# ARCTIC / SUB-ARCTIC OCEAN FLUXES STUDY

**Report of the 3rd meeting of**

*ASOF International Scientific Steering Group*

25-26 October 2003

Seattle, USA

**February 2004**

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# 1. Introduction

The third ASOF International Scientific Steering Group meeting was held on 25-26 October hosted by Peter Rhines at the Ocean Science Building of the University of Washington in Seattle, USA. Bob Dickson, chairman, opened the meeting by welcoming the participants (see Appendix B). After a short review of the meeting agenda (see Appendix A), Bob Dickson started by introducing the two themes of the meeting: “Towards Implementation” and “Keeping it going”.

Several elements of ASOF mentioned in the Implementation Plan have been funded. Building on the VEINS program of EC MAST-3 (1997-2000), the current ASOF-EC projects (2003-2005) will extend and develop the measurements of all the significant ocean fluxes that connect the North Atlantic with the Arctic Ocean via the Nordic Seas. Direct funding for ASOF-EC totals 4.81M Euros, with an equivalent sum in ‘matching contributions’ by participants institutions. In the western part of the ASOF domain, the pioneering measurements of flow through the main passageways of the Canadian Arctic Archipelago ---in Barrow Strait by S. Prinsenberg’s Group at BIO Dartmouth and in Cardigan Strait, Hell Gate and Jones Sound by H. Melling’s Group from IOS Sidney--- have been achieved under national funding by the Canadian departments of Fisheries and Oceans (DFO) and Natural Resources (NRCan). Efforts are underway to ensure that these important and technically-challenging measurements continue. The scope of related activities in the region has recently been expanded by two of the main projects of the Arctic Hydrology initiative of the US NSF Office of Polar Programs: “Variability and forcing of fluxes through Nares Strait and Jones Sound” ($1.33M led by K. Falkner of Oregon State University and $2.06M with $0.3M Uni. Delware matching funds, A. Muenchow of the University of Delaware) and “Observational Array for high resolution, year-round measurements of volume, freshwater and ice-flux variability in Davis Strait” ($3.48M led by C. Lee of University of Washington). Three smaller projects for the observation of climate change or freshwater dynamics in this Arctic-subpolar zone, led by P. Rhines and C. Eriksen of UW have been awarded by NSF-OPP, NOAA-ARCTIC and NOAA-ARCTIC/CIFAR respectively, to a total amount of $0.7M. And it is by no means unimportant that an occasional repeat-XCTD transect organized jointly by K. Shimada (JAMSTEC) and E. Carmack (DFO Sidney) is beginning to reveal previously-unattainable detail along the whole length of the important mixing zone between Baffin Bay and the Labrador Sea. Elsewhere, the RAPID Thematic Programme of UK-NERC is moving towards its 2nd call (see Appendix C). Importantly, this NERC initiative has itself been designed to interface with other national efforts: USA and Norway. In Norway itself, steps are underway to merge a number of existing research programmes on climate, to form a single over-arching national programme NORKLIMA.

Keeping the whole thing going is a major task since in most cases the funding system is limited to three years or so. New opportunities must be sought in order to continue the measurements. Two proposals were submitted to the October EC FP6 call: ASOF FRAM and ASOF-FAST. ASOF-FRAM is a Specific Support Action for international cooperation in the role of the Polar Oceans on the Global Water Cycle, providing a Pan-European contribution to setting up the International Polar Year (IPY) in 2007-8. ASOF-FAST is a Specific Targeted Research Project for international cooperation for an improved and more integrated observing system to measure the boundary fluxes of salt/freshwater into and around the Nordic Seas, to detect changes in these fluxes and to assess the impact of these changes on the freshwater balance of the Nordic Seas system.

On ASOF-W , according to Tom Pyle (NSF), signs are promising for extra money for Arctic Science as well as for SEARCH infrastructure. John Calder (NOAA) also stated that the role of the Arctic is well considered in the planning document "US Climate Change Science". There is certainly a will to develop an international framework for observing the earth and the Arctic is included. This high level thinking will eventually find expression in agencies budgets in the next few years. ASOF is encouraged to continue with the implementation, identifying the measurements that need to be sustained at multi-decadal scale and providing results to agencies so that in turn they can make the case for continuing funding. The ASOF-WEST community was encouraged to prepare a white paper that integrates all the current ASOF measurements into a science plan that can justify continued support of the time series, including the Canadian efforts. The aim is to make a plan for ASOF which is more than the sum of the parts.

> **ACTION ITEM 1**. The ASOF-WEST community should prepare a white paper, which gives an integrated science vision of the ASOF-WEST current measurements, and make the point of continuing those for a decade. (P. Rhines leading)

And for ASOF-EAST there will be a further call to EC FP6 which will likely include research questions already stated as of interest but which were not open in the previous calls: global water cycle and climate is one such.

A short discussion initiated on whether ASOF should consider ecosystem issues and socio-economic impacts in its future development. Opinion was strongly expressed that the physical aspects of our study should move along first. We need to understand and predict the physics and then apply our knowledge to the ecosystem. The ecosystem is perceived as the end point.

## 2. ASOF-WEST Status and Plans

### 2.1 Towards an Integrated Strategy (Peter Rhines)

ASOF is founded on the idea that oceanic freshwater and heat transports are both crucial to climate. However the importance of ocean circulation has been recently challenged by Seager et al. (2002) (see Rhines and Hakkinen, ASOF Newsletter, n.1, 2003). Bryden and Imawaki (2000) in their survey of oceanic heat transport emphasize the atmospheric flux as comprised of nearly equal contribution from latent and sensible heat. Latent heat is freshwater ---about 2.5 PW of meridional heat transport is carried by 1 Sv of freshwater--- and its transport is an intrinsically coupled atmosphere-ocean mode, which is energized particularly in the subtropical Atlantic. Thus, although the total heat transport of the atmosphere is significantly greater than that of the ocean, the moisture-bearing mode is by definition equally shared.

The Atlantic storm track (varying with NAO) can provide a specific integrating theme for ASOF-W. Climate models exhibit a big scatter in its prediction. The major cause seems to be the unsatisfactory representation of ice in the models and also the different representation of ocean circulation. What is the basin scale circulation of north Atlantic? And how sensitive is it to anthropogenic forcing? Many global climate models predict warming 2 - 4 times stronger in the Arctic than in global mean: ice-albedo feedback is one factor but dynamical shifts including ocean circulation may be another. Most of the IPCC climate models predict a decline in the rate of the Atlantic overturning circulation under a double $CO_2$ scenario. However in the Arctic and Arctic rim, most models "intensify" their meridional ocean heat transport. The North Atlantic transports of volume, heat and freshwater are difficult to observe but a few examples indicate a deceleration trend of the subpolar gyre.

New technology can also provide several integrating themes. Satellite sensors have reached a certain degree of sophistication: QuikSCAT and other scatterometer satellites reach resolutions of 10 to 100 sec/m (comparable to SAR/RADARSAT) and images of SST retrieved with the AMSR (EOS-AQUA) sensor are now cloud free. The Voluntary Observing Ships (VOS) programme provides us with a very efficient means of tracking ocean variability over long periods of time. The Oleander route (New York – Bermuda) crosses the Gulf Stream and since 1992 the ADCP mounted on the ship has provided useful timeseries like long-term transport and north wall position. The NUKA ARCTICA route (Norway-Greenland) has been in operation since 1999 with about 12 round trips per year (Apr.-Dec.). The ADCP data collected are used to quantify the upper ocean circulation and its spatio-temporal variability especially on interannual time scales. The SSS data collected since 1996 show a very strong seasonal cycle at the Greenland coast. The recent deployment of Seagliders in the Labrador Sea (see C. Eriksen in this report) aims at tracking the location and movement of low-salinity water masses, which pass into the Labrador Sea from the Arctic, via Baffin Bay. The Greenland Institute of Natural Resources at Nuuk hosted the launch group and provided many kinds of logistics and scientific support. The Seaglider hydrography will be merged with Erik Buch's annual survey extending into the coast of Greenland. It is hoped that a way will be found to deepen the collaboration between Greenland scientists and the ASOF community in the future. The Seaglider future developments include: Deepglider (for full ocean depth to 6 Km), Iceglider (needed for ice-covered regions) and Quickglider (needed to work on shallow continental shelves).

### 2.2 Pacific Gateway to the Arctic (Rebecca Woodgate)

The inflow of Pacific waters into the Arctic Ocean provides a key forcing for the Western Arctic shelf-slope-basin system. The Pacific influence can be traced across the Arctic Ocean into the northern North Atlantic. The Pacific waters are major nutrient source for the Arctic Ocean, and in the Chukchi Sea drive the largest biological production known for the Arctic. A particular important dynamical aspect of the Pacific presence in the Arctic Ocean is its contribution to stabilizing the upper ocean, thereby influencing ice thickness and upper ocean mixing. Long-term measurements have been made of the variable inflow of Pacific waters to the

Arctic Ocean through Bering Strait, together with the varying properties of those waters. Moorings have been deployed in the Bering Strait since 1990 at two or more locations, to monitor flow through the western and eastern channels of Bering Strait. One mooring is in the Russian EEZ, an area to which we have only had occasional access. In other years the western channel has been monitored by a proxy site. The timeseries of mean temperature and salinity exhibit a pronounced annual cycle. The average peak-to-peak amplitude of the salinity variation is about 1.5 psu and is driven by freezing, which expels salt into the water. In addition to the annual cycle of temperature and salinity, there are important longer-term variations. In particular, the record of salinity through the past decade shows that the Bering Strait inflow to the Arctic freshened about 1 psu during 1991-92 and then remained relatively fresh until 1999-2000, when about one-half of the earlier freshening effect was reversed. The temperature of the inflow has also changed significantly during the past decade, with a dramatic long-term warming that peaked during 1996-97. This was followed by rapid cooling, so that water as cold as observed in summer 2000 was last seen in 1990-91.

Further north, the entrance into the Arctic Ocean is marked by a complex area of tortuous topography. In this region of slopes, ridges and deep-sea plateaus, waters from the Pacific and from the Atlantic meet. The Atlantic waters are warmer, saltier and deeper. They have made their way anticlockwise around the Arctic Ocean, hugging the continental slope, in a journey that has taken them many years since leaving the Atlantic Ocean. The Pacific waters are colder and fresher and carry a rich nutrient load. The interplay of these water masses and their fate in the Arctic Ocean, both of which depend on the ice motion, the sea floor topography and the winds, is still much of a mystery today and is the focus of the NSF-sponsored Chukchi Borderland Project, a 3-year program led by UW, looking at mooring and hydrography data from the region.

Whilst the previous two projects are dominantly physical oceanography, the much larger Shelf Basin Interaction (SBI) program (2002-2004), sponsored by NSF and ONR, aims to study the biogeochemical processes that link the Arctic shelves and deep basins. The physical oceanographic portion of SBI has 3 main aims:

- Understand the ocean currents, what drives them and how they change
- Quantify the outflows from the Chukchi Sea
- Discover how Pacific waters move off the shelf and into the Arctic Ocean

Three hydrographic cruises have been performed in 2002 and two in 2003. Three more cruises are scheduled in 2004.

### 2.3 Flow through the Canadian Arctic Archipelago: What do we know? (Humfrey Melling)

The shallow straits in the Canadian Arctic that connect the waters of the Arctic Ocean to those of the Atlantic, play an important role for the global climate through their influence on deep convection. There are six choke points where the flux through the Canadian Arctic Archipelago must pass (see Table 1)

The most quoted estimates of the seawater flux through the Archipelago have their origins in hydrographic surveys of the 1960s with assumption of no motion at depth. Efforts were made in the early 1980s to reference geostrophic calculations to measured currents in a number of channels. Although the technology available at that time posed significant challenges, a general pattern emerged from this study: current near the surface flows towards Baffin Bay on the right side of the channels and counter flow on the left side creates a generally cyclonic circulation within the Archipelago. A "spectrum" of freshwater flux from the Arctic should be acknowledged. Salt stratification in the Arctic waters, moving ice and baroclinicity, concentrate freshwater flux very close to the surface, but spread it to seawater spanning a range in salinity. The freshwater flux spectrum evolves in transit. Sea ice within the Canadian Archipelago locks up to 3-5 m of freshwater and is land-fast for 6-10 months each year. This and other aspects related to the geometry and the conditions of the location, pose theoretical and technical challenges for measuring and estimating the Arctic freshwater volume flux.

| **Channel** | **Section area** *$m^2$* | **Share of total area** | **Section width** *km* | **Share of total width** | **Mean depth** *m* | **Sill depth** *m* |
|---|---|---|---|---|---|---|
| Kennedy Channel | 10,960,000 | 44.0% | 38.2 | 28.7% | 287 | 220 |
| Hell Gate & Cardigan Strait | 1,420,000 | 5.7% | 12.4 | 9.3% | 115 | 125<br>180 |
| Wellington Channel | 4,550,000 | 18.3% | 28.3 | 21.3% | 160 | 80 |
| Barrow Strait | 7,930,000 | 31.9% | 52.3 | 39.3% | 152 | 125 |
| Bellot Strait | 31,600 | 0.1% | 1.9 | 1.4% | 17 | 24 |
| Sum of Sections | 24,891,600 | 100% | 133.1 | 100% | 187 | |

*Table 1. Channel constrictions within the Canadian Arctic Archipelago*

The deployment of Doppler profiling sonars in the Arctic has stimulated new initiatives in measuring flow within the Archipelago. As part of the North Water Project (1997-98) an ADCP was deployed in one of the two moorings in Smith Sound. Data were acquired for 12 months at 20-100 m near the Canadian shore. The study in Cardigan and Hell Gate started in 1998 with a first phase aiming at evaluating a new torsionally rigid mooring for ADCP. During the second phase, the co-variability between Cardigan Strait and Hell Gate was investigated. The third phase is underway and will delineate the flow across the section of Cardigan Strait. The annual mean flow through Cardigan Strait and Hell Gate during 1998-2002 is about 0.23 Sv and 0.11 Sv respectively with a small year-to-year variation. Because of the small yearly variation, it is acceptable to interpret differences in current at the two sites in Cardigan Strait as evidence of spatial structure in the flow.

A recent funded proposal in US and Canada has allowed use of the theoretical and technological ideas developed in the study in Cardigan Strait for the measurements of fluxes in Nares Strait. Twenty-three moorings were deployed in summer 2003. Eight carry torsionally rigid ADCPs positioned at 5-km spacing across southern Kennedy Channel. The array in Nares Strait will operate initially for almost two years. It will be retrieved, serviced and re-deployed in May 2005 for a further two years. The exploratory study in Cardigan Strait and Hell Gate, initiated in 1998, will come to an end in August 2004. At present, there are insufficient resources within Canada to enhance this project in order to realize the measurement of fluxes or to prolong it for the lifetime of the Nares Strait array.

## 2.4 BIO/Canada Contribution to ASOF-WEST (Simon Prinsenberg)

The Bedford Institute of Oceanography is involved in several projects with mooring deployments in the passageways of the Canadian Arctic Archipelago. The aim is to better understand the importance of oceanographic and pack ice heat and freshwater fluxes passing through the Archipelago to the heat and freshwater budgets of the Arctic Ocean itself. Mooring observations will be used to calibrate simulations of a regional finite element numerical model that in turn will provide the total fluxes through the Archipelago, as not all the channels can be instrumented.

The field programme in Lancaster Sound started in August 1998. The channel at the mooring sites is 65km wide and reaches a maximum depth of 285m. Towards the west, Lancaster Sound shallows in Barrow Strait where sill depths of 150m occur; eastwards it deepens towards Baffin Bay. Both mobile and land-fast pack ice conditions occur normally for 10 months of the year. Ice ridges within the pack ice poses a threat to moorings which, for this reason, were designed not to extend into the top 25 m of the water column. This reduces the chance of losses due to ice. To reduce risk further, instrumentation was distributed over four moorings at each of the northern and southern sites with the higher risk, 25m level CTD (conductivity, temperature, depth) module on a single-instrument mooring. The four mooring arrays on both sides of the channel each supported two Acoustic Current Doppler Profilers (ADCPs) monitoring most of the 200m water column, and five self-contained CTD units monitoring the water properties at different depths. Year-long moorings have provided uninterrupted, bi-hourly time series of velocity, temperature and salinity data on both sides of Lancaster Sound for the period 1998-2001 (Table 2). The total oceanographic fluxes through the cross-section are assumed to be the sum of the observed fluxes from the southern array representing 2/3 of the cross-section and the observed fluxes from the northern array representing the remaining 1/3 of cross-section.

*Table 2. Estimated volume, heat and freshwater fluxes through Lancaster Sound. Units are: Heat in $10^{12}$W, Volume in $10^5 m^3/s$ and Freshwater in $10^4 m^3/s$.*

| | | Year | Fall | Winter | Spring | Summer |
|---|---|---|---|---|---|---|
| 1998/99 | Heat | -3.24 | -0.6 | -2.24 | -3.12 | -6.99 |
| | Volume | 5.35 | 1.03 | 3.74 | 4.81 | 11.8 |
| | Freshwater | 3.54 | 0.94 | 2.59 | 3.07 | 7.56 |
| | | | | | | |
| 1999/00 | Heat | -6.82 | -2.31 | -5.41 | -6.88 | -12.7 |
| | Volume | 12 | 4.34 | 9.14 | 10.9 | 23.5 |
| | Freshwater | 7.48 | 3.4 | 5.61 | 6.46 | 14.4 |
| | | | | | | |
| 2000/01 | Heat | -7.24 | -7.19 | -5.33 | -5.16 | -11.3 |
| | Volume | 12.3 | 13.6 | 8.27 | 8.1 | 19.4 |
| | Freshwater | 7.87 | 8.32 | 5.14 | 5.06 | 12.9 |

Since 2002 the array in the eastern side of the Sound comprises 13 CTDs, 5 ADCPs and 1 ICYCLER and new additional deployments are planned for 2003-2004 by UW namely 4 tide gauges, 1 ULS and 1 LRange ADCP. The ICYCLER is a subsurface mooring housing a CTD profiler; it is being designed to profile the surface (0-50m) water properties. The instrument is packaged into a two-float assembly, with the lower float containing ten times as much buoyancy as the upper float. Further development of the ICYCLER includes a new gear drive and an improved motor.

The Labrador Shelf Freshwater and Heat Fluxes project consists of a winter field survey and a year-long mooring and modelling project that studies the variability of the heat and freshwater fluxes in the form of ocean water and pack ice passing along the Labrador coast. The Labrador shelf mooring has been deployed in Oct. 2002 till June 2003 and consisted of 1 ADCP and 1 ULS-Microcat. Once the S/T profiler development of the Arctic ICYCLER has been completed, instrumentation development will be looking at adapting this technology to the Labrador shelf break (>400m) that will have to deal with both interfering fishing and icebergs.

In Canada there is no long-term plan for Arctic monitoring. The DFO present commitment of resources to Arctic science is rather small and plans are to downsize by 15% the staff and funds in 2004. Present funds used for Canadian Arctic science come from other agencies that are available for the University sector: CCGS icebreaker for science, CASES, ArcticNet. Science funding agencies are reluctant to provide funds to support logistics. Logistics are an expensive component of Arctic research: new instrumentation with greater reliability, longevity, harsh-climate and hazard tolerance could greatly reduce field costs. However Canada spends little on the development and evaluation of new tools for Arctic observations: there is a need to create an inter-agency coordination on logistics. Prolonged observations are essential to climate change detection and the evaluation of numerical models. However “monitoring” is generally regarded as unproductive science. Funding for climate research is awarded on expectation of definitive results in 3 years.

### 2.5 The Labrador Sea at Half a Knot on Half a Watt (Charlie Eriksen)

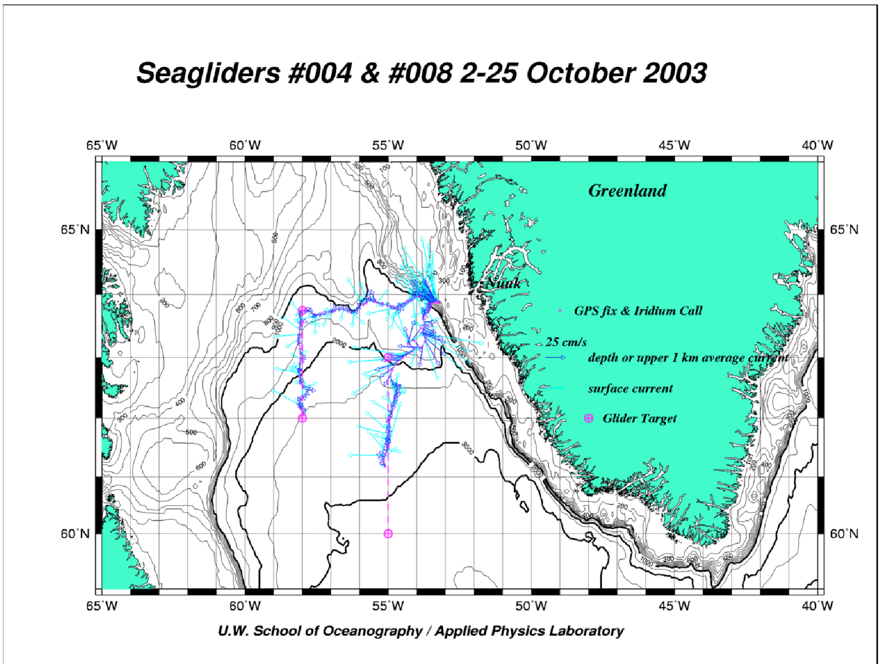

*Figure 1. Trajectories and positions of the two seagliders for the period 2-25 October 2003.*

The Seaglider is a new approach to a distributed observing network (http://www.apl.washington.edu/projects/seaglider/summary.html). Two seagliders were launched on 2nd October offshore the Greenland coast, close to Nuuk (Fig 1).

Gale force winds were supplied by fast-moving lows arriving from the Great Lakes, where a deep trough in the jetstream was stationary for some days. Three hurricanes reached Greenland in the four weeks prior the launch, energizing when they passed beneath the jetstream. It was frequently difficult to walk in Nuuk as winds averaged 60 knots for long periods. The two seagliders determine their position via GPS, call in via Iridium data telemetry satellite, upload the oceanographic data they just collected, and then download a file complete with any new instructions.

### 2.6 Fluxes Variability in Davis Strait (Craig Lee)

This project is a joint effort of the University of Washington's Applied Physics Laboratory (UW-APL) and the Bedford Institute of Oceanography (BIO). The integrated observing system that will be deployed is 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.

The UW/BIO array 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 observational system are:

- A sparse array of five subsurface moorings (400-1000m), each instrumented with an upward looking sonar (ULS), an Acoustic Doppler Current Profiler (ADCP 300 kHz, upward-looking), an Aanderaa current meter and a SBE Microcat at 300 and 500 m.
- 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. Bottom-laid SBE Microcats will be deployed in the site.
- 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.

Other additional elements might include:

- Low frequency acoustic propagation experiment consists of the integration of RAFOS positioning technology to Seagliders in order to extend operations in

ice-covered regions.
- Monitoring of Bowhead whales and other marine mammals with the addition of acoustic receivers
- Deployment of an IceCycler mooring in the Baffin slope and Greenland Shelf in collaboration with BIO
- Subsurface profiling mooring for one year in collaboration with WHOI

The initial moored array will be deployed in fall 2004. In 2005 during the first mooring turn-around, RAFOS and gliders deployments will be performed. Meanwhile the groups are working on the mooring design and early engineering for RAFOS gliders as well as establishing formal link with proposed ECOGREEN program (Buch, DMI).

### 2.7 Variability and Forcing of Fluxes through Nares Strait and Jones Sound: a Freshwater Emphasis (Kelly Falkner)

Funded by NSF and DFO for five years, this US-Canadian project will:
- Measure the fluxes via two of the three principal passages through the Canadian Arctic Archipelago
- Diagnose the dynamics of both oceanographic and atmospheric channel flows
- Map tracer distribution in Nares Strait and northern Baffin Bay
- Investigate bivalve shells for their potential as paleo-climatic proxy

On completion of the 5-years project, the PIs hope to recommend a more sustainable monitoring system to explore the variability of fluxes on decadal and longer timescales.

The focus is on Nares Strait north of 78°N and on 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 kilometers 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. That these channels are in very remote areas offers 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.

Moorings in Cardigan Strait were serviced in August 2002, for a third deployment of two years. In the late summer of 2003, the array in Nares Strait was successfully deployed 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 coordinated through the Polar Continental Shelf Project (PCSP) and VECO with support in the advance caching of fuel and heavy gear from Canadian and US Coast Guard icebreakers or by C-130 from the US National Guard. 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 recorders and two timed water samplers. The principal observational line cuts a 40-km wide cross-section between Greenland and Ellesmere Island at about 81.5°N. It incorporates seventeen moorings, seven with ADCPs, eight 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. An additional ADCP mooring has been placed on the western side of Nares Strait about 50 km northward of the main line. This mooring 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. Five bottom pressure recorders based on the Paroscientific sensor have been deployed in shallow water (20 m) between 78°N and 82°N to provide estimates of pressure-gradient forcing. The Canadian Government has recently installed three geodetically referenced tide-gauge stations in the Arctic, at Alert (82.5°N, 62°W), at Nain (57°N, 62°W) and at Holman Island (71°N, 118°W).

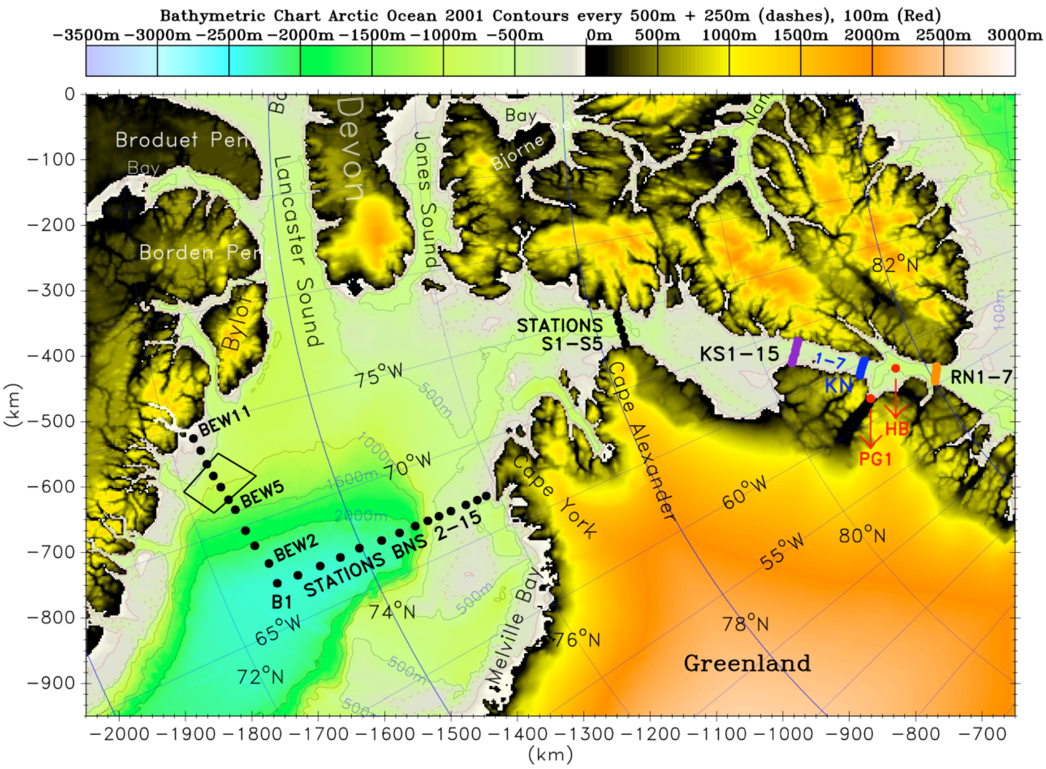


*Figure 2. Hydrographic transects carried out during summer 2003: Robeson Channel, Kennedy Channel north and south, Smith Sound and Baffin Bay.*

Modern tracer hydrography and velocity surveys have been conducted in conjunction with mooring deployments in 2003 (Figure 2). Multiple tracers have been used to decipher water mass origins, composition of freshwater sources (ice processes, runoff) and transformations through the straits. Parameters measured include pressure, temperature, salinity, $O_2$, nutrients, Chl-a, $^{18}O$, Ba, Alk, TIC, CFC's, $^{129}I$, $^{137}Cs$, Cd, and HCH's. An SBE-43 dissolved oxygen sensor was part of the CTD-rosette package, to acquire continuous profiles of DO concentration at about 10-m vertical resolution. A vessel-mounted ADCP with an Ashtech differential GPS system on the USCGS *Healy* provided continuous sections of ocean velocity for the first time in these waters. Two twelve-station sections across Baffin Bay were also completed along with four cross Strait sections extending the length of Nares St. The Canadian Coast Guard Ship *Louis S. St.-Laurent* will 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.

At three locations around northern Greenland, floating glacier tongues act like "plugs in the bathtub" preventing seawater from incurring under the ice sheet whose great mass depresses the continent below sea level. When these glacial tongues melt back to the grounding line, seawater can enter and lubricate the bed so that ice sheet motion and ice calving are greatly accelerated. This scenario has transpired at Jakobshavn Isbrea glacier further south. The existence of two such connections in Nares St., where floating glacial ice tongues are retreating (K. Steffen, personal communication), provides further justification for continuing monitoring there.

Within the SEARCH working groups, some discussions already took place on data management and distribution. It was suggested that the ASOF group should decide whether to follow the SEARCH strategy or develop its own data system.

> **ACTION 2** To form a group charged of setting priorities for ASOF data management and distribution and to find the best data system (Kelly Falkner)

**2.8 The Joint Western Arctic Climate Study: a Strategic Vision (Takashi Kikuchi)**

JWACS is a joint climate-oriented observational program being conducted by Japan and Canada in the Western Arctic Ocean. In 2002 and 2003, field expeditions were carried out jointly by R/V Mirai of Japan Marine Science & Technology Center (JAMSTEC) and CCGS Louis S. St-Laurent from the Canadian Coast Guard.

During the JWACS 2002-2003 field program (Figure 3a), the ice cover was significantly reduced in the western Canada Basin. The spatial distribution of the Pacific Summer Water was well correlated with the spatial pattern of summer ice reduction. In addition there was spatial and temporal variations in Pacific Winter Water, Atlantic-origin lower halocline and the Atlantic Layer. For example, the core temperature of the Atlantic Water is increasing in the Canada Basin, being warmer in the west than in the east. In contrast lower halocline water originated from Eastern Chukchi Sea has cooled since late 1990s. Investigating the cause and sources of variability in the different components of the water column is essential to understand the Arctic climate system. Changes in Canada Basin waters will, in turn, affect the subarctic ocean in the Atlantic region.

Our science strategy is to investigate Arctic climate with a pan-western Arctic scale involving basins, shelves and marginal seas. We established sustained climate stations in the Canada Basin and at the gateway of shelf water into the Basin, e.g. at the mouth of the Barrow Canyon. To achieve this scientific strategy, field observations in the both inflow and outflow region of the Arctic Waters are required. We have initiated long-term hydrographic section using XCTD from the Labrador Sea to Lancaster Sound through Baffin Bay since 2001 with supports of the Canadian Coast Guard and a program of "student on ice 2001" using a Russian Vessel (Figure 3b).

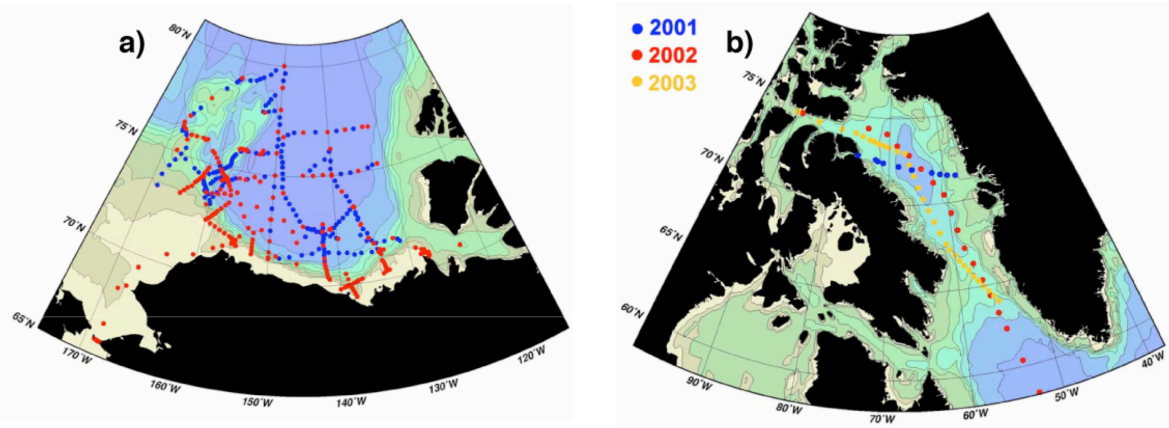


*Figure 3. a) JWACS CTD (red) and XCTD (blue) stations in 2002 and 2003. b) Sustaining XCYD observations of Baffin Bay in 2001, 2002 and 2003.*

JWACS future plans include the reoccupation of Canada Basin and to collect data from un-sampled regions including the eastern Canada Basin and Makarov Basin. In 2006 we plan to send R/V Mirai into the Baffin Bay through the Canadian Archipelago to investigate hydrographic exchange between Arctic and subarctic with pan-western Arctic scale.

### 2.9 Barium as a Freshwater Tracer in the Arctic (Kelly Falkner)

Barium is more enriched in river water than seawater and is about 5 times more concentrated in the Mackenzie River than in Eurasian rivers. The first application of barium as a tracer to distinguish North American and Russian river water influences in the Arctic was carried out in 1993 with data obtained during six oceanographic cruises. Highest barium concentrations were observed over most of the Canada basin indicating the influence of the Mackenzie River, while over the Mendeleyev Ridge and near the New Siberian Islands the intermediate barium concentrations suggested the influence of Eurasian river discharge. DOC is considerably more concentrated in Eurasian than in North American rivers emptying into the Arctic. Nutrients are useful in distinguishing water types in the Arctic, although their non-conservative behaviour makes it challenging to use them quantitatively. Nitrogen to phosphorus ratios can be used to distinguish Atlantic and Pacific waters. Dissolved barium (Ba) was measured along transects across Fram and Denmark Straits as part of the 1998 ARK-XIV/2 *Polarstern* expedition. Results are combined with nutrients, oxygen isotopes, and salinity to analyze water mass composition at Fram Strait. A combination of Pacific water and Eurasian river runoff dominated the upper East Greenland Current (EGC), while the remainder of the section was dominated by North Atlantic water. A much smaller contribution of Pacific water to the EGC at Fram Strait in 1987 suggests that this component can be quite variable in time. North American river water was not detectable at Fram Strait in 1998. Presumably, the Eurasian river water we observed at Fram Strait transited eastward along shelf within the Arctic, mixed with Pacific water in the vicinity of the East Siberian Sea, and was borne by the transpolar drift across the Arctic Ocean. In the absence of significant net ice formation along the way such a pathway can be expected to produce more pronounced freshening of the EGC than when Eurasian river water mixes more directly off shelf into salty Atlantic waters and Pacific water is diverted largely through the Canadian Archipelago. Existing measurements at the main Arctic gateways were used to construct a Ba budget for the Arctic Ocean under conditions of simultaneous mass, heat, and salt conservation. This preliminary budget is statistically consistent with the steady state hypothesis. On the Arctic basin scale, Ba appears to be conservative.

### 2.10 Modelling Arctic-North Atlantic Exchange and Decadal Variability (Sirpa Hakkinen)

This note summarizes results from a modeling study (Hakkinen and Proshutinsky, JGR 2004) on the interannual variability of freshwater in the Arctic Ocean and sources of this variability based on model simulation for the period 1951-2002. The model is a coupled ice-ocean model (Hakkinen and Mellor, 1992) covering the Arctic Ocean and Atlantic Ocean south to 16S. The coupled model is forced by NCEP/NCAR Reanalysis data after a spinup-phase of 26 years with 20 years using climatology computed from the Reanalysis data and 6 year transition phase to the start (1951) of the analyzed time series. River runoff, Bering Strait inflow and precipitation minus evaporation changes are not taken into account.

Three major processes are considered to be responsible for variations in the Arctic freshwater storage. The first process to be considered was Ekman pumping in the Beaufort Gyre as a cause for the accumulation and release of freshwater depending whether the circulation regime is anticyclonic/ cyclonic (Proshutinsky et al., 2002). We find that the effect of Ekman pumping is present but its impact on salinity distribution is not obvious. A factor contributing to the failure of the Ekman pumping related processes in the simulation is that the Beaufort Gyre in the model is very weak, and the stream function anomalies are strongly concentrated to a mode (over 70% of the variability) involving the whole basin and the GIN Seas. However, there are signals that the Arctic freshwater variability in general correlates with (Arctic Oscillation and) Arctic Ocean Oscillation (AOO) variations. One could point out that AOO clearly influences the location of the anticyclonic gyre in the Canada Basin shifting it further eastward for the anticyclonic regime and westward against the Alaskan-Canadian coast for the cyclonic regime.

The second process with an obvious potential to change the fresh water content is the variability of sea ice growth and melt and it is shown that it is not very important except changes in salinity associated with ice growth and melt in the Siberian and Canadian sectors of Arctic. However, the sea ice growth/melt anomalies in the East Siberian Sea could be important for the downstream stratification because these anomalies appear to propagate rapidly to the Greenland Sea where they have potential to disrupt the water renewal processes.

The third process to be considered was the exchange of water masses with the GIN Seas by the advection of Atlantic Waters to the Arctic Ocean. We find that this process explains most of variability in freshwater content in the top 1000 meters in this model simulation.  The most prominent signature of this process in the case of cyclonic regime is the intrusion of high salinity waters to the Canada Basin which displace the Beaufort Gyre further westward.   This process makes the positive salinity anomalies to appear off shore from the East Siberian Sea and negative anomalies (because the fresh waters of the gyre displaces the slightly more saline coastal waters) to appear at the southern rim of the Canada Basin along the Alaskan and Canadian Coasts.  It happens that Arctic Oscillation variability impacts also ice growth/melt in these areas, but the ice growth related anomalies are much smaller than the basin average anomalies.  A word of caution concerning the dominating role of exchange of water masses is appropriate because the model strongly concentrates the stream function anomalies to a pattern which connects the Arctic Basin to the GIN Seas.  Thus it is no surprise that the advective processes would be overriding any internal mechanisms.

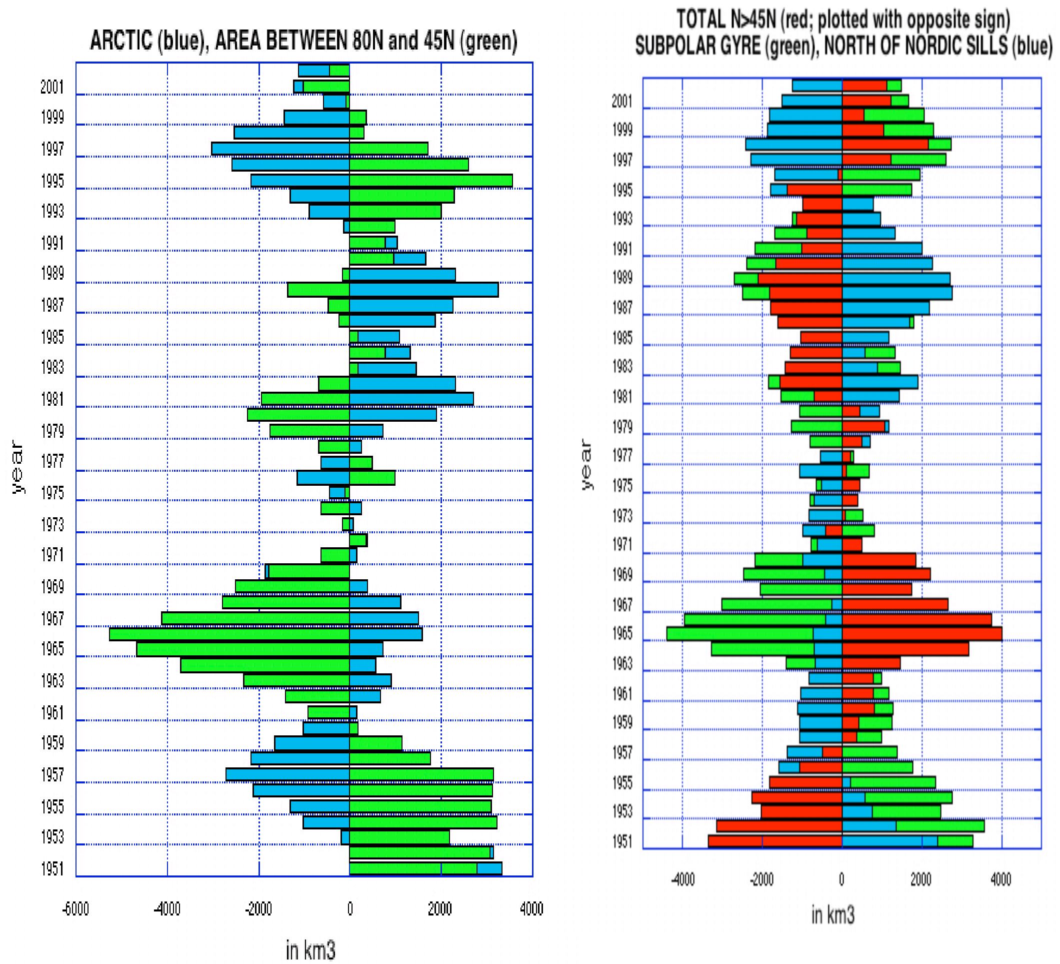

*Figure 4. Freshwater content anomaly in top 2000m.*

In summary we find that the exchange processes between Arctic Ocean and rest of the world oceans constitute the largest impact on the fresh water content variability in the Arctic at least in the numerical model we used.  The largest decrease in the simulated Arctic fresh water content, which started in the late 1980s and continued to the mid 1990s, coincides with the Arctic Atlantic layer warming (Carmack et al. 1995).   During this event, the frontal structures were displaced nearly 1000km further west from the Lomonosov Ridge to the Mendeleyev Ridge (Carmack et al. 1995).    Such a shift is difficult explain without invoking a large change in the volume transport of the Atlantic waters, and this is the key component in this model to explain the fresh water storage anomalies in the Arctic.

A further analysis of the model results reveal that the Arctic fresh water anomalies are usually connected (but not balanced completely) to opposite sign fresh water anomalies in the GIN Seas and in the subpolar gyre (Fig. 4 left). Overall the total fresh water excess or deficit of the areas north of 45N (to Bering Strait) is determined by the exchanges (due to overturning circulation) at the southern boundary of the subpolar gyre which is discussed in Hakkinen (JGR 2002). The internal distribution of the anomalies between the three components varies temporally. For instance in the 1960s, the subpolar gyre had a large fresh water deficit (Fig 4 right) which was not balanced by the opposite sign anomalies north of the Nordic Sills (the structure of the vertical salinity distribution from the central Labrador Sea in Dickson et al. Nature 2002 supports this result also). The 1980s to early 1990s have fresh water excess north of 45N which is mainly confined to areas north of the Nordic Sills. The overturning circulation in the North Atlantic determine the net deficit or excess at the high latitudes, but how it is distributed internally depends on the prevailing circulation anomalies in the GIN Seas and the Arctic Ocean. The conclusion of Hakkinen and Proshutinsky (2004) suggests that the internal distribution between the Arctic and GIN Seas is accomplished by the AO wind stress driven exchanges at the Fram Strait.

### 2.11 Northern Hemisphere Sea-ice Variability and its linkage to the NAO and ENSO (Jinro Ukita)

Using the SMMR, SSM/I, and SLP data for the period of 1979-2000, we addressed the following questions:

- What are temporal and spatial characteristics of Northern Hemisphere (NH) winter-to-winter sea-ice variability?
- Is there any hemispheric-scale modal structure? That is a composition and interplay between different modes.
- If there is, how is the structure related to the NAO, AO and ENSO, which have large impacts on the NH winter climatic conditions?

A combination of two modes accounts for significant parts of both spatial and temporal variations. One mode, which is defined as the first EOF of the mid-winter sea-ice concentration of the Northern Hemisphere, is closely linked to the NAO in the sense of the North Atlantic regional variability. However, its domain of influence includes the far-eastern part of Siberia and the northwest Pacific. In fact, the mode is composed of the North Atlantic and North Pacific sea-ice dipole modes.

The other mode is temporally correlated with the ENSO mode. Physically it is a sea-ice manifestation of the remote influence during the warm phase of ENSO, which is especially pronounced in the Bering Sea.

In the context of the ASOF research goals, the results suggest the importance of the hemispheric-scale influence of the atmospheric circulation on the upper ocean structure in the northern high-latitudes. For example, the sea-ice extent of the

Bering Sea is closely linked to both ENSO and the North Atlantic atmospheric dipole mode in a very systematic way. This would imply a potentially important role of the upstream region of the Arctic Ocean in the context of the ocean fluxes of the Atlantic sector. We intend to further elucidate this sea-ice's model structure and its relationship to ENSO, the AO, and the NAO, as well as to seek a mechanistic understanding of the Northern Hemisphere sea-ice and atmospheric variations.

### 3. Task 5. Overflows and Storage Basins (Tom Haine and *in absentia* Bob Pickart)

Recent results point to the southern Irminger Sea as another formation site of the weakly-stratified water of the mid-depth subpolar gyre (usually, but perhaps misleadingly, called Labrador Sea Water). Steered by the southern Greenland topography, frigid air periodically whips out across the Irminger Sea east of Cape Farewell --- the so called Greenland "Tip jet". The heat loss associated with this event is comparable to that in Labrador Sea winter storms and the windstress curl is also very intense. The NAO plays a role in the low pressure formation and tip jet modulation. The data recovered in summer 2003 from a pair of profiling CTD moorings deployed in the Irminger Sea off Cape Farewell since August 2002 should prove whether deep convection occurred in response to these events, although the NAO phase during this time was not favourable.

Apart from the Cape Farewell mooring recovery, a synoptic survey of the shelf-break circulation and hydrography of the Denmark Strait was also carried out on R/V *Oceanus* in August 2003. A similar survey was completed in August 2001 revealing a narrow plume of dense, fresh shelf water descending into the deep Irminger Sea immediately below the shelf break. The feature has been named the "spill-jet" and was seen again in August 2003. It appears to be a robust element of the shelf-break circulation, at least in summer, and is associated with a substantial export of fresh, dense water. Understanding the importance of this shelf-basin exchange for regional circulation, freshwater flux into the North Atlantic, and NADW export is a critical challenge facing ASOF.

During the *Oceanus* cruise in August 2003, a high-resolution (9 km, 30 levels)regional GCM was run on board in order to explore the circulation of the Denmark Strait and Irminger Sea. The GCM results were helpful in picturing the circulation and guiding the survey strategy. They suggest that local topographic steering is very important for the Spill Jet dynamics. The calculations were made using a laptop computer on board and with shore-based collaborators. Another aspect of this work was data assimilation of the cruise measurements (using the 4DVAR method). The systematic merging of field observation and GCM dynamics would be a major step toward a real-time state estimation that can monitor this area which is of great value to ASOF. The main long-term goals of the data assimilation are to:

- Estimate exchange of freshwater, heat, mass through Denmark Strait
- Diagnose water-mass transformation in Irminger Sea
- Design a long-term subpolar MOC monitoring system.

Preliminary results are encouraging although the study is at an early stage.

A return cruise to this area is scheduled in August 2004 (on RRS *James Clark Ross*) and the Cape Farewell moored profilers will be replaced with Ultramoor subsurface moorings. They will monitor deep convection until 2009. These data will be analysed in coordination with measurements from other nearby instruments (UK, German, and Dutch moorings are being deployed in the southern Irminger Sea and East Greenland shelf and slope).

The development of a Subpolar Gyre Experiment process study proposal has been supported, in principle, by ASOF and US CLIVAR. The main issues to be addressed are:

- What processes propagate Arctic/SubArctic freshwater anomalies into the deep subpolar Atlantic Ocean? How is it getting fresher?
- How predictable are these processes?
- How can they be modelled?
- What are the consequences for the Atlantic MOC?

Attention will be on interaction of Denmark Strait Overflow Water and Subpolar Mode Water. The Spill Jet is another likely focus for the study. The program will include process-oriented fieldwork, high-resolution process modelling and data assimilation, basin-scale modelling, and links to climate GCMs. It is envisioned to link this study to the CLIVAR Climate Process Team on “Gravity current entrainment”. Work on developing this proposal will proceed in 2004, probably at a Task 5 meeting in Baltimore in June.

> **ACTION ITEM 2**. Task 5 group to write a white paper by mid 2004 that outlines a strategy for ASOF implementation in the subpolar gyre (T. Haine leading).

Peter Rhines suggested to invite a representative from the German SFB460 project to learn about their mooring results in the Labrador Sea and Newfoundland Shelf.

### 4. ASOF-EAST Status and Plans (Bob Dickson)

ASOF in the eastern part of the North Atlantic has three main components:

- ASOF-EC West aims to measure the variability of the dense water and freshwater fluxes between the Arctic Ocean and the North Atlantic off SE Greenland and understand their response to climatic forcing, especially NAO
- ASOF-EC North aims to measure and model the transports across the boundaries between the Arctic Ocean and the Nordic Seas, understand the control processes, and establish a well-calibrated flux-array.
- ASOF-EC East aims to measure and model the fluxes and characteristics of exchanges between the North Atlantic and the Nordic Seas from direct and continuous measurements, and to assess the effect of anthropogenic climate change on the MOC

These projects are funded till 2006 but two new proposals have been submitted to EC that could provide continuation funding:

- ASOF-FRAM: a Specific Support Action for international cooperation in the role of the Polar Oceans on the Global Water Cycle, providing a pan-

European contribution to setting up the International Polar Year (IPY) in 2007-8

- ASOF-FAST: a Specific Targeted Research Project for international cooperation in providing an improved and more integrated observing system for measuring the boundary fluxes of salt/freshwater into and around the Nordic seas, for detecting changes in these fluxes and for assessing the impact of these changes on the freshwater balance of the Nordic Seas system.

Figure 5 shows the links of ASOF FRAM and FAST with international ASOF, SEARCH and other ongoing activities. Both projects have Jens Meicke and Roberta Boscolo as coordinator and officer respectively.

The result of the projects evaluation will be known at the end of 2003 and there will be a further 3rd funding call to EC which will likely include research questions already stated as of interest but which were not open in call 1 and 2.

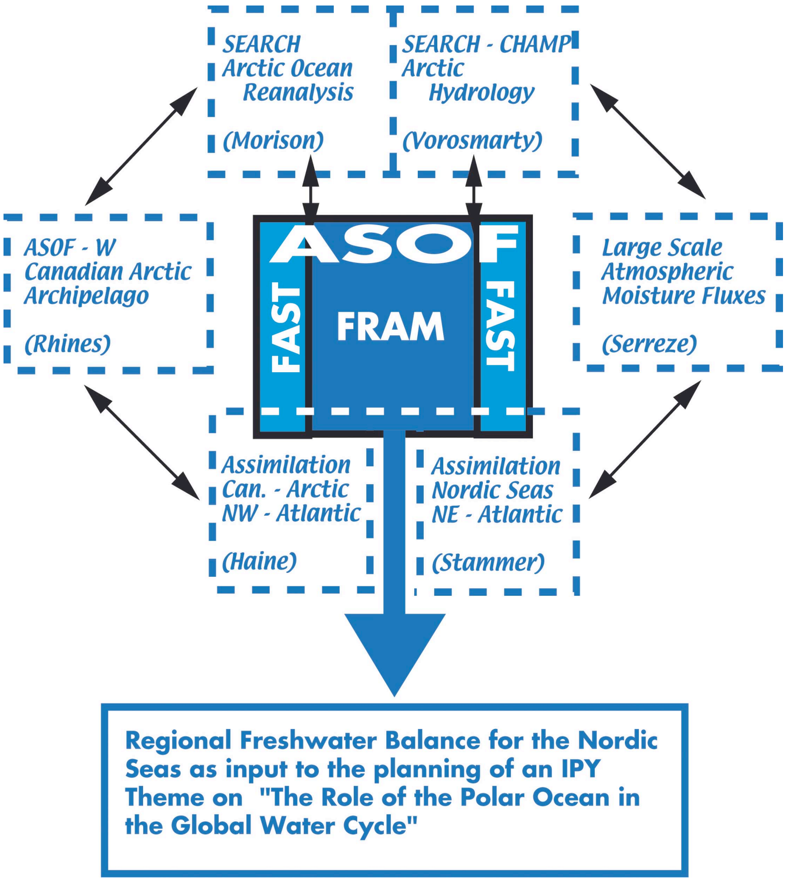


*Figure 5. Schematic representation of the interactions of ASOF FRAM and FAST with other international activities in the Arctic*

### 4.1 Future Strategy (Bert Rudels)

To determine the freshwater storage in the Nordic Seas, its time variability, and its coupling to the water mass formation processes in the Arctic Mediterranean Sea and to the characteristics of the overflow waters.

The Arctic Mediterranean Sea is the northernmost part of the North Atlantic and separated from the main ocean by the Greenland-Scotland Ridge. To a first approximation the waters of the Arctic Mediterranean can be regarded as mixing products between Atlantic water crossing the Greenland-Scotland Ridge and freshwater, supplied by net precipitation, ice melt and by the excessive river runoff to the Arctic Ocean. This approximation ignores the Pacific water entering through Bering Strait, which dominates a large fraction of the upper layers of the Arctic Ocean. However, an equal or slightly larger volume exits through the Canadian Arctic Archipelago, and since the low salinity Pacific water contributes almost exclusively to the upper layer, it can be considered as an additional freshwater source. The freshwater input is combined with other thermodynamic processes, which allow the added freshwater to be distributed over the entire water column.
The Atlantic water in the Norwegian Sea loses heat and receives freshwater from net precipitation and from the Norwegian Coastal Current. It becomes colder, less saline and slightly denser. As the Norwegian Atlantic Current reaches the latitude of the Bear Island channel, it splits. The eastern branch, comprising Atlantic water as well as the Norwegian Coastal Current, enters the Barents Sea. The strong heat loss in the Barents Sea in winter increases the density of the largest part of the inflow, and very high densities are reached through brine rejection over shallow areas, e.g. west of Novaya Zemlya and over the Central Bank. Nevertheless, net precipitation and ice melt make the surface layer less dense and stratify the Barents Sea branch water column. The main part of the Barents Sea inflow branch continues into the Kara Sea north of Novaya Zemlya and enters the Arctic Ocean in the St Anna Trough. A smaller fraction of the inflow, largely Norwegian Coastal Current water, remains on the shelf and follows the inner route south of Novaya Zemlya into the Kara Sea, where it incorporates the runoff of Ob and Yenisey. It continues into the Laptev through the Vilkitskij strait south of Severnaya Zemlya and receives the runoff of the Lena before a major part enters the Eurasian Basin as low salinity shelf water.
The Atlantic water remaining in the Norwegian Sea flows northward in the West Spitsbergen Current to Fram Strait. Here the current splits. Two (at least) streams enter the Arctic Ocean, one flows eastward along the northern Svalbard shelf and slope, and the other, outer, stream continues northward along the Yermak Plateau and then turns east north of the plateau. The upper layer encounters and melts sea ice and becomes transformed into a less saline surface layer that covers the warmer Atlantic core. The Atlantic water core supplies the Arctic Atlantic Water (AAW) in the Arctic Ocean, while the upper part become homogenised by local convection each winter forming a "winter mixed layer" in the Nansen Basin. North of St Anna Trough the Fram Strait inflow branch encounters the Barents Sea inflow branch and becomes displaced from the slope. East of the trough the two branches mix isopycnally, and the Fram Strait branch is cooled and freshened by incorporating colder Barents Sea branch water. The Barents Sea branch is generally denser than the Fram Strait branch and supplies the bulk of the intermediate water below the Atlantic layer, the upper Polar Deep Water (uPDW). North of the Laptev Sea a major outflow of low salinity shelf water covers the winter mixed layer and winter convection becomes limited to this upper low salinity layer that becomes the Polar Mixed Layer (PML). The winter mixed layer, once its connection with the sea surface is broken, evolves into a halocline. Part of the Fram Strait branch recirculates in the Nansen Basin, but the main recirculation, involving both branches, occurs in the Amundsen Basin along the Lomonosov

Ridge. However, a substantial part, mostly Barents Sea branch waters, crosses the Lomonosov Ridge and recirculates in different loops around the Makarov and Canada basins and then returns across the Lomonosov Ridge in the boundary current north of Greenland.
Brine rejection on the shelves creates dense shelf bottom water that convects as entraining boundary plumes down the continental slope, reaching into the Atlantic, intermediate and deep layers. The depth of the convection depends upon the initial salinity, and the higher the salinity the deeper the plumes sink. The volume of dense water formed on the shelves is small, but the entrainment increases the amount of water injected in the different layers considerably. The entrainment also increases the temperature of the plumes and the intermediate and deep waters from the Arctic Ocean, the uPDW and the Canadian and Eurasian basin deep waters (CBDW & EBDW) are generally warmer and more saline than the intermediate and deep waters of the Nordic Seas. The incorporating of cooler shelf water and the downward transport of heat caused by passing plumes are arguable the largest heat sinks for the Atlantic layer in the Arctic Ocean.
The main exit for the Arctic Ocean waters is Fram Strait. Here the less saline polar surface water, PML and halocline waters, and the denser AAW, uPDW, CBDW and EBDW enter the Nordic Seas in the East Greenland Current. In the strait they are joined by the Recirculating Atlantic Water (RAW) of the westward turning stream of the West Spitsbergen Current. As the East Greenland Current continues south it passes and interacts with the waters of the Greenland Sea, the second main deep water source in the Arctic Mediterranean.
The open ocean deep convection, taking place in the Greenland Sea, is radically different from the shelf/slope convection in the Arctic Ocean. No large density anomalies can form in the surface layer before they sink into the deep and the depth of the convection depends upon the stability of the water column. An inflow of low salinity water from the East Greenland Current could reduce the surface density and lead to a shallower convection. A caveat is, if the density contrast is large enough to allow ice to form. The larger density increase caused by brine rejection as compared to cooling may then induce deep reaching haline convection. The waters formed in the Greenland Sea, the Arctic Intermediate Water (AIW) and the Greenland Sea Deep Water (GSDW) are colder and less saline than the Arctic Ocean intermediate and deep waters.
The persistent presence of a deep less saline upper layer in the Greenland Sea during the last 10 years has limited the convection to 1000 – 2000m. The convection does not penetrate the mid-depth temperature maximum, ultimately deriving from the CBDW, and the Greenland Sea produces AIW rather than GSDW, which accumulates above the temperature maximum, and during this time the temperature maximum has descended about 800m. The deeper layers are presently not ventilated by convection and the GSDW has acquired a more Arctic character due to inflow of CBDW and EBDW from the East Greenland Current. Some of the AIW, together with displaced GSDW, flow northward to Fram Strait, leading to mixing between the Arctic Ocean and the Nordic Sea intermediate and deep waters in the strait, and also enter the Arctic Ocean north of the Yermak Plateau. The main part of the AIW, however, joins the East Greenland Current or enters the Norwegian Sea. Whether the AIW takes part in the Denmark Strait Overflow to the North Atlantic, or if it only passes through the deeper Faeroe-Shetland Channel is still to be determined.

The convection in the Iceland Sea is shallow compared to that in the Greenland Sea, 200-400m, and the created water mass, the Iceland Sea Arctic Intermediate Water (IAIW), is less dense than the AIW and contributes to the Denmark Strait overflow. There are thus two possible sources for the Denmark Strait overflow, the Iceland Sea or the East Greenland Current carrying RAW, AAW and the intermediate uPDW and AIW. The overflow may switch in time between the two sources. The denser overflow waters do not pass through Denmark Strait but flow through the deeper Faroe-Shetland Channel.
The strength of the overflow is expected to depend upon the density contrast between the deeper layers in the Arctic Mediterranean and the North Atlantic. This in turn depends upon the amount of freshwater present in the water column north of the Greenland-Scotland Ridge. It should then be possible to relate the variability of the strength and properties of the overflow to the time evolution of the freshwater content in the Nordic Seas.
As seen above the freshwater added to the inflowing, saline Atlantic water may lead to less dense surface water, or the density decrease caused by the added freshwater is to a large extent compensated by cooling, keeping the density close to that of the inflowing Atlantic water. The cooling may dominate strongly leading to freezing and brine rejection and the formation of dense water with little, or negative freshwater content, relative to the inflowing Atlantic water. To assess the relative importance of these different processes and how they vary in time a possible strategy would be to:

- Determine the time series of temperature, salinity and density at the Faroe-Shetland inflow (the salt source). Estimate averages and variability ranges.
- Determine the time series of temperature, salinity and density of the Atlantic water west of Spitsbergen. Estimate the density range and compute the variability of volume and salinity (freshwater content). This water eventually forms the RAW and supplies the AAW.
- Determine the volume and salinity (freshwater) of waters in the East Greenland Current less dense than the Atlantic water. These waters do not contribute to the overflow but their volume and salinity are necessary for closing the volume and freshwater budget.
- Formation of water masses denser than RAW occurs in the Barents Sea, on the shelves of the Arctic Ocean, and in the central Greenland Sea (and perhaps also in the Iceland Sea). In all cases it involves a transfer of freshwater into the deep interior of the water column. Most of the denser water masses participate in a circulation internal the Arctic Mediterranean and only the less dense waters supply the overflow. The (time variable) density surface separating these two water masses and their volumes and freshwater contents should be determined.
- Relate the changes in freshwater storage in the different density intervals, less (3), as dense (2), and denser (4) than the Atlantic water to atmospheric fluxes and runoff and the transports through the different openings.

## 5. Task 2 and ASOF-EC(North) Progress and Plans (Agnieszka Beszczynska-Moeller and Ursula Schauer)

The measurements performed during VEINS in the Fram Strait revealed a complicated structure of the Atlantic flow to the Arctic Ocean, mainly influenced by the topographic features. The West Spitsbergen Current splits in three branches:

- One following the shelf edge and entering the Arctic Ocean north of Svalbard
- One following northward along the north-western slope of the Yermak Plateau
- One recirculating immediately in the Fram Strait between 78° and 80°N.

To have accurate estimates of the volume and heat transports of the Atlantic flow through the Fram Strait is important for the impact that such water mass have in the ice-melting process and consequently in the freshwater input to the Nordic Seas.

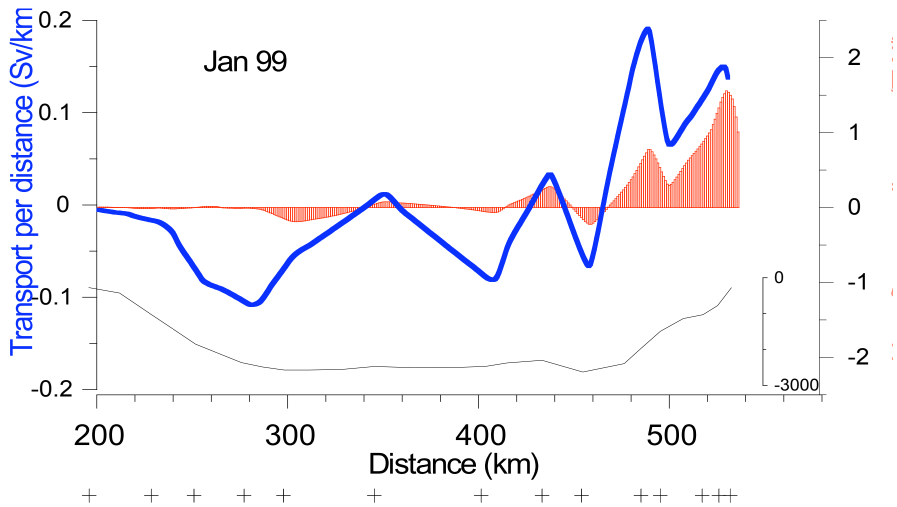


*Figure 6. Distribution of transport (blue line) and heatflow (red shaded) across the Fram Strait. The last two peaks on the right correspond to the Yermak Plateau and the Svalbard branches.*

The first mooring array was deployed in 1997 and re-deployments were performed every two years till present. The moorings covered the water column from 10m above the seabed to 50m below the surface. The measurements extended from the Eastern Greenland shelf break along 79°N until 0° and continued along 78° 50'N to the western shelf break of Spitsbergen. The estimates of transport for the period 1997-99 are: 9.5±1.4Sv northward, 11.1±1.7Sv southward and 4.2±2.3Sv net. The sources of uncertainties includes data gaps, unresolved recirculation and aliasing by mesoscale eddies. The distribution of transport and heat flow across the Fram Strait is shown in figure 6. The pathways of the two branches flowing northward after the Fram Strait remain unresolved. This and other issues related to the Arctic/Atlantic flux exchanges will be addressed in a proposed study under an EU Integrated Project called CARE (Climate in the Arctic and its Role for Europe).

Under the project ASOF-EC(N) one of the aim is to improve the mooring array by adding 2 additional moorings in the recirculation area and one additional level of instruments at 700m. The highly barotropic character of the currents allows US to estimate the transport variability from bottom pressure data (only for those instruments that resolve the seasonal range of pressure variations). Changes of the heat content can be captured by inverted echo sounders: three pressure-inverted echo sounders have been deployed in 2003 in order to determine the changes in density structure and estimate the baroclinic flow and heat transport. The use of POP-UP buoys with data memory and satellite transmitter for early data access and secure data coverage is still at an experimental stage but performances are encouraging. The first workshop of the ASOF-EC(N) will be held on 11-12 December at AWI, Bremerhaven Germany.

## 6. Task 3: Freshwater Fluxes (Svein Oesterhus)

The sea-ice velocity through the Fram Strait was measured by means of a new method using moored Doppler Current Meters in the period 1996-2000. Almost three years of ice velocity observations near 79°N 5°W have been analyzed. The average southward ice velocity was found to be 0.16m/s. The mean seasonal variability exhibits a minimum in August. Give the high correlation between the ice velocity and the cross-strait sea level pressure (SLP) difference, the sea ice area flux was computed for the period 1950-2000. The cross-strait SLP difference exhibits a positive trend since 1950 of 10% of the mean per decade. The ice thickness has been monitored with Upward Looking Sonars (ULS) since 1990. The combined data give a monthly ice volume flux of 200 $Km^3$ for last decade, with no significant trend. The ULS/Ice Profiling Sonar data, however are difficult to obtain: only few data sets have been published and generally the data processing is poorly documented. Perhaps all ULS data needs to be reprocessed.

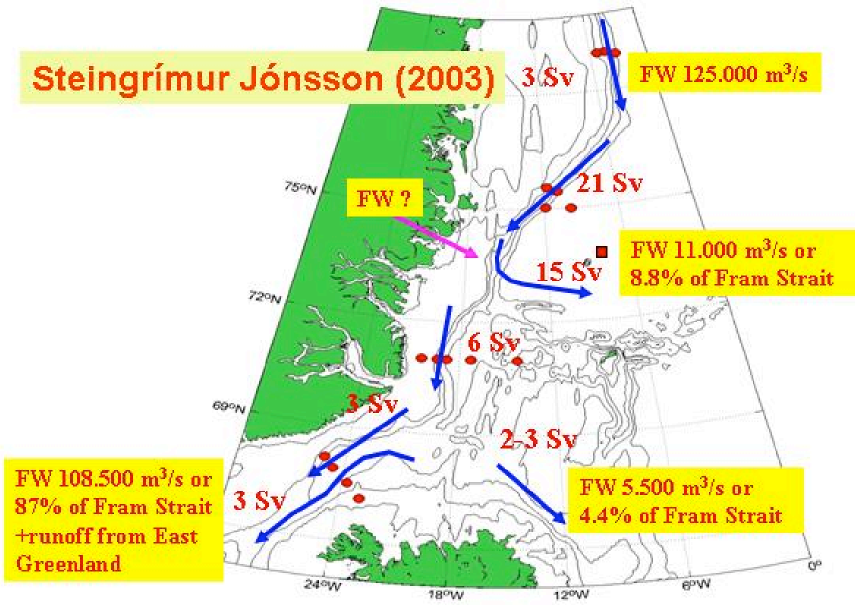


*Figure 7. Estimated freshwater flow from the Arctic to the Nordic Seas (S. Jonsson, 2003).*

### 6.1 Freshwater arrays along Greenland slope (M. Karcher and *in absentia* J. Meinke)

Important elements of the freshwater flux through Nordic Seas take place on the

East Greenland shelf and slope where the historic hydrographic record is slight to non-existent. The ASOF-EC freshwater array was deployed near 74°N, where the shelf is narrow and where the flow is therefore most focussed. The moorings are designed to provide measurements under the ice of the SE Greenland shelf by having the near-surface buoyancy and instrument packages enclosed in 45m-long, rigid, freely-flooding, PE plastic shells, designed by IFM Hamburg to deflect on impact with deep ice floes, then return to the vertical. By this technique, it is plan to deploy and maintain strings of temperature and salinity sensors (Seabird MICROCAT SM 37) throughout the water column, together with current meters of two types, to make the first measurements of the freshwater flux reaching the North Atlantic. Two trial moorings of this type were successfully deployed and recovered after one year on the East Greenland shelf in 2000/2001. Results show a freshwater transport maximum in summer with average of 2500 m3/sec. Figure 8 shows salinity and temperature timeseries.
The tube moorings work fine but don’t give the gradient close to the ice. For this reason the Microcat moorings will be supplemented with a new type of mooring which employs an undulating CTD capsule to measure conductivity, temperature and pressure during repeated (pre-programmed) vertical excursions from the bottom (HOMER). Initially, in the trial deployment as part of the DSOW slope array, HOMER will perform such a profile once each day for a period of a year. When laid on the East Greenland shelf, the vertical excursion will be limited to 300m above the bottom as this seems reasonably achievable and covers most of the water column over the East Greenland shelf.

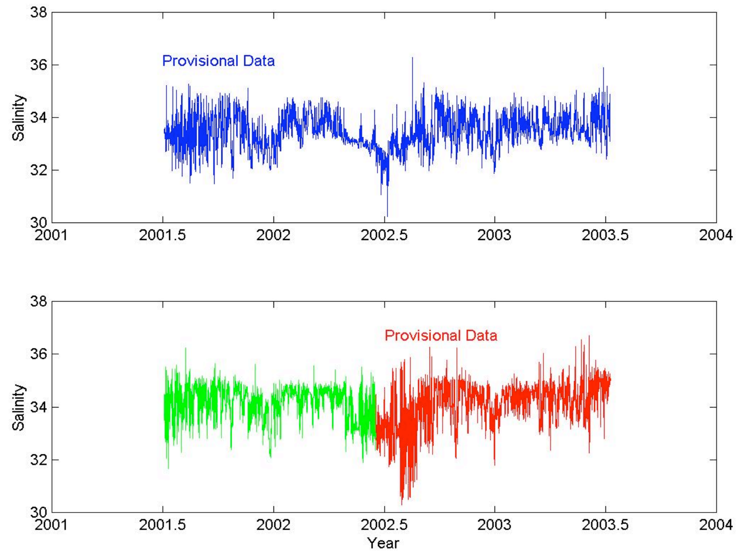


*Figure 8. First two-year records of salinity and temperature from the top Microcat sensors (z = 30m) on two tube moorings set 18 km apart under the ice of the Eastern Greenland shelf between June 2001 and July 2003 (provisional data, from an analysis by SR Dye CEFAS).*

### 7. Task 1 and ASOF Meridional Overturning Exchanges with the Nordic Seas (Bogi Hansen)

The main focus is on the 3 Atlantic inflows that constitute 90% of the total inflows to the Arctic Mediterranean and the 3 overflow branches that count 33% of the total overflows. The revised estimates of the fluxes carried by the three Atlantic Inflows branches give 0.8Sv for the branch that passes north of Iceland, 3.5Sv for the Iceland-Faroe branch and 3.2Sv for the Faroe-Shetland inflow. According to the Nordic Seas budget these new estimates suggest that between 2/3 and 4/5 of Atlantic Inflow return as overflow. The seasonal variation is less than 0.1Sv for the Iceland-Faroe gap, about 0.2Sv for the Faroe-Shetland gap (max in summer) and unknown for the Greenland-Iceland gap (max in summer). The Iceland-Faroe Atlantic water flux show a variability of about 3.5Sv from summer 1997 to summer 2001 with no evident trend. The key issues to be addressed in ASOF are:

- Refine estimate of average flux
- Refine estimate of seasonal variations
- Determine correlations between inflow branches
- Determine interannual variations
- Determine trends

There are three overflow areas between Iceland and Scotland: one in the Iceland-Faroe Ridge (IFR), one in the Faroe Bank Channel (FBC) and the last in the Wyville-Thompson Ridge (WTR). Measurements of the overflow at FBC started in 1995. Figure 9 shows the flux of the densest water (colder than 0.3°C) through the FBC. Within ASOF an experiment will be performed in order to determine the covariance between the temperature and the velocity fields of the FBC-overflow.

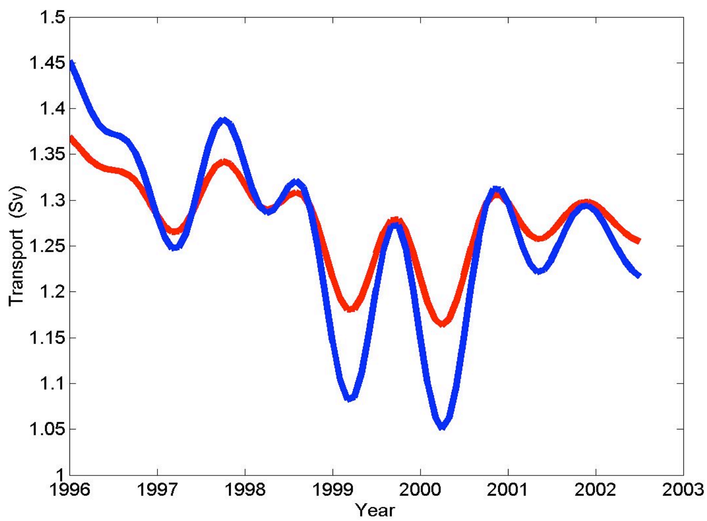


*Figure 9. Flux of the densest overflow water (colder than 0.3°C) through the Faroe Bank Channel calculated in two different ways.*

ADCPs in trawlproof frame have been deployed in IFR and WTR in 2003. The key issues for the Iceland-Scotland overflows are:

- Determine typical Iceland-Faroe overflow
- Determine typical WTR-overflow
- Refine watermass fluxes for FBC-overflow
- Determine FBC-overflow trend during last decade
- Validate FBC-overflow/OWS-M link and long term trend.

The first ASOF-EC(East) meeting is scheduled for 11-13 March in Oban, Scotland, where long-term monitoring strategy will be discussed. This meeting will be the workshop for the ASOF task 1 and 4 groups.

## 8. From MAIA to ASOF (J. Claude Gascard)

Our first results coming out of MAIA (Monitoring the Atlantic Inflow towards the Arctic, EU project) revealed strong interactions between the Norwegian Coastal current and the Norwegian Atlantic current. Some of these results have just been published in GRL (January 14, 2004).
From a detailed analysis of all existing data collected in the Norwegian Atlantic Current since 1978, we are able to better define the main pathways of the Atlantic water masses inflow towards the Arctic Ocean. The two main branches crossing the Lofoten and Boreas basins (the inner branch close to the continental margin west of Norway and the outer branch along the Arctic Front and above the Mohn Ridge and the Knipovich Ridge) are found as well as the important role of the Atlantic inflow in the Barents Sea is confirmed. All the observations show a strong space and time variability of the Norwegian Atlantic Current at the seasonal and interannual scales but also at the meso and submeso scales.

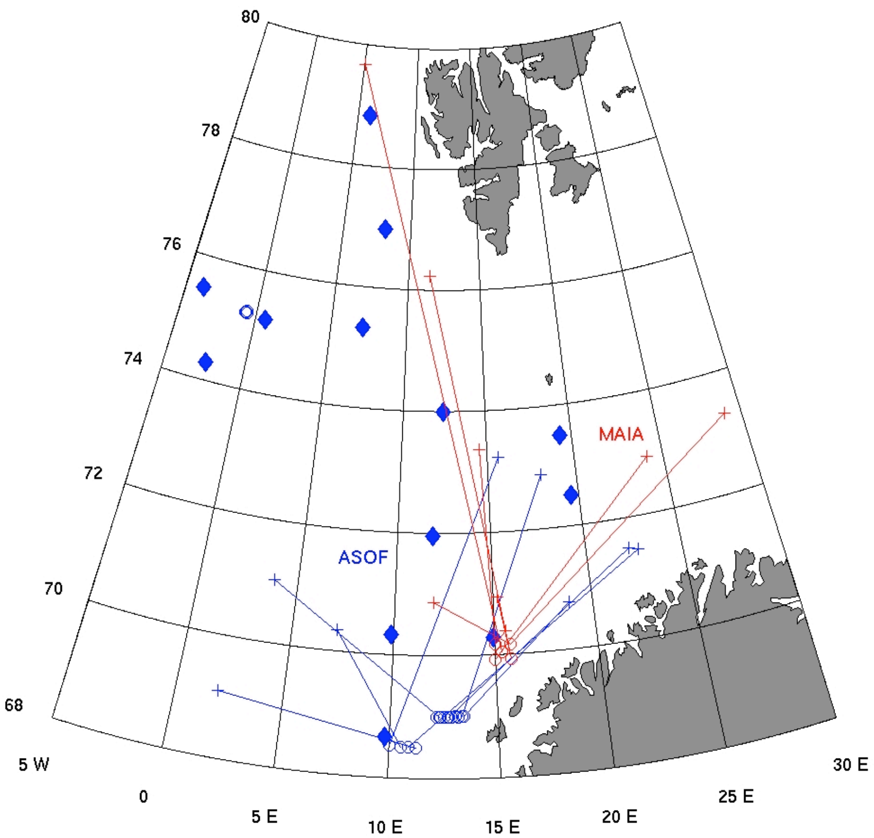


*Figure 10. Shown are the 5 floats deployed (red circle) west of the Lofoten islands during MAIA (May 19, 2001) and recovered (red crosses) on October 23, 2001, and the 8 floats deployed (blue circles) during ASOF on May 19, 2003 and recovered (blue crosses) on September 10, 2003. Also indicated are the 13 ASOF moorings (blue diamonds) deployed in 2003. These moorings are equipped with current meters and acoustic beacons for long range tracking of neutrally buoyant floats drifting at intermediate levels (300-350m depth) in the core of the Atlantic Inflow. The ASOF lagrangian floats experiment combined with hydrographic (CTDs), tracers and LADCP surveys will be extended over a two-year period (2003-2005).*

The strong warming (+0.8°C) observed across the Svinoy section in 2002 and 2003, did not show up across a section west of South Cape of Spitsbergen at 76°30N which in contrast revealed a net cooling of about -0.5°C instead. In 2002 the northward net heat transport estimated between 71°N and 73°N evidenced a sharp gradient indicative of (a) a strong inflow of warm Atlantic waters into the Barents Sea and/or (b) a strong recirculation of the Norwegian Atlantic current in the Lofoten basin. This pattern is coherent when comparing the behaviour of neutrally buoyant floats released in the Norwegian Atlantic current at 300-350m depth during MAIA in 2001 and ASOF in 2003.

## 9. Task 7. Numerical Experiments Group (Michael Karcher)

The thematic focus of WG7 is Freshwater. There are contradicting numerical results on the sensitivity of THC to freshwater export events as well as several uncertainties like the importance of Denmark Strait export and the recovery timescales. The 500 years control integration with present day GHG concentration shows a multidecadal variability in the AMOC. This variability seems related to convection in the Labrador Sea with several years of leading time-lag. However there seems to be an important contribution from Northern Seas: times of strong MOC are preceded by anomalously low freshwater flux through Denmark Strait.

A model hindcast for 1948–2002 shows several warming events in the Atlantic layer of the Arctic Ocean. The most recent warming event in the 1990s spread from Fram Strait to the Lomonosov Ridge and into the Canadian Basin. A warming event in the 1960s can also be followed into the eastern Eurasian Basin. These two warming events are reinforced by anomalously warm flow from the Barents Sea while warming events in the 1970s and 1980s encounter average or below normal temperatures in the Barents Sea branch of the Atlantic Water. The warm Barents Sea outflow in the 1960s is caused by extensive ice cover and a melt water induced halocline in the Barents Sea that reduced heat loss from the Atlantic water. In the 1990s, however, the warm inflow from the Nordic Seas was responsible for warmer than normal flow from the Barents Sea into the Arctic Ocean. The Barents Sea sea-ice balance variability seems as influential as Atlantic Water inflow variability. Both sea ice and oceanic fresh water in the Arctic reservoirs undergo decadal to multidecadal variability. Decadal variability in the sea ice volume is closely linked to Fram Strait ice export. Variability of sea-ice balance seems at least as important as the variability of liquid balance in the Nordic Sea freshwater budget. The model also appears to reproduce the decadal signals observed in the DSOW however the freshening trend is weaker in the model.

There are several research gaps that should be addressed in the future:

- Influence of dense water production in the Arctic Ocean (Barents Sea, Storfjord, other shelf areas) on the GIS-ridge overflow properties?
- Relative importance of deep water production areas (GS, LAB, IS, AO shelves)
- Storage and Release dynamics of basins
- Influence of Bering Strait variability?

- Relative influence of Salt Water inflow and Freshwater input?
- Response of THC to freshwater export events?
- Model development issues (spatial resolution, convection algorithms, forcing, initial conditions, tides, ice modelling in complicated topography: CA)

Potential projects could focus on storage and release dynamics of basins and response of THC to freshwater export events. While the observational community should provide:

- Timeseries of throughflows
- Ice thickness measurements (ice volume estimates)
- Freshwater source monitoring (Arctic and Norwegian runoff, precipitation…)
- Incorporation of model results into observational analysis
- Initial conditions for model runs (Arctic and Nordic Seas) – historic data

The WG7 is involved in the preparation of a white paper on the Freshwater dynamics in the northern high latitudes – its sources and consequences with the following foci:

- Variability of freshwater sources (runoff, precipitation, AW and Bering Strait inflow, Sea Ice growth/melt)
- Freshwater storage and release dynamics (basin freshwater inventories, freshwater exchange between the basins, drivers)
- Model – Data comparison (basin hydrography, timeseries at available locations)
- Consequences (local/regional consequences for the Arctic and Nordic Seas, large-scale/global consequences: influence/interaction on/with the MOC and/or the atmosphere)
- Scenarios and sensitivities (Climate change scenarios, sensitivity of the MOC response to hypothetical scenarios of changes in the hydrological cycle)

**ACTION ITEM 3.** The Modelling Group to prepare and circulate a white paper on the Freshwater dynamics in the Northern High Latitudes (Michael Karcher leading)

### 9.1 An overview of the large-scale modelling activity in Bergen (Tore Furevik)

The large-scale modelling group in Bergen uses a modified version of the Miami Isopycnic Coordinate Ocean Model (MICOM) with a dynamic-thermodynamic sea ice modules included. For the version presented in this talk, the vertical resolution exhibits 24 layers with potential density ranging from 23.54 to 28.10. The model has been run with daily atmospheric forcing (NCEP/NCAR reanalysis data) from the 1948 to present. The model results are encouraging: temperature and salinity values compare qualitatively well with observations from key sections in the Nordic Seas area.

The Bergen climate model couples the ocean model MICOM with the atmospheric model ARPEGE using the OASIS coupler. The resolution of the atmospheric grid was 2.8°x2.8° with 31 layers. The ocean grid has a resolution of 0.8°x2.4° at the equator but gradually transforming to a square grid cell towards the poles

(Mercator projection) with 26 vertical levels. Every 24 hours the coupler exchanges 11 fields with the atmosphere and ocean models. In the control simulation the model was run for 300 years. The model seems to reproduce well the modes of variability like ENSO and NAO. The simulated strength of the Atlantic Meridional overturning circulation (AMOC) is about 18Sv, with decadal variability of amplitude about 2Sv superposed on top (10% of the total). The AMOC variability in a timescale of about 10 years is directly related to the surface conditions in the Labrador Sea. A similar relation is not found between the open ocean convection and the Nordic Sea.

A sensitivity experiment has been performed with an enhanced (3 times) freshwater runoff from the Arctic region. For the present-day climate state, the strength of the AMOC was found to be quite robust to the isolated effect of high latitude freshwater forcing. After a weakening phase of about 55 years the AMOC starts to recover quite rapidly. The recovery is due to: a) change in the wind field, b) advection of tropical heat and salt anomalies to the high latitude convection regions (supported by Paleo data), and c) possibly enhanced vertical mixing.

Several model experiments have also been performed where the $CO_2$ concentration in the atmosphere has been increased by 1%/year (standard CMIP2 runs).

There are many important issues to be addressed by the modelling community in relation to the observed changes that occurred in the Nordic Seas. Some of them are listed below.

- Is there a seasonal cycle in the total inflow of Atlantic Water?
- What is the dynamics of the western branch of the AW? Is it anti-correlated with the eastern branch?
- What is causing the inflow to the Nordic Seas --- is it push or pull?
- Is the storage of AW (heat) in the Lofoten Basin of importance for the climate and circulation within the Nordic Seas and beyond?
- Is there a direct link between the inflowing AW and the overflow, where the AW is gradually freshened and cooled due to mixing with the coastal water or due to atmospheric forcing?
- What is the effect of upstream anomalies, e.g. the Great Salinity Anomaly, on the circulation and water mass transformation?
- What is the role of the Norwegian Coastal Current in the cooling and freshening of the Atlantic Water?
- What are the variability and the dynamics of freshwater (and ice) export through the connecting passages between Arctic and Sub-arctic Seas?
- What is the role of runoff and precipitation in the Arctic/Sub-arctic on the large (basin to THC) scale?
- What are the dynamics of cross-isobath transport of dense water and freshwater?
- What are the mechanisms for fresh water and heat exchange between warm, salty slope currents and cold, fresh shelf waters (eddies or Ekman dynamics?)
- What are the buffering capacities and release timescales of the ASOF basins for freshwater and heat?

- What are the mechanisms for producing the dense overflow water?
- Where are the sites of water mass conversion?
- How will the water mass conversion be affected by climate change? Can a reduction from one source be compensated by an increase from another?
- How stable are the pathways from the sinking regions to the overflow regions?
- How important is the density of the overflow water for the downstream mixing processes, the processes in the Labrador Sea, and for the total contribution to the AMOC?
- What part of the AMOC complex is most sensitive to climate change?
- What is the predictability of the system, going from global temperatures to jellyfish?

**9.2 Modelled Arctic-Subarctic Ocean Fluxes during 1979-2001 (Wieslaw Maslowski)**

The oceanic volume fluxes through the Arctic major passages were estimated with a regional model of 9km horizontal resolution. The model includes sea-ice and freshwater sources from Yukon, Mackenzie and Russian rivers. The model was run for 70 years forced with ECMWF data: 48 years of spin up and interannual simulation for the period 1979-2001. The modelled and the observed northward Bering Strait net transport fluxes are in good agreement. Table 3 shows the modelled mean net transport values at several passages.

| | Volume (Sv) | Heat (PW) | Freshwater ($10^3$ $m^3/s$) |
|---|---|---|---|
| Bering Strait | 0.649 | | |
| Davis Strait | -1.571 | 8.024 | -65.595 |
| Fram Strait | -2.346 | 7.750 | -20.251 |
| Barents Sea | 3.264 | 82.141 | -1.512 |
| **Total** | **-0.004** | | |

*Table 3. Net mean volume, heat and freshwater transport through selected sections. Positive and negative are defined as into and out of the Arctic respectively. Calculations are for the entire water column.*

It was found that the Eddy Kinetic Energy (EKE) in the Labrador Sea increases by a order of magnitude in passing from a 18 to 9 km model resolution. The results obtained with a 9 km resolution are more similar to those observed thus implying that mixing and transport are under-represented in conventional models. The same applies to the Nordic Seas.

An increase in vertical resolution has an impact in the velocity magnitudes and mean paths due to a better representation of the bathymetry. The 9km model circulation shows a good match to observations in the Barents Sea. This has implications for the locations of fronts, water mass transformations, heat and salt balances.

The time series of modelled monthly mean volume, heat and freshwater for 1979-2001 should be validated with observations and ASOF should be able to provide these data. However this model can provide interpretation/synthesis of limited temporal and spatial measurements like those presently in the Arctic and be of guidance for field studies.

Further needs are:

- Include tides into the model
- Use ERA40 forcing (ECMWF 1957-present at 100km resolution)
- Develop pan-Arctic eddy-resolving model (2-3 km resolution)
- Add freshwater sources
- Develop regional Arctic climate model to allow feedbacks and high resolution atmospheric forcing
- More data from observation available for model validation and improvements

## 10. Update on SEARCH (Jamie Morison)

SEARCH is celebrating its initial implementation plan with an open science meeting in October 2003 in Seattle. There will be about 400 people, denoting the great interest that the Arctic science is meeting around the world. US funding for the future of SEARCH seems quite encouraging. However the difficult thing is to specify what is doable today. Certainly the big challenge is to build a long-term observational system and analysis and also to make an effort to share info thus creating a new culture of research. ASOF in these aspects is a model for SEARCH.
One of the big issues that will be discussed at the next SEARCH SSC will be the internationalization of SEARCH, since the Arctic is not just US territory and research. Such discussion will start during a forum on SEARCH and its future at the Open Science Meeting. Another issue is the International Polar Year: the SEARCH vision is to propose a sustainable observational system that last for 10 years.

## 11. ASOF Outputs (Roberta Boscolo)

During the period since last ISSG meeting in Hamburg, the ASOF project officer produced the following material:

- ASOF poster presented at the WOCE final Conference, Nov.2002
- ASOF glossy brochure, distributed worldwide with the CLIVAR Newsletter, Feb. 2003
- First issue of the ASOF Newsletter, Sept. 2003
- SEARCH glossy brochure for the OSM in Seattle, Oct. 2003

The ASOF project officer also maintains the ASOF web site: http://asof.npolar.no/
The new features recently introduced are:

- A clickable organizational chart with info on ASOF EAST and WEST and regional tasks progress
- An output page with downloadable ASOF reports, presentations, publicity material and related articles
- IPY webpage that collects all the expression of interest prepared by international working groups and panels

There will be an ASOF poster displayed at the final ACSYS Conference in

November 2003 and a second issue of the ASOF Newsletter is planned for February 2004. It was decided that the focus for the second ASOF Newsletter will be the ASOF-WEST activities and their integration.

**12. ASOF Memberships and Next Meeting**

Bob Dickson recently contacted Bill Turrell regarding his future involvement with ASOF-East. In his new job as science director of the Marine Ecosystem Programme at Aberdeen, Bill Turrell has been too busy to adequately address ASOF's needs, so Bob Dickson proposed Bert Rudels to take his place. Both Bill and Bert accepted the arrangement. For ASOF-West it was proposed Mark Johnson and Rich Pawlowicz to rotate off and be substituted by Humfrey Melling and Sirpa Hakkinen.

> **ACTION ITEM 4**. To contact Mark Johnson and Rich Pawlowicz and ask whether they wish to step down as members of the ASOF ISSG (Peter Rhines)
>
> **ACTION ITEM 5.** To contact Igor Yashayaev and invite him to be part of the ISSG (Peter Rhines)

It was proposed to hold next ISSG meeting in Vigo, SPAIN. In a subsequent ballot the ISSG choose the dates of the meeting to be 21-23 October 2004.

## APPENDIX A. AGENDA

### Day 1. Saturday October 25th

**09:00** Welcome Remarks and review of the agenda (B. Dickson)
Housekeeping (P. Rhines)
**09:20** Introduction to the two themes of the meeting: “towards implementation” and “keeping it going” i.e. ASOF progress, plans and funding (B. Dickson)
**09:45** News from the US funding agencies (J. Calder/ T. Pyle)
**10:00** Introduction to ASOF-WEST: status and plans (P. Rhines)
**10.30** Coffee Break
**11:00** Pacific Gateway to the Arctic: Bering Strait and Chukchi Sea (R. Woodgate)
**11:30** Flow through the Canadian Archipelago: what do we know? (H. Melling)
**12:05** ASOF Projects at BIO (S. Prinsenberg)

**12:50** Lunch

**14:00** The Labrador Sea at half a knot on half a watt (C. Eriksen)
**14:45** Davis Strait Update (C. Lee)
**15:10** Coffee Break
**15:40** Variability and forcing of fluxes through Nares Strait and Jones Sound: a freshwater emphasis (K. Falkner)
**16:10** Joint Western Arctic Climate Studies (JWACS) Strategic Vision (T. Kikushi)
**16:20** Barium as a freshwater tracer in the Arctic (K. Falkner)
**16:40** Modelling Arctic-Atlantic exchanges and decadal variability (S. Hakkinen)
**16:50** Northern Hemisphere Sea-Ice variability and its linkage to the NAO and ENSO (J. Ukita)
**17:20** ISSG Membership issues (Dickson)

**19.00** ASOF Dinner

### Day 2. Sunday October 26th

**09:00** Task 5: Overflows and Storage Basins (T. Haines)
Discussion (all)
**10:15** ASOF-EAST the future: an introduction to ASOF-FRAM and ASOF-FAST (B. Dickson)
**10:25** ASOF-EAST future strategy (B. Rudels)
**11:00** Coffee Break
**11:25** Task 2: ASOF-EC(North) progress and plans (A. Beszczynska-Moeller and U. Schauer)
**12:00** Task 3: ASOF-EC(West) freshwater fluxes progress and plan (S. Oesterhus)

**12:20** Task 1: ASOF-EC(East) Meridional Overturning Exchanges with the Nordic Seas (B. Hansen)

**12:45** Lunch

**13:45** The freshwater array near 74°N (M. Karcher, inputs from J. Meincke)
**13:55** From MAIA to ASOF (J-C Gascard)
**14:30** An overview of the large-scale modelling activities in Bergen (T. Furevik)
**15:20** Modelled Arctic – Subarctic fluxes during 1979-2001 (W. Maslowski)
**16:10** Coffee
**16:30** Task 7: the ASOF Numerical Experimentation Group (NEG) (M. Karcher)
**17:00** SEARCH OSM and the future course of SEARCH (J. Morison)
**17:15** ASOF outputs: brochures, newsletter, website, posters (R. Boscolo)
Content of next newsletter
**17:45** Adjourn

## APPENDIX B. LIST OF PARTICIPANTS

| | | |
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## APPENDIX C: RAPID CLIMATE CHANGE PROGRAMME: STATUS AND PLANS

*By M. Srokosz (RAPID Science Coordinator). mas@soc.soton.ac.uk*

RAPID aims to investigate and understand the causes of rapid climate change, with a main (but not exclusive) focus on the role of the Atlantic Ocean's thermohaline circulation (THC). Using present day observations, palaeo data and a hierarchy of models RAPID intends to improve understanding of the roles of the THC and other processes in rapid climate change, and of the global and regional impacts of such change. The UK Natural Environment Research Council (NERC) has funded RAPID at a level of £20M over 6 years.

In 2002-2003 RAPID progressed through its first proposal evaluation round and 22 UK projects have been funded. With regard to the development of a pre-operational observing system for the meridional overturning circulation (MOC) of the North Atlantic, the UK proposals to the NERC were evaluated jointly with complementary proposals to the NSF (National Science Foundation) in the USA. 4 UK and 3 NSF proposals were funded at total costs of ~£5M and ~$7M, respectively (see table below for a list of funded proposals). Major aspects of the funded work are the monitoring of the MOC at 26.5˚N and the monitoring of the deep western boundary current (DWBC) along the western Atlantic seaboard. The first deployment of equipment to monitor the MOC will take place on cruises in early 2004.

In addition, a further 18 projects have been funded to a total of ~£6.5M (see table below) and these cover various aspects of palaeo data, modelling and present day observations that address the other science objectives of the RAPID programme (see http://rapid.nerc.ac.uk/ for the Science Plan and objectives). Of these 18 projects, 7 have a palaeo component, 14 include modelling activities and 5 will make use of present day observations. Of the present day observation projects, one is aimed at monitoring flow in the DWBC at Cape Farewell. The deployment of the equipment is expected in the summer of 2004.

The RAPID Steering Committee has set aside a sum of £0.5M to fund a coupled-model inter-comparison study that will examine the ability of a range (hierarchy) of models to simulate both idealised (e.g. so-called "freshwater hosing experiment") and past (e.g. 8.2kyear event) rapid climate change scenarios. A workshop for this activity is currently planned for February 2004.

RAPID has also funded 4 instrument development projects (see table below) at a cost of ~£0.5M under the NERC Small Business Research Initiative (SBRI). These include the development of HOMER (HOMing Environmental Recorder), which is a key instrument being used in the pre-operational MOC monitoring system, both for the 26.5˚N array and for the DWBC.

The next Announcement of Opportunity (AO) will be issued in October 2003, and will consist of two parts. The first will be a joint call for proposals with the Netherlands Organisation for Scientific Research (NWO) and the Norwegian Research Council (NRC). The total sum of money available for this call will be 4.5Meuros (NWO 1.5Meuros, NRC 1Meuros, NERC 1.5Meuros) and bids will need to have proposers from at least two of the three countries (each country will fund its own scientists) and can address any aspects of rapid climate change. The second part will be UK only and that will have particular (but not exclusive) focus on integration (that is linking across the various aspects of the RAPID programme). The sum of money available is of the order of £3M. Funding decisions are expected to be made late summer / early autumn 2004.

For further up-to-date details of the RAPID programme see:
http://rapid.nerc.ac.uk/
For details of the MOC monitoring projects, see also:
http://www.soc.soton.ac.uk/rapidmoc/

| **PI (institution)** | *Title* |
|---|---|
| | ***Monitoring the MOC (science objective 1)*** |
| Hughes C (POL) | *A monitoring array along the western margin of the Atlantic* |
| Bryden[1] H (SOC) | *Monitoring the Atlantic Meridional Overturning Circulation at 26.5°N* |
| Watson A (UEA) | *Time series of transient tracers in North Atlantic deep waters* |
| Cromwell D (SOC) | *Measuring the meridional overturning from space: a feasibility study* |
| | ***Complementary NSF funded studies*** |
| Johns W (U. of Miami) | *An Observing System for Meridional Heat Transport Variability in the Subtropical North Atlantic* |
| Rossby T (U. of Rhode Island) | *The Oleander Project: Sustained Observation of Ocean Currents and Transports in the Gulf Stream and Adjacent Waters from New York to Bermuda* |
| Toole J (WHOI) | *Investigating the Characteristics and Consequences of Interannual Variations in the Northwest Atlantic's Deep Western Boundary Current* |

[1] The original PI for this project was Prof. Jochem Marotzke, who moved from SOC to take up the post of Director of the Max Planck Institute in Hamburg, Germany. Therefore, Prof. Harry Bryden of SOC has taken on the role of PI.

| PI (institution) | *Title* |
|---|---|
| ***Science objectives 2-8 (see RAPID Science Plan http://rapid.nerc.ac.uk)*** | |
| Bacon S (SOC) | *Cape Farewell and Eirik Ridge: Interannual to Millennial Thermohaline Circulation Variability* |
| Bamber J (Bristol) | *The role of the cryosphere in modulating the thermohaline circulation of the North Atlantic* |
| Briffa K (UEA) | *Quantitative applications of high-resolution late Holocene proxy data sets: estimating climate sensitivity and thermohaline circulation influences* |
| Bryden H (SOC) | *Extending the time series of Atlantic Meridional Overturning backwards in time using historical measurements* |
| Challenor P (SOC) | *The Probability of Rapid Climate Change* |
| Fairchild I (Birmingham) | *Atlantic Seaboard Climate Responses including Bounding Errors (ASCRIBE)* |
| Guilyardi E (Reading) | *The role of salinity in ocean circulation and climate response to greenhouse gas forcing* |
| Holmes J (UCL) | *ISOMAP UK: a combined data-modelling investigation of water isotopes and their interpretation during rapid climate change events* |
| Hoskins B (Reading) | *The atmospheric water vapour budget and its relevance to the THC* |
| Josey S (SOC) | *The Role of Air-Sea Forcing in Causing Rapid Changes in the North Atlantic Thermohaline Circulation* |
| McCave IN (Cambridge) | *Hydrographic and flow changes at sharp climate transitions in the North Atlantic MOC, 0-16ka BP* |
| Pain C (Imperial) | *Better understanding of open ocean deep convection (OODC) with reference to the THC* |
| Tudhope A (Edinburgh) | *Improving our ability to predict rapid changes in the El Nino Southern Oscillation climatic phenomenon* |
| Watson A (UEA) | *Circulation, overflow, and deep convection studies in the Nordic Seas using tracers and models* |
| Wells N (SOC) | *The determination of heat transfer and storage, and their changes in the North Atlantic Ocean* |
| Williams R (Liverpool) | *The role of sloping topography in the overturning circulation of the North Atlantic* |
| Willmott A (Keele) | *Processes controlling dense water formation and transport on Arctic continental shelves* |
| Wolff E (BAS) | *High resolution anatomy of rapid climate transitions in the last glacial period from a Greenland ice core* |

**SBRI projects**

| Project Leader | Company | Project title |
|---|---|---|
| Mr Andrew Linton | PDZ Europa Ltd | Interfacing technology for high-resolution laser ablation-stable isotope ratio mass spectrometer analysis of natural archives and paleorecords |
| Dr Mark Inall | SAMS Research Services Ltd | Marine Intrument Development at SAMS (MIDAS) |
| Dr John M. (Ian) Vassie | SAMS Research Services Ltd | HOMER (HOMeing Environmental Recorder): A deep water vertical profiling vehicle |
| Miss Helen Cussen | Trident Sensors | Profilers for Ocean Research on Thermohalines (PORT) |