news from the aosb

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Arctic Ocean Sciences Board

Canadian Arctic Science Activities on the Go

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The previous two AOSB newsletters (April, 2002 and July 2002) have made reference to the increase in Arctic marine science activity internationally. Canada, in partnership with other northern nations, has recently made significant progress towards addressing issues such as climate change at both a scientific and political level. The following article describes some of the recent science activities which are impacting on our knowledge of Arctic marine systems.

Building on the more recent success of the Canada-US cruise to the North Pole (1994), the Northwater Polynya Study (1997-1999, endorsed by AOSB and IAPP), and the Joint Ocean Ice Studies (1997-2002, ongoing), Canadian scientists are fortunate to be presently organizing or participating in a number of important global research programs designed to help resolve many of the issues currently being faced in the North.

Arctic Research Icebreaker for International Science:

After many years of discussion among Canadian scientists, there is new excitement in Canada with the announcement of the conversion of the Canadian Coast Guard of the Department of Fisheries and Oceans Canada (DFO) icebreaker *CCGS Sir John Franklin* to a state-of-the-art science capable vessel for dedicated work in the Arctic.

News from the AOSB is issued by the Arctic Ocean Sciences Board (AOSB) and reports on various subjects for the information of Arctic Ocean research scientists. To obtain additional copies of this newsletter, to suggest subjects for future newsletters or to obtain further information from the Board, please contact the AOSB Staff Group, c/o Directorate for Geosciences, National Science Foundation, 4201 Wilson Boulevard, Room 1070, Arlington, Virginia 22230 USA. Telephone: (703) 292-7856, Fax: (703) 292-9152, Web: www.aosb.org

Designed to address the need in Canada for a platform to conduct research in Canada's vast northern marine territory, a consortium of Canadian universities and federal agencies will work closely with international agencies to conduct large-scale marine and vessel-based research for many years to come.

Over the next ten years, the vessel will support several major multidisciplinary international programs to advance Arctic science linked to ocean circulation, sea-ice dynamics, biology, biogeochemistry, paleoceanography and geology. The vessel will also support ship-based studies in the coastal inland regions of the Canadian Arctic tied to questions of climate impacts and epidemiological studies of the impact of climate change on the health of northerners. Led by Dr. Louis Fortier of Laval University, the first major project planned for the new science icebreaker is the Canadian Arctic Shelf Exchange Study (CASES) which includes an over-wintering program in 2003-04. The first field season for CASES was carried out in September and October 2002 and a summary report of this work by Dr. Jody Deming appears on in this edition of the AOSB Newsletter on page 10.

The science platform, designed specifically to work in Arctic waters, will be outfitted with the capacity to conduct ocean-floor mapping and shallow marine drilling operations deployed in conjunction with a moon pool and dynamic positioning system. Wet and dry laboratories, a fast-launch davit for deployment and recovery of a 7m survey boat while steaming at up to 6 knots, an acoustic well and meteorological instruments to enable atmospheric specialists to calibrate satellite images with direct observations along the ship's path all contribute to the ship's capacity to deliver on new Arctic science research objectives.

Arctic Research Cruises – 2002

Joint Western Arctic Climate Studies:

In 2002, two major marine programs have completed successful field seasons in the Canadian Arctic. Both the CASES and the Joint Western Arctic Climate Study (JWACS) initiated multi-year programs in the Beaufort Sea and Chukchi Sea region.

JWACS is an observationally driven programme whose study area extends across the Canada Basin and includes the Mackenzie Shelf with emphasis on the relationships between the physical environment and biota. The primary objective of JWACS in 2002 was to carry out a multi-vessel study along the full span of the Western Arctic shelf-break and ridge system from the Northwind Ridge to Banks Island; specifically:

1. To understand the impacts of global change on the physical environment and biological responses by tracking and linking decadal scale perturbations in the Arctic atmosphere (e.g. Arctic Oscillation) to inter-basin scale changes in ocean circulation and geochemical tracers (natural and anthropogenic).

2. To understand the impacts of global change on the distribution, abundance and biodiversity of associated biological communities (through multivariate analysis of virus, bacteria, ultra-plankton, phytoplankton, zooplankton fish and benthic communities).

3. To understand the impacts of global change on sea ice and other fresh water products by (a) establishing an Arctic Ocean Climate Station network in the Western Arctic and (b) utilizing a suite of stable isotopes and geochemical markers to inventory the storage and pathways of freshwater components derived from Pacific, river and ice melt sources.

4. To understand the impacts of global change on the carbon cycle and greenhouse gas sources and sinks by (a) examining the ratio of carbon burial versus export

using both radionuclide tracer techniques and the paleo-record, and by (b) measuring methane concentrations in coastal and marine permafrost domains.

This extensive work was carried out aboard the Canadian Coast Guard vessels: CCGS *Louis S. St-Laurent* and CCGS *Sir Wilfrid Laurier*, and the Japan Marine Science & Technology Center (JAMSTEC) research vessel R/V *Mirai* from August to early October. Scientists from Canada, Japan, US (NOAA Ocean Exploration program), and China participated in 100 ship days with more than 400 stations providing the most extensive coverage of the area to date. Preliminary results from the work will appear in a future edition of the AOSB newsletter.

Arctic Canada Ocean Watch:

For a number of years, scientists at the DFO have been involved with the Arctic Canada Ocean Watch (ACOW) program which was established in 1997 to monitor change in ice and ocean conditions within the Canadian Arctic Archipelago. It is a Canadian project affiliated with the ongoing Joint Ocean Ice Study (JOIS). ACOW shared moorings with the International North Water Project in northern Baffin Bay in 1997-99.

The Arctic Canada Ocean Watch has short-term (1-3 year) and long-term goals. In the short term, ACOW is exploring the seasonal and interannual variability of currents through the Canadian Arctic Archipelago and evaluating new technology for such measurements. Long term goals are 1) to develop an effective and affordable method for monitoring fluxes of ice and water through the Canadian Arctic Archipelago; 2) to understand the forcing of and controls on these fluxes so that they may be incorporated in global climate models.

The Arctic Canada Ocean Watch has initiated field programmes in both winter and summer. Since 1997 the Canadian Coast Guard has provided icebreaker support to ACOW during summer months in conjunction with its mandated Arctic Patrols.

At present, the DFO research Institute of Ocean Sciences maintains moorings to measure current in Cardigan Strait and Hell Gate as part of the Arctic Canada Ocean Watch. These moorings complement installations by the DFO Bedford Institute of Oceanography in Barrow Strait. The Cardigan/Hell Gate moorings are maintained on a biennial cycle in even numbered years. The Institute of Ocean Sciences also placed instruments in Smith Sound in 1997 and 1998. The prevalence of heavy ice, fast-moving ice in this area is proving a significant challenge to their maintaining these moorings.

Canadian Archipelago Throughflow Study

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1. Objectives

A collaborative US-Canadian research team will study the discharge of freshwater from the Arctic Ocean through northern passages of the Canadian Arctic Archipelago into the North Atlantic. The National Science Foundation (NSF) and the Canadian Department of Fisheries and Oceans are funding a largely observational program entitled "Variability and Forcing of Fluxes through Nares Strait and Jones Sound: A freshwater emphasis" for a 5-year period beginning in January of 2003. The study is designed to test descriptive as well as dynamical hypotheses such as:

- *Barotropic and remotely forced freshwater flux contributions dominate baroclinic and locally forced contributions;*

- *Tidally rectified flows contribute substantially to the net fluxes and these can be predicted from tide-gauge observations using a properly designed mooring array;*
- *Interannual changes in seawater and tracer characteristics in Baffin Bay and Davis Strait correlate strongly with changes of the freshwater flux through the Canadian Archipelago;*
- *Interannual variations in water masses characteristics and freshwater fluxes over the past few decades can be reconstructed via bivalve shell records.*

To test these hypotheses, we will

- *Measure fluxes via two of the three principal passages through the Canadian Arctic Archipelago;*
- *Map tracer distributions in Nares Strait and northern Baffin Bay;*
- *Diagnose the dynamics of both oceanographic and atmospheric channel flows*
- *Investigate bivalve shells for their potential as a paleo-climatic proxy; and, finally*

On completing this 5-year pilot project, we will have the knowledge to recommend a sustainable monitoring project to explore variability in fluxes on decadal and longer time scales.

Our program will be complemented by simultaneous observations at other key locations, all under the umbrella of the international Arctic Sub-Arctic Ocean Fluxes (ASOF) study. Canadians will maintain instruments that since 1998 have recorded flows in Barrow Strait (Simon Prinsenberg and Peter Rhines) and in Cardigan Strait & Hell Gate (Humfrey Melling). European colleagues will install moorings in Fram Strait and other areas east of Greenland. Observations will be initiated in the Arctic Ocean upstream of our site (Mike Steele) and in Davis Strait downstream (Craig Lee). Over the next five years, this integrated program will provide, for the first time, the foundation to study the full flux of freshwater out of the Arctic and its response to system-scale driving forces.

2. Strategy

Logistical and scientific considerations have lead us to focus our efforts in Nares Strait north of 78°N and in Hell Gate and Cardigan Strait at 90°W. Nares Strait is a narrow (40 km) and long (500 km) passage between high terrain in northern Ellesmere Island and Greenland, where the land rises to an elevation of 500-2000 m within a few kilometres on both sides of the strait. Hell Gate and Cardigan Strait are channels of 4-km and 8-km width, respectively, that separate Ellesmere and Devon Islands. These channels are in very remote areas, which also offer additional challenges – an extremely cold climate, a preponderance of multi-year ridged ice, plentiful icebergs, strong tides, persistent high winds and an elusive direction reference in the geomagnetic field.

The freshwater flux through Nares Strait is carried both by the flow of low salinity seawater and by the drift of ice. Topographically intensified wind is thought to be an important influence on oceanic flows. Our observational approach combines an array of moored instruments, hydrochemical surveys, satellite remote sensing, bivalve chemical record analyses and mesoscale atmospheric modelling.

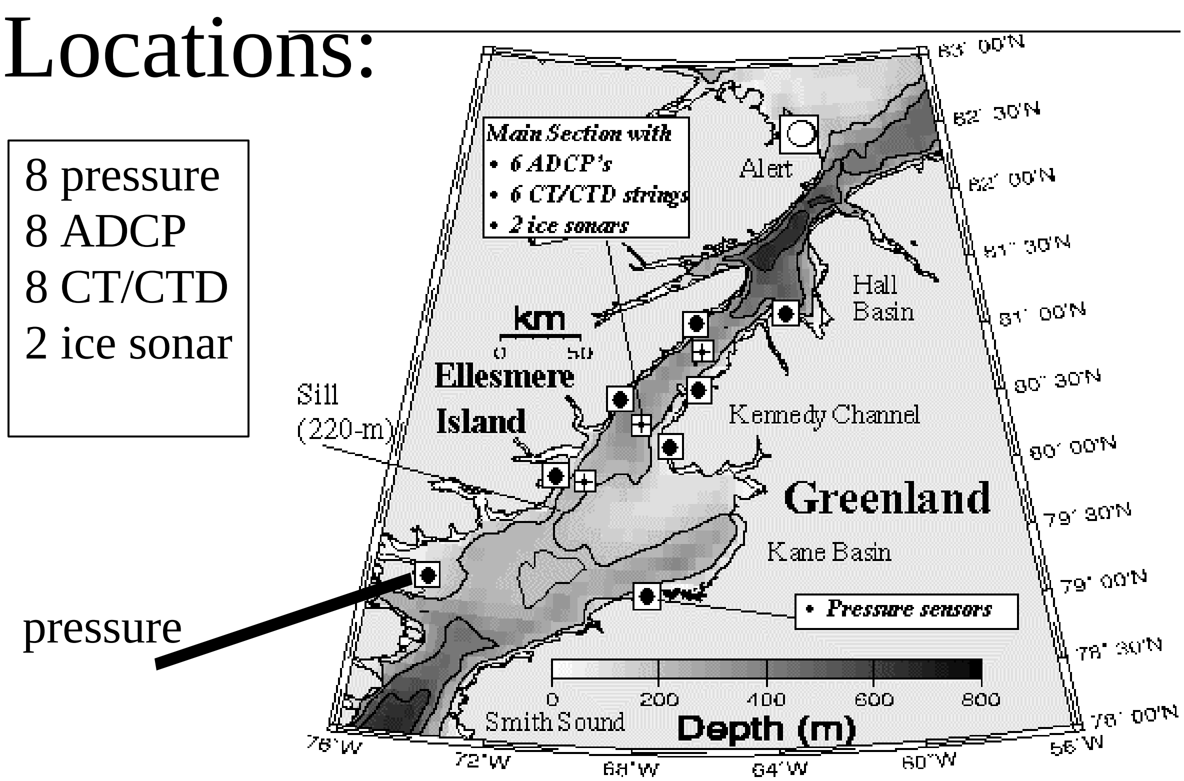

FIGURE 3. Proposed mooring deployment locations in Nares Strait and bottom topography. The main section across southern Kennedy Channel contains 6 upward looking ADCPs, 2 ice-sonars, and 2 pressure sensors. Symbols "●" and "✦" indicate pressure-sensor and ADCP mooring locations. Each ADCP mooring location also contains a CT/CTD string on a mooring line separate from the bottom mounted ADCPs. Note a referenced GOOS tide gauge "O" located at Alert on northern Ellesmere Island.

Moorings

Moorings in Cardigan Strait were serviced in August 2002, for a third deployment of two years. In the late summer of 2003, we plan to deploy an array of 26 moorings in Nares Strait using the USCGC *Healy*. The moorings will be retrieved and re-deployed in April 2005, working from the ice surface using aircraft for transport. The array will be recovered again from the ice in April 2007.

The working area is too far from any airport or existing field camp to permit daily outings. Hence a field camp will be set up specifically for this project. Wintertime logistics will be co-ordinated through the Polar Continental Shelf Project (PCSP) and VECO with support in the advance caching of fuel from Canadian and US Coast Guard icebreakers. Light helicopter and ski-equipped twin otter will be used to support mooring operations on the ice. The moored array consists of eight bottom-mounted 75-kHz acoustic doppler current profilers (ADCP), eight taut-line moorings carrying conductivity, temperature, depth (CTD) recorders, two taut-line moorings carrying ice-profiling sonar, eight shallow moorings carrying bottom pressure recorders and two timed water samplers. The principal observational line cuts a 35-km wide cross-section between Greenland and Ellesmere Island at about 81.5°N. It incorporates fourteen moorings, six with ADCPs, six with CTD recorders and two with ice-profiling sonar. The 5-km mooring separation should resolve the internal Rossby radius of deformation in this area. The low-frequency ADCPs should operate effectively in Arctic waters to the full 350-m range to the surface.

A specially designed torsionally rigid bottom mount will eliminate any reliance on the weak and variable geomagnetic field as a direction reference. The mooring holds the ADCP on a fixed (but unknown) heading throughout the deployment, while permitting the instrument to pitch and roll in response to current. The orientation of the ADCP will be determined a-posteriori from the principal axes of the dominant tidal currents in the along-channel direction. This novel approach overcomes the limitations of operating in the vicinity of the magnetic north pole. Humfrey Melling developed this design and has used it successfully in Cardigan Strait since 1998. (See: http://newark.cms.udel.edu/~muenchow/cats for schematic and pictures).

We will place two additional ADCP and CTD moorings in the center of Nares Strait about 50 km northward and 50 km southward of the main line. These moorings will provide data allowing diagnosis of the along-channel property gradients important in the flow dynamics. Ice-profiling sonar will measure ice draft that, in combination with ice velocity from the ADCPs and from feature tracking in satellite images, yields ice flux.

Eight bottom pressure recorders based on the paroscientific sensor will be deployed in shallow water (20 m) between 78°N and 83°N to provide estimates of pressure-gradient forcing. We will not attempt to measure absolute pressure gradients, since the levelling of gauges to geodetic datum is beyond our logistic capability. We will, however, detect temporal fluctuations in forcing up to annual period since our deployments will last 18-24 months. Recorders will be deployed in coastal embayments that afford some protection from scouring by drifting pack ice and icebergs. The Canadian Government will install three geodetically referenced tide-gauge stations in the Arctic in the time frame of this experiment, at Alert (82.5°N, 62°W), at Nain (57°N, 62°W) and at Holman Island (71°N, 118°W).

Surveys

Modern tracer hydrography and velocity surveys will be conducted in conjunction with mooring deployments in 2003. Multiple tracers will be used to decipher water mass origins, composition of freshwater sources (ice processes, runoff) and transformations through the straits. Parameters to be measured include pressure, temperature, salinity, O_2, nutrients, Chl-a, ä^{18}O, Ba, Alk, TIC, CFC's, ^{129}I, ^{137}Cs, Cd, and HCH's. An SBE-43 dissolved oxygen sensor will be part of the CTD-rosette package, to acquire continuous profiles of DO concentration at about 10-m vertical resolution. Samples could be made available to interested investigators for additional measurements.

A vessel-mounted ADCP with an Ashtech differential GPS system on the USCGS *Healy* will provide continuous sections of ocean velocity for the first time in these waters. We plan sections of eight stations each at the main mooring array in southern Kennedy Channel, across Smith Sound and across the eastern end of Jones Sound. We will also complete three twelve-station sections across Baffin Bay. We anticipate the scheduling of the Canadian Coast Guard Ship *Louis S. St.-Laurent* to reoccupy these sections in 2006. Additional sampling for fewer parameters will be conducted in conjunction with the aircraft missions in the late winter of 2005 and 2007.

Winds

The strong hydrostatic stability of the polar atmosphere, especially in winter, inhibits airflow over mountainous terrain. Consequently, wind in Nares Strait blows predominantly along the channel and its speed is enhanced above that associated with atmospheric pressure gradients on the synoptic scale. Katabatic drainage of cold air from adjacent ice sheets on both shores may enhance the stability and the flow of air along the strait. We hypothesize that channelling and acceleration of airflow along Nares Strait is an important contributor to the forcing of oceanic fluxes.

We will configure a multiply nested version of an atmospheric circulation model currently implemented for simulations on the Oregon coast (Default_XREF_styleREF, http://www-hce.coas.oregonstate.edu/~cmet/). We plan to use an inner grid with a 3-km mesh. The outermost model domain will be embedded in a global numerical weather prediction model. We will run daily forecast-mode simulations for 24-36 hours, and archive the surface and surface flux fields from the innermost nest for analysis. Thus we will produce a time-series of surface forcing, a climatology of surface wind fields and meso-scale dynamical analyses.

Remote Sensing

We will estimate ice motion from satellite imagery for the four-year period when moored instruments are in place. The Advance Microwave Scanning Radiometer (AMSR-E) on the recently launched EOS Aqua satellite has daily global coverage and the 89-GHz channel has 6 x 4-km spatial resolution. We will also extract daily ice motions from the 85-GHz vertical polarized channel on a 10-km regular grid using published techniques. We will screen AVHRR infrared imagery for cloud-free periods to extract daily ice motion on a 4-km grid. In combination with moored observations, we expect to quantify freshwater flux in the form of ice.

Paleo-Environmental Proxies

Bivalves preserve information on environmental conditions in annual growth layers not unlike tree rings. To extend our four-year study of water properties and circulation back in time, we will collect live bivalves for analysis of the shells.

During the *Healy* cruise in 2003 we will sample about 40 live bivalves and associated waters with the help of Inuit guides. The shells will be cut with a diamond saw in a manner consistent with the growth pattern of the species. From thin sections of the shells we will determine whether chemical ratios in most recent shell layers correlate with local water chemistry and whether the annual changes are spatially coherent.

Valuable paleo-environmental proxies have also been developed from marine sediment cores. Hence, we plan to acquire and archive cores from Nares Strait and Baffin Bay on behalf of the larger science community. These samples will be used to investigate variability in regional oceanic circulation on millennial and longer time scales.

Ocean Modelling

Ultimately, the results of this four-year study will be used to design a cost-effective and logistically practical plan for long-term monitoring of oceanic fluxes through the Canadian Arctic Archipelago. An important aspect of this plan will be the evaluation of means to parameterise these fluxes. In pursuit of this goal, we have a link with the climate modelling community, initially to the group at the University of Victoria. This group will explore the implications of our observational findings in an ensemble of ice-ocean and ice-ocean-atmosphere models on both regional, hemispheric and global scales. We will engage process-oriented modellers as our new data become available.

An Observational Array for High Resolution, Year-round Measurements of Volume, Freshwater, and Ice Flux Variability in Davis Strait

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As part of a coordinated international effort to quantify (and eventually monitor) the variability of fluxes connecting the Arctic and Atlantic Oceans and to understand the role played by the Arctic and sub-Arctic in steering decadal scale climate variability, a team of scientists from the University of Washington's Applied Physics Laboratory (UW) and the Bedford Institute of Oceanography (BIO) will deploy an integrated observing system designed to provide year-round measurements of volume, liquid freshwater and ice fluxes across Davis Strait. Fluxes through the Strait represent the net integrated Canadian Archipelago throughflow, modified by terrestrial inputs and oceanic processes during its southward transit through Baffin Bay. By the time they reach Davis Strait, Arctic waters already embody most of the transformations they undergo prior to exerting their influence on the deepwater formation sites in the Labrador Sea. This makes the strait an ideal site for monitoring temporal and spatial variability of the critical upstream boundary condition for Labrador Sea convection. Measurements at Davis Strait will be used to study how fluctuations in the Arctic freshwater system modulate deep water formation to the south, thus influencing the associated meridional overturning circulation (MOC).

Despite Davis Strait's importance, technological challenges associated with working year-round, operating beneath ice cover (first year sea ice of 0.8. – 1.8 m thickness covers the strait 6 months per year, with nearly ice-free conditions August - October) and over shallow shelves, obtaining near-surface measurements and achieving the necessary horizontal resolution over the broad strait have discouraged measurement efforts (Rudels, 1986; Melling, 1998). Most of the freshwater transport occurs in the upper 200 m, where the risk of damage from ice and icebergs severely restricts the use of conventional instrumentation. Additionally, the potentially small (O(10 km)) scales associated with along-strait flows require horizontal spacings that would be too costly to achieve with a moored array. The demanding, diverse nature of the required measurements, coupled with the need for year-round sampling capable of resolving seasonal variability, motivates the design of an integrated observing system employing several complementary technologies to resolve volume, liquid freshwater and ice fluxes at lateral scales as short as 3 km and temporal scales of 15 days. The UW/BIO array (Figure 2) will combine mature technologies with recent developments in autonomous gliders (presently undertaking their first extended science missions) to address all aspects of flow through Davis Strait.

The components of the proposed system include:

- Acoustically-navigated Seagliders will provide year-round, repeated, high-resolution hydrographic sections (temperature, conductivity and dissolved oxygen) across the Strait. These observations will be combined with the moored array data to produce estimates of absolute geostrophic velocity and to estimate volume and freshwater fluxes.

- A sparse array of four subsurface moorings, each instrumented with an upward looking sonar (ULS), an Acoustic Doppler Current Profiler (ADCP at 100 m) and a single conductivity-temperature (CT at 100 m) sensor, will provide time series of upper ocean currents, ice velocity and ice thickness. These measurements will be used to estimate the ice component of freshwater flux, provide an absolute velocity reference for geostrophic shears calculated from Seaglider hydrographic sections, and derive error estimates for lower-frequency flux calculations.

- Bottom-mounted ADCPs and CT sensors will also be deployed across the Baffin and Greenland shelves in instrument packages called bottom landers that are resistant to fishing trawlers and icebergs. These measurements will help quantify the variability associated with the strong, narrow coastal flows. These may be supplemented with profiling moorings and quasi-expendable CT sensors.

Although each of these components is critical, the adaptation of autonomous glider technology for high latitude operation warrants elaboration. The University of Washington's Seaglider (Eriksen et al., 2001) will provide a novel sampling capability, analogous to having a dedicated, albeit slow-moving, ship making continuous cross-strait profiles of basic hydrographic variables throughout the year.

Seagliders (Figure 1) are small, reusable autonomous underwater vehicles designed to glide from the ocean surface to as deep as 1000 m and back while collecting profiles of water properties (Eriksen et al., 2001). Mission durations depend largely on ambient stratification and profile depth, but in Davis Strait endurance should exceed one year. Seagliders receive commands and report their measurements via satellite telephone; they also store all data onboard for delayed mode transmission or post-recovery interrogation.

Figure 1. Jim Osse prepares Seaglider for launch from the University of Alaska - Seward Marine Center's inflatable boat. Seagliders can be easily manipulated by two people and are typically launched from small, flexible platforms such as inflatables and work boats. (Photo courtesy of Tom Lehman and Jim Osse.)

Currently, Seagliders use GPS navigation when at the sea surface to dead reckon toward commanded targets by assimilation with a Kalman filter. The vehicles receive new commands, upload data and obtain GPS fixes during a brief (5-10 minute) surface interval following each dive. Seagliders propel themselves by altering their buoyancy (inflating or deflating and oil-filled swim bladder) and change direction by adjusting their attitude (pitch and roll). Seagliders can maintain glide slopes ranging from 1:4 to 3:2, with typical horizontal speeds of approximately 0.25 m/s (22 km/day) and vertical speeds of 0.075 m/s providing horizontal resolutions of 1-4 km, depending on dive depth. Power limitations restrict sensor payload to temperature, conductivity, dissolved oxygen and a forward-looking altimeter, to be used both for ice and bottom avoidance, and for obtaining rough estimates of ice thickness. Navigation and knowledge of vehicle buoyancy and pitch angle allows estimation of depth-averaged current and suitably energetic vertical velocity fluctuations.

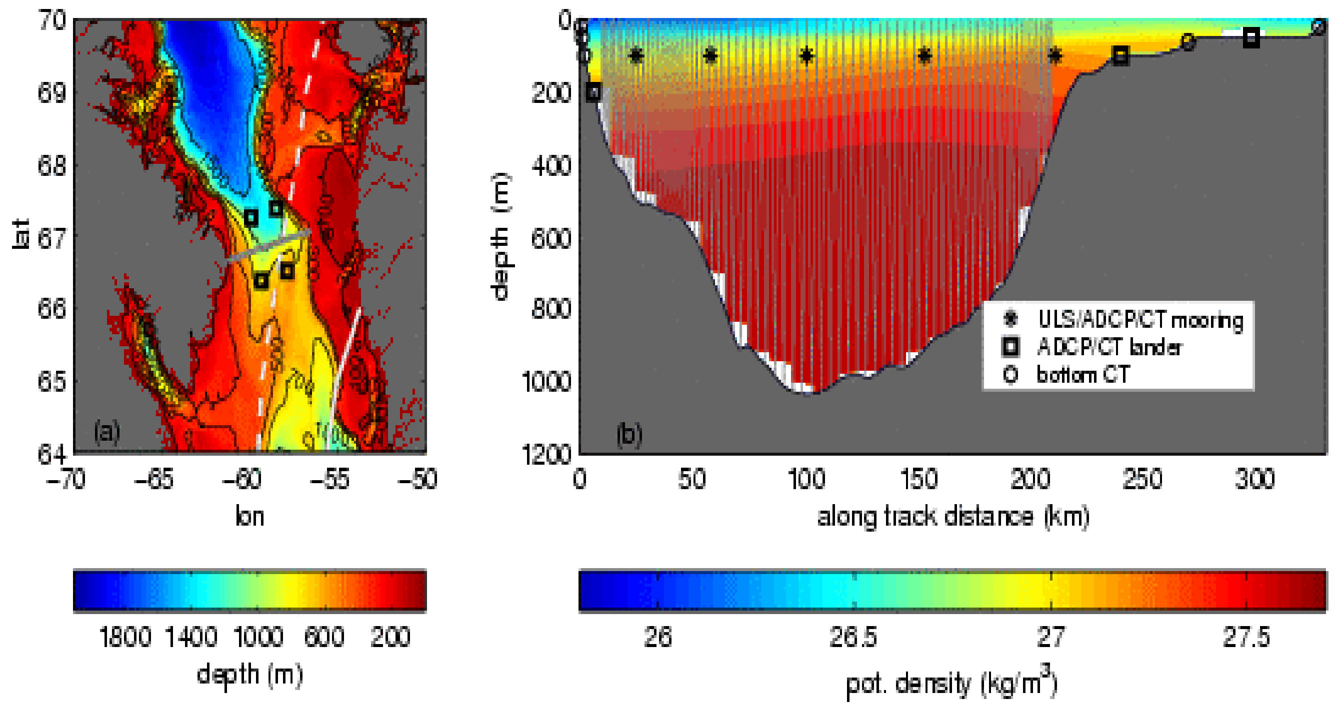

Figure 1. Array component locations and IBCAO bathymetry in Davis Strait.(a) RAFOS sources (squares) and glider survey route (solid grey line) between Baffin Island and Greenland. White lines indicate December (dashed) and March (solid) mean location of the 50% sea ice concentration contour extracted visually from National Ice Center data 1997-2002. (b) Moored sensor locations and the glider flight path (light blue line) plotted over an annually-averaged climatological potential density section extracted from Hydrobase (Curry, 1996).

With the integration of RAFOS positioning technology, Seagliders will be capable of extended operations in ice-covered regions, providing year-round, repeated (~15 days for Davis Strait), high-resolution (2-4 km, depending on profile depth) sections of temperature, salinity, dissolved oxygen and ice draft. They will sample the entire water column, from near the seafloor to either the surface or the ice bottom, providing finely resolved measurements of water properties and, when combined with the moored ADCPs, cross-strait sections of absolute geostrophic velocity. The integrated Seaglider-RAFOS system provides: (1) sampling the upper ocean in the presence of overhead ice, (2) measurements at short horizontal scales and (3) repeated year-long time series of sections.

The presence of sea ice complicates application of glider technology to Davis Strait monitoring. When operating under ice, the gliders will be unable to receive GPS fixes or communicate via Iridium satellite phone. The loss of GPS navigation is the most serious problem to be overcome when operating under ice. The glider navigates by flying from waypoint to waypoint along a specified track, using a Kalman filter that incorporates the depth averaged current (as determined from successive absolute position fixes) to select an appropriate heading. During a dive the glider dead reckons along this heading using only its glide angle, compass, and vertical descent rate. To replace the absolute position fixes normally provided by GPS, the gliders in Davis Strait will use RAFOS-based acoustic navigation. Historically, RAFOS (and SOFAR) navigation has been used to track free drifting subsurface floats (Rossby et al., 1986), but glider navigation is a relatively straightforward application of the technology. The primary differences are the need to do the navigation processing onboard, in real-time, and reduced acoustic propagation distances due to scattering losses off the ice.

The RAFOS system was chosen over other possible acoustic solutions because components are readily available and the expected signaling range is large enough that a relatively small number of sources need to be deployed. Both previous analysis of RAFOS signaling ranges in ice-covered environments (Manley et al., 1989) and UW-APL analysis of the Davis Strait case suggests that the four RAFOS sources (two north and two south of the sampling line) are sufficient to provide navigation for Seaglider operations within the strait (including substantial margin for vehicles that stray significantly from the survey line). Respective real-time and post-processing position accuracies should be 3 km and 1 km or better. Ice cover will prevent Seagliders from communicating for approximately nine months a year, preventing the vehicles from both uploading data and downloading new commands. Considerable effort must thus be invested in developing fully autonomous control strategies for extended under-ice operation, including ice avoidance and surfacing decision algorithms. Data from the under-ice period will be stored on board for transmission to shore as soon as ice free conditions allow the glider to surface and reestablish normal Irrdium telephone telemetry.

Employed together, several complementary technologies will provide comprehensive measurements of liquid freshwater and ice flux through Davis Strait. The UW-BIO effort hopes to overcome the challenges presented by demanding operating conditions and seasonal ice cover using a combination of moorings, bottom landers and acoustically navigated autonomous Seagliders. Plans call for the initial deployment of the moored array, complete with bottom landers over the Baffin and Greenland shelves, in late summer 2004. Array elements will be serviced annually, with the final recovery occurring in 2007. Seaglider-RAFOS integration and testing will extend through the early years of the program, marked by a series of increasingly demanding tests that include operation in open-water RAFOS fields and short-term under-ice operations. Seaglider deployments will proceed according to development and testing success, with initial operations in Davis Strait anticipated in 2005.

Eriksen, C., Osse, T.J., Light, R.D., Wen, T., Lehman, T.W., Sabin, P.L., Ballard, J.W., Chiodi, A.M., 2001: Seaglider: A long-range autonomous underwater vehicle for oceanographic research, *IEEE J. Oceanic Eng.*, 26, 424--436.

Melling, H., 1998. Exchanges of freshwater through the shallow straits of the North American Arctic. in The Freshwater Budget of the Arctic Ocean, E.L.~Lewis et al. eds., Kluwer Academic Publishers.

Rudels, B., 1986: The outflow of polar water through the Arctic Archipelago and the oceanographic conditions in Baffin Bay. *Polar Res.*, {\bf 4}, 161-180.

Curry, R.G., 1996: Hydrobase – A database of hydrographic stations and tools for climatological analysis, Woods Hole Oceanographic Inst. Tech. Rep., WHOI-96-01, 44 pp., Woods Hole Oceanographic Inst., Woods Hole, MA 1996

An Update on IAPP Activities and CASES

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The Year 2002 brought important advances for both present and future goals of the International Arctic Polynya Program (IAPP). In April, the AOSB approved the newly proposed goal to establish decade-long programs for integrated multidisciplinary time-series work in the major polynyas of the Arctic. The IAPP Science Coordinating Group (SCG) was encouraged to develop a scientific blueprint for this new, and increasingly pan-Arctic, approach to polynya research. The developing plan goes by the acronym PACE, for Polynyas in the Arctic's Changing Environment, to emphasize the potential instability, at both the physical and ecosystem levels, of these previously reliable formations in response to environmental changes of a broader scale, as well as their likely feedbacks to the larger Arctic system. The first international PACE effort is expected to be a Canadian–led program known as IMPACS, for International Monitoring Program of Arctic Canadian Seas. IMPACS, which could begin as soon as 2005-2006, would address inter-annual variability of the physics and ecosystems of the North Water (northern Baffin Bay) and the Cape Bathurst Polynya (Mackenzie Shelf and Amundsen Gulf region).

Simultaneously with the push to develop PACE has come the launching of the program that will fulfill the original terms of reference for the IAPP. Those terms called for significant advances in knowledge of three major Arctic polynyas at a highly integrated multi-disciplinary level. The final program in this series of three examines the Cape Bathurst Polynya. It builds upon the successful models of the first two IAPP studies, the International Northeast Water Polynya Study (NEW, 1991-1993, using German and US icebreakers) and the International North Water Polynya Study (NOW, 1997-1999, using Canadian icebreakers with Japanese and US fuel support in 1999). Study of the Cape Bathurst Polynya falls under the international Canadian-led project known as the Canadian Arctic Shelf Exchange Study (CASES, 2002-2004, Canadian icebreakers, with fuel support from other nations anticipated). This June, the opportunities for success with both the present (CASES) and future (PACE) goals of the IAPP received a major boost with the announcement of an award from the Canadian Foundation for Innovation (CFI) to establish a long-term Arctic research facility in the form of a research-dedicated icebreaker and associated scientific equipment (see companion article by Marty Bergmann). This facility can be deployed annually, in both the North Water and Cape Bathurst polynyas, over the next 15 years or so.

As experiences with the first single-polynya studies evolved in the 1990s, the need for measurements in all seasons, not just during the classic Arctic bloom months of June and July, was quickly realized. While the field season for NEW was largely limited to late spring and summer, with long-term moorings and satellite imagery providing data remotely during the rest of the year, the NOW icebreaker-sampling season was successfully extended from March to October. This extension allowed documentation of the extraordinarily long and productive bloom season of the North Water, which rivals that of other polar and even many temperate ecosystems (see Deep-Sea Research Part II Special Issue 49, October 2002, on the NOW). A central aim of the CASES field program is to study not only the bloom season of the Cape Bathurst Polynya but also, as an important new dimension, the fall and winter pre-conditioning of the broader Mackenzie Shelf/Amundsen Gulf ecosystem. This pre-conditioning is a function of the minimum fall and winter discharge of the Mackenzie River, just as the spring and summer development of the bloom is in response to the intense freshet and variable ice break-up. Thus, this third IAPP study represents the first international and fully interdisciplinary examination of an Arctic polynya that is influenced by a major river (the other river-impacted polynyas form on the Russian shelf, a region not yet available for IAPP-style international study). Because the Mackenzie Shelf area cannot be reached from southern ports until August, when the ice has retreated, the only possible way to achieve the goals of CASES is to over-winter a research icebreaker in the area.

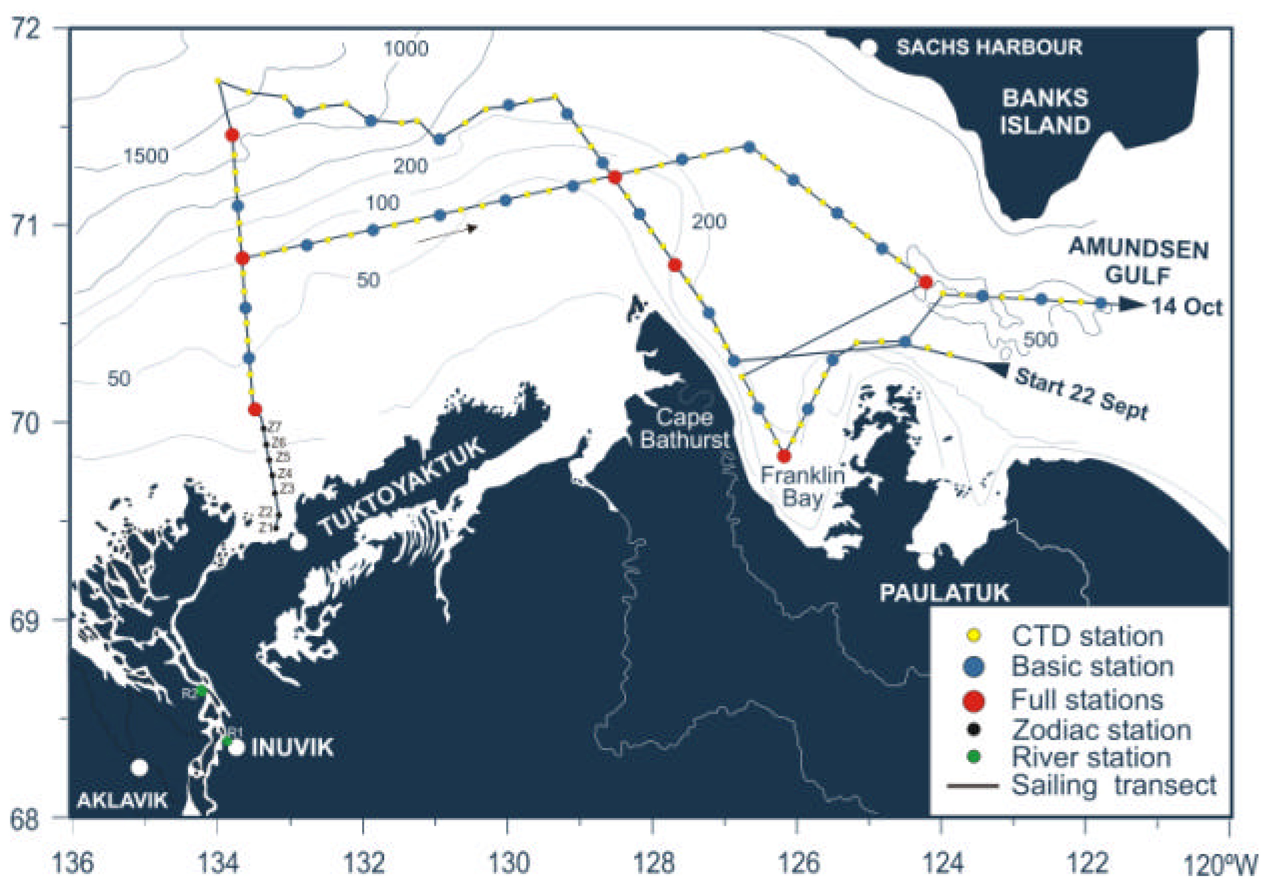

Figure 1. Cruise track of the CCGS *Pierre Radisson* and sampling stations visited during the CASES 2002 expedition to the Mackenzie Shelf/Amundsen Gulf study area.

In preparation for this overwintering, scheduled for 2003-2004, two expeditions were conducted in the fall of 2002. During the first, eight CASES mooring lines supporting current meters and sediment traps were moored in the study area as part of the 6–24 September expedition of the CCGS *Sir Wilfrid Laurier*. From 22 September to 14 October, the second expedition completed a multidisciplinary synoptic survey of the physical and biogeochemical properties of the study area onboard the CCGS *Pierre Radisson*. A science party of 34 CASES researchers sampled over 110 stations covering the Mackenzie Shelf and Amundsen Gulf area (see figure above). At that time, the flaw-lead polynya system was fully developed and real-time measurements indicated that the bloom season had peaked. Continuous profiles of temperature, salinity, light transmittance, chlorophyll *a* fluorescence, oxygen and pH were conducted at all stations using a Seabird 911+ profiler. Sampling at Basic stations included the same profiles plus Rosette sampling of DOC, DIC, nutrients, total and fractionated Chl *a*, viral, bacterial, microbial and picoplankton densities at selected depths and plankton nets tows for the determination of zooplankton and juvenile fish densities. Operations at full stations included basic sampling plus measurements of physiological rates and diversity of microorganisms, phytoplankton and zooplankton, deployment and recovery of floating sediment traps, boxcoring of shelf and gulf sediments, large-volume pumping for contaminants and thorium profiles, profiles of UV light penetration, ice algal sampling and helicopter surveys for satellite validation of the snow-ice fields. As the ship moved through the study region, atmospheric conditions, heat and gas fluxes and contaminant levels were monitored continuously.

Building on these two highly successful expeditions, the main thrust of the CASES program will be the 2003–2004 one-year overwintering of the newly refitted and equipped Canadian research icebreaker, starting in September 2003. During this annual cycle, the ship and landfast ice camps will support the year-round sampling of the polynya and shelf ecosystem. Ship-based sampling will be conducted along a series of sampling transects, adjusted seasonally with the expansion-reduction of the open water (navigable) area. Foreign contributions to the costs of fuel for icebreaking are expected to maximize opportunities for shipboard sampling even during wintertime.

Overall, this proposed plan will guarantee a three-year interannual comparison of ecosystem maturity in September, in response to oceanic, sea-ice and atmospheric forcings. It will also represent the first ever, year-round, highly integrated, multidisciplinary study of an Arctic shelf ecosystem, including the IAPP's targeted third polynya. Unlike the Northeast Water and North Water, the Cape Bathurst Polynya represents a segment of the comparatively understudied circum-Arctic flaw-polynya system.

Because planning for CASES is proceeding in parallel with the development of PACE (and IMPACS), polynya research under CASES can be seen as the beginning of PACE's long-term field activities. The IAPP-SCG is currently expanding the PACE plan, in full cognizance of the CASES plan, to include a detailed rendition of multidisciplinary measurements that can and should be made annually from an icebreaker in order to evaluate the maturity of the ecosystem, as well as critical forcing factors, at the end of each the bloom season. The latter corresponds with the most reliable periods of open water for navigational purposes, in both the North Water and the Cape Bathurst Polynya, and thus the schedule of the newly funded Canadian research icebreaker.

Both the CASES and the PACE plan are benefiting from increased participation at the international level. The last IAPP meeting held in Riga, Latvia, on 7–8 November, represented an extension in many ways of a very stimulating educational forum for junior Nordic and senior Arctic researchers, organized by IAPP-SCG member Paul Wassmann in Sigulda, Latvia, 1–7 November. As a result of the interests gathered at that forum, CASES and PACE have entrained new players, insights and opportunities from students and investigators in Canada, Denmark, Finland, Germany, Greenland, Norway, Sweden, and the USA. The pan-Arctic aspect of IAPP research is becoming increasingly healthy as momentum builds for the long-term time-series studies of the future.

International Shelf-Basin Exchange in the Arctic (SBE) Working Group

Jackie Grebmeier
Chair, SBE Working Group
University of Tennessee

An accumulated body of research indicates that climate change will significantly impact the physical and biological linkages between the Arctic shelves and adjacent ocean basins. Both on-going and planned scientific studies of shelf-basin exchange of water, particulate and dissolved materials influenced by physical and biogeochemical processes are being undertaken by various countries in the Arctic. In the framework of international collaboration, a pan-Arctic group of scientists have been organized into a working group under the direction of the Arctic Ocean Studies Board to update and coordinate these activities. The goal of the International Shelf-Basin Exchange (SBE) working group is "to provide a forum for idea exchange and coordination of on-going and planned shelf-basin exchange science projects and goals in a pan-Arctic sense." There are four major objectives of this working group:

- Develop common Arctic Shelf-Basin Exchange science questions
- Provide a forum for developing thematic pan-Arctic studies
- Allow opportunities for cross-platform cooperative studies in different Arctic regions, and
- Devise a set of standard, long-term measurements that can be collected across the Arctic.

The twelve committee members in the SBI working group, by country, study focus, and discipline, are:

1. Leif Anderson-Sweden (Arctic Ocean, 2005 Beringia Cruise*, chemical oceanography)
2. Eddy Carmack-Canada (Beaufort sea, JWACS*, physical oceanography)
3. Mickle Flint-Russia (Russian SBI: E. Siberian/Chukchi seas; biological oceanography)
4. Louis Fortier-Canada, CASES* (eastern Beaufort Sea, biological oceanography)
5. Jackie Grebmeier (acting chair)-USA (SBI*, Chukchi & Beaufort seas, biological oceanography
6. Heidemarie Kassens-Germany (Laptev Sea; geology)
7. Wieslaw Maslowski-USA (Arctic modeling)
8. Ruediger Stein-Germany/Kara Sea; geology)
9. Koji Shimada-Japan (JWACS, Chukchi/Beaufort seas; physical oceanography)
10. Leonid Timokov-Russia (Laptev Sea/ESS/Russian SBI; physical oceanography)
11. Paul Wassman-Norway (Barents Sea/biological oceanography)
12. Jinping Zhao-China (Chukchi Sea/Arctic/2003 cruise; physical oceanography)

*CASES=Canadian Arctic Shelf-Exchange Project
*JWACS=Joint Western Arctic Climate Study
*2005 Beringia Cruise on the RV Oden
*SBI=Western Arctic Shelf-Basin Interactions Project

Each member represents an ongoing or planned research program in the Arctic as described in brief summaries below. Figure 1 outlines the regional locations of these programs, with further information provided as web links.

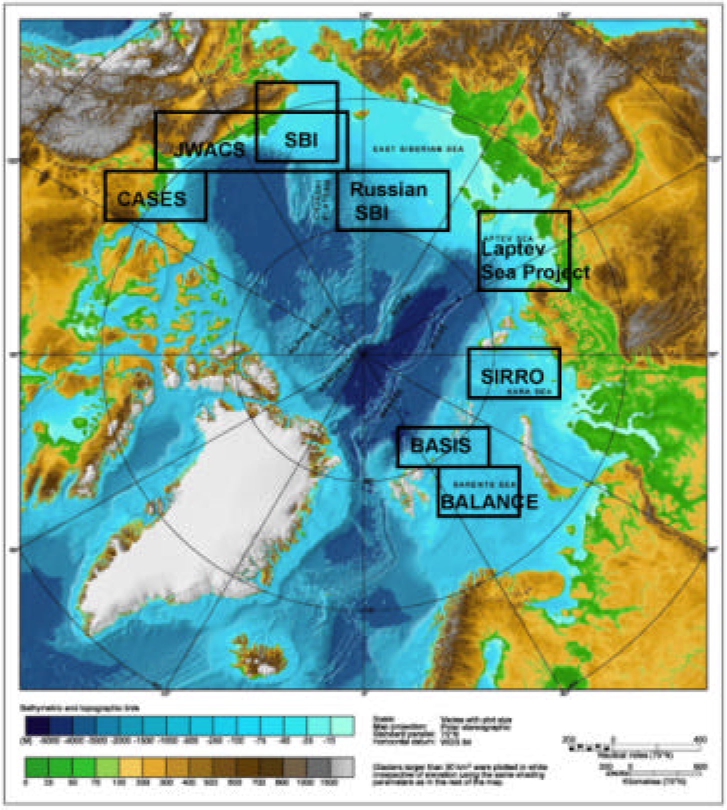

Figure 1. Location of on-going SBE-relevant projects in the Arctic.

SBI-Western Arctic Shelf-Basin Interactions (US-led, international partners)-SBI is investigating the input of northward fluxes of water and bioactive elements through the Bering Strait, the seasonal and spatial variability in the production and recycling of biogenic matter on the shelf-slope area, and temporal and spatial variability of exchanges across the shelf/slope region into the Canada Basin (http://utk-biogw.bio.utk.edu/SBI.nsf/; Grebmeier, Maslowski-USA)

JWACS-Joint Western Arctic Climate Study (JAMSTEC-Japanese Marine Science & Technology Center and Canadian government labs)-similar to SBI and SEARCH (Study of Environmental Arctic Change) objectives, with focus on the role of the western Arctic Ocean in climate variability. The study area encompasses the whole of the Canadian Basin, with current focus on shelf and basin domains from the Chukchi Borderland complex to Banks Island; physical, biochemical and paleoceanography work; interface US SBI and Canadian CASES (Carmack-Canada, Shimada-Japan)

CASES-Canadian Arctic Shelf Exchange Study: The central objective of CASES (http://www.giroq.ulaval.ca/cases/) is to understand and model the response of the Mackenzie Shelf ecosystem to atmospheric, oceanic and continental forcing of sea-ice cover variability; starting 2002, with ship frozen in ice in 2003 (Fortier-Canada)

Russian SBI: Cooperative agreement between University of Alaska Fairbanks and Shirshov Institute of Oceanology in Moscow, discussion with Arctic and Antarctic Research Institute (AARI) in St. Petersburg; work toward US SBI-type study focusing on physical and biogeochemical shelf-basin exchange topics (Flint and Timokov-Russia, Grebmeier-USA)

China (2003 Arctic cruise, 5 yr plan)-physical shelf-basin interactions in the Chukchi and Beaufort seas, and Canadian Abyssal Plain; impact freshwater input, sea ice variability on global climate change, warming of Arctic; use deep moorings and free-floating buoys; cooperate with US SBI (Zhao-China)

Sweden-Barents Sea is a region where changes in the driving forces could have a significant impact on the thermohaline circulation, and thus on climate. The study would focus on the biochemcial transformation of Atlantic

Water, which sets the initial properties (primarily through the large air-sea fluxes of heat and CO2) of close to 50% of the overflow water that enters the North Atlantic much further downstream; contact for 2005 trans-Arctic Oden cruise [http://www.polar.se/english/expeditions/beringia2005] (Anderson-Sweden)

Norway (Nordic Network)-to create synergy between the Nordic countries, and to increase the activity between the Nordic and non-Nordic countries under the title "Carbon and ecosystem feed back in the Nordic Seas in an era of climate change." Our main goal is to add to a pan-Arctic perspective, which is a necessary perspective for Arctic research in the future. Also BASIS (Barents Sea Impact Study) and BALANCE (Wassman-Norway)

Germany/Russia (Kara Sea)-interest to expand SIRRO ("Siberian River Runoff" project to outer shelf-slope of Kara Sea; possibly include biological, (bio-)geochemical and geological processes associated with input by the Siberian rivers Ob and Yenisei and its impacts and influence in the environment of the outer shelf and slope; also expansion of Laptev Sea project to outer shelf and slope. (Stein-Germany, Russia-Timokov)

Further information and updates on the SBE working group can be found at the AOSB website: http://www.aosb.org or by contacting Dr. Jackie Grebmeier, Director and SBI Project Chief Scientist (ph.+1-865-974-2592, fax: +1-865-974-7896; email: jgrebmei@utk.edu).

The 22nd Arctic Ocean Sciences Board Meeting

March 29 – March 31, 2003

Kiruna, Sweden

More information at:
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In conjunction with the Arctic Science Summit Week

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