September 06, 2002

Arctic Ocean Observing Plan

Dear Commissioners and Admiral Watkins:

In response to your questions about an Arctic Ocean observing and prediction system in your letter of August 6, 2002, I have attached a proposed draft plan. As you can see from the title page, it is based on the Science and Implementation Plan and for the SEARCH (Study of Environmental Arctic Change) program. The science plans for SEARCH, which is essentially an Arctic Ocean observing system, have been under development with NSF support for several years, and they are in the initial stages of implementation. SEARCH has support from a broad segment of the U.S. Arctic Ocean science community. It is an excellent starting point for the long-term observations and analysis studies that are required to understand environmental change in the Arctic and ultimately its effects on weather, climate, fisheries and marine resources.

The attached plan contains a budget estimate. In summary, the estimated total annual cost of the system is $27,350,00/yr. Of this amount, about $11,450,000/yr is either in-place now, or anticipated to be in place. Thus, the estimated total immediate new funding required is $15,900,000/yr. In the long term, because the in-place programs are not all scheduled to continue, it is probably best to think of a total approximate annual cost of roughly $30M.

You also asked whether we should look towards a formal International cooperation arrangement for the Arctic similar perhaps to what is now in place for the Antarctic. I believe we should. I emphasized in my testimony the problem of research access to an ocean that is subject to a bewildering set of jurisdictional claims by countries, native peoples, and other claimants. Any future plan for Arctic Ocean research has to include a diplomatic element--an International cooperative agreement--to ensure scientific research access.

Thank you for allowing me to provide you with this information. I am happy to provide more details as required.

Robert C. Spindel

DRAFT

U.S. Plan for Arctic Ocean Long-term Observing System

Based on the SEARCH Science Plan and SEARCH Implementation Framework

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*** Membership in the SEARCH SSC is given Appendix A**

Background

The Study of Environmental Arctic Change (SEARCH) has been 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. This event is affecting every part of the Arctic environment and is having repercussions on society. There is evidence that these changes are connected with the rising 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 and mid-latitudes is substantial.

Though SEARCH aims to detect and understand a pattern of change that is pan-Arctic, ocean observations are a major thrust. This is because many of the most significant changes have occurred in the Arctic Ocean and sub-Arctic Seas. In the 1990s the Arctic Ocean shifted to a more cyclonic (counterclockwise) circulation pattern with a consequent shift in the front between Atlantic and Pacific-derived waters. Atlantic Water along the dominant, topographically controlled pathways underwent substantial warming. Largely in response to the change in circulation, ice is now exported more quickly from the Arctic Ocean. As a result of ice spending less time growing in the Arctic Ocean, the average ice thickness has decreased 43% over the last 25 years. Ice extent has decreased 3% per decade over the same time. The changes in ice conditions are in important to global climate because they affect the albedo (amount of sunlight reflected) of the surface and the global heat balance. Likely related to these changes in the Arctic Basin is a massive decline in salinity communicated to the northern Atlantic, Labrador and Nordic Seas over the past 30 years (since about 1972). In the Labrador Sea this is equivalent to about 6m of fresh water deposited on the ocean surface, yet the freshening is evident right to the sea floor. The dynamical effect of this buoyant water may be great, particularly if the trend continues into the future. Evidence for the slowing, over the past 50 years, of the dense, deep overflows entering the Atlantic east of Iceland adds to the growing evidence that Arctic effects on the global ocean system are being felt. This arguably sets the stage for rapid changes in ocean circulation patterns important to the climate of Europe and North America.

Long-term observations to track key modes of Arctic Ocean and sea ice variability

Owing to the importance of change in the Arctic Ocean, the Arctic research community, in numerous planning meetings and documents (e.g., SEARCH Science Plan, 2000) has repeatedly affirmed the high priority of an Arctic Ocean observing long-term observing system. The SEARCH planning process has produced a draft SEARCH

Implementation Strategy that among other things outlines the elements of this observing system. These elements taken from Section 5.1.1.3 are:

a. Establish mooring arrays to monitor key water and sea ice pathways in the Arctic Ocean (e.g., Eurasian continental slope, Lomonosov Ridge, Northwind Rise, Canada/Alaska continental slope). One to three moorings in the center of key basins (e.g. Canadian, Makarov, and Amundsen) should also be included.

b. Periodically conduct hydrographic surveys (including water sampling for nutrients, oxygen, tracers etc.) across 3 or 4 key regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea-Pole, and Lincoln Sea-Pole). The surveys would optimally be repeated annually and at a minimum once per 4 years. Surface ship, aircraft, submarine or autonomous ocean "gliders" may do sections. The latter, buoyancy driven vehicles that have very long endurance—ranges of 1000's of km and lifetimes of many months—plus GPS navigation and satellite data transfer, could provide orders of magnitude increase in hydrographic and ice draft data in the Arctic Basin. In planning the sections there should be coordination with CliC Implementation Plan sections.

c. 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.

d. Measure sea level or 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 tide gauges at the coasts. Deep-sea pressure gauges (combined with hydrography and associated with moorings e.g., 5.1.1.3a, c) should be used at key sites along the continental slope and in the central basins. A variety of remote sensing techniques should be used to extend the point measurements over most of the Arctic Ocean

e. Implement a sea ice thickness monitoring program. Use upward looking sonar data from moorings (5.1.1.3a, c), remote sensing (satellite and aircraft), and submarine profiles, along with current generation sea ice models (see Understanding Change section) to design a system for direct observations and to track changes in ice thickness.

f. Periodically conduct hydrographic surveys (including water sampling for nutrients, oxygen, tracers etc.) in the sub-Arctic sea regions adjacent to the critical straits. See the SEARCH-ASOF Implementation Plan.

g. Maintain at least two complete drifting automated stations measuring upper ocean conditions, ocean heat flux, ice mass balance and atmospheric surface fluxes (5.1.1.2c) in the Arctic Ocean (e.g., initially sited Beaufort Sea and North Pole regions).

h. Begin or continue periodic census of key species in specific regions of the marine environment

i. Establish automated sampling of biologically relevant parameters at moorings in the key ice and ocean pathways (See 5.1.3a and c). 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. Such advected carbon supports the rich benthic communities of the Chukchi Sea and may be 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, gray whales, and bowhead whales. Thus, it is important that we add biological and biogeochemical tracers to mooring observations in key pathways. Currently existing instruments that that might be added include:

i. Chlorophyll sensors
ii. PAR sensors
iii. Nutrient sensors (we now possess in situ ammonium, nitrate, nitrite, phosphate and silicate sensors which can telemeter data)
iv. TCO2 sensors (G. Friederich at MBARI has one that works on moorings)
v. Water samplers/sediment traps
vi. Acoustic fish and zooplankton sensors (these have been deployed in other regions).
vii. Primary productivity sensors (we are not sure of the state of readiness here, but know that two different types of instrument have been tested at lower latitudes).

j. Establish automated sampling of biologically relevant parameters at automated drifting stations. (See 5.1.3e 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 of which end in the benthos and others support pelagic systems. At present, we do not know whether global change will favor one of these pathways over another. To examine in situ changes, parameters such as i through vii in 5.1.1.3i should be added to automated drifting stations in the basin. Further, because the timing of snow melt and surface water temperature and salinity greatly affect the sea ice and upper ocean ecosystems, biochemical sensing should be added to the systems for monitoring the thickness and extent of sea-ice. Specific examples of research activities might include:

i. Routinely monitoring the snow cover on Arctic Sea ice, since 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. Detecting chlorophyll in sea ice, or at least under the ice.

k. Monitor biologically and biogeochemically important parameters (such as in 5.1.1.3h and 5.1.13I) in river outflows. River inflows impact the Arctic Ocean by contributing fresh water, nutrients, silt and organic material that may impact the nearshore environment, and pollutants. Additionally pollutants will reach the Arctic Ocean through atmospheric deposition. We need to monitor the content of major riverine inflows to the Arctic as well as sample snow and ice for evidence of pollutant deposition. Since 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 kills of subsistence hunters would provide a direct measure of the level of contaminants to which people dependent on these resources are exposed

l. Periodically conduct biological sampling (including water sampling for nutrients, oxygen, tracers etc.) in 3 or 4 representative regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea, and Lincoln Sea-Pole). (See also 5.1.3b, d)

m. Generally encourage the development and use of new technologies such as profiling mooring instruments, gliders, AUVs, tomography, new tracer techniques, and new biology and biogeochemistry sensors. These are in some cases essential to measuring the proper parameters on moorings, drifters, and hydrographic surveys. Extensive arrays (e.g., ARGO) of profiling drifters are planned for monitoring 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. Certainly remote sensing tools will be important, especially with regard to sea ice, sea level, snow cover, and biological parameters.

Long-term observations and the Arctic System Reanalysis

The SEARCH Science Steering Committee and the Arctic research community recognizes that many critical variables are difficult to measure adequately and recommends that we develop means of data assimilation that will combine disparate types of observations to produce optimum estimates of important variables such as sea ice thickness, ice and freshwater export, and outflow through the Canadian Archipelago. Although this is part of the modeling and analysis portion of the Implementation Strategy, Section 5.1.2.2, many parts of it should be considered as a critical aspect of the Arctic Ocean long-term observing system. The part of Section 5.1.2.2 that is particularly important in this respect is:

c. Expand the Arctic System Reanalysis 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 atmosphere, ocean, terrestrial, ecological, and social parts of the system. Useful models already exist for the physical parts of the system. Ecological and social models only exist for small regions of the Arctic. System reanalysis is likely to require use of ultra simple ecological and social models or models extrapolated from small regions pending significant improvement in these areas.

Estimated Costs

Most of the following costs are annual costs, and most include logistics costs. There are a few items that assume certain infrastructure, such as the 10 ULS instruments (Item e) that go on the moorings, but this infrastructure exists. The cost of certain other items in the list assumes that some scheduled programs will be implemented. Also note that observations in the Bering Sea will necessarily be required in a comprehensive Arctic Ocean Observation System, and are expected ultimately to be part of SEARCH. Costs for this are not included in the estimates below since the science community as a whole has not addressed this issue.

Thus, the estimates below are to be taken as fairly good ballpark figures, not precise costs.

Estimated Costs: (A) Total, (B) In-Place, and (A-B) New Required

A) Estimated Annual Total Costs of the Ocean Observing System

a. Basin Mooring Arrays (13) **7,800,000**

Eurasian continental slope- 4 X (200k Inst. +200k anal. + 200k logistics) = 2.4 m$/yr
Pole-Lomonosov Ridge- 600k$/year
Northwind Rise - 600k$/year
Canada/Alaska continental slope - 4 X (200k Inst. +200k anal. + 200k logistics) = 2.4 m$/yr
Beaufort - 600k$/year
Makarov - 600k$/year
Amundsen - 600k$/year

b. Basin Hydrographic Surveys (4) **1,800,000**

key regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea-Pole, and Lincoln Sea-Pole).

c. Critical Strait Mooring Arrays **3,900,000**

Monitor the Arctic Ocean exchanges (including sea ice) through Fram Strait, 2.4 M$/yr
Barents Inflow Region, 1M$/yr
Bering Strait, 500k$/yr
Canadian Archipelago. 700 k$/yr (Craig Lee proposal?)
(These are described largely in the SEARCH-ASOF Implementation Plan. - Talk to Peter Rhines for reality check)

d. Sea-level or Ocean Bottom Pressure **950,000**

Variation in the Arctic Ocean and subarctic seas.
- Direct observation and tide gauges at the coasts - 500 k$/yr for 10 coastal sites.
- Deep-sea pressure at one extra mooring site150 k$/yr
- A variety of remote sensing sites should be used to extend the point measurements over most of the Arctic Ocean - Including North Pole in situ gauge and Satellite remote sensing = 300 k$/yr

e. Sea ice thickness **950,000**

- moorings (5.1.1.3a, c), 50 k$/yr/ULS X 10 = 500 k$/yr
- remote sensing (satellite and aircraft) use existing data sources 300 k$/yr
-submarine profiles, - to process SCICEX and historical data costs 150 k$/yr

f. Sub-Arctic Seas Hydrographic Surveys **1,800,000**

in the regions adjacent to the critical straits

g. Automated Drifting Stations (2) **1,400,000**

A least two complete = 2 x (700 k$/yr) = 1.4 M$/yr

h. Census of Key Species **1,200,000**

In specific regions of the marine environment (6 species x 200k/soecies)

i. Automated Biology Sampling at Moorings (13) 2,600,000

- Sample biologically relevant parameters at moorings in the key ice and ocean pathways - 13 moorings x (50 k$ +150 k$) = 2.6 M$/yr

j. Automated Biology Sampling at Drifting Stations (2) 400,000

Establish automated sampling of biologically relevant parameters at automated drifting stations. 2 drifting stations x (50 k$ +150 k$) = 400 k$/yr

k. Biological/Biogeological Sampling at River Outlets (5) 1,500,000

-Monitor biologically and biogeochemically important parameters (such as in 5.1.1.3h and 5.1.13I) in river outflows. - 5? Rivers x 300 k$/river/yr

l. Biological/Biogeological Sampling in Rep. Regions (4) 600,000

- Biological sampling in 3 or 4 representative regions (e.g., Nansen-Amundsen Basins, Makarov Basin, Beaufort Sea, and Lincoln Sea-Pole). (See also 5.1.3b, d) - 4 sections x (150 k$/section/yr) = 600 k$/yr

m. New Technologies 2,000,000

- Encourage the development and use of new technologies - lump in with other costs

and from Section 5.1.2.2:

Expand Arctic System Reanalysis to Ocean Variables 450,000

- Expand to the Arctic System Reanalysis to estimate hard-to-measure variables that pertain to the ocean and sea ice - 3 investigators x (150%k/yr/investigator) = $450 k$/yr

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Total (A) - Total Required 27,350,000

B) Anticipated Non-U.S. Funding Equivalents and U.S. Funding Estimated In-Place

ASOF EU Funding for Fram Strait & Barents Moorings	**3,400,000**
ASOF EU Funding for Greenland & Barents Seas Hydro	**800,000**
JWACS Canadian Basin Moorings (2)	**1,200,000**
JWACS Canadian Basin Drifting Stations	**200,000**
JWACS Canadian Basin Hydro Surveys	**200,000**
NSF Freshwater Canadian Basin Mooring (Proshutinsky)	**600,000**
NSF Freshwater Canadian Archipelago Monitoring (Lee)	**700,000**
NSF Freshwater Basin Hydro (Steele)	**450,000**
North Pole Station Hydro, Mooring, Drifting Station (NSF&JAMSTEC)	**1,500,000**
NABOS Eurasian Slope Moorings (4)	**2,400,000**
Total (B) - Anticipated In-Place	**11,450**
Estimated Total New Funding Required (A-B)	**15,900,000**

Appendix A

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