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?