct workshops for resource managers, stakeholders, and communities on applications of SEARCH science to resource management and land-use decisions.

  ii. Community/Industry Data Networks II. Establish community and industry data gathering networks that provide data that are important to the communities and industries.

  iii. Establish science/local community communication forums in which researchers share data and findings with local governments and citizens and receive regular feedback on issues of concern, research hypotheses, and explanations of observed and predicted change.

c. *Assess responsiveness and effectiveness of local, regional, and national institutions in addressing social and economic concerns associated with Unaami*.

  i. Undertake comparative studies of the effectiveness of institutions of arctic nations to address the effects of Unaami on arctic populations and industries. Assess the comparative responsiveness of those institutions to stakeholder interests and community needs. Analyze impediments to resource managers applying SEARCH and related research on climate variability.

  ii. Gauge the community, industry, and government perception of and response to Arctic environmental risks and uncertainties. Analyze how uncertainty affects societal response to perceived threats, and how the responses affect ecosystem dynamics. For example, if reanalysis were to predict that the bowhead whale population may decline, but the decline is uncertain, how do local hunters, the Alaska Eskimo Whaling Commission, and the International Arctic Whaling Commission perceive the risk of decline, and do they change their harvest quotas and hunting practices? Consider how culture affects perception and response to environmental uncertainty, and what strategies might change these perceptions and responses.

5. SEARCH ACTIVITY AREA PHASING, SUMMARIES, STATUS, AND PRIORITY EFFORTS

Our goal is to understand Unaami and to be able to respond appropriately to its consequences. Given the decline of several historically important observations, our highest priority must be to establish a program of long-term observations. However, the implementation schedule will be affected by existing research activities and the constraints and strengths of an interagency program. For example, while establishing a system of long-term observations is our highest priority, we recognize that many parts of the system are in place, even if in incomplete form. The system will be brought to complete status through a variety of funding mechanisms appropriate to the various agencies. Other high priority activities such as the ASR are new and will require immediate interagency effort to implement. Therefore, in addition to identifying the highest priority activities within each activity area, a three-tiered scheduling guideline has been established. This is not meant to be a rigid schedule. If other factors make it appropriate for an activity to be done earlier, position in the three-tiered scheme should not stand in the way. These are all important activities.

In the first part of this section the SEARCH activity areas are summarized in a rough order from overarching analysis activities, to observations, to understanding change activities. Activities already underway will be briefly mentioned and highest priority new components will be discussed. In the second part of the section, established and regional programs that are part of SEARCH are summarized in the same way. In the third part of the section, the three-tiered scheduling of the activity areas is described.

5.1 Summaries, Status, and Priorities

5.1.1 *ASR* - Arctic System Reanalysis

a. *Summary Description*. The activity will assimilate data into models of various components of the arctic system to produce optimum estimates of key, and often unobservable, variables.

b. *Most Relevant Science Questions*. The ASR is an overarching SEARCH activity that addresses the needs of every question in Section 2.

c. *Panel with Primary Responsibility*. Understanding Change Panel

d. *Components in Place*. Next-generation atmospheric reanalysis efforts have been undertaken by National Center for Environmental Protection (NCEP) with its North American Regional Reanalysis (NARR) and by the European Centre for Medium Range Weather Forecasting (ECMWF ERA-40). NCEP will soon be implementing the new Weather Research and Forecast system. SEARCH can capitalize on these efforts to assess present representations of the arctic atmosphere and surface fluxes and to identify and subsequently implement needed improvements.

   The RadarSat Geophysical Processing System (RGPS) assimilates data from RadarSat and other sources to estimate a wide variety of sea-ice properties.

   The Arctic Ocean Model Intercomparison project (AOMIP) is an example of how the ASR might be extended to marine parameters. AOMIP is performing coordinated model runs to reconstruct Arctic Ocean conditions including sea ice parameters from 1948 to the present and plans to extend the runs back to 1870. The runs are based on all available and reconstructed forcing parameters.

e. *Highest Priority New Components.* ASR is an overarching activity that will motivate the integration of the various other components of SEARCH. Within ASR, the high priority activities are development of the Arctic Atmospheric Reanalysis and experimentation to improve data assimilation methods for the non-atmospheric parts of the arctic system. With respect to the atmospheric reanalysis, it will be necessary to develop strong links with NCEP to take advantage of their modeling expertise and infrastructure. In the area of data assimilation, the proper incorporation of TOVS satellite data must be a priority.

   There are also many non-atmospheric variables critical to the arctic system and Unaami that are difficult to measure at the required spatial and temporal resolution. Only with a systematic method of combining observations and modeling results will we be able to see the connections among these important but often unobservable parameters, Unaami, and global climate. For these variables we must begin to develop the non-atmospheric modules of the ASR.

It will be important to develop a data management structure that goes beyond archiving data; it must feed a wide variety of data to the developing ASR system.

5.1.2 *DQU* - Detecting and Quantifying Unaami and Other Modes of Variability

a. *Summary Description*. The activity will use paleoclimate, historical, and archeological records as well as more recent observations to better define the scope of Unaami and its relation to other decadal modes of variability.

b. *Most Relevant Science Questions*. The most relevant questions include SEARCH science questions 1, 2, and 11.

c. *Panel with Primary Responsibility*. Understanding Change Panel will be primary though the Detecting Change Panel as well as the PARCS program will be very important.

d. *Components in Place*. PARCS is undertaking many of the paleoclimate studies pertinent to ARS and DQU. The Unaami study of the SEARCH project office being carried out at PMEL is a solid start on the physical and ecological activities of DQU.

e. *Highest Priority New Components*. The highest priority tasks are those linking the long historical, paleo, archeological and modern records and the ASR effort. This assumes continuation and coordination with the existing PARCS and PMEL Unaami activities. Examination of historical records is needed to determine the full scope of Unaami in space and time, to determine if it is related to the strength of the Northern Hemisphere polar vortex, and to provide data to test ideas about how coupling within the arctic system and with global climate affect Unaami.

5.1.3 *SEI* - Social and Economic Interactions

a. *Summary Description*. The activity will examine the interactions of the physical and biological elements of Unaami and the social and economic systems within the context of other forces of social change.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 6, 7, 8, and 9; those with importance are 10 and 11.

c. *Panel with Primary Responsibility*. Understanding Change Panel

d. *Components in Place*. Some local and traditional knowledge co-ops (cooperative groups of local citizens and researchers) are already established, but co-ops need to be expanded, with greater use of standardized protocols, requiring a coordinated program.

Working with co-ops, SEARCH data collection can build on existing programs such as CAFF, a biodiversity monitoring initiative that is species oriented (e.g., reindeer and caribou, polar bears, and sea birds).

e. *Highest Priority New Components*. Participate in ASR by developing models of historical shifts in resource use and settlement patterns associated with climate variation, compiling pan-arctic and subarctic data sets through local and traditional knowledge co-ops and industry data sharing networks, and applying models to estimate unobserved variables. Integrating the human dimension into the ASR is the way to understand the impacts of the physical and ecological aspects of Unaami on society. This understanding will be the key to responding to Unaami in an intelligent manner.

5.1.4 *LAO* - Large-scale Atmospheric Observatories

a. *Summary Description*. The activity will make large-scale atmospheric observations without a specific operational or logistical link with marine or terrestrial observing systems. Extensive surface atmospheric observations will also be made as part of DMO and DTO.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3 and 4; most others are important.

c. *Panel with Primary Responsibility*. Detecting Change Panel

d. *Components in Place*. GCOS exists but SEARCH is not taking full advantage of it. The Department of Energy Atmospheric Radiation Measurement Program (DOE-ARM) supports a major weather station at Barrow and quality foreign stations exist at Alert and Ny-Ålesund.

e. *Highest Priority New Components.* Take advantage of GCOS and GTOS, develop TOVS, and seek to augment non-U.S. stations to the ARM standard. These are necessary to avoid gaps in the large-scale atmospheric record that would be critical to understanding the full scope of Unaami and the linkages between elements of the arctic system and linkages to Northern Hemisphere atmospheric circulation and global climate.

5.1.5 *DMO* - Distributed Marine Observatories

a. *Summary Description*. The activity will make large-scale atmospheric, oceanographic, sea ice and ecosystem observations in the marine environment.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, 5, and 6; most others are important.

c. *Panel with Primary Responsibility*. Detecting Change Panel

d. *Components in Place*. IABP, NPEO Bering Strait Environmental Observatory, NABOS, SEARCH Freshwater Projects: Switchyard and Beaufort Sea Moorings, and the Canadian-Japanese Joint Western Arctic Climate Study. SEARCH-NOAA augmentation of the IABP is an early anticipated contribution.

e. *Highest Priority New Components.* Generally better use should be made of the existing components. Augment the IABP. Maintain the observations of existing programs such as the NPEO, IABP, and fresh water–Beaufort Sea mooring programs. Adapt the combined mooring/drifting-station/hydro-surveys approaches of these programs to the Makarov Basin. Expand moorings along critical pathways as feasible. Add deep-sea pressure sensors, and other new sensors to existing program installations. Make better use of new and existing remote sensing methods. These are necessary to avoid gaps in the large-scale atmospheric record that would be critical to understanding the full scope of Unaami, the linkages between elements of the arctic system, and linkages to Northern Hemisphere atmospheric circulation and global climate. Add biological sensors and other new sensors to existing program installations. This is necessary to test the hypothesis that aspects of the marine ecosystem will respond to the physical changes of Unaami.

5.1.6 *DTO* - Distributed Terrestrial Observatories

a. *Summary Description*. The activity will make large-scale atmospheric, hydrological, glaciological, and ecosystem observations in the terrestrial environment.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, 5, 6, and 7; most others are important.

c. *Panel with Primary Responsibility*. Detecting Change Panel

d. *Components in Place*. Several candidate intensive sites already exist, such as the Barrow Environmental Observatory, the Toolik Lake LTER site, and Bonanza Creek Experimental Forest in Alaska, the Abisko Station in Sweden, Alexandra Fiord in Canada, and Zackenberg in Greenland. Although there is already considerable overlap in the time series being collected at these sites, eventually a standard set of variables should be defined for measurement at all intensive sites.

   The ITEX network and other less intensively studied sites represent existing candidates for intermediate or extensive sites within the DTO network.

SEARCH should also coordinate closely with developing CAFF efforts that are designed to monitor biodiversity across the Arctic.

CHAMP observations are funded under the NSF-OPP-ARCSS-sponsored SEARCH Freshwater Initiative which should contribute a great deal of hydrological and hydrology-related information to DTO.

e. *Highest Priority New Components.* A high priority for the immediate future is to maintain the current time series of observations without interruption as SEARCH plans develop. These time series are valuable as the foundation for implementation of DTO. Examples of time series at risk include 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. A deficiency in existing terrestrial observations in the Arctic requiring remedy is the relatively small number of sites at which coincident measurements of ecological, hydrological, and surface energy flux (radiative and turbulent) data are collected. 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.

5.1.7 *LGC* - Linkages and Global Coupling

a. *Summary Description*. The activity uses modeling and analysis to elucidate the connections between Unaami and global climate and the connections within the arctic system as they pertain to Unaami.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, and 5; most others are important.

c. *Panel with Primary Responsibility*. Understanding Change Panel

d. *Components in Place*. The SEARCH Freshwater Initiative including CHAMP, ASOF, and the Arctic Ocean efforts examine linkages associated with freshwater. SHEBA observed key energy balance processes in sea ice, and the NPEO Automated Drifting Station is continuing this observational type of effort on an automated basis.

e. *Highest Priority New Components.* Two key hypotheses of SEARCH are that Unaami is related to global climate and that feedbacks within the arctic system are important to Unaami. These hypotheses should be tested by undertaking analysis and modeling efforts aimed at the various linkages in the arctic system and with global climate. The freshwater linkages are being studied under the SEARCH Freshwater Initiative. Thermodynamic and dynamic linkages should receive added attention in future SEARCH initiatives.

5.1.8 *SOR* - Social Response

a. *Summary Description*. Research social and economic adaptation to climate change in the past and apply research on Unaami to economic and social concerns in the future. Find ways to communicate the results of SEARCH to decision makers.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, 5, and 6; most others are important.

c. *Panel with Primary Responsibility*. Responding to Change Panel

d. Components in Place. Some local and traditional knowledge co-ops are already established, but co-ops need to be expanded, with greater use of standardized protocols, requiring a coordinated program.

Working with co-ops, SEARCH data collection can build on existing programs such as CAFF, the biodiversity monitoring initiative that is species oriented (e.g., reindeer and caribou, polar bears, and sea birds).

e. *Highest Priority New Components.* The fourth key hypothesis of SEARCH maintains that the physical and ecological aspects of Unaami impact social and economic systems. To test this idea long-term information is needed on social and economic parameters. This information and understanding the connections among the social and economic systems and the physical and biological components of Unaami are necessary to develop reasonable strategies to respond to arctic change. Also to understand the full scope of Unaami it is necessary to utilize all possible long-term observations of the physical and biological aspects of Unaami. Toward these ends SEARCH should establish the system of coordinated local and traditional knowledge co-ops and community data networks with a view to help the investigations of social adaptation inherent in the SOR. This will help further the aims of the SEI Activity Area as it relates to the ASR.

5.2 Established and Regional SEARCH Programs

5.2.1 Arctic and Sub-Arctic Flux Study (ASOF)

a. *Summary Description*. The established SEARCH program will measure ocean fluxes between the Arctic Ocean and the subarctic seas and the consequences for global thermohaline circulation. Thus is the subarctic physical component of the DMO.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, 5, and 6, directly 4a, b, and c.

c. *Panel with Primary Responsibility*. Detecting Change Panel

d. *Components in Place*. Most of the ASOF mooring installations and hydrographic surveys as described in the ASOF *Science Plan* (see http://psc.apl.washington.edu /search/ASOF.html) are funded or underway.

e. *Highest Priority New Components*. ASOF is a key existing SEARCH element that is essentially a semi-independent component of DMO and shares the aims of that activity area, with a special and emphatic focus on understanding the linkages between Unaami and global climate. SEARCH should work for the full implementation of ASOF.

5.2.2 Bering Sea Program (BSP)

a. *Summary Description*. This regional SEARCH program will perform the measurements and modeling aspects of SEARCH that are relevant to the Bering Sea, with added emphasis to fisheries questions.

b. *Most Relevant Science Questions*. The most relevant SEARCH science questions include 3, 4, 5, and 6 especially as reflected in the Bering Sea.

c. *Panel with Primary Responsibility*. Detecting Change Panel

d. *Components in Place*. Various research activities are ongoing in the Bering Sea that will prove relevant, but plans for BSP are not firm enough to relate to the ongoing activities.

e. *Highest Priority New Components*. The Bering Sea is a region where the ecological, social, and economic impact of the physical aspects of Unaami are substantial. The linkages with global climate are complicated by the powerful climate characteristics of the Western Hemisphere (e.g., El Niño, Pacific Decadal Oscillation). To address the key hypotheses of SEARCH in the context of the Bering Sea warrants planning of a SEARCH Bering Sea regional study including substantial elements of the SEARCH activity areas.

5.3 Scheduling

5.3.1 First-Tier SEARCH Activities

The first tier consists of activities that maintain existing observational elements and establish the overarching structure we need to combine information from all disciplines and regions to detect, understand, and respond to Unaami. The overarching analysis efforts are natural for coordinated interagency funding and center around the ASR. This is a new development, but the emphasis on analysis and modeling make this tier possible without heavy new logistics expenses. The ASR efforts and ancillary data analysis will help to further refine the observational strategy to improve, in particular, the location and scope of individual observatory units.

Activity Area	First-Tier Activity
LAO *DMO* *DTO*	Maintain existing high priority, large-scale observational programs (e.g., GCOS, DOE-ARM, Bering Strait, IABP, Beaufort and Central Arctic Observatories, ASOF Moorings, LTER sites, Barrow Environmental Observatory, ITEX sites) and incrementally improve them where possible
ASR	Begin development of Arctic Atmospheric Reanalysis, experimentation to improve data assimilation methods for the non-atmospheric parts of the arctic system, and development of objective techniques to improve the observation system
DQU	Begin linking the long historical, paleo, archeological, and modern records and the ASR effort
SEI	Participate in ASR by developing models of historical shifts in resource use and settlement patterns associated with climate variation, compiling pan-arctic and subarctic data sets through existing (and possibly new prototype) local and traditional knowledge co-ops and industry data sharing networks, and applying models to estimate unobserved variables

5.2.2 Second-Tier Activities

The second tier consists of detecting change elements that should be augmented or improved under SEARCH. The motivation is to avoid data gaps in time and space that will prevent measuring the scope of Unaami and its connections to the rest of the climate system. Observing systems have the highest priority of all activities, but as long as existing observing systems under Tier 1 are maintained or incrementally improved, and the observational gaps are not allowed to worsen, the existing gaps subsequently can be closed to begin the activities of the first tier.

Activity Area	Second-Tier Activity
LAO	Continue to take advantage of and improve GCOS and GTOS, develop TOVS, and actively seek to augment non-U.S. stations to the ARM standard
DMO	Continue to maintain existing observational programs. Augment the IABP. Adapt the NPEO, IABP or FW -Beaufort Sea mooring approaches of combined moorings, drifting stations, and hydro-surveys to the Makarov Basin. Expand moorings along critical pathways as feasible. Add deep-sea pressure sensors, and other new sensors to existing program installations. Make better use of new and existing remote sensing methods. Add biological sensors and other new sensors to existing program installations.
DTO	Continue to maintain the current time series of observations. These are valuable as the foundation for implementation of DTO. Increase the number of sites at which coincident measurements of ecological, hydrological, and surface energy flux (radiative and turbulent) data are collected. These sites should be in each of 8–10 regions that characterize different ecosystem types. They will comprise the DTO intensive sites. ITEX sites should be standardized and augmented to form the DTO intermediate and extensive sites.

5.2.3 Third-Tier Activities

The third tier consists of understanding change and responding to change elements that can follow after the overarching and detecting change or observational elements are started. They are, however, a high priority. To the extent they are already underway, they should be encouraged and continued. In the event early funding opportunities arise that especially fit these activities, they should be started.

Activity Area	Second-Tier Activity
LGC	Undertake analysis and modeling efforts aimed at the various linkages in the arctic system and with global climate. The freshwater linkages are being studied under the SEARCH Freshwater Initiative. Thermodynamic and dynamic linkages should receive added attention in future SEARCH initiatives.
SOR	Develop the system of coordinated SEARCH local and traditional knowledge co-ops and community data networks with a view to help the investigations of social adaptation inherent in the SOR. This will help further the aims of the SEI activity area.

6. SUMMARY RECOMMENDATIONS

The goal of SEARCH is to understand Unaami and to be able to respond appropriately to its consequences. Given the decline of several historically important observations, the highest implementation priority has always been to establish a program of long-term observations. However, the implementation schedule is affected by existing research activities and the funding constraints and strengths of an interagency program. Therefore, in addition to identifying the highest priority activities within each activity area, SEARCH establishes a three-tiered scheduling guideline (Figure 7). Note that this is not meant to be a rigid schedule. If other factors make it appropriate for an activity to be done earlier, position in the three-tiered scheme should not stand in the way.

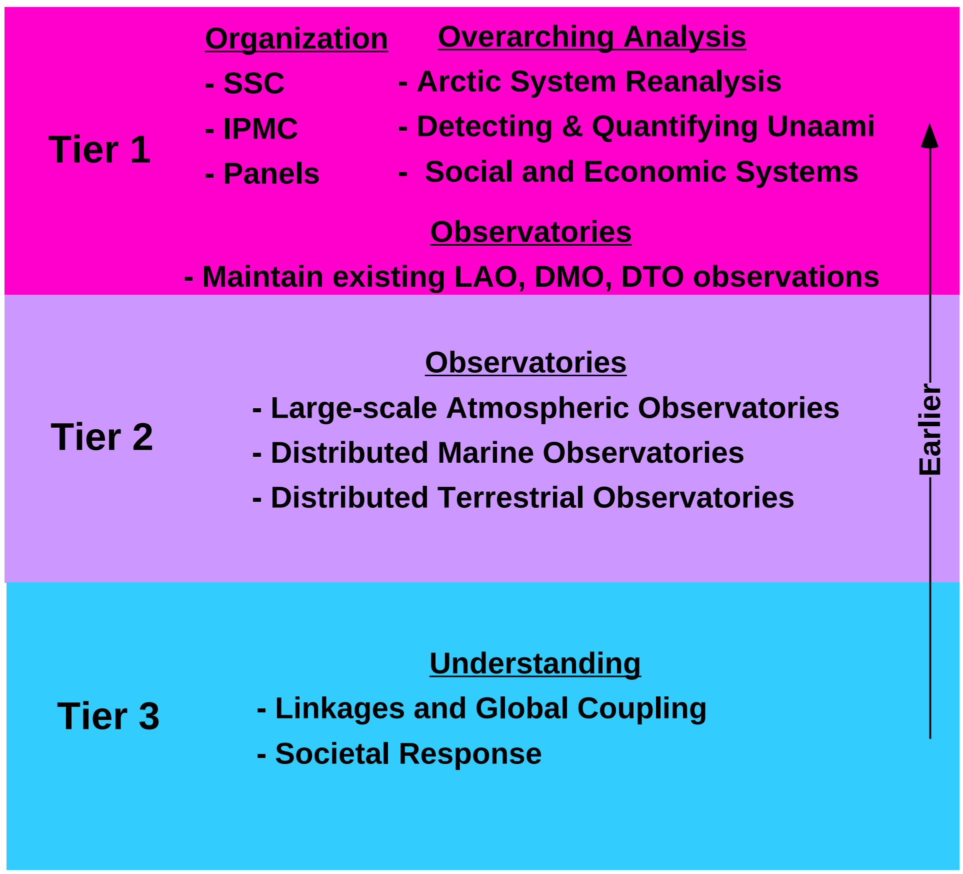

Figure 7. SEARCH implementation schedule guideline. The first tier includes maintaining existing observations and beginning overarching activities that combine information from all disciplines and regions. The second tier consists of detecting change elements that should be improved or augmented under SEARCH. The third tier consists of understanding change and responding to change elements that can follow after the overarching and detecting change elements are begun.

6.1 Organization and Operation

As a scheduling first-tier effort, the SEARCH SSC and IWG should implement the organizational plan described in Section 3 of this *Implementation Strategy*. The SEARCH Science Steering Committee, Detecting Change Panel, Understanding Change Panel, and Responding to Change Panel should be established, and the IPMC reconstituted from the IWG. These groups will continue to develop the *Implementation Strategy* and seek funding to execute it. The SSC and IPMC should continue to seek high-level international cooperation and promote development of the BSP.

The SEARCH Project Office should shift emphasis from developing SEARCH to coordinating the execution of SEARCH. In addition to facilitating the activities of the SSC, DCP, UCP, RCP and ICMP, the new Project Office should develop a Web-based SEARCH data directory, help to coordinate and support the ASR effort, and integrate the data directory, ASR, and existing data archival facilities into a data management system. The Project Office should expand the communication component of SEARCH by starting a SEARCH newsletter, and planning international SEARCH workshops and symposia. It should continue to develop the international ties of SEARCH as directed by the SSC and IPMC.

6.2 SEARCH Activities Areas: Tiers 1, 2, and 3

The new first-tier SEARCH activities, ASR and elements of DQU and SEI should be undertaken to provide the overarching SEARCH activities that will spur further work and keep future activities coordinated. To understand the full scope of Unaami, SEARCH must continue to build interdisciplinary time series data sets. Within ASR, the high priority activities are: development of the Arctic Atmospheric Reanalysis; experimentation with methods to improve data assimilation for the non-atmospheric parts of the arctic system; development of objective techniques for improving the observation system, and development of a data management structure that goes beyond data archiving to feed a wide variety of data to the developing ASR system. DQU should help with this by linking long historical, paleoclimate, and archeological records with modern records. SEI should collaborate in ASR by developing models of historical shifts in resource use and settlement patterns associated with climate variation, compiling pan-arctic and subarctic data sets through existing or prototype local and traditional knowledge co-ops and industry data sharing networks, and developing methods of applying models to estimate unobserved variables.

SEARCH must enhance the long-term observations in the Arctic, but in the very near-term, as a Tier 1 activity, must at least continue the long-term observation programs already in place. Maintaining existing observation programs should not require large sources of new funding. Specifically, LAO should use GCOS and GTOS, TOVS, and the Barrow ARM station. It can encourage bringing non-U.S. stations to the ARM standard. DMO should continue existing observational efforts in the central Arctic Ocean and Beaufort Sea. Limited improvements to the IABP should be possible. DTO should extend time series of observations at risk of being discontinued such as the 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. CHAMP activities should be integrated into DTO and other SEARCH activity areas as appropriate. Where feasible for either DMO or DTO, existing observation systems should be augmented with new sensors measuring new types of variables. For example chemical and biological sensors might be added to existing physical instrumentation sites. This would give the multivariable data sets SEARCH needs at a few prototype sites at modest incremental cost.

The second tier includes establishing new observations under LAO, DMO, and DTO. LAO should augment its observation base by increasing the number of GCOS, GTOS sites, further developing TOVS, and bringing non-U.S. stations to the ARM standard. Weather observations at the DTO stations should be brought up to WMO standards. DMO should adapt the NPEO or IABP approach of combined moorings, drifting stations, and hydro-surveys to the Makarov Basin. Where possible the DMO should expand moorings along critical pathways. The ASOF program should continue to be implemented as planned. It should extend the first-tier activities by continuing to add biological sensors, deep-sea pressure sensors, and other new sensors to existing program installations, and make better use of new and existing remote sensing methods. DTO should identify existing stations (e.g., LTER, major weather stations of the LAO) as prototypes and implement new intensive DTO sites. Intermediate and extensive sites should also be established. These may be DTO observatories.

The third tier includes the LGC and SOR. The LGC activity area will examine two key hypotheses of SEARCH, that Unaami is related to global climate and that feedbacks within the arctic system are important to Unaami. To test these hypotheses, analysis and modeling efforts will be aimed at the various linkages in the arctic system and with global climate. These efforts should be funded as soon as possible to take advantage of the observational analysis and observational efforts in tiers 1 and 2. The SOR activity area will research social and economic adaptation to climate change in the past and apply research on Unaami to economic and social concerns in the future. To accomplish this connections with communities and industries are needed.

Therefore, SEARCH should begin establishing a system of coordinated local and traditional knowledge co-ops and community data networks with a view to help the investigations of social adaptation inherent in the SOR. This will help further the aims of the first-tier SEI activities as they relate to the ASR.

APPENDIX A: SEARCH SCIENCE STEERING COMMITTEE MEMBERSHIP, JANUARY 2003

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APPENDIX B: LIST OF ABBREVIATIONS AND ACRONYMS

ACSYS/CliC	Arctic Climate Study System/Climate in Cryosphere
AIRS	Atmospheric Infrared Sounder
AO	Arctic Oscillation
AOMIP	Arctic Ocean Model Intercomparison Project
ASOF	Arctic and Sub-arctic Ocean Flux
ASR	Arctic System Reanalysis
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATOVS	Advanced TOVS
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BSP	Bering Sea Program
CAFF	Conservation of Arctic Flora and Fauna
CALM	Circumpolar Active Layer Monitoring
CEON	Circumpolar Environmental Observatories Network
CERES	Clouds and Earth's Radiant Energy System
CHAMP	Community-wide Hydrological Analysis and Monitoring Program
CLIVAR	International Program on Climate Variability
DCP	Detecting Change Panel
DMO	Distributed Marine Observatories
DOE-ARM	Department of Energy Atmospheric Radiation Measurement Program
DQU	Detecting and Quantifying Unaami
ENSO	El Nino Southern Oscillation
ENVISat	
GCOS	Global Climate Observing System
GLAS	Geoscience Laser Altimeter
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Ocultation of Star
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
ICESat	Ice, Cloud, and land Elevation Satellite
ISCCP	International Satellite Cloud Climatology Project
ITEX	International Tundra Experiment
IWG	Interagency Working Group
JWACS	Joint-Western Arctic Climate Studies (Japan-Canada)

LAO	Large-scale Atmospheric Observatories
LGC	Linkages and Global Coupling
LTER	Long-term Ecological Research
MODIS	Moderate Resolution Imaging Spectroradiometer
NABOS	Nansen and Amundsen Basins Observing System
NARR	North American Regional Reanalysis
NCEP	National Center for Environmental Protection
NOAA	National Oceanographic and Atmospheric Administration
NPEO	North Pole Environmental Observatory
RCP	Responding to Change Panel
RGPS	RadarSat Geophysical Processing System
SAGE	Stratospheric Aerosol and Gas Experiment
SEI	Social and Economic Interactions
SOR	Social Response
SSM/I	Special Sensor Microwave/Imager
TAO	Tropical Atmosphere Ocean
TOGA	Tropical Ocean Global Atmosphere
TOVS Path-P	TIROS-N Operational Vertical Sounder Polar Pathfinder
UARS	Upper Air Research Satellite
UCP	Understanding Change Panel
VTPR	Vertical Temperature Profile Radiometer
WCRP CEOP	Coordinated Enhanced Observing Period
WMO	World Meteorological Organization