ESF-Exploratory Workshop on the Arctic/Subarctic Ocean Fluxes Study (ASOF)

Hamburg, October 18-19, 2002

Chair: Dr. R. R: Dickson, CEFAS, Lowestoft, UK
Co-Chair: Prof. Dr. J. Meincke, Hamburg, GER

– Scientific Report –

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1. Executive Summary

The role of the ocean in the observed global warming of the last decades is likely to involve the redistribution of heat by the Meridional Overturning Circulation, notably that of the Atlantic Ocean. Warm waters pass north through the Atlantic near the surface, they get cold and dense in the Arctic/Subarctic regions and return south at great depth. Present climate models anticipate a slowdown of the overturning under enhanced greenhouse gas forcing as a result of freshening and warming of the subpolar seas. Observations in the Nordic Seas show that the loop is currently experiencing an enormous perturbation. These observations of decadal signals imposed onto the Meridional Overturning Circulation have lead European and North American oceanographers and climatologists to initiate an Arctic/Subarctic Ocean Fluxes Study (ASOF) with the objective to measure and to model the variability of fluxes between the Arctic Ocean and the North Atlantic Ocean with a view to implementing a longer –term system of critical measurements needed to understand the high latitude ocean's steering role in decadal climate variability.

The Exploratory Workshop was held during the critical phase in the ASOF planning, i.e. the transition from science discussion to implementation. This is particularly important for progress on the European side of this trans-Atlantic study, since coordination and funding of larger scale projects in Europe is more complex. The workshop succeeded in breaking down the ASOF project into seven scientifically well founded and handable task, which will allow to carry out the distributed system of ASOF-measurements and modelling:

Task 1:	Warm water inflow into the Nordic Seas (Co-chairs: H. Loeng, NOR, and P. Haugan, NOR)
Task 2.	Exchanges of heat, salt and mass with the Arctic Ocean (Co-chairs: E. Fahrbach, GER, C. Mauritzen, NOR)
Task 3:	Ice and freshwater flux passing Fram Strait, Greenland and Denmark Strait (Co-chairs: S. Østerhus, NOR, J. Meincke, GER)
Task 4:	Greenland-Scotland Ridge Exchanges (Co-chairs: B. Hansen, FAR, B. Turrell, UK)
Task 5:	Overflows and storage basins to Deep Western Boundary Current (Co-chairs: T. Haine, USA, R. Pickart, USA)
Task 6:	Canadian Arctic Archipelago, Baffin Bay and Davis Strait throughflow (Co-chairs: P. Rhines, USA, S. Prinsenberg, CAN)
Task 7:	Numerical modelling (Co-chairs: M. Karcher, GER, R. Wood, UK)

With funding becoming available from the European Commission and national contributions for 2003-2006 for Tasks 1, 2, 3, 4 and 7and from NSF, NOAA and ONR plus national contributions for Tasks 5, 6 and 7 ASOF will start in 2003. New instrumentations for time series measurements in seasonally ice-covered waters will be available so that ASOF is expected to deliver for the first time all ocean fluxes, including freshwater, between the Arctic and the North Atlantic Ocean.

2. Scientific Content of the ASOF-Exploratory Workshop

2.1 The Scientific Problem

Plotting air temperature as functions of latitude and time it becomes clear that in the last two decades the distribution of warming has become global. The role of the ocean in this temperature change is likely to involve the redistribution of heat by the so-called "great conveyor". Passing north through Atlantic near surface and returning south at depth, this forms a "Meridional Overturning Circulation"(MOC). Most Coupled Climate Models (CCM) anticipates a slowdown of the MOC under greenhouse forcing as a result of freshening and warming the subpolar seas. The large discrepancy between the CCM's on the degree of slowdown is probably due to the lack of realism in describing the loop of the MOC in the Northern North Atlantic. Observations in the Nordic Seas show that the loop is currently experiencing an enormous perturbation. Freshwater accession to the Nordic Seas has been increased steadily over the last four decades, leading to a freshening to depths exceeding one kilometer. Consequently, the dense overflows across Greenland-Scotland Ridge that renew and ventilate the deep oceans have also freshened. The freshening signal has been measured in the deep Labrador Sea and is presently spreading south in the Deep Western Boundary Current. As we follow the deep freshening south in the Western Atlantic evidence of a salinifiying upper layer is found spreading in from the subtropics.

These observations of decadal signals imposed onto the MOC have lead European North American oceanographers and climatologists to initiate an Arctic/Subarctic Ocean Fluxes Study (ASOF) with the objective to **measure and to model the variability of fluxes between the Arctic Ocean and the North Atlantic Ocean with a view to implementing a longer – term system of critical measurements needed to understand the high latitude ocean's steering role in decadal climate variability.**

2.2 The Aim of the ASOF-Exploratory Workshop

Planning for a multi-year project of pan-Arctic scale requires stepwise implementation. After the initial steps of forming an International Science Steering Group (ASOF-ISSG chair R.R. Dickson, UK) and establishing a North American (ASOF-WEST, deputy-chair P.Rhines, USA) and an European (ASOF-EAST, deputy-chair J. Meincke, Germany,) management group, to cope with the trans-Atlantic differences in science planning and funding, the ASOF-science has been discussed during a workshop in Washington DC, in October 2001. From this, a draft implementation plan has been developed by the ISSG. It is this plan that was to be discussed during the Exploratory Workshop by the observationalists and the modellers from the ASOF-community in order to secure that:

- the science issues are completely covered
- the adequate measurement techniques are employed
- the state of the art modelling is available to the project
- the project is broken down into tasks that are handable in terms of financing, logistics and in-situ experience
- the contacts to relevant national and international programmes are established.

2.3. The Achievements of the ASOF-Exploratory Workshop

Science overview

The chairman, R. Dickson (UK), provided an updated and amply illustrated overview of the high-latitude ocean's role in climate change (see.2.1). He emphasized, that it is now that we observe the distribution of warming to be global, it is now that the high-latitude portion of the MOC is experiencing enormous perturbations, it is now that coupled climate models can cope with the basic modes of climate change and it is now that we have the observational means available for long-term measurements of the exchanges between the Arctic and the Atlantic Ocean.

ASOF-Tasks

Based on the draft ASOF-implementation plan the ISSG had proposed seven tasks to carry out the distributed system of ASOF-measurements and modelling and had identified colleagues to prepare a scientific overview as well as critical issues prior to the Exploratory Workshop. These presentations and their discussions formed the bulk of the workshop-programme.

Regional Task 1: Warm water inflow into the Nordic Seas
(Co-chairs H. Loeng, NOR, and P. Haugan, NOR)

Focus is on continued long-term instrumented moorings and repeat hydrography in the key regions of the Faroes, Svinoy, Barents Sea opening and Fram Strait. Observation in the 1990's have shown a close correlation between northward heat salt flux and the large scale atmospheric driving as represented by the North Atlantic Oscillation index. Modelling has revealed, that baroclinic perturbations from south of the Greenland-Scotland Ridge can propagate far north into the Arctic. Critical issues: How sufficient is the NAO as a climate index for the warm inflow at all times? In what ways are the wind/buoyancy forcing important?

Regional Task 2. Exchanges of heat, salt and mass with the Arctic Ocean
(Co-chairs E. Fahrbach, GER, C. Mauritzen, NOR)

Fram Strait and Barents Sea Opening are the loci for heat and salt fluxes to the Arctic Ocean and sea ice and fresh water as well as polar waters to the Nordic Seas. The width of the passages allows for complex recirculation pattern, which require high-density measurement arrays and careful choice of averaging intervals. From existing measurements transport variations are of the order of 50%. Critical issues: How far does the barotropic character of the current field allow to replace current meter moorings by bottom pressure recorders? How likely do inverted echo sounders capture the variations in heat content of the fluxes? Are the fluxes through Fram Strait correlated with those through the Barents Sea opening?

Regional Task 3: Ice and freshwater flux passing Fram Strait, Greenland and Denmark Strait (Co-chairs S. Østerhus, NOR, J. Meincke, GER)

The freshwater output from the Arctic Ocean into the North Atlantic is a major control of the intensity of the MOC. The flux through Fram Strait is the world second largest fresh water input into the ocean. Whereas numbers on the ice flux through Fram Strait are available this is not the case for the liquid contribution from the Arctic. Direct measurements of the liquid component are hard to obtain, since the pathway of the low salinity waters is over the Eastgreenland shelf immediately underneath the ice. Recent developments of profiling sensor-

packages operated from bottom-mounted winches or sensors mounted in rugged long tubes that are deflected by drifting ice have yielded first time-series of salinity-profiles underneath the ice. Critical issues: How much freshwater from the Eastgreenland Current is injected into the convective gyres of the Greenland and the Iceland Seas? How is the total freshwater flux from the Arctic Ocean portioned between the Nordic Seas and the Canadian Arctic Archipelago?

Regional Task 4: Greenland-Scotland Ridge Exchanges
(Co-chairs B. Hansen, FAR, B. Turrell, UK)

The Greenland-Scotland Ridge exchanges include the systems of the Atlantic inflow in the upper layers, the surface outflow in the Eastgreenland Current and the deep overflows. In the budget for the Arctic Mediterranean the Greenland-Scotland Ridge accounts for all the Atlantic inflow (90% of the total inflow) and 90% of the total outflow. The basic exchange pattern is relatively well known, however time series analyses from existing time series measurements and proxy data indicate significant decadal variability. The example of the Faroer Bank Channel shows a decrease of the deep overflow by 25% since 1950. More over all outflows across the ridge system show a clear trend of decreasing salinity by about 0.04psu over the last four decades. Critical issues: The overflow areas of the Greenland-Scotland Ridge are very dissimilar in terms of topography and dynamic controls. Mesoscale eddy processes and recirculations require an enormous observational effort.

Regional Task 5: Overflows and storage basins to Deep Western Boundary Current
(Co-chairs T. Haine, USA, R. Pickart, USA)

The basins to the south of the Greenland-Scotland Ridge, notably the Irminger and Labrador Basins are the recipients of the outflows from the Arctic Ocean/Nordic Seas. The subpolar gyre and a series of sub-basin scale recirculations together with the processes of entrainment and mixing lead to the transformation of the deep overflows to North Atlantic Deep Water and to its export into the Atlantic with the Deep Western Boundary Current. The shallow outflows determine the convective effectivity of the subpolar seas, i.e. mainly the warm to cold conversion of the subpolar mode waters. Major progress in this field can be obtained by the extended use of profiling floats, remote sensing of sea surface heights and repeat hydrography. Critical issues: The role of mesoscale variability resulting from instabilities of the boundary currents and effecting convection in the center of the Labrador Sea.

Regional Task 6: Canadian Arctic Archipelago, Baffin Bay and Davis Strait through flow
(Co-chairs P. Rhines, USA, S. Prinsenberg, CAN)

This component will provide year round measurements of volume, freshwater and ice flux across Davis Strait. These fluxes represent the net integrated Canadian Archipelago throughflow, modified by terrestrial inputs and oceanic processes during its southward transit through Baffin Bay. The measurements at Davis Strait will be used to study how fluctuations in the Arctic freshwater system modulate deep-water formation in the Labrador Sea to the south, thus influencing the MOC. An important component of the measurements will be the emerging technique of acoustically navigated sea gliders, which provide high-resolution hydrographic sections in support of a sparse array of moored instrumentation. Critical issues: Special precaution needed on measuring current directions because of proximity to the magnetic North Pole.

Regional Task 7: *Numerical modelling*
(Co-chairs M. Karcher, GER, R. Wood, UK)

A cross-cutting modelling group was considered necessary to coordinate the modelling efforts needed for measurement array design, for simulating observed changes, for prediction trials and ultimately for a synthesis of the results from the regional tasks. A special presentations by J. Dengg from the FLAME-group in Kiel on the results of eddy-permitting and eddy-resolving modelling activities on the temporal variability of the Atlantic MOC and on the effect of overflows across the Greenland-Scotland Ridge on the basin-wide circulation was provided. Although non eddy-resolving model versions were shown to be adequate for the study of large-scale variability in the subpolar North Atlantic, on eddy-resolving model is essential for reproducing the dynamically relevant features such as boundary current paths and its recirculations and the effect of the eddy-field on the restratification of convective patches. Critical issues: The complexity of scales and process to be observed in the ASOF domain requires the availability of a hierarchy of models with special emphasis on dynamical interpretations of observed variability. Close liaison with North Atlantic/Arctic modelling groups and participation in model intercomparison studies are essential.

ASOF-links to relevant national and international projects

The presentations and discussions on the ASOF-Tasks included a brief overview on ongoing and planned international and national programmes contributing to the ASOF-Objectives. The list ranges from North Atlantic/Arctic components of the WCRP-programmes CLIC and CLIVAR to national projects in Norway (NoClim), Germany (SFB 460, SFB 512), UK (RAPID), Canada/Japan (JWACS) and North America (SEARCH, Arctic Freshwater Cycle). Liaison between ASOF and other programmes is established through relevant joint participation of members of the ASOF-ISSG and of the ASOF-TASK Groups.

ASOF Data policy

The discussion on data quality standards, data submissions and archiving priority access and availability to the community clearly resulted in following the CLIVAR-data management strategy, which is presently developing. Thus ASOF will strive to become one of the intended CLIVAR-Regional Application Centers.

New instrumentation

The seasonal ice cover in parts of the ASOF-area, the strong near surface gradients of the freshwater flows and the strong near bottom gradients of the dense overflows are extremely demanding on the use of moored sensors and research vessels. Several areas a heavily fished as well. Therefore the use of trawl proof, bottom-mounted instrumentation like ADCP's, IES's and ULS's is necessary in many cases. New instrumentation is becoming available: HOMER is a bottom mounted package with a buoyant CTD-capsule, which is regularly winched through the water column to immediately beneath the ice. New whole water samplers to be used in a moored mode are available for time-series of water samples. Sea gliders promise acoustically navigated high-resolution CTD-profiling along sections even under ice. Reliable CTD's profiling along a mooring cable and free drifting profiling floats are long wanted

systems for detailed hydrography. New satellite sensors for ice thickness (ICESAT and CRYOSAT) will improve the estimates of ice volume fluxes considerably.

Sustaining the future to ASOF: Funding opportunities

ASOF will start its fieldwork in 2003/2004. Funds are available from the EC and from national source for a cluster of Tasks 1,2,3, 4 and 7 until 2006. Funding of Task 6 is becoming available in 2003/2004 in NSF- and ONR-projects up to 2007, including the further development of the sea glider system, Task 5 and 7 will be funded under the UK-RAPID and the CLIVAR related hydrography in the subpolar Atlantic from UK and North American sources for several years from 2003/2004 onwards. The future prospects on the European side call for an Integrated Project under the EC-Framework Programme VI, the relevant proposal WATCHER will be submitted in 2004. On the North American side there are positive signs for a longer-term funding of the ASOF-related projects.

Following a review of ESF-activities and funding instruments, which were presented by M. Hildebrand, the ESF-LESC Senior Scientist Secretary, the workshop expressed the need for an effective and longer-term coordination of the European contribution to ASOF. Members of the Steering Group will discuss with the LESC Secretariat the optimal instrument to apply for.

Next steps

- The Task Groups further refine the plans for fieldwork and modelling, coordinate the deployment of ships and moored instrumentation and arrange for early data availability for modelling. Task Group chairs report to the Science Steering Group.
- Update the ASOF-brochure, manage the ASOF webpage (http://asof.npolar.no) create and manage an ASOF-mailing list and calendar, publish an ASOF-Newsletter. These tasks will be carried out by Roberta Boscolo, Vigo, Spain, who has taken on the job as ASOF Project Scientist next to her main activity as CLIVAR Project Scientist.
- Prepare proposal for an Integrated Project on ASOF-objectives to the EC 6th Framework Programme.
- Prepare proposal for ESF-support to the European coordination of ASOF after consultation with ESF-LESC.

Concluding remarks

In his concluding remarks the chairman expressed his satisfaction, that the intense two days of the Exploratory Workshop have succeeded in organizing ASOF in a task related mode, with teams of regional experts taking on the responsibility to contribute to the ASOF objectives in the best possible way.

The participants expressed their thanks to the ESF for funding and organisational assistance and they thanked the local organizers for providing an effective working environment.

R.R. Dickson
J. Meincke

3. Final Programme

Day 1. Friday October 18th

9.30 Welcome Remarks and revision of the agenda (Dickson)
Housekeeping (Meincke)
10.00 Introduction: ASOF science in a broader perspective (Dickson)
10:30 Coffee break
11.00 Review ASOF-draft implementation plan and organisational structure (Dickson)

12.45 Lunch

13.15 European Funding of ASOF (Meincke)
13.30 North American Funding of ASOF (Rhines)
14.00 ASOF publications and tasks of project scientist (Boscolo)
14.30 ASOF Circum-Arctic Assessment initiative (Calder)
14.45 TASK 2 Overview of science and critical issues (Fahrbach)
15.30 Coffee break
16.00 TASK 7 Overview of science and critical issues (Karcher)
Science talk (Dengg)

Day 2. Saturday October 19th

9.00 TASK 1 Overview of science and critical issues (Loeng)
NoCLIM project phase II (Mauritzen)
9.30 ACSYC-CLIC link to ASOF and issues related to ESA projects to study ice fluxes from SAR images (Fahrbach)
9.50 TASK 4 Overview of science and critical issues (B. Hansen)
Denmark Strait Overflow - results from VEINS (Meinke)
10.30 Coffee break
11.00 TASK 3 Overview of science and critical issues (Østerhus)
12.00 TASK 5 Overview of science and critical issues (Haine)
observational system (Pickart)

13.00 Lunch

13.45 TASK 6 Overview of science and critical issues (Rhines)
New USA measurements with gliders (Lee)
Canadian Activities (Prinsenberg)
Coastal processes studies (Münchow)
15.30 Coffee break
16.00 New Instrumentations overview
HOMER (Vassie)

Mooring Profilers (Pickart)

16.45 Sustaining the future of ASOF
ESF possible funding source (Hildebrand)
EC (Meincke)
US funding post 2005 (Rhines)

17.15 SEARCH Links to ASOF (Morrison)

17.30 UK RAPID programme and link to ASOF (Marotzke)

18.00 JAMSTEC activities and interest in ASOF (Ukita)

18:15 Concluding remarks '(Dickson)

1830 End of the Exploratory Workshop.

4. Final List of Participants

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4.1 Statistics on participants

Total participants	**27**
Female participants	4
Age group 20-30	0
30-40	8
40-50	5
50-60	12
>60	2

National participation	
Canada	1
Denmark	1
ESF	1
Faroe Isl.	1
Finland	1
France	1
Germany	3
Norway	4
Spain	1
UK	4
USA	9