SCICEX Phase II Science Plan

PART 1: TECHNICAL GUIDANCE FOR PLANNING SCIENCE ACCOMMODATION MISSIONS

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SCICEX Phase II Science Plan

PART 1: TECHNICAL GUIDANCE FOR PLANNING SCIENCE ACCOMMODATION MISSIONS

Science Ice Exercise (SCICEX) Phase II Science Plan
Interagency Committee Endorsement
June 17, 2010

The Arctic system is changing. Arctic warming is widespread, and in some cases, dramatic. Links among air, land, sea, and biology are evident. Federal agencies funding Arctic marine science believe nuclear submarines (SSNs) offer unique Arctic research opportunities. The Arctic research community developed this science plan in close coordination with the Navy's Arctic Submarine Laboratory to facilitate the collection of scientific data by submarines during Arctic operations. The plan's main goals are to maximize contributions toward understanding Arctic Ocean processes and their role in Earth's climate system through Science Accommodation Mission cruises of opportunity, and to collect baseline data on the ice canopy; physical, chemical, and biological water properties; and the seafloor, as scheduled operations allow.

For almost 70 years, the United States Navy has operated in Arctic waters. The Navy believes its submarines must retain a global ocean operational capability and the Submarine Force is committed to sustaining Arctic training and readiness through recurring Arctic deployments.

In many respects, a critical portion of the foundational data that helped scientists recognize Earth's climate was changing were gathered during SCICEX Phase I dedicated submarine science missions between 1993 and 1999. The success of the USS PARGO (SSN 650) proof of concept science cruise in 1993 led to the signing of the first SCICEX agreement in 1994. The unmatched mobility of submarines in ice-covered oceans allowed data to be collected from over 100,000 miles of ship track in the Arctic Ocean and changed the world view of deep Arctic Ocean bathymetry. SCICEX accommodation cruises have taken place in 2000, 2001, 2003, and 2005.

It is our hope that through this science plan and continued close collaboration among research sponsors, the United States Navy, and the Arctic science community we will add to the body of scientific knowledge and increase understanding of the dynamic Arctic system.

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The U.S. Navy Arctic Submarine Lab has reviewed the Science Plan for operational feasibility.

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Abstract

The SCience ICe EXercise (SCICEX) program, formally established in 1994, recognizes the unique capabilities of nuclear-powered submarines as data-collection platforms in the ice-covered Arctic Ocean. In reaction to a decision to end an initial sequence of cruises solely dedicated to science, the SCICEX program was modified in 2000 to include Science Accommodation Missions (SAMs). In the course of a SAM, some time is set aside for the collection of unclassified data during otherwise classified submarine exercises. Due to security issues, the SAM process does not allow for significant advance planning of scientific activities. Instead, the Navy's Arctic Submarine Laboratory (ASL) will work with the operational Navy to identify and plan SCICEX SAM opportunities. Input to ASL from the scientific community regarding data collection is provided via this science plan. The centerpiece of the SCICEX Science Plan, Part 1, is a detailed, prioritized list of sampling recommendations for sea ice draft profiling; ocean hydrography, chemistry, and biology; and bathymetry. The recommendations are based on the current state of knowledge as derived from observations and models. Management and community access to these data will be the focus of part 2 of the science plan. The SCICEX Science Advisory Committee (SAC) is responsible for periodic review and, if appropriate, updating the science plan to keep pace with the advancement of state-of-the-art knowledge and technology. The SCICEX SAC will also assist the Navy in evaluating the efficacy of SAMs to generate suggestions aimed at improving future missions.

Introduction

In 1993, the United States Navy and the Arctic marine research community undertook a scientific research cruise aboard a nuclear-powered submarine in an ambitious program to evaluate the use of nuclear-powered submarines for scientific studies of the Arctic Ocean (Figure 1). This collaboration recognized the unique capabilities of these submarines as data-collection platforms in the Arctic Ocean, coupling the ability to travel at high speed with the ability to operate across the region regardless of the state of the sea ice cover. It was anticipated that these capabilities could be applied to collecting data that describe the ice canopy; physical, chemical, and biological water properties; and the seafloor and underlying sediments and bedrock. In contrast to standard operating procedures for naval nuclear submarines, data collected within a designated area (Figure 1) during the cruise were disseminated to participating scientists shortly after completion of the survey.

The success of this initial collaboration and the associated pilot cruise served to launch the **SC**ience **IC**e **EX**ercise (SCICEX) program. The initial SCICEX Memorandum of Agreement (MOA; Appendix B) was signed in 1994 by elements of the U.S. Navy, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS). The MOA stated:

The overall goal of SCICEX is to improve understanding of Arctic Ocean processes and their role in the Earth's climate system by dual use of nuclear submarines, thus fully capitalizing on existing national platform capabilities. This Agreement is intended to mutually support the objectives of both the civilian and military communities.

The original MOA supported five more dedicated science cruises aboard nuclear-powered submarines between 1995 and 1999. In October 1998, the U.S. Navy determined that it would no longer be able to support dedicated science cruises. Rather than terminate the SCICEX program, a second MOA was negotiated and signed in 2000 between elements of the U.S. Navy and NSF (Appendix C). Maintaining the same core goals and objectives, the SCICEX Phase II MOA modified the scope of the

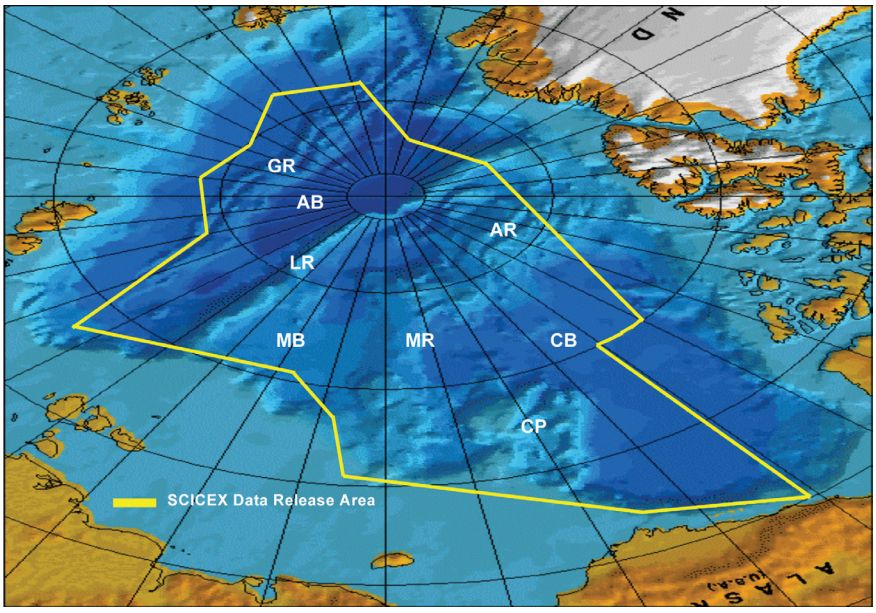


Figure 1. Arctic Ocean bathymetry with identified geographic features referred to in the text: Gakkel Ridge (GR), Amundsen Basin (AB), Lomonosov Ridge (LR), Makarov Basin (MB), Mendeleyev Ridge (MR), Alpha Ridge (AR), Chukchi Plateau (CP), and Canada Basin (CB). The SCICEX Data Release Area is outlined in yellow.

collaboration to include Science Accommodation Missions (SAMs). During a SAM, some time is set aside for the collection of unclassified data during otherwise classified submarine exercises. SCICEX accommodation cruises have taken place in 2000, 2001, 2003, and 2005. The Phase II MOA is, and will remain, in effect until it is deemed obsolete or impractical by the parties involved in its application.

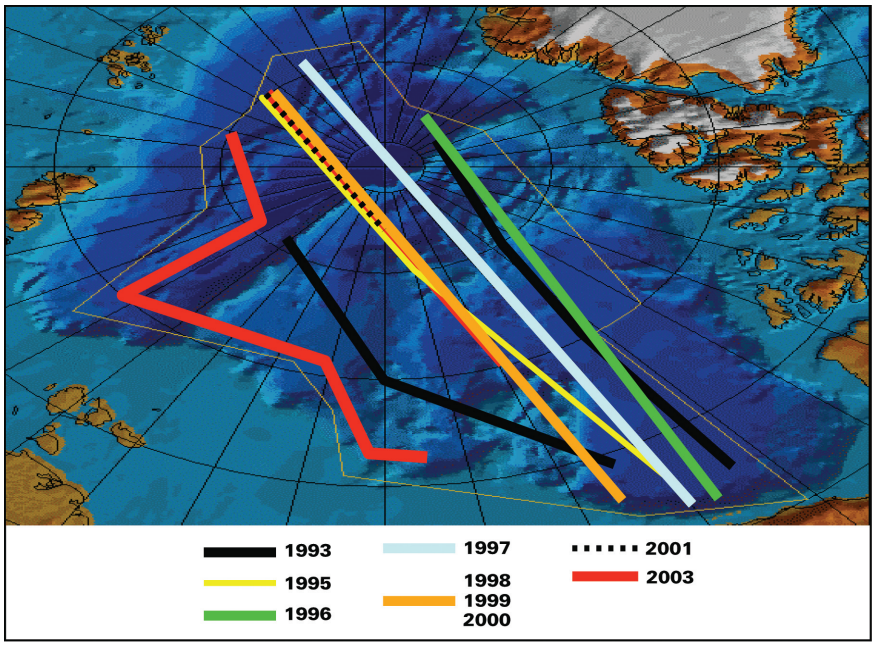


Figure 2. Summary of SCICEX cruise tracks to date.

Comprehensive summaries of SCICEX cruises prior to 2001 can be found in Rothrock et al. (1999a) and Edwards and Coakley (2003). Figure 2 shows SCICEX transits to date, including both dedicated and SAM deployments.

The Navy continues to send submarines to the Arctic. The expectation is that, for the foreseeable future, small amounts of time during selected cruises will be available for science data acquisition. The process by which the Navy expects to make unclassified Arctic submarine sampling time available to the scientific community through SCICEX SAMs does not allow for significant advance planning of scientific activities. As a result, detailed cruise-specific scientific civilian planning cannot be carried out prior to these missions. Instead, the science community has the opportunity, via this Science Plan, Part 1, to provide a detailed, prioritized list of data-collection efforts considered suitable for SCICEX accommodation cruises. This guidance, provided in a Planning Matrix (Appendix A), is intended to serve as a planning tool for SAMs, while at the same time understanding and appreciating that priority will be given to operational requirements during the cruise.

The Arctic research community developed the Science Plan, Part 1, to maximize SCICEX contributions toward understanding Arctic Ocean processes and their role in Earth's climate system. Specifically, SAM cruises will collect baseline data on the ice canopy; physical, chemical, and biological water properties; and the seafloor. The science plan presents priority recommendations, structured within the framework of the SCICEX Phase II MOA, for scientific data collection during SAM cruises. Detailed SCICEX data-collection plans for a particular cruise will depend strongly on cruise mission requirements and the collection capabilities of the submarine involved. These constraints

necessitate a science plan that is inherently flexible, outlining a wide range of sampling options to maximize data-collection opportunities.

Science Plan, Part 1, recommendations were developed with an eye toward making SCICEX an integral element of the Arctic Observing Network (AON; IARPC, 2007), itself an integral component of the Study of Environmental Arctic Change (SEARCH) program. AON's objectives are to enhance, coordinate, and sustain observing sites, systems, and networks in the Arctic. It is expected that data from this coordinated network will contribute information on the magnitude, variation, and rate of current and past environmental change. Further, these data will be used to initialize, validate, and improve computer models that allow simulation and prediction of the Arctic environmental system and its global connections. SCICEX data are well suited to contribute to AON. In particular, SCICEX looks to support repeated surveys of ice, ocean, and seabed properties in specific regions of the Arctic Basin (particularly those areas difficult to access by other means) that build on the historical records from SCICEX and other programs.

The Science Plan, Part 1, includes sampling recommendations for ice draft profiling; ocean hydrography, chemistry, and biology; and bathymetry. The recommendations are explained in the context of past related SCICEX contributions and the current understanding of the Arctic Ocean environment, identified knowledge gaps, and submarine sampling capabilities. The current understanding is based on direct observations, process studies, and computer model simulations. The science plan is developed with the expectation that the recommended sampling strategies will be reviewed and updated by the SCICEX Science Advisory Committee (SAC) to keep pace with the advancement of state-of-the-art knowledge and technology and, hence, the evolution of new scientific questions and needs.

Part 1 of the science plan responds to the urgent requirement to provide sampling guidance to the U.S. Navy Arctic Submarine Laboratory (ASL) to facilitate the continuation of the SCICEX program. Notably absent from this part of the plan is detailed guidance on another critical issue: community access to SCICEX data. This topic will be addressed in a separate, companion document that focuses on the management, quality control, and availability of data collected via a SCICEX SAM. Although the details remain to be worked out, it is the intention that data collected during the science elements of a SAM cruise will be publicly available as soon a possible after completion of the cruise. In contrast to the dedicated SCICEX missions, data from the SAMs will be disseminated in the public domain without first being held for exclusive use by any particular scientist or group of scientists. In accordance with the SCICEX Phase II MOA, all SCICEX SAM data will be accessible through the National Snow and Ice Data Center (NSIDC). The SCICEX SAC, in coordination with the SCICEX Interagency Committee, will inform the scientific community of the release of declassified SCICEX SAM data to the NSIDC through the best available medium (e.g., ArcticInfo information server operated by the Untied States Arctic Research Consortium).

Framework

As outlined in the SCICEX Phase II MOA, the primary objective of Science Accommodation Missions is to collect baseline data rather than to conduct individual experiments. These baseline data are intended to permit continued monitoring of evolving sea ice and ocean conditions and, potentially, contaminant concentrations, as well as mapping of seafloor morphology in the Arctic Ocean. Navy personnel embarked on the ship, including ASL personnel, will be responsible for collecting the data and samples. It is not expected that civilian scientists will embark on SAM cruises.

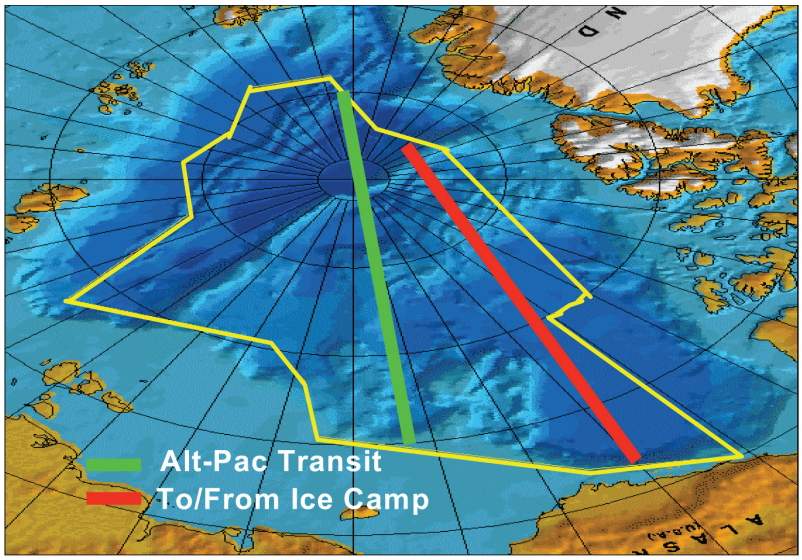


Figure 3. Cruise tracks for routine, direct crossings.

Currently, there are two types of Arctic missions conducted by U.S. submarines that can be used as SAMs (Figure 3):

a. Direct transits. Submarine transits occur across the Arctic Basin, from the Atlantic to the Pacific Ocean or from the Pacific to the Atlantic, typically one to three times per year.
b. Ice camps. Approximately every two years, the Navy will establish an ice camp in the southern Beaufort Sea to support its submarine Ice Exercise (ICEX) activities. Submarines operating at the ice camp will transit the Arctic Basin en route to the camp. These missions typically occur in March and April.

Data collection during a SCICEX SAM is restricted to the Data Release Area, also referred to as the SCICEX box (Figure 1). The Navy has approved declassification and release of data in this region. Data release is further restricted to times when the submarine is operating at depths less than or equal to 244 m (800 ft) and speeds less than or equal to 25 kt. Designation of an Arctic submarine cruise as a SCICEX SAM by the Navy provides assurance to the scientific community that the Navy will make an effort to operate continuously within the parameters identified above, thus ensuring expeditious release of the data for scientific purposes.

Baseline data collected during a SCICEX SAM will normally be limited to measurements that can be obtained using standard submarine equipment, systems that have been installed by ASL to support ICEX cruises, and other sensors that can be readily accommodated. Specific data sets and equipment will vary depending on the submarine class conducting the operations but will generally include:

- Conductivity, temperature, depth (CTD) profiles taken by expendable probes
- CTD and other sensor data taken from hull-mounted systems
- Bathymetry recorded by installed fathometers

- Ice profile data from upward-looking sonar
- Water samples for salinity calibration and other later analyses
- Supporting navigation from the submarine's inertial navigation system, and operational data at a nonclassified level

Although collection of baseline data, as described in this report, is the primary objective of a SCICEX SAM, independent proposals may be entertained. These proposals may include, but are not limited to, individual experiments or installation of auxiliary equipment. It needs to be understood that the proposed work must be consistent with maintaining the security of planned submarine operations. The decision to support proposed sampling will be made by the SCICEX Interagency Committee (IAC), with concurrence from an identified funding source. The SCICEX IAC includes representatives from NSF, the Office of Naval Research (ONR), and ASL. Investigators seeking funding for SCICEX-related observations and/or research should contact either the ONR (Division Director, Ocean-Atmosphere-Space Research Division, Code 322, phone 703-696-4118) or NSF (Office of Polar Programs, Program Director, Arctic Observing Network, phone: 703-292-7442) to discuss the proposed work and for advice about submitting proposals. Investigators planning a proposal to ONR or NSF should also contact the Technical Director, ASL, to discuss the feasibility of their plans (http://www.csp.navy.mil/asl/index.htm). Proposals must be submitted to each agency according to their established guidelines and procedures, and they will be subject to each agency's normal review/approval/funding process. Neither ONR nor NSF guarantees that funding will be made available. Questions regarding the process of proposal submission can also be directed to the Chair, SCICEX Science Advisory Committee (contact information for current chair is available from the U.S. Arctic Research Commission Web site at http://www.arctic.gov). SCICEX IAC points of contact can also be found at http://www.scicex.org.

Approach

When submarines are scheduled for Arctic operations, ASL will examine each mission for its potential to collect SCICEX data. In doing so, they will consider the following:

- Type/destination of the transit
- Priorities laid out in the Science Plan, Part 1 (this document)
- Suitability of the submarine's equipment for data collection
- Amount of time that might be added to the transit to perform data collection
- Time of year
- Complementary plans of other elements within AON
- Sampling conducted on recent previous SAM cruises
- Feasibility and cost-effectiveness of installing extra scientific equipment on board the submarine

The science plan is built around five recommended sampling corridors within the SCICEX Data Release Area (Figure 4). Specific cruise tracks, formed either within single corridors or as combinations of segments of one or more corridors, provide examples of what is anticipated to be executed, in actual practice, by the submarine (Figure 5, Table 1). These cruise tracks represent variations on the two most likely Navy scenarios under which SAM time will become available. As described earlier, these scenarios include (1) Atlantic-Pacific submarine transfers (i.e., transits from the Pacific to the Atlantic Ocean and vice versa), and (2) transits to and from a dedicated ice camp in the Beaufort Sea (Figure 3). The extent of the deviations of these cruise tracks from the pure transit tracks depends on the amount of additional science sampling time to be made available by the Navy. The additional sampling time is not anticipated to exceed three days for a single cruise. The sample cruise tracks are intended to provide a planning tool to the Navy, via ASL, for specific SAM opportunities. They also offer guidance to the scientific community with respect to sampling expectations.

Specific sampling recommendations are outlined in a Planning Matrix (Appendix A), as a function of candidate cruise tracks and various allotments of additional sampling time. These recommendations address specific scientific objectives as outlined in the next section. Individual recommendations address bathymetric, ice

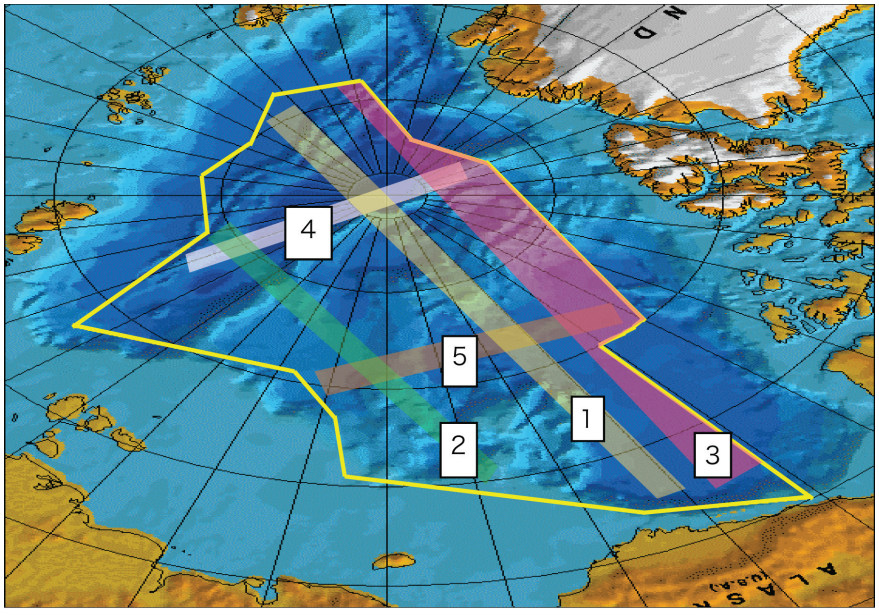


Figure 4. Recommended sampling corridors.

cover, and ocean water measurements. The ocean water measurements are further subdivided into hydrography, chemistry, and biology. Each set of recommendations assumes that the time available for SCICEX measurements during a particular deployment can be fully dedicated to that particular topical emphasis. For example, given a one-day window for sampling, the recommended ice cover measurements assume one day of sampling time independent of the other recommendations. This approach is consistent with the objective of providing maximum flexibility and, hence, maximizing the opportunities to collect SCICEX data.

The dedicated science cruises of the 1990s balanced the sampling needs of the different marine science communities represented in the program. Similarly, the science plan presented here is an attempt to balance the sampling needs and priorities of these communities. By presenting a plan that targets sampling within discrete corridors (rather than specific track lines) we aim to introduce the flexibility to simultaneously meet the objectives of more than one constituency. For example, repeated sampling of the long, central cruise track of the late 1990s and early 2000s (Figure 2) is a high priority for the oceanographic and sea ice

Table 1. Description of sample cruise tracks. The minimum time required is referenced to the time required to complete the basic crossing for either the Atlantic-Pacific transit or the ice camp transit and gives the additional time necessary to complete the route, with no additional time dedicated to the collection of SCICEX data. Although the track descriptions generally start from the Atlantic Ocean, all of these tracks could be performed in either direction.

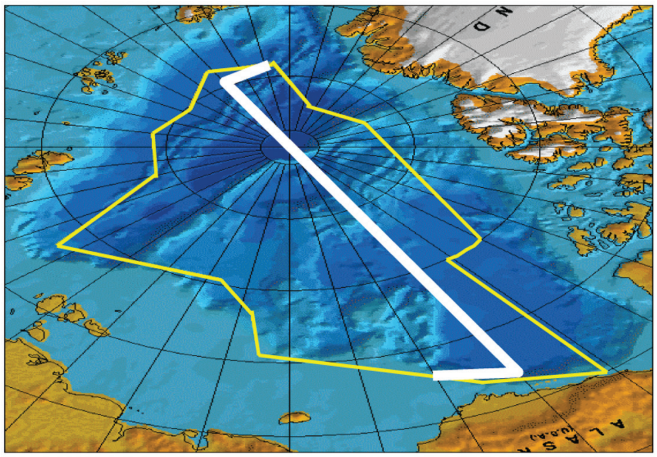
CRUISE TRACK	SAMPLING CORRIDOR	TRACK	FIGURE NUMBER	MIN TIME REQUIRED	DESCRIPTION
Atlantic-Pacific Transits		Direct Atlantic-Pacific Crossing	3	none	Direct transit between Atlantic and Pacific oceans
	1	North Pole	5a	2 days	A track roughly parallel to the recent SCICEX track but displaced toward the Canadian side of the basin so as to pass through the North Pole
	1	Recent SCICEX	5b	3 days	Designed to replicate the cruise tracks conducted on several of the dedicated SCICEX cruises. The endpoints of this track were initially selected in the mid-1990s to support the Acoustic Thermometry of Ocean Climate (ATOC) program.
	2 and 4	Eastern Offset	5c	1 day	Enters the Data Release Area at about 60°W (north of the Lincoln Sea), crosses to the North Pole to the Gakkel Ridge, then makes a perpendicular crossing of the Makarov Basin. The first leg of the track is designed to collect ice data along a line roughly perpendicular to the ice thickness gradients.
	2, 3, and 5	Cross Canada Basin	5d	2.5 days	After passing though the North Pole, this track hugs the Canadian boundary of the Data Release Area, then continues eastward across the breadth of the Canada Basin before exiting.
Ice Camp Transits		Direct Ice Camp Crossing	3	none	Direct transit between Atlantic or Pacific Ocean and the Beaufort Ice Camp
	1	North Pole	5a	0.5 days	Similar to Atlantic-Pacific North Pole track
	1	Recent SCICEX	5b	1 day	Similar to Atlantic-Pacific recent SCICEX track
	3	Canadian Margin	5e	0.5 days	Hugging the Canadian boundary of the Data Release Area from the entry point to the southern Beaufort Sea

communities. Repeating this transect at 5–10 km lateral offsets will satisfy most oceanographic objectives while adding new bathymetric lines for the marine geology community.

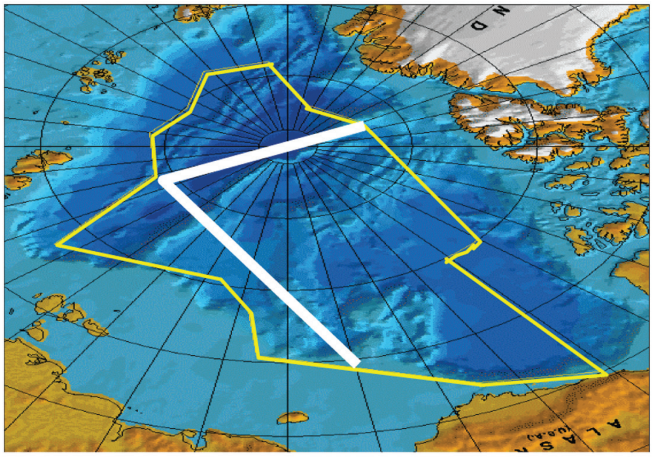
Although not a part of the SCICEX program, the SCICEX SAC acknowledges that the ice camps established in the Alaskan Beaufort Sea as part of the Navy's (typically biannual) ICEX offer an important opportunity to conduct focused experiments. Unique to these ice camps, and in contrast to the transits, is the chance for advanced and coordinated planning. Thus, studies can be designed to explore new or improved techniques for submarine-based sampling. There is frequently an unclassified extension to the ice camp that facilitates research by civilian scientists. In these cases, the Navy transfers operation of the established ice camp over to the organizations funding the research (e.g., NSF, NASA). This transfer is made in recognition that the ice camp is a valuable platform for conducting process-oriented investigations and testing new data-collection technologies. For example, during 2007, the unclassified extension of the ICEX ice camp was successfully used to test the integration of various above-ice and below-ice systems for measurement of sea ice thickness (Hutchings et al., 2008). Researchers interested in pursuing these opportunities should contact appropriate agency program managers.

In support of developing and maintaining a sustained AON, the SCICEX planning recommendations seek to complement and contribute to other observing system components. For instance, SCICEX sampling in and around the North Pole (corridors 1 and 4) can augment ice and ocean observations made as part of the North Pole Environmental Observatory program (http://psc.apl.washington.edu/northpole). Sampling along the Atlantic ends of corridors 1 and 4 complements the work of the Freshwater Switchyard Project (http://psc.apl.washington.edu/switchyard/index.html), aimed at improving understanding of freshwater circulation in the region between Ellesmere Island and the North Pole. Studies conducted as part of the Beaufort Gyre Exploration Project (BGEP, http://www.whoi.edu/beaufortgyre/index.html) will benefit from SCICEX measurements made in the Canada Basin (corridors 1, 2, 3, and 5).

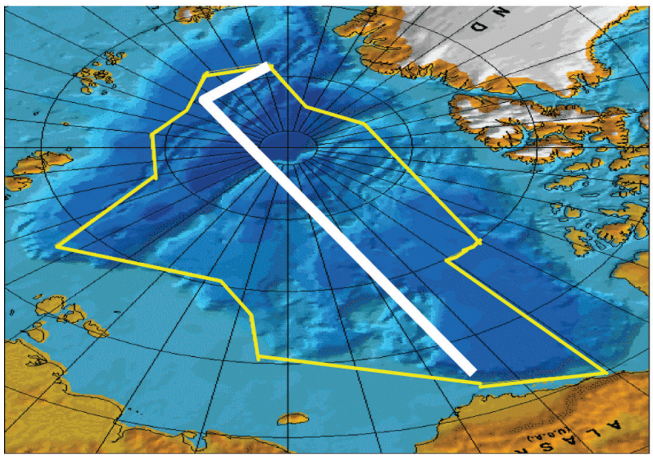
The inherent flexibility of the sampling recommendations laid out in the SCICEX Science Plan, Part 1, lends itself to successfully coordinating with other existing AON elements. For example, where an existing AON program samples within a specific geographic region during summer, the SCICEX program could provide complementary sampling during spring conditions. If that summer AON sampling program were to end, the SCICEX program could refocus its priority to extend the summertime sampling in that region.



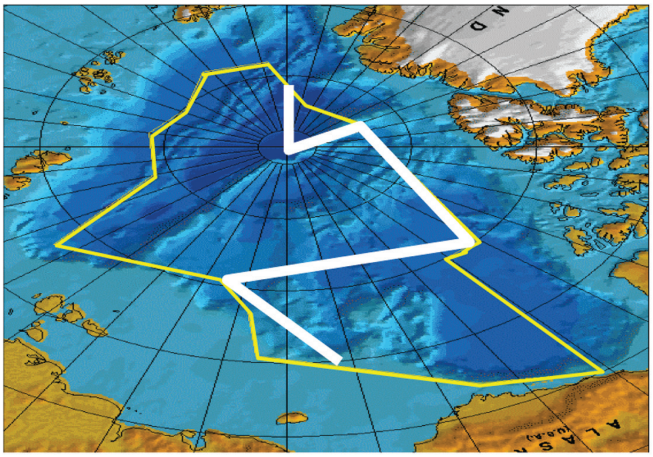
(a) North Pole Track (Corridor 1)



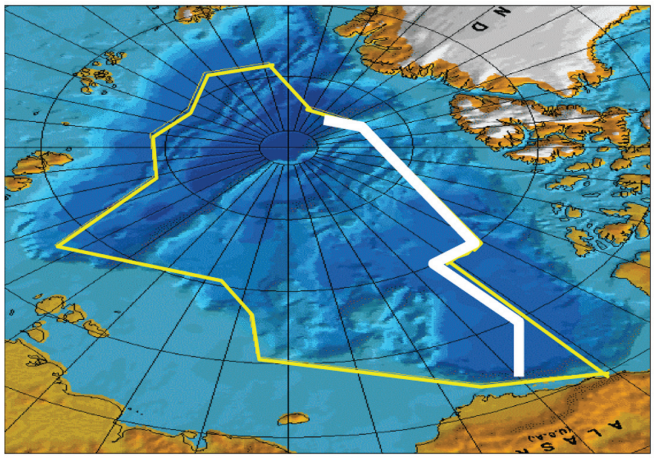
(c) Eastern Offset Track (Corridors 2 and 4)



(b) Recent SCICEX Track (Corridor 1)



(d) Cross Canada Basin Track (Corridors 2, 3, and 5)



(e) Canadian Margin Track (Corridor 3)

Figure 5. Example cruise tracks. Times for each of these tracks are given in Table 1.

SAMs Sampling Priorities and Recommendations

OVERARCHING

The overarching recommendation is that the ASL seek additional SCICEX sampling time from the operational Navy to collect measurements within specific corridors of interest (Figure 4). The scientific justifications and prioritizations, which form the core of this SCICEX Science Plan, are intended to give guidance to ASL in negotiating and planning for the additional sampling time to collect data along specific tracks within these corridors.

It is also a high priority that SCICEX sampling become a routine part of the direct Arctic crossing transits (Figure 3) in the event that there is not sufficient time to deviate to one of the more desirable tracks. The Atlantic-Pacific transit crossing line is the shortest route between the Atlantic and Pacific oceans and is anticipated to be routinely occupied. The direct transit in support of ice camp operations is another track that will be routinely occupied, albeit at an expected frequency of only once every two years. Taken together, these tracks traverse most of the major Arctic Ocean bathymetric and ocean circulation features within the SCICEX Data Release Area.

ICE DRAFT PROFILING

Background

Profiles of sea ice draft obtained from the upward-looking sonars of submarines transiting the Arctic Ocean have provided the bulk of our current knowledge of ice thickness over the Arctic basin. Early analyses of ice draft data compiled from one or more cruises revealed aspects of spatial ice thickness variability (Bourke and Garrett, 1987; Bourke and McLaren, 1992). These early analyses also initiated discussions about the possible thinning of the ice cover, even in the face of a limited knowledge of natural variability (McLaren et al., 1990; Wadhams, 1990; Shy and Walsh, 1996).

The advent of the SCICEX program in the 1990s greatly expanded the available unclassified ice draft data (Rothrock et al., 1999a) and allowed comparison of 1990s ice drafts with earlier previously published data (Rothrock, et al., 1999b; Yu et al., 2004). These analyses established that, indeed, the ice had thinned significantly within the Data Release Area between 1950–1970 and the 1990s. With the subsequent declassification of ice draft data collected on many earlier cruises, as well as the availability of some ice draft data collected by submarines from the United Kingdom, interannual changes have been examined in greater detail. As a result, rapid decreases in thickness have been confirmed in some regions of the Arctic (Wadhams and Davis, 2000; Tucker, et al., 2001).

The recent digitization of analog recordings of ice draft has generated a great deal more data (Wenshahan and Rothrock, 2005; Rothrock and Wensnahan, 2007; Wensnahan, et al., 2007), which has allowed even more detailed analyses of ice draft spatial distribution as well as annual and interannual variability. Rothrock et al. (2008) found a marked decrease in mean ice draft from 1980 to 2000, with the largest rate of decline occurring in 1990 and a lesser rate toward the end of the period. However, Kwok and Rothrock (2009) found even larger annual declines during the period 2003–2008 using ice thickness derived from satellite altimetry to extend the submarine data record.

It is likely that the submarine will continue to play a key role in an integrated strategy for monitoring ice thickness. Kwok et al. (2009) demonstrated that satellite altimetry could provide reasonable estimates of large-scale ice thickness by comparing the altimetry to submarine and moored sonar records of ice draft. This development is timely given the more recent large reductions in ice extent and thickness (Richter-Menge et al., 2008). Ideally, it will become more commonplace for SCICEX-derived ice thickness data to be effectively combined with data collected from satellite-borne instruments (e.g., Kwok et al., 2007, 2009; Nghiem et al., 2007; Giles et al., 2008), moorings (e.g., Melling et al., 2005), ice mass balance buoys (Richter-Menge et al., 2006), and computer model simulations (e.g., Rothrock and Zhang, 2005; Maslowski at al., 2007; Lindsay et al., 2009). Each sensor platform has its own unique capabilities and limitations. Although the capability of satellite-borne instruments to measure ice thickness variability over large regions has improved, submarines continue to provide the most accurate, detailed, large-scale thickness information. Although the submarine data are recognized to be temporally and spatially limited, they will continue to provide critical monitoring of the ice pack and, hence, data that are key for the validation and calibration of the satellite data and model output. Conversely, satellite data and model output can be used to identify regions of particularly high importance for sampling during a SCICEX SAM.

Sampling Recommendations

The ice draft profiling strategy aims to (a) collect high-quality information to add to the existing archive of ice draft data and (b) continue to monitor the ongoing dramatic changes in ice thickness distribution. The areas identified as high sampling priorities include regions that have been heavily profiled in the past, areas where significant changes in ice thickness have taken place or appear imminent, and regions where little is known about the ice thickness distribution because of data scarcity. These sampling regions, in priority order, are:

1. The North Pole region (within corridors 1 and 4)
2. A north-south track extending from near or at the North Pole south to near the coast of Alaska (corridor 1)
3. Two tracks crossing the release area from near the Canadian Archipelago to the Russian side of the box, nearly perpendicular to the north-south track (corridors 4 and 5)
4. A track adjacent to the Canadian Archipelago (corridor 3)

The North Pole area is selected as the highest priority sampling region because it has the greatest historical coverage of ice profile data, and future submarine transits are likely to pass near it. The sampling preference is for two 50-km legs, one passing to either side of the North Pole.

Although ice near the North Pole is of interest from a historical perspective, the central Canada Basin (central and northern Beaufort Sea) has undergone some of the most significant changes in ice cover, within the SCICEX Data Release Area, since the late 1980s. Satellite remote sensing and modeling results indicate that the Arctic has experienced a significant decline in the amount of perennial ice (Rigor and Wallace, 2004; Nghiem et al. 2007), due in large part to changes in atmospheric circulation that have weakened or interrupted the Beaufort Gyre (Tucker, et al., 2001; Pfirman et al., 2004; Rigor and Wallace, 2004), and

subsequent purging of much of the older ice through Fram Strait. A high priority, then, is to provide the most frequent sampling possible to assess the relative volume of older, thicker ice. A track extending from the region of the North Pole southward toward Alaska, using either the North Pole transect (Figure 5a) or the traditional SCICEX transect (Figure 5b, used frequently on SCICEX cruises in the 1990s), will cross this important region.

Another high-priority region for sampling extends across the Canada Basin from the Canadian side to the Russian side of the SCICEX box, essentially bisecting the Canada Basin. These tracks cross some of the thickest ice in the Arctic, near the Canadian Archipelago, and traverse the region of transition from multiyear ice in the Beaufort Gyre to younger ice originating in the Chukchi and East Siberian seas. The track along the Data Release Area's Canadian margin provides information about this historically thick ice region, where there are currently very limited data.

For consistency and comparison with prior data, it is recommended that ice profiles be collected over 50-km sample lengths along all sample transects while operating at a submarine depth of approximately 122 m (400 ft) and a speed of 14 kt. Most submarine ice draft data analyses have used a 50-km-long sampling interval for reporting ice draft statistics, and this interval has become the *de facto* standard (Rothrock et al., 2008). With regard to U.S. Navy submarine operations, the optimal ice draft data are obtained when the ship operates at slower speeds and shallower depths. In the past, high-quality data have been obtained at operating depths and speeds standardized to about 122 m and 14 kts, respectively.

Sampling strategies are identified based on the time available for ice profiling and on the geographic priorities (Appendix A). Take, for instance, the ice sampling recommendations made for the high-priority corridor 1. Even with no additional time available, continuous sampling is recommended with the expectation that useful data will be obtained even at the greater depths and higher speeds likely to be used when the submarine is transiting the Arctic. Given a half day of additional sampling time, the preference is to slow the submarine to 14 kt and come to a depth of 122 m for sampling along two 50-km segments to either side (Atlantic and Pacific) of the Pole and six 50-km segments evenly distributed along the north-south track within corridor 1. With more time available, more 50-km segments can be sampled. The second priority for ice draft data collection is the cross-Canada Basin track encompassed by corridor 5. Appendix A also shows the sampling strategies for other geographic regions. If different tracks are chosen to satisfy the different scientific disciplines, the ice sampling strategies spell out how the ice profiling segments should be allocated.

Methods and Implementation

U.S. Navy submarines routinely obtain observations of sea ice draft in the Arctic Ocean using upward-looking sonar. These operational instruments are used to ensure safe maneuvering of the submarine, and were not designed to collect scientific data. Draft measurements are made by a sonar transducer mounted in the submarine's sail. A highly focused beam of sound (2–3° beam width) is transmitted upward through the water column, reflecting off the bottom of the sea ice and returning to the transducer. The system uses the signal travel time and an assumed sound speed to estimate the distance from the transducer to the ice. The ice draft is then calculated as the difference between the depth of the ship, as measured by a pressure transducer, and the distance to the ice. It is this approximate draft that is recorded by the ship system.

The data are recorded either digitally or on analog paper charts, or a combination of the two. The digital recording system uses a set of hard-coded thresholds to determine whether the signal has sufficient strength and duration to count as a valid return, in which case the leading edge of this return is recorded. The recorded draft is therefore the deepest ice from the return and is referred to as the "first return." The

analog charts in the ASL archive have been processed to approximate the equivalent of a digital first return product (Wensnahan and Rothrock, 2005).

The draft is measured and recorded about six times per second. At typical submarine speeds, this recording frequency provides a spatial profile of draft with a data spacing of about 1 m for digital data. Overwriting of successive measurements on the paper chart limits these data to a resolution of about 1 ping per second (at 14 kt, 1 ping per second translates to a ~7-m spacing).

A significant amount of data in the NSIDC archive was collected at greater depths and higher speeds than the typical 122 m and 14 kt, respectively. The ICEX-09 submarine exercises in the southern Beaufort Sea during March 2009 provided an opportunity to make repeated submarine runs at different depths and speeds over the same underice track. Ongoing analyses will determine the quality of the ice draft data collected at different depth/speed combinations and the impact of acquiring data at greater speeds and depths than in the past.

Raw data are normally designated as "classified" by the Navy and are then archived at ASL. Processing of the raw data includes: (a) editing to remove spurious points, (b) calibrating the draft to sea level, (c) tying the draft to navigation data, and (d) stripping out segments during submarine maneuvers when the data are difficult or impossible to interpret. The result is a sequence of profiles, varying in length from a few to several hundred kilometers, along the submarine track.

Ice draft data are taken as a normal part of ship operations and are available for the entire cruise. To clear the classified data taken during normal operations for public release, times are rounded to the nearest third of a month and positions are rounded to the nearest five minutes of latitude and longitude. These constraints are relaxed during SCICEX missions, when the data include accurate (unrounded) time and position information. All data are reviewed by ASL and are approved for public release as unclassified. Data have been released, with very few exceptions, only within the SCICEX Data Release Area, which covers roughly half of the central Arctic Ocean (Figure 1). Draft data are now publicly available from some 40 cruises from 1975 to 2000, covering over 120,000 km of track. Draft data from two cruises in 2005 have been processed and will be archived at NSIDC. Because the submarine routinely collects ice draft data, it remains possible for additional data to be made available via the funding of independent proposals. All processed ice draft data are archived for public use at NSIDC (go to http://nsidc.org/data/g01360.html).

As explained in Rothrock and Wensnahan (2007), the major sources of error in the draft measurements include: (a) inaccuracy in the selection of open water for calibration, (b) variation in the upward-looking sonar power and gain settings, which affect thresholding, and (c) bias due to the finite footprint size of the sonar system. Errors due to submarine orientation (e.g., pitch, roll, yaw), which occur primarily when the submarine is maneuvering, are removed from the record during processing. The standard deviation of the error in the draft measurement is 22 cm. This number estimates the repeatability and comparability of draft measurements by U.S. Navy submarines. The bias in the submarine-based measurement of ice draft with respect to the actual draft is +29 ± 12 cm.

OCEAN: HYDROGRAPHY

Background

During the 15-year period since the beginning of the SCICEX program, our knowledge of the circulation and distribution of water mass properties within the upper layers of the Arctic Ocean has increased significantly. Yet, due to the Arctic's many scales of variability and continuing inaccessibility, we are still hard pressed to provide details on the variability of many of these features. CTD and expendable CTD (XCTD) data collected during the six dedicated-science SCICEX cruises (1993, 1995–1999) contributed early to the awareness

of variability in the peripheral flow of Atlantic Water (AW). In particular, they revealed the increasing temperature in the early 1990s of the core Atlantic Water layer flowing along the Lomonosov Ridge (Morison et al., 1998; Gunn and Muench, 2001) and large-scale variations in the salinity of the halocline in the Amundsen and Makarov basins (Steele and Boyd, 1998; Boyd et al., 2002). These studies made use of the submarine's capability to make synoptic basin-spanning observations of the upper ocean temperature and salinity fields. The submarines were also used within the dedicated science program to conduct focused studies in specific regions and on specific processes, such as the Canada Basin eddy study of Muench et al. (2000). These experiments demonstrated the value of externally mounted chemical sensors in conditions where temperature and salinity alone are not sufficient to distinguish water mass origins (Guay et al., 1999). XCTD observations contributed to studies that focused primarily on upper ocean water analysis (e.g., Smith et al., 1999). Accuracy of the XCTD salinities were considered insufficient, however, to contribute significantly to the understanding of deep variability, such as revealed in Smethie et al.'s (2000) study of ventilation of Canada Basin intermediate waters.

Whereas several early analyses by SCICEX-funded investigators focused on upper ocean changes through comparison of the SCICEX data with climatic data, more recent analyses (often conducted by the broader oceanographic community) have treated the SCICEX archive as one of several contemporary data sources. These subsequent studies, which have focused on several different aspects of upper ocean circulation and water mass distribution in various parts of the Arctic Ocean, illustrate the value of the SCICEX data to the oceanographic community. For example, Kikuchi et al. (2004) combined SCICEX data with icebreaker and drifter data to examine the distribution of convectively formed lower halocline water in the Amundsen and Nansen basins. Kikuchi et al. (2005) also used data from this suite of platforms to demonstrate the cyclonic circulation of AW on the Makarov Basin side of the Lomonosov Ridge and the increased time lag of AW warming there relative to the circulation of AW on the European side of the ridge. Shimada et al. (2004) used SCICEX, icebreaker, and drifter data from the Canada Basin to describe the movement of the 1990s AW warm temperature anomaly along the base of the Mendeleyev Ridge and Chukchi Plateau and into the Beaufort Sea. Woodgate et al. (2007) analyzed the structure of intrusions in the core of the Atlantic layer to extract details on the flow of Atlantic Water over the base of the Mendeleyev Ridge and Chukchi Plateau, but found that salinity spiking in the XCTD data marginalized the SCICEX contribution to the analysis. Steele et al. (2004) used SCICEX and other data to investigate the 1990s distribution of water masses of Pacific origin in the central basin and its relationship to atmospheric forcing and ice motion. Shimada et al. (2006) used SCICEX and other data from the 1990s to consider the positive feedback of Pacific Water temperature on sea ice concentration in the Beaufort Sea through increased coupling of wind forcing to the ocean.

As the SCICEX data archive has grown, it has played a greater role in climate and modeling studies. For example, the cross-basin synoptic XCTD sampling of the dedicated-science cruises provided much of the 1990s data used in Polyakov et al.'s (2004) analysis of multidecadal variability of AW core temperature. Recently, the SCICEX XCTD data have been used as a point of comparison for numerical modeling studies to validate model results of temperature and salinity distributions (e.g., Karcher et al., 2003), and to evaluate the dynamical implications of mixing parameterization in Arctic regional models (Zhang and Steele, 2007).

Sampling Recommendations

The hydrographic sampling program recommended here is intended to enhance and broaden the data archive that has made possible studies such as those briefly described above. In particular, the sampling should contribute observations that allow monitoring and detection of:

- Movement of the upper ocean water mass boundaries, and variability of the water mass characteristics
- Variability of the temperature and pathways of upper ocean currents
- Variability of upper ocean freshwater content (salinity deficit) and static stability

These general objectives will be addressed in the SAMs by obtaining vertical profiles and continuous horizontal time series of temperature, salinity, and, as possible, other variables of interest. The following list of specific sampling objectives is in order of decreasing priority.

1. The existing time series of across-basin SCICEX transects have contributed to understanding AW temperature and salinity distribution variability along the peripheral and along-ridge pathways of the central basin, and the static stability variability of the Amundsen and Makarov basins' upper layers. Continuation of this time series is the highest sampling priority, and can best be accomplished by repeating the canonical across-basin transects of the late 1990s/early 2000s (sampling corridor 1 in Figure 4; cruise tracks a and b in Figure 5).
2. Temperature and salinity variability along transport pathways from the Russian margins to the central basins can be sampled on cruise tracks that cross the Lomonosov Ridge (sampling corridor 2; cruise track c) and the Mendeleyev Ridge (sampling corridors 2 and 5; cruise tracks c and d). These cruise tracks will contribute data that are less directly comparable to the previous SCICEX data, but that are from a region of the Arctic that historically has been difficult to access, and remains difficult to sample even with icebreaker-deployed, ice-based, autonomous sampling systems.
3. Freshwater and heat content variability in the upper layers of the Beaufort Gyre can be sampled along cruise tracks that pass through the Canada Basin (sampling corridors 1, 3, and 5; cruise tracks a, b, d, and e). Model results (W. Maslowski, Naval Postgraduate School, *pers. comm*., 2010) suggest that the Chukchi Plateau (aka Chukchi Borderlands) is presently the region of strongest influence of warm summer Pacific Water on sea ice. This region will be sampled along cruise tracks at the Alaskan end of corridors 1 and 2.
4. Variability in the location and movement of the Atlantic/Pacific front separating Atlantic and Pacific water mass assemblies can be sampled along cruise tracks that pass through the Makarov Basin (sampling corridors 2 and 5; cruise tracks c and d).
5. Variability in the pathway followed by Pacific Water in flowing from the Arctic Ocean to the North Atlantic can be sampled along tracks that pass through the western Amundsen Basin (sampling corridor 3; cruise tracks d and e).
6. The rates and impact of mixing of AW into ambient waters of the Canada Basin can be addressed through sampling along cruise tracks that cut across the AW pathway near the base of the Mendeleyev Ridge, the Chukchi Plateau, and the Chukchi Sea edge of the Data Release Area (sampling corridors 2 and 5; cruise tracks b, c, and d).

The hydrographic sampling priorities shown in the Planning Matrix (Appendix A) indicate regions along the cruise tracks where XCTD deployments should be concentrated, the numbers of additional probes that could be used for the increments of sampling time shown, and the desired horizontal resolution of vertical profiles along each transect. It is noted that many of the objectives identified above will be served by sampling along the direct Atlantic-Pacific transit, and some will be served by sampling along the direct ice camp transit. Although sampling along the direct transits will not meet the objectives as well as the tailored sampling corridors and cruise tracks, we expect that the direct transit opportunities may be more frequent and thus may represent the best opportunities to increase the archival database.

Methods and Implementation

The hydrographic sampling program will take advantage of the submarine's capability to make two types of measurements: (1) vertical profiles of conductivity, temperature, and depth, and (2) along-track time series

of conductivity, temperature, and depth, and, as possible, other relevant chemical variables at the submarine's operating depth.

Vertical profiles will be obtained using the most current, vetted version of under-ice submarine-launched XCTD probes. The XCTDs are launched from the operating depth of the submarine, rise toward the surface, and then invert and profile downward, currently to a maximum depth of 1000 m. Each XCTD deployment requires about 45 minutes for the submarine to complete. To date, the dedicated-science missions and SAMS have largely made use of an analog probe that is no longer available. In the near future, SAM cruises will make use of TSK/Sippican digital XCTD probes that are identical to the XCTD probes presently available for use from surface vessels, but which are packaged for use by submarines and employ launch and data acquisition systems that are unique to submarines.

Sippican specifies the accuracy (and resolution) of the XCTD as ± 0.02 (0.01) ºC for temperature, ± 0.03 (0.017) mS/cm for conductivity, and ± 2% or 20 m (0.17 cm) for depth, where depth is not directly measured but is inferred from the elapsed time and a known rate of descent. Testing of the TSK/Sippican XCTDs was conducted by ASL and Navy personnel during the ICEX-09 submarine exercises in the southern Beaufort Sea during March 2009. Testing consisted of comparing CTD casts conducted at the ICEX-09 ice camp to XCTDs launched nearby from USS *Helena* (SSN 725). Preliminary analysis of the test results show that the probes suffered a higher failure rate than experienced with analog probes of the dedicated-science program of the 1990s, which had typical success rates of >90%. Twelve of the 16 probes (75%) tested during ICEX-09 returned profile data, all of which provided accurate values of temperature and salinity from the base of the mixed layer to the maximum depth sampled. None of the probes sampled to a depth greater than 600 m (design maximum depth is 1000 m), and the maximum depth for seven of the probes was less than 400 m. Notably, the raw profile data from these probes did not exhibit salinity spiking, such as was typical of the earlier analog probe data (Woodgate et al., 2007). In summary, the ICEX-09 XCTD test revealed that: (1) TSK/Sippican XCTD probes yield data of quality that will be useful to the SCICEX program, but (2) the failure rate is high, and (3) the failure to achieve data to the design depth is an unresolved issue. The SCICEX SAC is planning additional testing to resolve the issues of reliability and maximum sampling depth prior to routine XCTD use on SAM cruises.

Although the accuracy of the digital XCTDs is better than that of the analog probes of the 1990s (Gunn and Muench, 2001), the salinity accuracy (approximately 0.04 psu; Mizuno and Watanbe, 1998) is still significantly worse than industry-standard CTDs and is not considered sufficient to resolve much of the anticipated salinity variability below the halocline. The XCTD probe accuracy should be sufficient to resolve the water mass differences and much of the variability at shallower depths, as well as temperature changes throughout much of the upper ocean. The most significant improvement resulting from the introduction of the digital XCTDs is the reduction of salinity spiking due to the improved matching of the response times of temperature and conductivity sensors. This improvement should, for example, increase the suitability of the SCICEX data for analyses conducted in the AW intrusions (e.g., Woodgate et al., 2007). Because of thermal mass issues directly following launch from the submarine, the XCTDs do not typically obtain valid data shallower than 15–20 m and, therefore, may not be suitable for determining freshwater and heat balance in the uppermost mixed layer.

Time series at the depth of the submarine will be obtained using a pumped CTD that will be mounted in a free-flood space in the submarine sail, typically about 15 m (50 ft) above the keel depth, and plumbed to the exterior of the submarine. At present, Sea-Bird Electronics model SBE-19 and SBE-49 CTDs are the only units that have been approved for use on the submarine classes that will be used for SAMs. The manufacturer's specified accuracies (and resolutions)

for the SBE-19 are ± 5 x 10^{-3} (1 x 10^{-4}) °C for temperature and ± 7 x 10^{-3} (0.7 x 10^{-3}) psu for salinity. Values for the SBE-49 are ± 2 x 10^{-3} (1 x 10^{-4}) °C and ± 4 x 10^{-3} (0.7 x 10^{-3}) psu, respectively. The model SBE-19 CTD can provide power to and accept signals from external sensors (the current model, SBE-19plus V2, has six A/D and one RS-232 input channels), whereas the SBE-49 CTD does not accept any auxiliary signals. Thus, opportunities for addition of other sensors (e.g., dissolved oxygen, fluorescence) for continuous measurement will more easily arise on SAM cruises in which model SBE-19 CTDs are used. At present, ASL plans to use SBE-19 CTDs during SAMs whenever possible. The addition of auxiliary sensors may require a hardware approval (TEMPALT) from the Navy. A separate TEMPALT would be required for each class of submarine on which the hardware will be used. This process is costly and time-consuming. Members of the science community interested in the inclusion of additional underway sampling sensors or systems, whether commercial-off-the-shelf or custom designed, should consult the ASL Technical Director for advice and recommendations prior to submitting proposals that include such sampling.

The SCICEX underway CTD data have been used successfully to identify water mass boundaries (Morison et al., 1998, Muench et al., 2000) when the submarine was traveling with the CTD at depths ranging from 104 m to 218 m. When crossing the ridges and slopes along which the peripheral currents flow, it is considered preferable for the submarine to operate close to the maximum operating keel depth of 244 m (800 ft) to be as close as possible to the depth of the AW's warm core and to avoid, insofar as possible, the strong vertical salinity gradients associated with the halocline. The underway CTD typically has been mounted in the top forward part of the sail, and plumbed to the outside with as short a hose as feasible to minimize the flushing time. Correlation with vertical profile data led Morison et al. (1998) to conclude that the externally pumped, sail-mounted underway CTD drew water from about 20 m beneath the CTD depth due to flow distortion around the submarine.

Auxiliary data were recorded by the underway CTD system during some of the dedicated science cruises of the 1990s, conducted aboard the now-retired Sturgeon (637) Class submarines. As an example of the utility of these measurements, Muench et al. (2000) used dissolved oxygen data, along with temperature and salinity, to distinguish between eddy and ambient water in the interior of the Canada Basin. It is well known that temperature and salinity alone do not provide sufficient information to distinguish between water masses in the upper Arctic Ocean (McLaughlin et al., 1996; Macdonald et al., 1996; Swift et al., 1997; Wheeler et al., 1997). Consequently, sensors that can provide reliable data on concentrations of O_2, dissolved organic carbon (DOC), NO_3, and other nutrients should be incorporated into the time-series measurement program as they become available (see Table 2). As mentioned earlier, the Navy will require a TEMPALT prior to introduction of any new sampling sensor or system for each class of submarine on which it will be used. Interested parties should contact the ASL Technical Director for advice and recommendations regarding the process of adding sensors.

OCEAN: CHEMISTRY

Background

Chemical measurements have been used extensively to investigate physical and biological processes in the Arctic Ocean. Numerous measurements were made on the SCICEX cruises of the 1990s, during which circulation patterns and time scales were investigated using the transient tracers tritium, ^{3}He, chlorofluorocarbons (CFCs), and ^{129}I. Smethie et al. (2000) showed from tritium, ^{3}He, and CFC measurements made on the 1996 SCICEX cruise that the central Canada Basin is ventilated with Atlantic Water on a time scale of one to two decades and that the oldest intermediate water in the Canada Basin was located in the northern end of the basin. There are two layers of Atlantic Water: the Fram Strait Branch, which is responsible for the temperature

maximum beneath the halocline found throughout the Arctic Ocean, and the Barents Sea Branch, which is denser and underlies the Fram Strait Branch. Smethie et al. (2000) also showed that the Fram Strait Branch was diluted by a factor of five due to exchange with shelf water along its flow path, but that the deeper Barents Sea Branch (core depth about 800 m) was diluted by only a factor of about two. Using ^{129}I data collected from the 1995 and 1996 SCICEX cruises, Smith et al. (1999) showed that the intermediate water (Barents Sea Branch) in the central Canada Basin was recently ventilated and that the ventilation time for the northern Canada Basin was in agreement with Smethie et al.'s (2000) results. They estimated the transit time for upper Atlantic Water (Fram Strait Branch) from the Norwegian Current was about seven years and slightly less for the overlying halocline water.

Exchange between the continental shelf and interior of the Arctic Ocean has been investigated from naturally occurring chemical substances measured on the SCICEX cruises. Guay et al. (1999) used salinity, chlorophyll *a*, barium, total organic carbon (TOC), and DOC to identify locations where river water crosses the continental shelf break between the Alaskan coast and the Laptev Sea to enter the interior of the Arctic Ocean. River water was identified as local minima in salinity and maxima in barium, TOC, and DOC. Kadko and Aagaard (2009) used the ^{228}Ra:^{226}Ra ratio to identify shelf water in the interior of the Arctic Ocean from measurements on the 2000 SCICEX cruise. Water in contact with the extensive shelf sediments acquires a radium signal with a high ^{228}Ra:^{226}Ra ratio. At 132-m depth, the ^{228}Ra:^{226}Ra ratio varied by a factor of about seven along a line extending through the center of the Canada Basin from Alaska to the Gakkel Ridge. The ratio was lowest between Gakkel Ridge and Lomonosov Ridge, indicating relatively little shelf water. The ratio varied by a factor of three in the Canada Basin, suggesting that the inflow of shelf water to the interior was episodic in space and time.

One mechanism for shelf basin exchange is eddies. As mentioned in the section on ocean hydrography, on the 1997 SCICEX cruise, Muench et al. (2000) observed such an eddy and mapped its temperature, salinity, and velocity fields. They also measured a suite of tracers inside and outside the eddy. It was determined from ^{18}O and tritium that the origin of the eddy was the Alaska Chukchi coast and that it was less than two years old.

More recently, SCICEX data have been combined with data from other icebreaker-based cruises. For instance, Tanhua et al. (2009) combined SCICEX CFC data with CFC data collected from icebreaker cruises between 1983 and 2005 to calculate the transit-time distribution for water to flow from its sources to the Arctic Ocean interior. From this, they calculated the anthropogenic CO_2 inventory. The amount is 2.5–3.3 Pg-C, which is about 2% of the total in the world ocean. Relative to its volume, the Arctic Ocean takes up two times more than the average of the global ocean.

The Arctic Ocean is sensitive to the global rise in temperature and atmospheric carbon dioxide. One response has been a steady decrease in sea ice extent during summer. As the amount of open water increases, there is expected to be biogeochemical consequences, which could be documented along the SAM submarine tracks. Also, as a result of the enhanced CO_2 uptake and the relatively low buffer capacity afforded by river and ice-melt-freshened Arctic Ocean surface waters, the Arctic is particularly vulnerable to ocean acidification. Models suggest that uptake of anthropogenic CO_2 by Arctic Ocean surface waters will drive the largest and fastest pH decreases in all the world's oceans (Steinacher et al., 2008). This pH decrease has already and will continue to increase sound transmission in the circa 10 kHz frequency range (Hester et al., 2008). The implications of decreasing pH for organisms, particularly those that form calcium carbonate shells, are likely to be important and are only beginning to be understood (Doney 2006; Doney et al., 2009; Orr et al., 2005, 2009). With appropriate instrumentation, SCICEX SAMs can

make a very important contribution to this issue by providing much-needed baseline data for relevant in situ sensed variables such as alkalinity, pH, and pCO_2.

Global warming will also cause other changes in Arctic Ocean biogeochemistry that can be documented by submarine-based observations. For example, warming is thought to be causing an increase in methane release from shelf sediments, which could be detected from collection of water samples for shore-based methane measurements along SAM submarine tracks.

Sampling Recommendations

The chemistry program's objectives, in priority order, are:

Table 2. Recommended water properties to measure on SCICEX Science Accommodation Mission cruises. Samples **highlighted in blue** can be made using current equipment and protocols. Others will require additional equipment or protocols, facilitated through independent proposals and coordination with the U.S. Navy Arctic Submarine Laboratory.

SAMPLE	PURPOSE	SIZE	COLLECTION PROCEDURE	ON BOARD PROCESSING	STORAGE REQUIREMENTS
UNDERWAY CONTINUOUS SAMPLING VIA SENSORS					
Temperature	Core water property	N/A	Hull-mounted CTD	None	N/A
Salinity	Core water property	N/A	Hull-mounted CTD	None	N/A
Oxygen	Water mass tracer; biological production and recycling	N/A	Hull-mounted CTD	None	N/A
Nitrate	Water mass tracer; biological production and recycling	N/A	Hull-mounted CTD	None	N/A
DOC	Water mass tracer	N/A	Hull-mounted CTD	None	N/A
Alkalinity, pH, pCO_2	CO_2 uptake, ocean acidification	N/A	Pumped stream from hull-mounted CTD	None	N/A
Chl *a*, variable fluorescence	Phytoplankton abundance, photosynthetic capacity	N/A	Pumped stream from hull-mounted CTD	None	N/A
Spectral radiometry, light scattering, and absorption	Chemical and biological properties (CDOM; overlying phytoplankton levels, particulate characterization)	N/A	Upward-looking sensors; pumped stream from hull-mounted CTD	None	N/A
DISCRETE WATER SAMPLES					
Salinity	Core water property; calibrate salinty sensor on CTD	200 ml	Rinse, fill, and cap a 200 ml glass bottle	Can be stored for shore-based measurement or measured on board with an Autosal	Room temperature
Oxygen	Water mass tracer; Biological production and recycling; calibrate O_2 sensor on CTD	120 ml	Rinse and fill 120 ml flask	Add reagents, follow Winkler titration procedures	Room temperature covered with water for up to one day prior to titration
Chl *a*, HPLC pigments	Phytoplankton levels and community composition; calibrate Chl *a* fluorometer on CTD	500 ml (Chl *a* only) or 1–3 L for HPLC	Chl *a*—filter and place filter into 10 ml 90% acetone; HPLC samples—freeze filter	Chll *a* can be measured in an on-board fluorometer or stored for shore based measurement like HPLC	–20°C, must not thaw (–80° if possible for HPLC)

Continued on next page...

1. Monitor the spatial and temporal (including seasonal) variability and longer-term trends of freshwater distribution and composition in the mixed layer and in the halocline.
2. Monitor the spatial and temporal (including seasonal) variability and longer-term trends of CO_2, alkalinity, and pH in the mixed layer and in the halocline and compare these observations to variability and trends in plankton community structure.
3. Monitor the spatial and temporal variability and longer-term trends in the composition of the halocline and upper Atlantic layer.
4. Delineate circulation pathways for Atlantic and Pacific waters within the halocline and upper Atlantic layer, and estimate flow rates within the main upper ocean currents and transit times from source water regions to the interior.

Table 2. Continued.

SAMPLE	PURPOSE	SIZE	COLLECTION PROCEDURE	ON BOARD PROCESSING	STORAGE REQUIREMENTS
DISCRETE WATER SAMPLES, CONTINUED					
Flow cytometry	Microbial abundance	10 ml	Rinse and fill 15 ml tube	Add formalin and freeze	−20°C, must not thaw (−80° if possible)
Nutrients (PO_4, NO_3, SiO_2)	Water mass tracers; biological production and recycling	50 ml	Rinse, partially fill, and cap a 50 ml plastic tube; keep upright and ensure cap is tight	Quick freeze as soon as possible at −20°C	−20°C, must not thaw
^{18}O	Determine freshwater sources	100 ml	Rinse, fill, and cap 100 ml glass bottles	None	Room temperature
Alkalinity	CO_2 uptake, ocean acidification	250 ml	Rinse and fill 250 ml glass bottle with screw cap leaving a 2 ml headspace	None	Keep in dark at room temperature
SF_6, CFCs	Age information; calculation of anthropogenic CO_2; water mass tracer	1–2 L	Rinse and fill a 250–500 ml glass stoppered bottle, insert glass stopper, place the bottle in a jar and fill the jar with sample water	None	Refrigerated at a temperature of 0–2°C
Helium isotopes	Age information; water mass tracer	50 ml	Flush a 50 ml copper tube with the sample and crimp the ends of the tube with the water flowing; rinse the crimped ends with freshwater	None	Room temperature
Tritium	Age information; water mass tracer	500 ml	Fill a 500 ml bottle without rinsing and cap	None	Room temperature
^{129}I	Circulation time of Atlantic water	1 L	Rinse, fill, and cap a 1 L plastic bottle	None	Room temperature
Radium isotopes	Circulation of shelf water into the interior	130 L	Filter water through a cartiridge while the submarine is underway	Change cartiridge approx every three hours while submarine is underway	Room temperature

The freshwater volume and composition of the Arctic Ocean (mainly river runoff and sea ice melt) is expected to change as the sea ice continues to melt. To understand the causes of this change, freshwater volume and composition need to be documented as a function of time and space. This monitoring is best done by repeat measurements in specific regions. The highest priority for SCICEX SAM cruises is sampling corridor 1 and the direct Atlantic-to-Pacific transit crossing line. Corridor 1 provides a long section extending across the entire Canada Basin and across the Amundsen Basin to the Gakkel Ridge (Figure 4), crossing many of the major circulation pathways of the upper waters of the Arctic Ocean and, thus, is well situated for monitoring changes in freshwater and circulation. The Atlantic-Pacific transit crossing line is the shortest route between the Atlantic and Pacific oceans (Figure 3) and will be the most frequently occupied line; thus it provides the opportunity for the most frequent sampling. All of the sampling corridors provide valuable information on the changing Arctic Ocean and should be sampled as the opportunity arises, but they have a lower priority. The same rationale holds for objectives 3 and 4, but for objective 2, all lines are of equal priority. With respect to timing, there are very few chemical data from the winter, so any winter cruises have a relatively high priority for all measurements.

Methods and Implementation

Table 2 provides the proposed chemical measurements, purpose of the measurements, and sampling and storage requirements. Some of the recommended measurements can be made with equipment that currently exists on the submarines. For instance, water temperature and salinity can be measured with the CTD that is now available. Most of the discrete water samples can be collected and then transferred to a shore-based lab for analysis. These samples basically require filling a sample container, without addition of chemicals, and storage at room temperature, refrigerated storage, or storage at -20°C. Some of the other measurements in Table 2 require additional equipment. If the underway CTD system includes a dissolved oxygen sensor (see discussion in ocean hydrography section regarding Sea-Bird Electronics model SBE-19 and SBE-49 CTDs, which are the only units that have been approved for use on the classes of submarine that will be used for SAMS), underway water samples will need to be collected periodically for calibration purposes. An oxygen titration system is needed for on-board measurement of oxygen in underway samples. A method needs to be devised for handling waste water, particularly for microplankton samples and radium isotopes. Scientific freezers are needed to store frozen samples. As previously discussed, independent proposals will be required to address these additional needs.

The highest-priority measurements are salinity, ^{18}O, nutrients, and dissolved oxygen. ^{18}O has a much lower signal in river water than in seawater and sea ice melt, and thus allows the amount of these two freshwater sources to be estimated. Pacific Water has a different nutrient concentration than Atlantic Water. As it flows over the broad Chukchi shelf region, the nutrient and oxygen content is further modified by biological processes in the upper sediments, resulting in low oxygen concentration, high nutrient concentration, and a lower nitrate:phosphate ratio. Thus, nutrients and oxygen allow the amount of Pacific and Atlantic waters to be estimated. The water mass composition for the mixed layer and underlying halocline and intermediate water can be determined from temperature, salinity, and this suite of measurements. Of equal priority is the measurement of carbon chemistry parameters to determine if acidification is occurring and how it is affecting life in the Arctic Ocean. The transient tracers (tritium, ^{3}He, ^{129}I, SF_6, and CFCs) and radium isotopes have a slightly lower priority for measurement, but only because their sampling requires more time and storage space and may not be possible on some cruises where time is limited.

Water sampling will be accomplished through the hull of the submarine. Salinity, nutrient, carbon chemistry, and ^{18}O samples should be taken hourly on the transits to provide good horizontal resolution within the halocline and upper Atlantic Water along the transit

lines. Radium isotopes should also be taken on the transits because they provide information on basin/shelf exchange. Sampling involves continuously flowing water through a cartridge for several hours per sample while the submarine is underway. Vertical profiles of these parameters (except radium isotopes) and the transient tracers should be taken at the locations of 12 to 18 of the XCTD stations, roughly evenly spaced along the cruise track. Five depths between the surface mixed layer and the deepest operating depth of the submarine (~230 m) should be taken. Vertical sampling can be accomplished by a spiral station (i.e., a vertical excursion performed while executing a tight turn so as to minimize distance traveled) or by stair-step sampling at a speed of about 2 kts, so the vertical profile is confined to a small region. The stair-step method is preferred because a tight spiral vertical excursion of the submarine may result in significant vertical mixing of the water that will be sampled. It is very important to obtain a surface mixed layer sample at all XCTD stations to provide good spatial and temporal resolution of the distribution of freshwater components in the mixed layer.

This sampling scheme will also be useful for other chemical constituents that may be desired in the future.

OCEAN: BIOLOGY

Background

Ocean biology is concerned with the interaction of marine organisms and their environment. These interactions are the basis for evaluating the response of marine biota to environmental and climate variations and are key aspects for predicting the health of marine populations as well as potential changes in biogeochemical cycles (Anderson and Kaltin, 2001; Smetacek and Nicol, 2005; Bluhm and Gradinger, 2008). All major taxonomic groups of organisms from microbes to fish, birds, and marine mammals are represented in the Arctic Ocean. The passive acoustic capabilities of the submarine fleet have not been used to observe marine mammals and fish, and would need specific authorization. Information from SCICEX has contributed significantly to the other aspects of biological/environmental interaction in the Arctic, however, and the rapid evolution of in situ, biological sensing technologies, and molecular characterizations of collected material are well suited for more detailed observations on future SAMs. In addition, the parallel physical and chemical observations within SCICEX provide an important ecological context for the biological measurements. Several research issues, such as ice cover, Arctic Ocean circulation, river/shelf/basin exchange, and the role and extent of eddies, cut across several disciplines and help to define the processes by which Arctic biological systems respond to climate change.

Biological sampling within the SCICEX program has focused mainly on microbial life due to its poorly understood diversity and its importance to the flows of nutrients and carbon (Falkowski et al., 2008). SCICEX sampling provided one of the first characterizations of the bacterial assemblages in the Arctic Ocean based on genetic sequence analysis (Bano and Hollibaugh, 2002). The surface mixed layer and the halocline were found to harbor distinct bacterial assemblages and, despite the relatively small sampling effort (three SCICEX cruises), changes in the seasonal distribution of some bacterial groups were detected.

The SCICEX program can continue to contribute significantly to the growing information on the ocean's microbial diversity (Gross, 2007; DeLong, 2009). Current molecular approaches offer a way to analyze the detailed ecological dynamics of Arctic microbes from samples that can be collected from submarines. Properly frozen samples maintain their genomic integrity for years and can continue to be a rich source of biological information. For example, the same SCICEX samples that were analyzed for bacterial composition were used to characterize Archaea populations (Bano et al., 2004) and to compare Arctic with Antarctic nitrifying Archaea (Kalenetra et al., 2009). These analyses also suggest that there are distinct, environmentally

associated differences within bacterial and archaeal groups, and are helping to flesh out the structure of polar microbial communities. Importantly, as in other ocean regions, most of the bacterial and archaeal groups recorded were uncultured forms and many of the Arctic groups were distinct from previously recorded prokaryotes in lower latitudes. Thus, data from future SAMs can continue to contribute to the understanding of marine biodiversity.

Microbial growth in Arctic waters is closely associated with the turnover of large amounts of organic carbon that can be produced locally or can be derived from rivers (Wheeler et al., 1996). Arctic shelves are another source of organic carbon to the halocline layer of the deeper basin (Bates et al., 2005). Understanding the biogeochemical role of the Arctic in global carbon cycling, therefore, requires more information on the activities of its microbial communities that, despite the cold temperatures, can maintain rapid rates of organic matter degradation (Rich et al., 1997; Kirchman et al., 2005). Although information on microbial community composition continues to accumulate (Lovejoy et al., 2006), synoptic spatial and seasonal data are not presently available. Better seasonal data on microbial community associations could aid significantly in biogeochemical analyses of the Arctic. Measurements of microbial composition and oxygen levels in both the surface layer and the upper halocline have high biological importance. For example, the abundance of groups such as the Cytophaga-like bacteria and the Gammaproteobacteria may reflect particulate production in the overlying waters (Elifantz et al., 2007). SCICEX measurements of dissolved organic matter (DOM) demonstrate the utility of autonomous instrumentation (Guay et al., 1999). The submarine sampling depths include the upper halocline and surface waters where large stocks of DOM have been recorded (Guéguen et al., 2005).

Currently, one of the most far-reaching biological issues in the Arctic is the response of phytoplankton production to the reduced summer ice cover extent, which has decreased by ~2.5 million square kilometers in comparison to the average from the late twentieth century. The input of organic matter from ice-edge and open-water production impacts both ecological dynamics and biogeochemical fluxes of the Arctic. Although the ultimate impact of the rapid increase in open-water regions for phytoplankton growth remains unclear, the response is already significant. For instance, the longer open-water season appears to be the main factor responsible for increased phytoplankton levels adjacent to the Laptev and East Siberian shelves and the Canada Basin (Pabi et al., 2008). Current nutrient levels in the surface waters of most of the Arctic are believed to be insufficient to support greatly increased productivity. However, nutrient levels could change if mixing and circulation patterns are altered in association with changing ice conditions. These issues are closely integrated with those of the physical response of the Arctic, including potential changes in the eddy field of the Arctic Basin, which could have significant impacts on its production patterns. Another critical biological issue in the Arctic Ocean is the response of its plankton communities to acidification. Calcareous forms such as coccolithophores and pteropods are particularly susceptible to lower pH (Doney et al., 2009; Orr et al., 2005, 2009). This issue relates directly to objectives already outlined in the ocean chemistry section.

SCICEX sampling has included underway sensors for chlorophyll *a* and oxygen that provide information on phytoplankton biomass and net community production. Current optically based sensors for oxygen collect data much faster than the initial versions and are resistant to damage by ice crystals, as compared to the Clark-type membrane sensors. Such sensors are useful for measurements of photosynthetic production and respiration in the surface layer and deeper depths. A variety of in situ methods exist to measure phytoplankton biomass and production by fluorescence and other optical approaches. In situ measurements of bulk fluorescence are sensitive but fairly crude due to the impact of non-photochemical quenching. These problems are significantly less in the next-generation instruments, which correct for such effects

using parallel measurements of variable fluorescence (Chekalyuk and Hafez, 2008). Variable fluorescence also provides an index of photosynthetic capacity to enhance the information from the biomass measurement alone. These and additional in situ sensors of phytoplankton populations and growth should soon be commercially available.

Sampling Recommendations

The major objective of the recommended SCICEX biology sampling program is to document the response of Arctic biology to changes in ice cover and other climate-induced variability. To this end, we suggest the following priority order regarding sampling:

1. Document the response of Arctic Ocean productivity to reduced sea ice cover.
2. Quantify the interaction between biological processes and changes in the nutrient and carbon systems, including the impact of ocean acidification.
3. Characterize the microbial populations across the Arctic Ocean.
4. Record the time-space variation in megafauna distributions.

Methods and Implementation

The newly ice-free regions of the Arctic Ocean in summer can be sampled along several of the possible SCICEX transects, including the Canada Basin and Chukchi Plateau (aka Chukchi Borderlands; corridor 1) and the Makarov Basin (corridor 2). The orthogonal corridors 4 and 5 are of particular interest because they traverse a broad region of deep water adjacent to the East Siberian and Laptev seas, which have been the regions of some of the most dramatic increases in open water during summer. The optimal months for tracking the response of primary productivity to changing Arctic conditions are spring (May–June just before ice retreat) and summer (July–September during the expected minimum ice extent). Spring sampling provides information on the end-of-winter nutrient levels that control the subsequent amount of surface productivity, and summer data reflect the actual extent of biological production. Nutrient samples can be collected jointly with the ocean chemistry component and production can be mapped using data from in situ fluorescence sensors.

Periodic vertical sampling from the surface layer (<100 m) is a high priority. It permits the nutrient and biomass levels from the depth of transit (~125 m) to be extrapolated to surface conditions. This type of vertical sampling is similar to that outlined in the ocean chemistry section and, in most cases, the same vertical profile will serve both disciplines. Discrete biological samples are needed for phytoplankton identification and enumeration, and molecular methods. On-board filtration is needed for the molecular samples as well as for the chlorophyll *a* samples to calibrate the external fluorometer. The samples must be frozen and otherwise handled as outlined in Table 2. In the past, sampling during a vertical excursion of the submarine has proved satisfactory for this purpose and requires approximately 40 minutes. Several sampling profiles should be included in each crossing. Optimal locations are in the permanently ice covered and seasonally ice-free regions of corridors 1, 3, 4, and 5. Excursions around solar noon would be most useful for assessing the submarine light field.

Information on the distribution of bacteria, Archaea, and the nutrient, oxygen, and carbon systems is a high priority during all seasons. Net production can be estimated from the seasonal changes in upper-halocline oxygen and nutrient levels. Nutrient data from the winter in all areas of the Arctic Ocean are needed. Nitrate sensors that could aid in this goal are now commercially available and have been field-tested. Mapping the seasonal impact of high-Arctic productivity on the nutrient fields would be most valuable in the northern Canada Basin and areas adjacent to the Laptev and East Siberian shelf regions. This sampling also addresses the goal of bacterial and archaeal community structure and distributions.

A variety of additional biological measurements while in transit are possible using current sensors or experimental methods with varying amounts of technical and methodological development. The planned use of the SBE-19 package as described in the ocean hydrography section is recommended because this instrument is able to accommodate a variety of additional bio-chemical sensors. Deploying fluorescence and oxygen sensors is a high priority. More-advanced sensors capable of recording variable fluorescence, phytoplankton community composition, and DOM are also recommended. Other useful biological information can be collected on any of the SAM transits with little or no modification to transit depth or other operations. For example, during daylight hours, the submarine remote video system (SRVS) can be used to record the distribution and abundance of large invertebrates, fish, and cetaceans. The population of large medusae dramatically increased in the Chukchi and Beaufort seas in the 1990s (Brodeur et al., 1999) and were clearly visible from the SRVS during the SCICEX cruises of the 1990s.

Direct measurements of phytoplankton biomass and productivity, bacterial levels, oxygen, and nutrients in the water just below the ice will require a dedicated effort because these depths are not accessible by the submarine. These depths are some of the most productive, however, and have been well characterized on shelves (Cota et al., 1996; Bates et al., 2005). Such measurements may be best coordinated with ICEX experiments.

BATHYMETRY

Background

Despite the existence of detailed bathymetric maps of the northern polar region, such as the International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2008), much of the Arctic Basin has never been mapped using modern sounding techniques. This lack of data limits geological and geophysical investigations of the Arctic Basin and, because topography influences Arctic Ocean circulation, it also impacts oceanographic research. U.S. Navy nuclear-powered submarines played a critical role in acquiring bathymetric data for the Arctic. In particular, the SCICEX dedicated-science missions systematically mapped portions of several of the major topographic provinces (Gakkel Ridge, Lomonosov Ridge, and Chukchi Borderland) that have been inaccessible to icebreakers because of perennial sea-ice cover (see Edwards and Coakley, 2003, and references therein). SCICEX bathymetry and backscatter data collected in 1998 and 1999 contributed to two important paradigm shifts in understanding the Arctic Basin. First, that thick ice, either in the form of ice shelves (Polyak et al., 2001) or deep draft icebergs (Kristoffersen et al., 2004) had extended into the interior of the Arctic Basin during the Pleistocene, eroding shallow regions of the Alaska Margin, Chukchi Borderland, and Lomonosov Ridge. Second, Gakkel Ridge is volcanically active and may have erupted as recently as 1999, despite being the slowest-spreading mid-ocean ridge on Earth (Edwards et al., 2001; Müller and Jokat, 2001; Tolstoy et al., 2001).

Bathymetry and backscatter data acquired by USS *Hawkbill* during the 1998 and 1999 SCICEX missions provided a base map for the 2001 Arctic Mid-Ocean Ridge Expedition (AMORE; Michael et al., 2003; Schlindwein et al., 2005) and the 2007 Arctic Gakkel Vents (AGAVE) expedition (Sohn et al., 2008). The latter programs confirmed the existence of volcanism and hydrothermal venting (Edmonds et al., 2003; Baker et al., 2004; Sohn et al., 2008) on Gakkel Ridge and led to distinctly novel models describing ultra-slow seafloor spreading (Dick et al., 2003; Snow and Edmonds, 2007). In an interesting twist, the AMORE data for the axis of Gakkel Ridge also provided a base map for the SCICEX data; because GPS navigation was used while collecting AMORE data, they provided an important resource for re-navigating SCICEX data to minimize positional errors associated with USS *Hawkbill's* inertial navigation system. Although both AMORE and AGAVE increased the total area

of Gakkel Ridge that has been mapped, SCICEX data still provide the most comprehensive coverage of this spreading center.

SCICEX data for Lomonosov Ridge informed the Integrated Ocean Drilling Program's 2004 Arctic Coring Expedition (ACEX), which successfully collected a 400-m-long composite core containing sediments that span the Cenozoic era (0–65 Ma). Among ACEX's reported findings are warm (~24°C) surface waters in the Arctic during the Paleocene/Eocene Thermal Maximum (PETM), fresh surface water above Lomonosov Ridge ~49 Ma, the first occurrence of ice-rafted debris in the core ~45 Ma, and the suggestion that the Arctic Ocean's perennial ice cover has existed for at least 14 million years (Backman et al., 2006; Moran et al., 2006). A year after ACEX, the Healy-Oden Trans-Arctic Expedition (HOTRAX) became only the second scientific investigation to cross the Arctic Basin using surface vessels. HOTRAX researchers collected cores and multichannel seismic data, primarily along Chukchi Borderland, Mendeleev Ridge, and Lomonosov Ridge, to produce a modern, basin-wide paleoclimate record (Darby et al., 2009) as well as stratigraphic sections (Polyak et al., 2009).

Sampling Recommendations

Bathymetric mapping during a SCICEX SAM will be limited to data that will be collected while underway. Thus, the priority for this element of the program is to investigate regions in the Arctic Basin that remain poorly surveyed and difficult to access via surface vessels. The primary focus is Alpha Ridge, a broad topographic high located in the Canada Basin that extends from the Canadian continental margin to the Mendeleev Ridge (Figure 1), but bathymetry data for any terrain that has not been mapped previously will contribute to the expanding Arctic Basin geophysical database. Alpha Ridge is identified as a priority because it has the least coverage of any Arctic Basin ridge and because its origin remains controversial—at various points its formation and evolution have been ascribed to processes including continental fragmentation (Sweeney et al., 1982), mid-ocean ridge volcanism (Vogt and Ostenso, 1970), hotspot volcanism (Vogt et al., 1982), and island arc volcanism (Herron et al., 1974). Currently, the prevailing opinion is that Alpha Ridge had an oceanic origin (Jackson et al., 1986; Weber and Sweeney, 1990), but that it may have been modified by a large impact event (Kristoffersen et al., 2009). Resolving the processes that formed Alpha Ridge is not merely an academic question; claims that the Alpha and Mendeleev ridges may be geologically linked have political and economic relevance, especially with sea ice cover diminishing, and increasing demand for oil, gas, and minerals, which exist in the Arctic.

The nature of future SCICEX SAMs does not allow for the systemic "lawn-mowing" types of seafloor surveys that were accomplished during the dedicated science SCICEX missions. Most SAMs will collect a single profile of bathymetric soundings along a transit from one side of the Arctic Ocean to the other, or to an ice camp and back again. Therefore, the recommended strategy is to establish a survey plan that crosses major topographic features, including Alpha, Mendeleev, Lomonosov, and Gakkel ridges in non-overlapping corridors, with emphasis on areas that have not been mapped previously. Bathymetric soundings will be collected continuously along these tracklines using the submarine's own single-beam echosounder except in cases when collection of these data would interfere with other science measurements. All three of the long, Atlantic-to-Pacific corridors (1, 2, and 3 in Figure 4) cross Gakkel and Lomonosov ridges as well as either Alpha or Mendeleev Ridge. Corridors 1 and 3 in particular cross portions of topographic ridges in the Arctic Basin that have very few soundings associated with them. Corridor 4 extends from the easternmost part of Gakkel Ridge across the portion of Lomonosov Ridge attached to Greenland; neither was mapped during previous SCICEX missions nor the icebreaker expeditions that followed. Corridor 5 runs almost perpendicular to Mendeleev Ridge and data collected along this path will extend existing coverage in the third dimension.

Methods and Implementation

SCICEX SAMs will benefit from the best available navigation data that the Navy can provide to the science community. At present, it is anticipated that a ring-laser gyro navigation (RLGN) system will provide inertial navigation for each bathymetry track. Typically, the submarine's RLGN is synched to locations provided by GPS satellites when the submarine surfaces. Experience with previous SCICEX data sets, which included navigation acquired by the submarine's inertial navigation system, has shown that the locations provided by inertial systems while underway can drift with time. Thus, it seems prudent, given constraints of systems and available time, for the science community to assume that the submarines will not be able to cross any of the major topographic features at a specific location and instead plan for more general sites within a given survey track. Whenever possible, the expectation is that, in addition to bathymetric soundings and submarine location, platform attitude and relevant metadata will be released upon completion of the SAMs.

Summary

The primary objective of the SCICEX Science Plan, Part 1, is to provide the Navy's Arctic Submarine Laboratory with guidance in planning SCICEX Science Accommodation Missions. In contrast to the SCICEX cruises that were dedicated to the collection of scientific data, the objective of a SAM is to collect unclassified data during an otherwise classified submarine exercise. By its nature, the time available to plan for a SAM is severely limited. Further, the scientific sampling requested during a SAM must dovetail with the planned mission objectives, including location, time of year, and submarine class selected for the mission.

The sampling recommendations provided in this element of the SCICEX Science Plan are intended to maximize the opportunities to collect scientific data, taking advantage of the unique capabilities of the submarine platform. This objective is achieved by laying out a wide range of options. The common foundation for these options is a set of recommended sampling corridors. Within these sampling corridors, priorities are set for ice; ocean hydrography, chemistry, and biology; and bathymetry measurements. The individual topical priorities are based on the current state of knowledge, derived from observations and models. Each topical area assumes that all of the time available during the SAM will be used to make measurements of interest to that area. No effort has been made to resolve apparently conflicting recommendations. Rather, it will be the critical responsibility of ASL to consider the full range of recommendations in negotiating a SAM with the operational Navy. ASL, with intimate knowledge of the planned mission, will develop a specific SAM, taking into account and balancing the various priorities, the constraints of the submarine selected for the planned mission, the past sampling history, time of the cruise, and other parameters. ASL will also consider complementary sampling activities taking place during the ice camps established to support ICEX and as part of the Arctic Observing Network, to maximize the SCICEX contribution to this integrated network.

In spite of the independent development of the priorities, there are some common and distinct points:

a. The routine collection of SCICEX data during direct submarine transits between the Atlantic and Pacific oceans and in support of ice camp exercises is strongly encouraged, as past and recent experience has shown the value of virtually all of the historic submarine-based data.
b. Sampling corridor 1, which runs roughly parallel to 150°W and includes both the Recent SCICEX and North Pole tracks, is a high priority on a once-per-year basis for all topical areas.
c. Sampling corridors 2, 4, and 5 are most effectively reached during a SAM designed in conjunction with a direct crossing between the Atlantic and Pacific oceans.
d. Sampling corridor 3 is most effectively reached during a SAM designed in conjunction with an ICEX.

Details regarding the management, quality control, and availability of data collected via a SCICEX SAM remain to be worked out by the SCICEX SAC. This guidance will be provided in a separate, companion document. The expectation is that all data collected during a SCICEX SAM will be accessible via the National Snow and Ice Data Center, in accordance with the SCICEX Phase II MOA.

A key element in the success of the SCICEX SAMs will be their periodic review by the SCICEX Science Advisory Committee, specifically, reviewing the utility of the Planning Matrix (Appendix A) that forms the centerpiece of the science plan. It is expected that modifications will be made to the SCICEX Science Plan as a result of these reviews, taking into consideration new sampling technologies and insights of the dynamic Arctic Ocean.

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APPENDIX A

Planning Matrix

General Remarks

- For safe operation, submarines will travel more slowly at shallower depths; typical past SCICEX operating speeds have been around 14 kts at keel depth of 134 m (440 ft) and 16 kts at keel depth of 229 m (750 ft)

Terminology

- Ice draft sampling: Spacing between segments is the distance from the end of one segment to the beginning of the next
- Ocean chemistry sampling: Transient tracers include tritium, ^{3}He, SF_6, ^{129}I, and CFCs; the vertical suite includes salinity, nutrients (frozen), oxygen, ^{18}O, and transient tracers

Sampling Requests

ICE DRAFT
- Prefer sampling in April–May and September–November

OCEAN HYDROGRAPHY
- Prefer sampling in spring or ice minimum thru freeze
- Samples collected as deep as possible (keel depth near 244 m [800 ft]), particularly when passing over (within ±100 km) ridges, to sample variability of along-ridge AW flows
- When possible, loiter at ice edge to collect a dense sampling array of water conditions

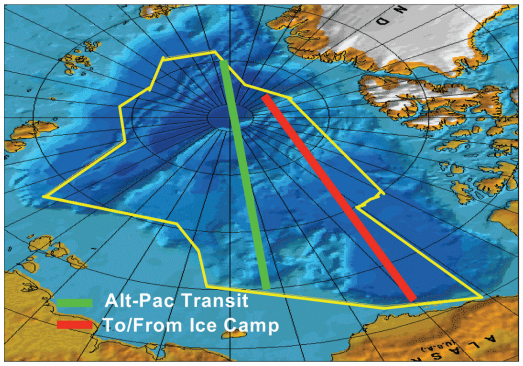
OCEAN CHEMISTRY AND BIOLOGY
- Prefer transit depth of 61 m (200 ft), near the top of the halocline

OCEAN CHEMISTRY
- Prefer sampling in spring–September with highest priority in September

OCEAN BIOLOGY
- Prefer sampling in spring–September with high priority at ice minimum in September

Table A-1. Atlantic-Pacific Transit: Direct Crossing

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
	0	0	0	In general: If no time available to deviate to higher priority track, request collection of SCICEX data along direct transit			All: 1 per year	
	0	0.5	0.5					
	0	1	1					
	0	1.5	1.5					

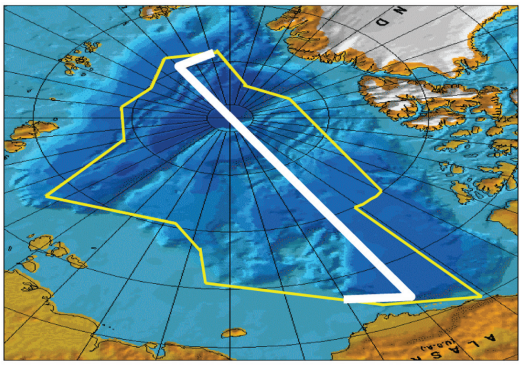


Direct Crossings

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Continuous	Continuous at transit speed	General approach: Focus XCTDs from Amundsen Basin to Mendeleyev Ridge (85°N 5°E to 83°N 173°W is approx 1300 km)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs
		10 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side, 2 Pacific side of NP, 6 Pacific side @ 200-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km = 9.7 deg of lat	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations
		20 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, 2 Pacific side of NP, 16 Pacific side @ 50-km spacing, Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km = 12.9 deg of lat		
		30 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side of NP, Remainder continuous Pacific side	54 extra XCTDs @ 40-km spacing = 2160 km = 19.5 deg of lat (transit is approx 2200 km in length)		

Table A-2. Atlantic-Pacific Transit: North Pole Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
1	2	0	2	Ice: 1 Hydro: 1 Chem: 1 Bio: 2			All: 1 per year for either North Pole Track or Recent SCICEX Track	
	2	0.5	2.5					
	2	1	3					
	2	1.5	3.5					
	2	2	4					

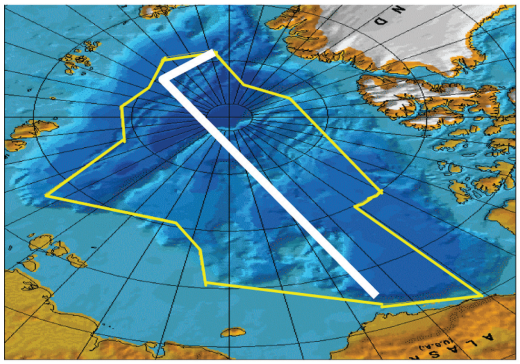


North Pole Track (corridor 1)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Deploy XCTDs with finer resolution over Lomonosov R, coarser resolution over Amundsen B and Canadian B (track from 85°N 30°E to 73°N 150°W is approx 2500 km)	Up to full samples ICW XCTDs ^{18}O and nutrients (frozen) hourly Transient tracers every 2 hrs	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs
		10 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, 2 Pacific side NP, 6 Pacific side @ 260-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km = 9.7 deg of lat	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Aug–Sep
		20 50-km segments @ 14 kt, 400 ft depth: 2 Atlantic side NP, 2 Pacific side of NP, 16 Pacific side @ 70-km spacing, Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km = 12.9 deg of lat		
		30 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side of NP, 2 Pacific side of NP, 26 Pacific side @ 25-km spacing, Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km = 19.5 deg of lat		
		40 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, Continuous Pacific side	72 extra XCTDs @ 40-km spacing = 2880 km = 25.9 deg of lat		

Table A-3. Atlantic-Pacific Transit: Recent SCICEX Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
1	3	0	3	All: 1		Preference to repeat 1998–2003 transects, if time allows	All: 1 per year for either North Pole Track or recent SCICEX Track	
	3	0.5	3.5					
	3	1	4					

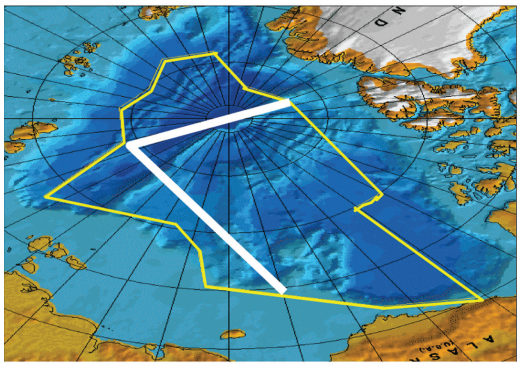


Recent SCICEX Track (corridor 1)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Deploy XCTDs with finer resolution over Lomonosov R, coarser resolution over Amundsen B and Canadian B (track from 85°N 45°E to 73°N 156°W is approx 2500 km)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Aug–Sep
		10 50-km segments @ 14 kt, 122-m depth: 4 in region nearest NP, 6 Pacific side @ 260-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km = 9.7 deg of lat	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hours) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	
		20 50-km segments @ 14 kt, 122-m depth: 4 in region nearest NP, 16 Pacific side @ 70-km spacing, Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km = 12.9 deg of lat		

Table A-4. Atlantic-Pacific Transit: Eastern Offset Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
2 & 4	1	0	1	Ice: 2 Hydro: 2 Chem: 2 Bio: 1	Fast outside E-W line	*Ice: E-W section (through North Pole) of more interest Loiter at ice edge in summer	Ice: 1 per 2 years Hydro: 1 per 2 years Chem: 1 per year Bio: 1 per year	
	1	0.5	1.5					
	1	1	2					
	1	1.5	2.5					
	1	2	3					

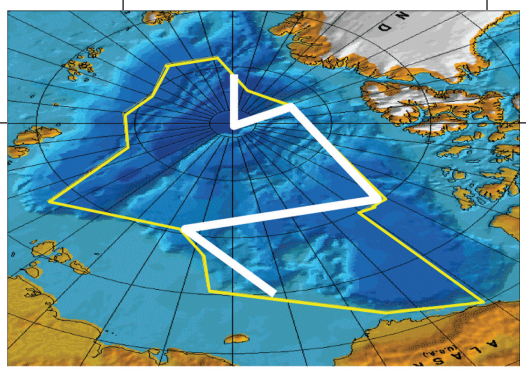


Eastern Offset Track (corridors 2 and 4)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Continuous	Continuous at transit speed	General approach: Focus XCTDs in Makarov Basin (corridor 2), then deploy additional XCTDs in Amundsen Basin (corridor 4)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs	Chlorophyll fluoresence, oxygen, submarine light, and nitrate measured continuously Genetic material frozen every 2 hrs
		10 50-km segments @ 14 kt, 122-m depth: 10 E-W lines @ 40-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60 km spacing = 1080 km (84°N 135°E to 78°N 173°W is approx 1100 km along corridor 2)	^{18}O, salinity, nutrients (frozen) hourly Transient every tracers 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Aug–Sep
		20 50-km segments @ 14 kt, 122-m depth: 20 continuous E-W lines, Remainder continuous at transit speed	36 extra XCTDs @ 40 km spacing = 1440 km (84°N 120°E to 76°N 165°E is approx 1200 km along corridor 2)		
		30 50-segments @ 14 kt, 122-m depth: 18 continuous E-W lines, 12 N-S lines @ 100-km spacing, Remainder continuous at transit speed	54 extra XCTDs @ 40 km spacing = 2160 km (NP to 84°N 120°E adds approx 700 km along corridor 4)		
		40 50-km segments @ 14 kt, 122-m depth: 18 continuous E-W lines, 22 N-S lines @ 35-km spacing, Remainder continuous at transit speed	72 extra XCTDs @ 30-km spacing = 2160 km (87°N 60°W to 84°N 120°E adds approx 1000 km along corridor 4)		

Table A-5. Atlantic-Pacific Transit: Cross Canada Basin Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
2, 3, & 5	2.5	0	2.5	Ice: 2 Hydro: 3 Chem: 2 Bio: 1		Hydro: Prefer sampling along corridor 2, assuming sampling along the Canadian Margin (corridor 3) is likely to take place on ice camp transit Hydro: Spring and summer cruises should consider coordination with Beaufort Gyre experiment (e.g., tend to prefer spring cruise, due to summer coverage via Beaufort Gyre experiment; however, summer cruises extend work beyond the sunset of BG Exp)	Ice: 1 per 2 years Hydro: 1 per 2 years Chem: 1 per 2 years Bio: 1 per year	
	2.5	0.5	3					
	2.5	1	3.5					
	2.5	1.5	4					

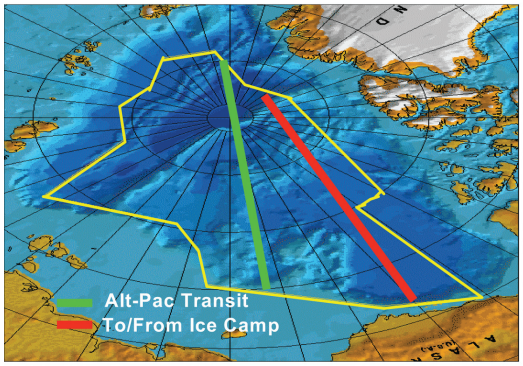


Cross Canada Basin Track (corridors 2, 3, and 5)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Focus XCTDs in Canada Basin (corridor 5), then deploy additional XCTDs along Canadian margin (corridor 3)	Up to full samples ICW XCTDs ^{18}O and nutrients (frozen) hourly Transient tracers every 2 hrs Spring: 1. Cross-track and Canadian margin; 2. E. Siberian margin Summer/fall: 1. Ice edge; 2. Cross-track, and Canadian margin	Chlorophyl fluorescence, oxygen, submarine light, and nitrate measured continuously Genetic material frozen every 2 hrs
		10 50-km segments @ 14 kt, 12-m depth: 1 at NP, 3 Canada Margin @ 300-km spacing, 6 E-W lines @ 200-km spacing, Remainder continuous at transit speed	18 extra XCTDs in Canada Basin @ 50-km spacing = 900 km (81°N 130°W to 81°N 180°W is approx 850 km along corridor 5)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light, and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Aug–Sep on Mendelyev side of track
		20 50-km segments @ 14 kt,122-m depth: 1 at NP, 2 northern E-W lines @ 15- km spacing, 6 Canadian Margin @ 125-km spacing, 11 E-W lines @ 100-km spacing, Remainder continuous at transit speed	36 extra XCTDs in Canada Basin @ 40-km spacing = 1440 km (81°N 130°W to 80°N 165°E is approx 1150 km along corridor 5)		
		30 50-km segments @ 14 kt, 122 m depth: 1 at NP, 3 northern E-W lines @ 50-km spacing, 10 Canadian Margin @ 50-km spacing, 16 E-W lines @ 50-km spacing, Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km (81°N 130°W to 87°N 60°W adds approx 950 km along corridor 3)		

Table A-6. Ice-Camp Transit: Direct Atlantic-Pacific Crossing via Ice Camp

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
	0	0	0	In general: If no time available to deviate to higher priority track, request collection of SCICEX data along direct transit			All: 1 per 2 year	
	0	0.5	0.5					
	0	1	1					
	0	1.5	1.5					

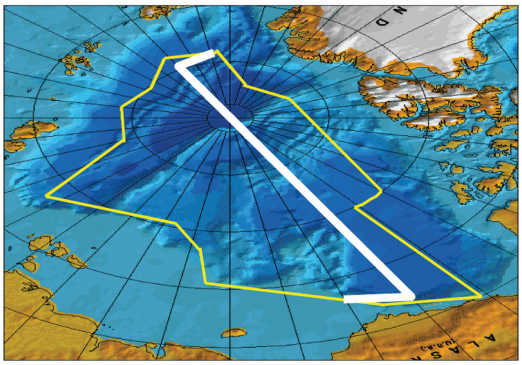


Direct Crossings

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Focus XCTDs first from Lomonosov R to Canada B. (87°N 45°W to 82°N 140°W is approx 1200 km)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers 2 hrs	Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously
		10 50-km segments @ 14 kt, 122-m depth @ 150-km spacing Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Jun–Sep
		20 50-km segments @ 14 kt, 122-m depth @ 50-km spacing Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km @ 60-km spacing = 2160 km		
		30 50-km segments @ 14 kt, 122-m depth @ 20-km spacing Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km (transit from 87°N 45°W to 72°N 145°W is approx 2200 km)		

Table A-7. Ice-Camp Transit: North Pole Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
1	0.5	0	0.5	Ice: 1 Hydro: 1 Chem: 1 Bio: 2			All: 1 per 2 year for either North Pole Track or recent SCICEX Track	
	0.5	0.5	1					
	0.5	1	1.5					
	0.5	1.5	2					
	0.5	2	2.5					

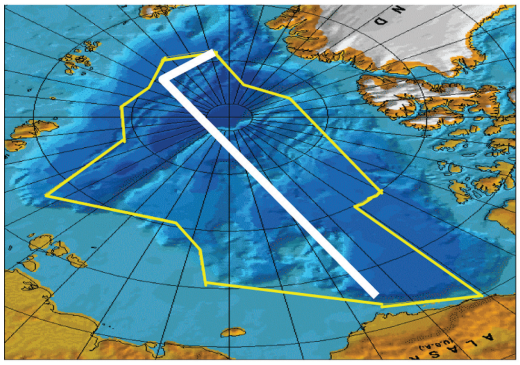


North Pole Track (corridor 1)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Deploy XCTDs with finer resolution over Lomonosov R, coarser resolution over Amundsen B and Canadian B (track from 85°N 30°E to 72°N 150°W is approx 2500 km)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously
		10 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, 2 Pacific side NP, 6 Pacific side @ 260-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km = 9.7 deg of lat		Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5-6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Jun–Sep
		20 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, 2 Pacific side of NP, 16 Pacific side @ 70-km spacing, Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km = 12.9 deg of lat		
		30 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side of NP, 2 Pacific side of NP, 26 Pacific side @ 25-km spacing, Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km = 19.5 deg of lat		
		40 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side NP, Continuous Pacific side	72 extra XCTDs @ 50-km spacing = 2880 km = 25.9 deg of lat		

Table A-8. Ice-Camp Transit: Recent SCICEX Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
1	1	0	1	All: 1			All: 1 per 2 years for either North Pole Track or recent SCICEX Track	
	1	0.5	1.5					
	1	1	2					
	1	1.5	2.5					

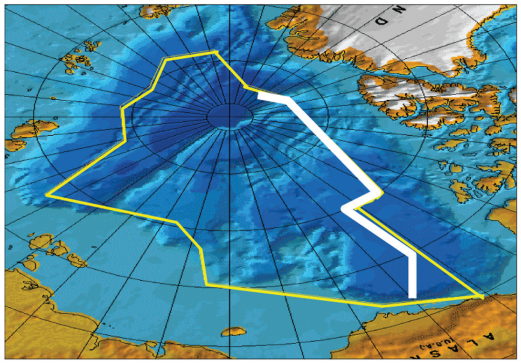


Recent SCICEX Track (corridor 1)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Continuous	Continuous at transit speed	General approach: Deploy XCTDs with finer resolution over Lomonosov R, coarser resolution over Amundsen B and Canadian B	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously
		10 50-km segments @ 14 kt, 122-m depth: 4 in region nearest NP, 6 Pac side @ 260-km spacing, Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km = 9.7 deg of lat		Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Jun–Sep
		20 50-km segments @ 14 kt, 122-m depth: 4 in region nearest NP, 16 Pacific side @ 70-km spacing, Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km = 12.9 deg of lat		
		30 50-km segments @ 14 kt, 122-m depth: 2 Atlantic side of NP, 2 Pacific side of NP, 26 Pacific side @ 25-km spacing, Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km = 19.5 deg of lat		

Table A- 9. Ice-Camp Transit: Canadian Margin Track

SAMPLING CORRIDOR	TIME REQUIRED (DAYS)			PRIORITY	SHIP'S PARAMETERS	COMMENTS	REVISIT FREQUENCY	
	TRANSIT	SCIENCE	TOTAL					
3	0.5	0	0.5	Ice: 2 Hydro: 3 Chem: 2 Bio: 3			Ice: 1 per 2 years Hydro: 1 per 2 years Chem: 1 per 2 years Bio: 1 per 2 years	
	0.5	0.5	1					
	0.5	1	1.5					
	0.5	1.5	2					
	0.5	2	2.5					



Canadian Margin Track (corridor 3)

	SCIENCE PRIORITIES				
	BATHY	ICE	OCEAN		
			HYDROGRAPHY	CHEMISTRY	BIOLOGY
	Choose an Alpha Ridge line; Otherwise continuous	Continuous at transit speed	General approach: Focus XCTDs first on middle segment (87°N 60°W to 80°N 130°W is approx 1000 km)	^{18}O, salinity, nutrients (frozen) hourly Transient tracers every 2 hrs ^{18}O, salinity, nutrients (frozen) from mixed layer at each XCTD station Underway radium sampling Vertical sampling suite: (Estimated time: 12–18 hrs) 5–6 depth stairstep extending from surface mixed layer to 230 m at approximately 12–16 XCTD stations evenly distributed along track	Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously
		10 50-km segments @ 14 kt, 122-m depth @ 170-km spacing Remainder continuous at transit speed	18 extra XCTDs @ 60-km spacing = 1080 km		Chlorophyll fluorescence, oxygen, submarine light and nitrate measured continuously Particulate material frozen every 2 hrs Carbon system every 2 hrs Vertical sampling for discrete samples as for chemistry: 5–6 depth stairstep extending from surface mixed layer to 230 m at XCTD stations Concentrate sampling across the ice edge in Jun–Sep
		20 50-km segments @ 14 kt, 122-m depth @ 60-km spacing Remainder continuous at transit speed	36 extra XCTDs @ 40-km spacing = 1440 km		
		30 50-km segments @ 14 kt, 122-m depth @ 25-km spacing Remainder continuous at transit speed	54 extra XCTDs @ 40-km spacing = 2160 km		
		Continuous 14 kt, 122-m depth	72 extra XCTDs @ 50-km spacing = 2880 km (transit from 84°N 15°E to 72°N 145°W is approx 2600 km)		

APPENDIX B

Original SCICEX Memorandum of Agreement

MEMORANDUM OF AGREEMENT

I. PURPOSE

The purpose of this Memorandum of Agreement (MOA) is to facilitate the use of U.S. Navy submarines for scientific research in the Arctic. This MOA sets forth the functions, responsibilities, and actions of the Chief of Naval Research (CNR), the Chief of Naval Operations (CNO), the U.S. Submarine Force, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS).

II. BACKGROUND

The federal agencies that fund Arctic marine science believe that existing fleet nuclear submarines (SSN) are invaluable research platforms in the Arctic, as was demonstrated during Arctic Submarine Science Cruise 1993. These agencies are seriously interested in continued utilization of U.S. SSN's for science. The Navy believes that SSN's must retain a global ocean operational capability. The Submarine Force is committed to sustaining its Arctic training and readiness levels through recurring deployments to that area.

III. GOALS

The overall goal of the Submarine Arctic Science Program is to improve understanding of Arctic Ocean processes and their role in the earth's climate system by dual use of nuclear submarines, thus fully capitalizing on existing national platform capabilities. This Agreement is intended to mutually support the objectives of both the civilian and military communities.

IV. DEFINITIONS

A. Parties to Agreement. The following parties are entering into this Agreement:

1. CNO, represented by the Attack Submarine Branch of the Submarine Warfare Division (N872).

2. U. S. Submarine Force, represented by Commander Submarine Force, U. S. Atlantic Fleet for Atlantic submarine involvement and Commander Submarine Force, U.S. Pacific Fleet for Pacific submarine involvement.

3. CNR, represented by the Ocean and Atmosphere and Space Science and Technology Department (ONR 32).

4. NSF, represented by the Office of Polar Programs (OPP) and the Division of Ocean Sciences (OCE).

5. NOAA, represented by the Ocean and Atmospheric Research Directorate (OAR).

6. USGS, represented by the Chief Office of Energy and Marine Geology.

B. Functioning Bodies. The following bodies are established by this Agreement:

1. Operational Planning Board (BOARD). The BOARD shall have five members: a representative of ONR, CNO, the U.S. Submarine Force, the Naval Undersea Warfare Center/Division Keyport/Arctic Submarine Laboratory (ASL) and the Arctic Research Commission.

2. Science Steering Committee (COMMITTEE). The COMMITTEE shall have eleven members: a representative of ONR, NSF, NOAA, and USGS, a member of the science community designated by each Agency, a member of the Polar Research Board and a member of the Naval Studies Board. The ONR representative will serve on both the COMMITTEE and the BOARD. One additional representative from the BOARD will be nominated as a standing member of the COMMITTEE. Representatives from other interested agencies may serve as ad hoc members of the COMMITTEE by request.

V. FUNCTIONS, RESPONSIBILITIES & ACTIONS

A. The CNO agrees to:

1. Establish and chair the BOARD to plan and execute Arctic submarine science cruises. The functions of the BOARD are to:

   a. Review proposed projects to verify technical and operational feasibility and data declassification. The BOARD will not review scientific merit, but may limit the extent of some investigations based on operational issues.

   b. Nominate a member to sit on the COMMITTEE who will serve to assist the science community in early screening of the technical feasibility of research proposals.

   c. Apprise the COMMITTEE of operational matters such as schedules, berthing for embarked scientists and status of installations.

2. Authorize the ASL as the CNO and Submarine Force Arctic Advisor to coordinate the operational and technical aspects of each Arctic submarine science cruise. Coordination includes managing with ONR an annual advance planning process.

3. Provide a Technical Advisor (TA), knowledgeable in submarine Arctic operations, who will facilitate equipment installation, load out and data collection, and will be on board for the duration of the science cruise. The TA will serve in a liaison role between the embarked scientists and the submarine crew.

B. **The U. S. Submarine Force agrees to:**

1. Provide SSN assets for Arctic scientific research on a periodic schedule and of a duration agreed to by both the ONR and the Submarine Force. These deployments must be consistent with availability and military commitments as determined by the Fleet Commander. The Submarine Force retains the right to cancel or shorten any cruise if operationally required.

2. Provide all operational support for the submarine cruise to include training, operating orders and associated support.

3. Make available space for scientific personnel and equipment as feasible.

4. Obtain data specified in the Science Plan. This Plan, composed by the Chief Scientist in collaboration with all principal investigators and approved by the COMMITTEE and BOARD, establishes the cruise priorities for collection of baseline and special data as defined in Paragraph VI. The Commanding Officer of the participating submarine retains the absolute right to modify or delete portions of the Science Plan consistent with the ship's safety. The Science Plan may also be modified at sea in response to:

   a. unanticipated environmental conditions;

   b. instrumentation malfunctions or failures;

   c. unplanned contingencies or limitations.

   At sea modifications to the Science Plan will be recommended by the Chief Scientist in consultation with the TA. The Commanding Officer will execute such changes subject to maintaining safety and remaining within overall

operational directives.

5. Make science data sets available to principal investigators as soon as possible consistent with the submarine's operational employment and declassification requirements.

C. The CNR agrees to:

1. Serve as the focal point for the scientific aspects of the Submarine Arctic Science Program, ensuring multi-agency participation in identifying science requirements and evaluation of proposals, thereby making available the unique attributes of a nuclear submarine to as many in the science community as possible.

2. Initiate a Broad Agency Announcement (BAA) requesting proposals from the science community for each planned Arctic submarine science cruise. The BAA and subsequent funding process will be multi-agency, fulfilling the intent of the Arctic Research and Policy Act as implemented by the Interagency Arctic Research and Policy Committee. The BAA ensures fair and open competition in selecting the best science for use of nuclear submarines in Arctic research.

3. Implement with ASL an annual advance planning process involving both the science and operational communities. This process provides adequate time for BAA response, review of candidate investigations, funding decisions and deployment preparation.

4. Establish and chair the COMMITTEE to work directly with the science community. The COMMITTEE will orchestrate the overall Science Plan including both long term and short term projects. For each planned cruise, the functions of the COMMITTEE are to:

   a. Establish broad scientific priorities and review and approve with the BOARD the Science Plan drafted by the Chief Scientist;

   b. Ensure that interested scientists are informed of the nature and objectives of the exercise, including limitations and prioritizations;

   c. Evaluate proposed science projects based on scientific merit, the ability to obtain adequate funding, and the applicability of results to national research goals;

   d. Ensure that proposed scientific projects fully address all temporary

installations, equipment load plans, and storage space requirements;

e. Recommend onboard scientists using berthing allowances provided by the BOARD. Within this group, the COMMITTEE will designate a Chief Scientist who will draft the Science Plan and have final decision authority on scientific issues at sea. Each onboard scientist must meet the security and physical requirements specified by the CNO, and be approved by the Submarine Type Commander conducting the deployment.

5. Establish a system to provide independent and periodic review of procedures and achievements.

D. **The NSF, NOAA, and USGS each agree to:**

1. Endorse the multi-agency BAA, and identify funds available to support research and coordination services for each cruise. Each agency reserves the right to select and review proposals according to its own policy.

2. Designate an agency representative and a science community representative as members of the COMMITTEE and participate actively in the annual advance planning process and periodic reviews.

VI. DATA

A. Baseline data included under this agreement are:

1. water samples;
2. temperature or sound velocity profiles taken by expendable probe;
3. Conductivity, Temperature, Depth (CTD) profiles taken by expendable probe;
4. CTD data taken from sail mounted SUBCTD system;
5. bathymetry recorded by installed fathometers;
6. ice profile data from upward looking, narrow beam sonar;
7. ice image data from upward looking video and sidescan sonar if available;
8. supporting navigation and operational data at a non-classified level.

B. Other special data included under this agreement are those specified in the approved Science Plan.

VII. FISCAL

A. This Agreement identifies three fiscal elements required for the Arctic

Submarine Science Cruise Program. Parties to the Agreement who are actively participating in a planned Arctic submarine science cruise will contribute as follows:

1. Ship Costs. The Submarine Force will provide funds for the shiptime component of the deployment.

2. Baseline and Special Data Acquisition Costs. Participating parties will provide equal share funds to support baseline data acquisition and fair share funds for special data acquisition related to specific science investigations. Costs will be determined by the Submarine Force and ASL as part of the proposal evaluation process. Funds will be provided to ASL at least three months prior to installation. This acquisition includes:

   a. installing, removing and operating (if required) equipment and instrumentation for science;

   b. classification review, copying, packaging and forwarding data.

3. Coordination Costs. Participating parties will provide funds in equal shares to support TA services from ASL. These services include liaison with the fleet, review of proposal feasibility and estimation of data acquisition costs. Six months prior to each cruise, ASL will propose funding rates and a payment schedule associated with these services based on anticipated level of effort. This proposal will be reviewed and endorsed by the BOARD and forwarded to the COMMITTEE as part of the proposal evaluation process.

VIII. SECURITY

All scientific and other data collected on each cruise will be evaluated for security purposes by a USN representative selected by the BOARD. This evaluation will be completed as soon as possible, nominally within 30 days after the ship's return to home port. The BOARD will make every effort to ensure the acquired data are declassified; however, all data will be afforded proper protection if determined to be classified due to extenuating circumstances.

IX. PERIOD OF AGREEMENT

This agreement shall be effective upon the date of the last signature below, and will remain in effect until terminated or modified by mutual agreement of all the parties.

X. SIGNATURES

T. D. RYAN
RADM, U.S. Navy
Director
Submarine Warfare Division

M. Y. E. PELAEZ
RADM, U.S. Navy
Chief of Naval Research

G. W. EMERY
VADM, U.S. Navy
Commander Submarine Force,
U.S. Atlantic Fleet

J. M. BARR
RADM, U.S. Navy
Commander Submarine Force,
U.S. Pacific Fleet

N. F. LANE, Ph.D.
Director
National Science Foundation

D. J. BAKER, Ph.D.
Under Secretary of Commerce
for Oceans and Atmosphere
National Oceanic and
Atmospheric Administration

G. P. Eaton, Ph.D.
Director
U.S. Geological Survey

APPENDIX C

Current (Phase II) SCICEX Memorandum of Agreement

MEMORANDUM OF AGREEMENT
SUBMARINE ARCTIC SCIENCE PROGRAM – PHASE 2

1. **PURPOSE**. The purpose of this Memorandum of Agreement (MOA) is to facilitate the use of U.S. Navy submarines for scientific research in the Arctic. This MOA sets forth the functions, responsibilities, and actions of participating parties. Details governing different types of data collection opportunities are delineated in Appendices A and B.

2. **BACKGROUND**. The federal agencies that fund Arctic marine science believe that existing fleet nuclear submarines (SSNs) are unique research platforms in the Arctic, as was demonstrated during the six Submarine Arctic Science Cruises (SCICEXs) conducted from 1993 until 1999. The Navy believes that SSNs must retain a global ocean operational capability. The Submarine Force is committed to sustaining its Arctic training and readiness levels through recurring deployments to that area.

3. **GOALS**. The overall goal of this Submarine Arctic Science Program (SCICEX Phase 2) is to improve understanding of Arctic Ocean processes and their role in the earth's climate system by dual use of nuclear submarines, thus capitalizing on existing national platform capabilities. This Agreement is intended to mutually support the objectives of both the civilian science and military communities. Toward this end, it is intended that all data collected under this agreement be made publically available as soon as possible after collection, following the data policies of the respective sponsors.

4. **DEFINITIONS**.

   a. Parties to Agreement. The following parties are entering into this Agreement:

      (1) The U. S. Submarine Force, represented by Commander Submarine Force, U. S. Atlantic Fleet (COMSUBLANT) and Commander Submarine Force, U.S. Pacific Fleet (COMSUBPAC).

      (2) Chief of Naval Research (CNR), represented by the Ocean, Atmosphere and Space Science and Technology Department (ONR 32).

      (3) National Science Foundation (NSF), represented by the Office of Polar Programs.

   b. Functioning Bodies. The following bodies are established by this Agreement. Specific responsibilities vary with the type of mission (Dedicated or Accommodation) and are detailed in Appendices A and B.

(1) Operational Planning Board (OPB). The OPB shall be chaired by the Arctic Submarine Laboratory (ASL) and include representatives from COMSUBLANT, COMSUBPAC, and CNO.

(2) Interagency Committee (IAC). The IAC shall be chaired by ONR and include representatives from NSF, ASL, CNO, and the Arctic Research Commission. Other agencies may be represented at the invitation of any of the above listed members.

(3) Science Advisory Committee (SAC). The SAC shall be chaired by an individual designated by the IAC with ONR, NSF, and ASL as permanent members. An additional six non-permanent members will be selected from within the scientific community with ONR and NSF each selecting three of these representatives.

5. **FUNCTIONS, RESPONSIBILITIES & ACTIONS**.

a. The U.S. Submarine Force agrees to:

(1) Establish the Operational Planning Board (OPB) to coordinate the oversight of the Submarine Arctic Science Program.

(2) Authorize ASL as the Submarine Force Arctic Advisor to coordinate the operational and technical aspects of each cruise, including planning interface with ONR.

(3) Provide all operational support for the submarine cruise to include training, operating orders, and associated operational support.

(4) Carry out other functions described in Appendices A and B.

b. The CNR agrees to:

(1) Serve as the focal point for the scientific aspects of the Submarine Arctic Science Program, making available the unique attributes of a nuclear submarine to as many in the science community as possible.

(2) Assist ASL in the science coordination aspects of cruise planning.

(3) Establish and chair the Interagency Committee (IAC).

(4) Establish policies to assure that data distributed to ONR-supported investigators are made available to the public at the earliest date possible after collection, following ONR data policies.

(5) Take action to encourage the declassification and release of archived Navy submarine-collected environmental data.

(6) Carry out other functions described in Appendices A and B.

c. NSF agrees to:

(1) Designate an agency representative as a member of the IAC and SAC and participate actively in the program.

(2) Assist CNR in carrying out the scientific aspects of this program.

(3) Establish policies to assure that data distributed to NSF-supported investigators are made available to the public at the earliest date possible after collection, following NSF data policies.

6. **SECURITY**. All scientific and other data collected on each cruise will be evaluated for security purposes by ASL. This evaluation will be completed as soon as possible, normally within 30 days after the ship's return to a U.S. port. The OPB will make every effort to ensure the acquired data are declassified. However, all data will be afforded proper protection if determined to be classified due to extenuating circumstances or existing national security guidance.

7. **PERIOD OF AGREEMENT**. This agreement supercedes the previous MOA established 20 June 1994. It shall be effective upon the date of the last signature below. It may be modified by mutual agreement of all of the parties. Signatory parties may terminate their participation with 6 months notice to all other parties.

E/ [signature] 5/2/00 [signature] 11 Apr 00
COMSUBLANT Date for CNR Date

[signature] 3/15/00 [signature] 6/12/00
COMSUBPAC Date for NSF Date

APPENDIX A
DEDICATED SCIENCE MISSIONS

1. **GOALS**. The goal of the Dedicated Science Missions is the collection of new sets of Arctic environmental data during submarine cruises dedicated to this purpose.

2. **DESCRIPTION**. Under this agreement, the Submarine Force will allocate either individual cruises or commit a series of cruises as Arctic science missions. This effort will be specifically aimed at improving upon the successes of the first six SCICEX cruises in supporting high priority Arctic environmental scientific research.

3. **RESPONSIBILITIES**.

   a. The U.S. Submarine Force agrees to:

      (1) As available, provide SSN assets for Arctic scientific research. These deployments must be consistent with availability and military commitments as determined by the Fleet Commander. The Submarine Force retains the authority to cancel or shorten any cruise if operationally required. Final commitment of submarine time will be based upon the Science Plan prepared by the IAC and approved by the OPB.

      (2) Provide an ASL Technical Advisor, knowledgeable in submarine Arctic operations, who will facilitate equipment installation, load out, and data collection, and will be on board for the duration of the science cruise. The Technical Advisor will serve in a liaison role between the embarked scientists and the submarine crew.

      (3) Make space available for scientific personnel and equipment, as feasible.

      (4) Obtain data specified in the Science Test Plan. This plan is a classified detailing of the submarine's planned operations developed by the ASL Technical Advisor and Chief Scientist in consultation with all participating investigators. The Commanding Officer of the participating submarine retains the absolute authority to modify or delete portions of the Science Test Plan consistent with the ship's safety. The Chief Scientist may also recommend modifications to the Science Test Plan at sea. These recommendations should be made to the Commanding Officer via the Technical Advisor and only in response to unanticipated environmental conditions, instrumentation malfunctions or failures, or unplanned contingencies/limitations. The

Commanding Officer will execute such changes subject to maintaining safety and remaining within overall operational directives.

(5) Make science data sets available to principal investigators as soon as possible consistent with the submarine's employment and declassification requirements.

b. The OPB shall:

(1) Via ASL, inform the IAC of the availability and duration of Dedicated Science Missions.

(2) Review nominated projects to verify technical and operational feasibility and data declassification. The OPB may limit the extent of some investigations based on operational concerns and to ensure that the research proposed is consistent with efficient and safe use of the submarine.

(3) Approve the Science Plan submitted by the IAC.

(4) Approve, in conjunction with the ship's Commanding Officer, the scientific riders nominated by the IAC.

c. The IAC shall:

(1) Based upon the recommendations from the SAC, submit to the OPB the long-range scientific plan for this program. Where more than one cruise is envisioned, this plan should include the intended focus of each cruise.

(2) For each Dedicated Science Mission planned:

(a) Initiate a Broad Agency Announcement (BAA) requesting proposals from the science community.

(b) Based upon the recommendations of the SAC and the ability to provide adequate funding, nominate experiments to the OPB and fund the research to be conducted on each mission.

(c) Within one month of science selection, submit to the OPB, a Science Plan delineating the scientific objectives and priorities for the cruise.

(d) Based on the science planned, nominate to the OPB the scientists to be embarked on each mission, designating one of these to act as Chief Scientist. Each embarked scientist must meet the

security and physical requirements specified by the Submarine Force and be approved by the OPB.

d. The SAC shall advise the IAC on overall scientific priorities and specific experiment selection. This will include:

(1) Recommending broad scientific priorities and long-range goals for this program.

(2) Recommending baseline data to be collected on all cruises.

(3) Evaluating proposed science projects based on scientific merit, suitability to this program, and the applicability of results to program goals.

4. **DATA**.

a. Specific Data sets and equipments may vary depending upon the submarine conducting the operation. In general, baseline data under this agreement can include:

(1) Conductivity, Temperature, Depth (CTD) profiles taken by expendable probes.

(2) CTD data taken from hull-mounted systems.

(3) Bathymetry recorded by installed fathometers.

(4) Ice profile data from upward-looking sonars.

(5) Salinities from water samples.

(6) Supporting navigation and operational data at a non-classified level.

b. Other special data included under this agreement will be proposed by the IAC and approved by the OPB.

c. Baseline data shall be forwarded by ASL to a national data repository designated by ONR at the same time it is distributed to investigators. Where data needs to be reformatted/calibrated prior to release, water samples require analysis, or data is distributed under a proprietary agreement, the sponsoring agencies will ensure that the investigators involved forward their data to the repository as soon as possible after collection, following the data policies of the respective sponsors.

5. **FISCAL**. This Agreement identifies four fiscal elements required for the Dedicated Science Missions. Parties to the Agreement will contribute as follows:

   a. Ship Costs. The Submarine Force will provide funds for the ship time component of the deployment. This is subject to modification by other agreements regarding ship availability and costs.

   b. Coordination Costs. The costs for ASL to act as liaison between the Submarine Force and the scientific community, attend meetings, and to conduct the overall planning will be shared by the Submarine Force and the sponsoring scientific agencies (e.g., ONR and NSF) on an equal-share basis. The scientific agencies' share of the costs will be apportioned on a pro-rata share basis relative to the funded research.

   c. Baseline Data Acquisition Costs. The Submarine Force and the sponsoring scientific agencies will equally share the costs for the installation of baseline equipment, for the embarked Technical Advisor(s), and declassification/distribution of baseline data. Costs for expendable probes/consumables and costs associated with the processing/analysis of data will be borne by the sponsoring scientific agencies. The scientific agencies' share of these costs will be apportioned on a pro-rata share basis relative to the funded research.

   d. Special Data Collection Costs. The sponsoring scientific agencies will provide funding for all effort associated with Special Data. This includes costs for development/installation of equipment, expendables/ consumables, declassification/distribution of data, and data analysis.

APPENDIX B
SCIENCE ACCOMMODATION MISSIONS

1. **GOALS**. The goal of the Science Accommodation Missions is to facilitate the collection of scientific data by U.S. Navy submarines during classified Arctic operations.

2. **DESCRIPTION**. Under this agreement, the Submarine Force will, on a case basis, allocate limited portions of otherwise classified submarine Arctic missions to collect high priority environmental data. This collection effort will be specifically aimed at continued monitoring of evolving oceanographic conditions, ice distribution, and contaminant concentrations in the Arctic Ocean. In general, this program differs from Dedicated Science Missions in that it will concentrate on baseline data collection rather than individual experiments. A set of baseline data to be collected will be identified by the IAC as advised by a SAC. These data will then be collected by the embarked Arctic Submarine Laboratory (ASL) personnel, assisted by the submarines' crews.

   Within this context, the following specific differences between these and Dedicated Science Missions will also apply:

   a. Science Accommodation Missions will concentrate on data collection of general interest rather than specific experiments to support individual investigators. Most of the submarine-collected data will immediately be declassified and transferred to a repository designated by ONR. Where initial processing/calibration of data or analysis of water samples is required, this effort will be conducted by laboratories designated by ONR with the stipulation that these data be transferred to a designated repository at the earliest opportunity. No data collected under this agreement may have proprietary use by any individual for any period of time.

   b. Proposals for individual experiments or installation of an individual's equipment on board may be entertained consistent with maintaining the security of the planned submarine operations.

   c. Because of the nature of the submarine missions, it is not anticipated that civilian scientists will be embarked.

3. **RESPONSIBILITIES**.

   a. The U.S. Submarine Force shall:

(1) Provide SSN assets for Arctic scientific accommodation as available. The duration of these accommodation periods must be consistent with availability and military commitments as determined by the Fleet Commander. Start points and endpoints for the accommodation will be selected to avoid any inference of the classified aspects of the submarine's mission. The Submarine Force retains the authority to cancel or shorten any cruise if operationally required.

(2) Coordinate through ASL the operational and technical aspects of each cruise, including planning interface with ONR.

(3) Provide a Technical Director (TD), knowledgeable in submarine Arctic operations, who will facilitate equipment installation, load out, and data collection, and will be on board for the duration of the cruise. The embarked ASL Technical Director(s), aided by the submarine crew, will be responsible for the collection of scientific data.

(4) Make available space for scientific equipment, as feasible.

(5) Obtain data specified in the Science Plan. This Plan will be proposed by ASL based on the advice of the IAC and approved by the OPB prior to final commitment of submarine time to science accommodation. The Commanding Officer of the participating submarine retains the absolute authority to modify or delete portions of the Science Plan consistent with the ship's safety. The Science Plan may also be modified at sea in response to unanticipated environmental conditions, instrumentation malfunctions/failures, or unplanned contingencies or limitations. At-sea modifications to the Science Plan will be recommended by the TD. The Commanding Officer will execute such changes subject to maintaining safety and remaining within overall operational directives.

(6) Make science data sets available to the repository designated by ONR as soon as possible consistent with the submarine's operational employment and declassification requirements. On those occasions when experiments may be conducted for specific individuals or such individuals are designated to conduct initial analysis of the data, provide data sets within the same constraints.

b. The OPB will:

(1) Review proposed research to verify feasibility/safety and the ability to rapidly declassify the data. The OPB may limit the extent of some investigations based on operational concerns and to ensure that the research proposed is consistent with efficient and safe use of the submarine.

(2) Approve the Science Plan prepared by ASL prior to final commitment of science accommodation time.

c. The IAC will orchestrate the definition of the Science Plan including both baseline data collection (collected on all cruises) and any special (one-time) data collection. The classified nature of the cruises covered by this Agreement will normally preclude prior announcement to the scientific community. However, where possible, IAC will initiate a Broad Agency Announcement (BAA) requesting proposals from the science community. These proposals may cover specific experiments or the installation of specialized equipment on an individual cruise. For each planned cruise, the functions of the IAC are to:

(1) Establish broad scientific priorities and define specific baseline data to be collected.

(2) If appropriate, initiate the BAA process to solicit individual science projects.

(3) If a BAA has been issued, use the recommendations of the SAC and ability to provide adequate funding to nominate experiments to the OPB and fund the research to be conducted on each mission.

d. The SAC shall:

(1) Periodically review the baseline data collection agenda and recommend modifications/improvements to the IAC.

(2) If a BAA has been issued, evaluate proposed science projects based on scientific merit, suitability to this program, and the applicability of results to program goals.

4. **DATA**.

a. Baseline Data. Baseline data included under this agreement will normally be limited to those data sets available using standard submarine equipment and those systems typically installed by ASL for Submarine Ice Exercise (ICEX) cruises. Specific data sets and equipments may vary depending upon the submarine conducting the operation. In general, the baseline data set will include:

(1) Conductivity, Temperature, Depth (CTD) profiles taken by expendable probes.

(2) CTD data taken from hull-mounted CTD systems.

(3) Bathymetry recorded by installed fathometers.

(4) Ice profile data from upward-looking sonars.

(5) Salinities from water samples.

(6) Supporting navigation and operational data at a non-classified level.

b. Special Data. Other special data included under this agreement will be proposed by the IAC and approved by the OPB.

5. **FISCAL**. This Agreement identifies four fiscal elements required for the Science Accommodation Missions. Parties to the Agreement will contribute as follows:

a. Ship Costs. The Submarine Force will provide funds for the ship time component of these missions.

b. Coordination Costs. The costs for ASL to act as liaison between the Submarine Force and the scientific community, attend meetings, and conduct the overall planning will be shared by the Submarine Force and the sponsoring scientific agencies on an equal-share basis.

c. Baseline Data Acquisition Costs. The Submarine Force will provide funding for the installation of baseline ICEX equipment and for an embarked Technical Director. Funding for additional baseline equipment, expendable probes and consumables, additional embarked ASL personnel, and the declassification/distribution of baseline data will be shared by the Submarine Force and the sponsoring scientific agencies on an equal-share basis. Costs for processing/analysis of data will be borne by the sponsoring scientific agencies.

d. Special Data Collection Costs. The sponsoring scientific agencies will provide funding for all effort associated with Special Data. This includes costs for development/ installation of equipment, expendables/ consumables, additional embarked ASL personnel, declassification/distribution of data, and data analysis.

Operational Planning Board (OPB):

-- Chaired by ASL
-- Representatives from
    CNO
    COMSUBLANT
    COMSUBPAC

Interagency Committee (IAC):

-- Chaired by ONR
-- Representatives from
    NSF
    ASL
    CNO
    Arctic Research Commission
    Other agencies (at the invitation of any above)

Science Advisory Committee (SAC):

-- Chaired by an individual designated by the IAC
-- Permanent members
    ONR
    NSF
    ASL
-- Non-permanent members (6) selected from scientific community with ONR and NSF each selecting three

APPENDIX D
Acronyms

ACEX ..... Arctic Coring Expedition
AGAVE ..... Arctic Gakkel Vents
AMORE ..... Arctic Mid-Ocean Ridge Expedition
AON ..... Arctic Observing Network
ASL ..... Navy's Arctic Submarine Laboratory
ATOC..... Acoustic Thermometry of Ocean Climate
AW..... Atlantic Water
BGEP..... Beaufort Gyre Exploration Project
CDOM ..... Colored Dissolved Organic Matter
CFC ..... Chlorofluorocarbon
CTD..... Conductivity, Temperature, Depth Sensor
DOC..... Dissolved Organic Carbon
DOM ..... Dissolved Organic Matter
HOTRAX..... Healy-Oden Trans-Arctic Expedition
IAC ..... Interagency Committee
IARPC..... Interagency Arctic Research Policy Committee
ICEX..... Ice Exercise
MOA..... Memorandum of Agreement
NASA ..... National Aeronautics and Space Administration
NSF..... National Science Foundation
NOAA ..... National Oceanic and Atmospheric Administration
NSIDC..... National Snow and Ice Data Center
ONR ..... Office of Naval Research
PETM ..... Paleocene/Eocene Thermal Maximum
RLGN ..... Ring-Laser Gyro Navigation
SAC..... Science Advisory Committee
SAM..... Science Accommodation Mission
SCICEX..... SCience ICe EXercise
SEARCH ..... Study of Environmental Arctic Change

SRVS..... Submarine Remote Video System
TEMPALT..... Temporary Alteration (any alteration that provides given capabilities on a temporary basis in support of mission requirements)
TOC..... Total Organic Carbon
USARC..... U.S. Arctic Research Commission
USGS..... U.S. Geological Survey
XCTD..... Expendable Conductivity, Temperature, Depth Sensor

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SCICEX: Science Ice Exercise | http://www.scicex.org

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