ARCTIC / SUB-ARCTIC
OCEAN FLUXES STUDY

Draft Report of the 5th meeting of

ASOF International Scientific Steering Group

16-18 November 2005

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1. Introduction

B. Dickson, ISSG chairman, opened the 5th ASOF ISSG meeting by welcoming the participants (see Appendix A). P. Nival, ex Director of the Oceanographic Laboratory of Villefranche sur mer also welcomed the participants on behalf of the hosting institution. Like last year, as part of the meeting programme the ASOF ISSG organized a one-day workshop. The topic of this year workshop is the use of tracers for estimates of oceanic fluxes (see Appendix B), promoted by M. Karcher and B. Dickson.

In his introduction, B. Dickson focused on the future of ASOF and mentioned the recently funded EU Integrated Project DAMOCLES, under which some the ASOF-East arrays will continue to be sustained. Some other key ASOF measurements will be maintained under the activities promoted by iAOOS (integrated Arctic Ocean Observing System), an initiative for the International Polar Year. Figure 1 shows schematically the time lines of the existing and future initiatives in the Arctic. The International Study of Arctic Change (ISAC, yellow) will supplement the existing US Study of Environmental Arctic Change (SEARCH, blue) with a correspondingly large and complete major international effort that will coordinate multidecadal and multi-disciplinary pan-Arctic activities. ISAC will be organized under the aegis of the non-governmental Arctic Ocean Science Board (AOSB) and International Arctic Science Committee (IASC).

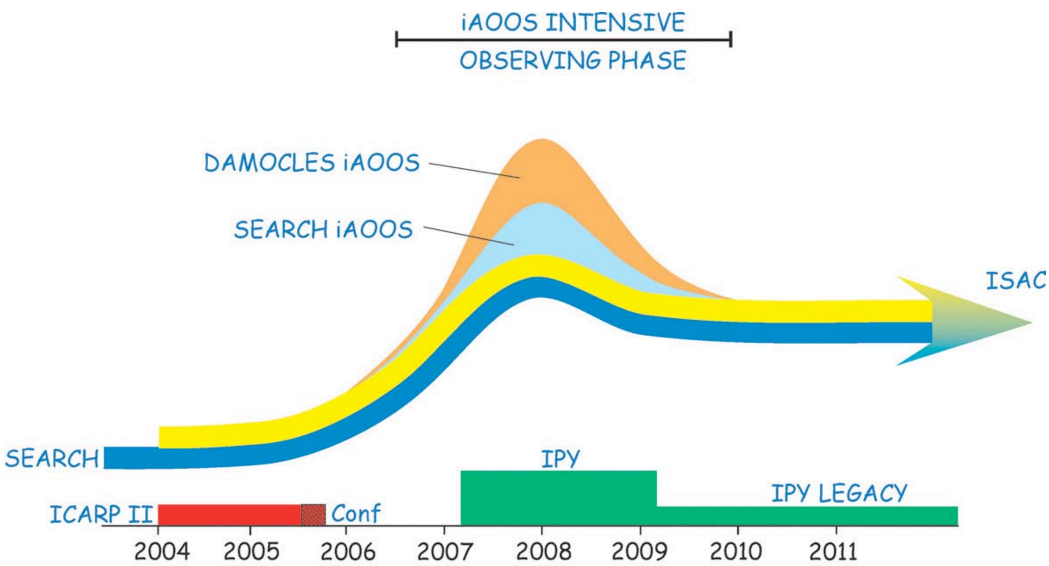

Figure 1. The integrated Arctic Ocean Observing System (iAOOS) in relation to ICARP, DAMOCLES and the multidecadal SEARCH and ISAC studies of Arctic change.

B. Dickson also reported on the ICARP II conference, which was held in Copenhagen in November 2005. The goal of ICARP II was to prepare Arctic research plans to guide international cooperation over the next 10-15 years. The conference was the culmination of a 24-month planning process involving over 140 scientists working to develop research plans around eleven critical research themes. Conference participants were actively involved in modifying and improving these plans for future implementation.
It became clear during the work of the Conference that the Arctic is a system that can no longer be divided into traditional disciplines. The linkages to other disciplines and

other knowledge systems and to the global system are critical and must be addressed in the post-conference process. Four organizing issues were identified:

- The shrinking realm of snow and ice
- Fluxes in and out
- The Arctic as the “canary in the mine”
- Adapting to change

Conference participants also raised continued concern about issues surrounding data management, interoperability and dissemination. It is clear that in light of the International Polar Year and implementation of ICARP II plans over the next decade that the research community must urgently address this issue. The need for enabling infrastructure to provide the platforms for the next generation of users is a critical need highlighted in the reports and during the conference plenary sessions..

2. Update on ASOF-East Activities

2.1 ASOF-EC(North) (*A. Beszczynska*)

The European project ASOF-EC(North), which is linked to ASOF task 2, has the overall objective of establishing the appropriate components of the global observing system in the choke points of the Nordic Seas necessary to obtain the long term consolidated data set required to determine the variability of dense water, freshwater, and heat fluxes between the Arctic Ocean and the North Atlantic, of understanding and predicting how the fluxes respond to climatic forcing, and of providing the tools needed to asses the risks of abrupt changes. The project is divided in 6 work packages:

- WP1: Atlantic water pathways. The data collected with acoustic floats and annual cruises reveal that the Norwegian Atlantic Current is not restricted to a narrow swift boundary current along the continental margin west of northern Norway but rather to a broad (100km) and slow (less than 5 cm/s) current progressing to the North and/or recirculating to the west in the Lofoetn basin or heading east towards the Barents Sea. The seasonal variability when comparing the behaviors of the floats trajectories in summer and in winter exhibits a more intense eastward Atlantic flow entering the Barents Sea in winter time and a more intense northward Atlantic flow progressing northward towards Fram Strait in summer time. The barotropic component of the flow changes on short-time scale while the baroclinic flow is closer to the climatic tendency of the transports.
- WP2: Fluxes across the Western Barents slope. In the 1996-97 the temperature was below the long-term average while in 2004 it was higher than the average with a maximum in October. For the first time the average temperature in the core of the Atlantic inflow passed 7°C in this area. The seasonal variability shows a maximum transport during spring and a 25% higher inflow during winter compared to summer. During winter the stratification is weaker due to frequent atmospheric lows while during summer the inflowing area is wider with lower velocities. The Annual mean transport of the Atlantic water is estimated at 1.5±1.0 Sv with 1.3 Sv in summer and 1.7 Sv in winter. The monthly mean volume flux fluctuates between 5.5 Sv into and 6 Sv out of the Barents Sea with a recirculation more stable at a value of about 1 Sv. There is no correlation between the fluxes and the temperature of the inflowing water. The temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea while the volume flux depends mainly on the local wind field. Regional high-

resolution numerical models have been set up in order to assess the importance of processes and parameters responsible for the transport variability, such as boundary currents, eddies and meanders, bottom topography, winter cooling and meteorological parameters.

- WP3: Heat flow through Fram Strait. The mooring array along the Fram Strait which was first deployed in 1997, is currently maintained with 17 moorings. The sections exhibit a general increase of temperature anomalies from 1997 to 2005. The total volume transport oscillates around the zero value while the heat transport is always northward. A high-resolution model has been set up for the area using the result from a ¼° model and forced with ERA 40 reanalysis. The model was run from 1.1.1990 to 2004.
- WP4: Fresh water flow through the Fram Strait. The mooring array includes 2 tube moorings and 1 ADCP mooring on the shelf and 4 moorings across the East Greenland Current (EGC). With the tube moorings it was possible to measure temperature and salinity in about 24dbar and 64dbar depth on the East Greenland shelf. There is a relationship between salinity and ice-cover although not as strong as at 74N: advective processes may play an important role here. There is a large difference between the near surface data (~60m) and the climatologies.
- WP5: Data management. The main objectives are: to achieve a consistent, quality-controlled and publishable set of direct observations (from ship borne and from autonomous measurements), derived quantities (e.g. transports) and model-output. It is also intended to provide full access for all project participants and for the scientific community to electronic information on the project and its aims, on the actual status of field and modelling work and on the data inventory. Two web pages provide information on the data and data flow:
  http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ASOF/index.htm
  http://www.awi-bremerhaven.de/OZE/ocdb/oc_java/moor/ocdb_flux.html
- WP6: Integration and Synthesis. The project aims: To determine water mass transformations in the Arctic Mediterranean that are the means by which the oceanic heat transported to the Arctic becomes available to the Arctic environment; to combine the measurements of property changes at choke points which give evidence of how and how strongly the ocean transports influence the Arctic and how their influence varies with time and atmospheric forcing; to evaluate the performance of the deployed arrays and to design an array of minimum effort and assess the uncertainty. Some key issues for the W6 are: optimization of the mooring arrays in Fram Strait and BSO, comparison between geostrophically computed transports and the ADCP/LADCP measurements, questions concerning the AO volume and freshwater balances for the measured net inflow through Fram Strait, detailed water mass classification, the fate of the Atlantic contributions to the halocline water in the AO, exploring the possibility to compute the changes (in time) of heat and salt (freshwater), or rather the temperature and salinity fluxes through Fram Strait using variable reference salinities and temperatures, based on the mean inflow salinity and the mean outflow temperature.

2.2. ASOF-EC(MOEN) (*B. Hansen*)

The project ASOF-MOEN (Meridional Overturning Exchange with the Nordic seas), linked to ASOF task 1, consists of 5 tasks:

- Measure the total flux and characteristic of Atlantic water passing into the Nordic Seas across the Greenland- Scotland Ridge
- Measure the flux and characteristic of the eastern component of the overflows from the Nordic Seas to the North-Atlantic
- Estimate the contribution of meso- and small scale processes to these fluxes
- Model the fluxes and reconstruct their variability since the onset of the 20th century
- Relate strengths and variability of the fluxes to local and remote forcing mechanisms as well as to internal modes of oscillation.

MOEN covers 90% of the total warm water inflows to the Arctic Mediterranean and 30% of the total outflow. There are 3 inflow and 3 overflow branches. One branch of the Atlantic inflow passes through the Denmark Strait and then eastwards, north of Iceland where the ASOF mooring array is deployed. ADCP moorings are presently collecting data between Iceland and Scotland. The revised estimates of the fluxes carried by the three Atlantic Inflows branches give 0.8Sv for the branch that passes north of Iceland, 3.8Sv for the Iceland-Faroe branch and 3.8Sv for the Faroe-Shetland inflow. According to the updated Arctic Mediterranean budget these new estimates suggest that 3Sv correspond to the Denmark Strait Overflow, 3Sv to the Iceland-Scotland Overflow and 3.5Sv to the surface outflow along the Greenland slope. There are 3 Iceland-Scotland overflow areas. An experiment is underway since 1995, the covariance between temperature and velocity fields shows that the FBC overflow is very stable. The standard sections over the Iceland-Faroe Ridge reveal a varying overflow both spatially and temporally.

2.3 ASOF-EC(West) (*B. Dickson and J. Meincke*)

The project ASOF(EC)-West, which is linked to the ASOF tasks 3 and 4, has been designed to meet the following overall objective: to measure the variability of the dense water and freshwater fluxes between the Arctic Ocean and the North Atlantic in the critical region off Southeast Greenland with a view to understanding and predicting their response to climate forcing. The freshwater array was deployed near 64°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. These moorings have been reasonably successful since the first experimental trial except for last deployment in 2004. The losses in 2005 is probably due to a massive acceleration of two major glaciers in southeast Greenland that resulted in 120 cubic km/yr ice loss from ice dynamics: 210% increase in discharge with respect to years previous 1996. However in its present form the freshwater array has been used to provide the first estimate (64 mSv) for the flux along the outer part of the SE Greenland shelf. The core of the Denmark Strait Overflow is captured by the dense overflow array that is a continuation of the deployments carried out from 1997 to 2000 under the EU-MAST VEINS project. The Denmark Strait overflow has been measured since 1986 by CEFAS (UK), latterly with UHH and FIMR. In 2000 the array was extended to the west to cover the freshwater flux passing south on the SE Greenland shelf. The dense water transports at densities greater than 27.85 show no significant trend over the 8-9 year period in the Angmagssalik array. However it has been stated that DSO transport measured close at the sill has decreased remarkably during last 4 years. Correlation between the time-series of overflow transport close to Denmark Strait sill and the ASOF-W current meter array is good when the sill leads Angmagssalik by 70 days. The temperatures recorded since 1986 in the bottom 100m in the core of the DSO off Angmagssalik show decadal fluctuations while salinity decreases in the early part of the year and extreme freshening happened in Jan to July 2004. The 2004 freshening occupied the full width of the overflow. The freshwater array was redeployed with 1 tube and ADCP, the second tube was replaced by 3 SBE-37 microcat sensors, 1 profiling current meter with salinity sensor. GET few paragraphs from Jens to complete the section

3. Updates on ASOF WG7, Numerical Experiments Groups (*M. Karcher*)

The working group WG7 (the Numerical Modelling) aims at integration of knowledge gained from numerical modelling into the picture, encompassing the entire Arctic and Subarctic domain and linking it to the global thermohaline circulation. The focus of the activities of WG7 is a better understanding of the role of 'freshwater' and its dynamics. In this context WG7 has been asked by the ASOF steering committee to set up a 'white paper' attempting at a summary of the state of the discussion about freshwater dynamics in the Arctic and Subarctic, and its influence on the Meridional Overturning Circulation from the point of view of numerical modelling. For this purpose the chair of the WG7 (M. Karcher) has asked a number of experts for their personal view and have summarized these contributions, amalgamating them with other published or unpublished work, an attempt necessarily doomed to be incomplete. The first draft of the whitepaper on " The dynamics of freshwater storage and release in the Arctic and subarctic and its interaction with the meridional overturning circulation –insights from numerical modeling" was distributed at the meeting. Two groups of questions are addressed in order to capture the regional aspects and the link to the global scale, respectively:

- Regional
    - What are the long-term behaviour and the dynamics of the freshwater storage and release in the Arctic/Subarctic Basins?
    - What are the source areas for the overflow/outflow water masses and what determines the variability of their hydrographic characteristics and volume?
    - What are the governing factors for freshwater outflow via Fram Strait and the Canadian Archipelago?
    - What is the role of Freshwater/Salt Inputs (i.e. external forcing by rivers, precipitation/evaporation, Atlantic Water and Bering Strait inflow) for the storage and release dynamics of freshwater in the Arctic/Subarctic Oceans ?
- Global
    - What is the response of the thermohaline circulation (THC) or meridional overturning circulation (MOC) to releases of Freshwater from the Arctic/Subarctic Oceans? Does the MOC overturning strength show a different behaviour than the poleward heat/salt transports?
    - What is the relative importance of surface and subsurface outflows from the Arctic/Subarctic Oceans in comparison with each other and with processes south of those oceans for the variability of the MOC?
    - Do we get different answers on the question for the freshwater storage and release in the Arctic/Subarctic Oceans if we use ice/ocean models

in contrast to fully coupled ice/ocean/atmosphere models? If so, where do the answers differ?

The content of the whitepaper includes:

- Freshwater dynamics in the Arctic/Subarctic Oceans
    - The Arctic as a source of salinity anomalies on different time-scales: interannual to decadal oscillations of outflow salinity linked to arctic state of oscillation
    - Extreme events like GSA and 90s anomalies
    - Actual influence on convection
- Arctic/Subarctic freshwater releases and MOC
    - Influence of export depth on MOC sensitivity
    - Overflow volume and composition – which is stable or unstable
    - Link between convection and MOC strength
    - Link of MOC with northward fluxes
    - Stabilizing effects

It has been highlighted the necessity of model/observations joint work and model sensitivity analysis and model intercomparison.

M. Karcher and I. Yashayaev organized a theme session at the EGU general assembly (Vienna, Austria, 24–29 April) devoted to observational monitoring and modeling of the oceanic heat and fresh water budgets and transports. The session primarily aimed to provide a better understanding of the temporal and spatial changes, local and remote interactions in the Arctic and Subarctic Oceans from observational and modelling points of view. 33 poster and oral presentations spanned a range of topics from local process studies to global syntheses. The session was organized proceeding from large scale syntheses of observed and modelled variability to regional and local studies. Where possible, the conveners drew links between presentations and promoted discussions on the nature of the changes and possible mechanisms involved. Five articles prepared by session participants based on their presentations are included in the November issue of the ASOF Newsletter.

M. Karcher also reported on last activities of the Arctic Ocean Model Intercomparison (AOMIP) project. A new 50-year coordinated experiment with new forcing data set is under discussion meanwhile a JGR special issue is in preparation and a PIs meeting is proposed within the Ocean Science Conference, in Honululu February 2006.

Part of the WG7 activities will be carried out under the new project DAMOCLES which has a core theme called "Integration by Modelling":

- To progress the understanding of the fate of sea ice and its interaction with ocean and atmosphere by means of observation-supported model improvement and sensitivity studies.
- To develop assimilation methods with the goal of producing fields of key arctic variables for the DAMOCLES period that combine information from observations and models.
- To quantify the effects of improved understanding and process description or assimilation techniques on simulation capabilities

4. Status and Prospects in the Subpolar Gyre *(T. Haine)*

The group reviewed the status of current and pending fieldwork in the western subpolar gyre relevant to ASOF in order to: compile a comprehensive list of activities, establish priorities in this list of field projects and identify gaps in the observing network. Worth mentioning is a Discovery cruise (23 Aug – 26 Sept 2005) deployed several moorings in Cape Farewell extending the IFREMER moorings array. 63 CTD/LADCP/CFC/18-O stations were performed too. A new array of moorings was deployed in Orphan Basin in May 2005 and will stay till spring 2006. Some process studies have been proposed:

- Shelf/basin exchanges East of Greenland: forcing, dynamics and large-scale impact south of Denmark Strait and "spill-jet" phenomena observations at adequate time/space resolution. The main hypothesis is that hydrodynamic instability and atmospheric lead to intense shelf-basin exchanges East of Greenland, which influences both the downstream boundary current system and the interior subpolar gyre. The implications are that the local dynamics of the shelf-edge current south of Denmark Strait impact to first order the fate of the Arctic outflow and its influence on the North Atlantic. The overall goal to use a combination of detailed field measurements and regional numerical modelling to quantify the complex shelf-edge boundary current system south of Denmark Strait and determine the basin-scale impact of its variability. The specific objectives are: 1) to quantify the mean and seasonally-varying transport, structure and kinematics of the East Greenland/Irminger Current system; 2) to determine the nature and dynamics of the mesoscale variability that leads to shelf-basin exchange; 3) to document the cascading of dense water and formation of the east Greenland Spill Jet; 4) to quantify the large-scale impact of the flux of mass and properties from the East Greenland shelf to the North Atlantic subpolar gyre. A mooring array is proposed to be deployed at 65.5N 33E in summer 2007 for 12 months. GET paragraph from Svein and the new tube mooring that is under development. The modelling experiment will use a 2km resolution 100-level ocean/ice model with data assimilation already supported by NSF/NASA projects.
- Intense air/sea interaction off Greenland: tip jets, barrier wind and reverse tip jets are poorly observed and understood. Dedicated regional atmospheric models may have skill. But reanalysis fluxes are unsuitable for driving ocean models during intense subpolar Atlantic weather.
- Greenland flow distortion experiment (GFDex) focus on the role of Greenland in distorting atmospheric flow and creating high-impact, intense systems. About 50 FAAM flying hours are proposed from Reykjavik in Feb/March 2007 with 50 drop sondes. Mesoscale modelling will be done with the UKMO Unified Model.

  ACTION ITEM: Communicate to B. Dickson and J. Meincke what the ASOF-EC(West) array can do downstream to help with the spill jet mooring array (*T. Haine*)

5. Progress and Challenges for ASOF Task 6

5.1 Canadian Arctic Archipelago Update on Activities (*H. Melling)*

The Canadian polar shelf is 3.3 million km^2 with a marine portion of 1.9 million km^2. There are six choke points where the flux through the Canadian Arctic Archipelago must pass (see Table 1). The moorings in Cardigan Strait and Hell Gate have been recovered after three years. This contributes to a 7-year period of observations. The ADCP moorings have been redeployed for another 3 years. Also in the Barrow Strait 9 of 11 moorings were recovered completing the 7^{th} year of observations. Measurements will continue with 8 moorings deployed at 4 locations. The array in Nares Strait that operated for almost two years, was supposed to be retrieved, serviced and re-deployed in May 2005 for a further two years. In April-May 2005 the fuel cache and camp was established in Lafayette Bay but due to bad weather the expedition was aborted. It is planned to recover the 18 sub-sea moorings in Nares Strait in August 2006.

Channel	Section area *m^2*	Share of total area	Section width *km*	Share of total width	Mean depth *m*	Length k*m*
Kennedy Channel	10,370,000	42.7%	27.7	22.6%	374	1250
Hell Gate & Cardigan Strait	1,420,000	5.8%	12.4	10.1%	115	1200
Wellington Channel	4,550,000	18.7%	28.3	21.1%	160	1450
Barrow Strait	7,930,000	32.6%	52.3	42.6%	152	1700
Bellot Strait	31,600	0.1%	1.9	1.5%	17	
Sum of Sections	24,301,600	100%	122.6	100%	198	

Table 1. Channel constrictions within the Canadian Arctic Archipelago

Sea ice within the Canadian Archipelago locks up 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. One technique, which has been established, is to track features with AMST-E and Radarsat.
Another activity undergoing is the modelling of topographic channelling of wind using a triple-nested MM5 model to get down to 6km resolution. The model have been running for two years starting August 2003.
Baffin Bay will be surveyed with ArcticNet expedition (2004-2010), the long-term observations will address physical processes as well as environmental changes (marine environment and biological systems)

5.2 Ongoing Activities in Davis Strait (*C. Lee*)

A hydrographic survey took place in the Davis Strait in September/October 2004, data collected included O_2 isotopes, nutrients, trace metals and CFCs. Also 6 subsurface moorings, 8 bottom landers and 2 acoustic sources were deployed. The project is funded till autumn 2007 but it has been proposed to continue through the IPY as an US-Canada-Greenland-Denmark collaborative effort with an expanded biological and chemical sampling.
P. Rhines and C. Eriksen successfully resurveyed the Labrador Sea with gliders in September 2004-March 2005. Unfortunately such program is not currently funded, however there is a proposal to survey the Faroe region.

A workshop on Arctic navigation and telemetry will take place in February 2006 at NSF Office of Polar Programs. The objectives are to specify acoustic navigation and telemetry system for immediate use by developers, to identify additional research needs and to promote activities for establishing long-term coordination and collaboration.
New platforms are under developments:

- Deepgliders – 6000m
- Icegliders – operations under ice
- Acoustic navigation and communications-gliders integration
- Arctic navigation and communications
- ICECAT moorings for ice covered shelves

5.3 Labrador Sea and Orphan Basin Cruises (*I. Yashayaev*)
The Labrador Sea is the major supplier of fresh and cold intermediate waters to the North Atlantic, it receives, transforms and transfers waters from and to other basins. Over the past 16 years (1990-2005), the Ocean Sciences Division of the Bedford Institute of Oceanography (BIO) has conducted annual occupations of a hydrographic section across the Labrador Sea. These observations, when combined with the U. S. Coast Guard's *Ocean Weather Ship (OWS) Bravo* time series (1950-1974) and other archived data, document prominent interannual and decadal changes at all depths. The May 2004 survey showed that the upper 1500 metres of the Labrador Sea were the warmest since the beginning of annual occupations of AR7W in 1990. The most rapid warming of this layer occurred between 2003 and 2004. This warming was not simply a consequence of the warming in the surface and LSW layers. In 2004, a large volume of warm and salty water appeared over the continental slopes on the Greenland and Labrador ends of the section. This water is thought to have come from the Irminger Sea, carried north and west by the Irminger Sea branch of the North Atlantic Current. This warm and salty water from the Irminger Sea, seen along the eastern and (in some years) western rims of the Labrador Sea, spread out to the centre of the Labrador Basin in 2004, filling the whole eastern part of the basin between 100 m and 800 m. As a result, temperature and salinity at 700 m in the eastern part of the Labrador Sea increased in a year by 0.6°C and 0.05.
Although the volume of these Irminger Sea waters did not further increase in the most recent occupation (May–June, 2005), the warming trend in the upper 2000 metres over most of the AR7W line did persist. The Labrador Sea is approaching the conditions last seen in the late 1960s. If these trends continue, the Labrador Sea temperatures could soon become the warmest ever recorded.

In May of 2005 the CCGS Hudson successfully recovered five moorings from Orphan Basin on the Eastern Newfoundland Slope, and redeployed six moorings. The vessel also occupied a CTD section across Orphan Basin and several CTD stations in Flemish Pass, partially repeating sampling conducted in June of 2004. This work was carried out as part of the Canadian Program on Energy Research and Development, and DFO climate and environmental variability programs at the Bedford Institute of Oceanography (BIO).
The hydrographic sections across Orphan Basin revealed significant basin-wide changes in the upper, intermediate, deep and bottom waters. Even though the section was occupied earlier in 2005 than in 2004 (so that colder sea surface conditions were expected), the upper and intermediate waters in 2005 were notably

warmer (by more than 1°C), especially in the eastern part of Orphan Basin. While the intermediate waters (Labrador Sea Water) were saltier in 2005 than in 2004, the upper 300 m layer was notably fresher (by 0.3). Between 2004 and 2005 the bottom waters of Orphan Basin became fresher (~0.015) and colder (~0.2°C), especially between 2500 and 3000 m. This bottom water represents the densest limb of the DWBC which enters the North Atlantic across the sills of the Denmark Strait. The first indication of this freshening was observed entering the eastern Labrador Sea in May 2004 so that it has moved around the Labrador Sea to Orphan Basin in less than a year, giving an average current speed (for the DWBC) of ~10cm/s. It is expected that the penetration of this signal through the western North Atlantic will be observed by a coordinated international set of mooring and survey programs extending from the Nordic Seas to the Bahamas as part of the ASOF, Atlantic CLIVAR (*Climate Variability*) and related programs. This should provide new insights into variability in the North Atlantic's thermohaline overturning circulation and lead to a better understanding of the global ocean's response and contributions to climate change.

6. Related ASOF Activities

6.1 Untethered Underwater Vehicle Workshop (*S. Østerhus*)

An Untethered Underwater Vehicle workshop was held in Bergen on 29 August 2005 followed up by a BCCR Observing System Forum meeting. The participants were from several research institutes in Europe with the addition of few experts from the University of Washington, Seattle USA. The programme of the workshop included a discussion on the potential formation of an European Gliders Consortium for users and developers. C. Lee added that in US there are some talks on having a US community facility for gliders in order to share the costs and use. Technical facilities should be in place where the prototypes of gliders are under developments, i.e. in UW and WHOI. However this initiative is still to be defined but it is envisage that the expertises will be available for European projects.

> ACTION ITEM: Prepare a requirement list from ASOF in support of European Gliders consortium (*S. Østerhus, A. Beszczynska and C. Lee*)

6.2 The Oden Transpolar Cruise 2005 *(B. Rudels)*

In fall 2005 the Swedish icebreaker Oden completed a transpolar hydrographic section from Alaska to Svalbard. Preliminary results, especially about the circulation in the Atlantic layer and the ventilation of the deep and bottom waters, from this cruise were compared with the Arctic Ocean hydrography and circulation observed during the ACSYS (Arctic Climate SYstem Study) decade 1994 - 2004. The interpretation of the observed changes in the last 14 years is in progress and will be reported in upcoming articles.

6.3 ESSAS—the Ecosystem Study of SubArctic Seas *(H. Loeng)*

The idea for a Ecosystem Studies of Sub-Arctic Seas (ESSAS) programme was conceived at a workshop in California, September 2002 with the aim of identifying research priorities for a major research initiative in the Bering Sea, and to investigate the possibility of developing a series of comparative studies of the marine ecosystems of the sub-arctic seas. The first planning workshop for the programme

was held in Norway in May 2003 to identify the most pressing questions concerning the impact of global change on the sub-arctic seas, and to suggest innovative approaches to improving our understanding and ability to manage these important regions during a period of rapid environmental change.
An international symposium on Climate Variability and Sub-Arctic Marine Ecosystems, including a 1-day ESSAS workshop and an ESSAS Steering Committee meeting was held in Victoria, Canada on 16-20 May 2005. The science plan of ESSAS was published in May 2005 as part of the GLOBEC Report series (http://www.pml.ac.uk/globec/structure/regional/essas/essas.htm). The objective of ESSAS is to compare, quantify and predict the impact of climate variability on the productivity and sustainability of Sub-Arctic marine ecosystems. The science plan addresses three major areas:

1) What are the external forcing functions that link global and regional climate processes to the physical oceanography of the Sub-Arctic Seas?
2) How does variability in the physical aspects of the marine systems affect ecosystem processes and structure?
3) How can we integrate across spatial and temporal scales to permit forecasting how changes in climate may affect the productivity and sustainability of the marine ecosystems of the Sub-Arctic Seas?

The Norwegian component of ESSAS has as overall goal to quantify the impact of climate variability and global change on the structure and function of the Barents Sea marine ecosystem in order to predict the ecosystem response to possible future climate changes and its possible economic impact. NESSAS is divided in 4 modules:

1) What are the processes linking global to regional climate variability to the physical oceanography of the Barents Sea?
2) How dies the variability in the ocean climate affect ecosystem processes and tructure within the Barents Sea?
3) Predicting how changes in future climate will affect the productivity and structure of marine ecosystems in the Barents Sea
4) How does the climate forcing of the structure and function of the marine ecosystem in the Barents sea compare to other sub-Arctic Seas?

The productive and ecologically diverse Bering Sea is economically and culturally important. Recent evidence of change in Bering Sea ecosystems has raised concerns and engendered research efforts by several agencies. One of these efforts is the Bering Ecosystem Study (BEST). Still in the planning stages, BEST is supported by the National Science Foundation Office of Polar Programs. The BEST science plan, published in October 2004, provides background information and frames science questions to guide future integrated, interdisciplinary studies of eastern Bering Sea marine ecosystems. The proposed research priorities are:

1) How is the disappearance of Sea Ice affecting the Bearing Sea ecosystem?
2) What controls the abundance of nutrients on the shelf and what is the influence of climate variability?
3) What will be the ecosystem effects of a warmer and more stratified Bearing Sea?

The BEST program will interface with other national and international programs investigating the effects of climate change on high-latitude marine ecosystems. A goal of the plan is to initiate collaborative studies of the sub-arctic seas, culminating in cooperative ecological research of the eastern, western and basin areas by Japan,

Russia and the United States.
The implementation plan is available since June 2005 and it is anticipated that the field program will begin in March 2007 after a call of proposals in Jan-Feb 2006. To complement the BEST natural science research program, a social sciences research plan is being developed, with support from the NSF Arctic Social Sciences program, to investigate how humans use and organize themselves around the Bering Sea system. This program will seek to develop a broader understanding of the social and science-information needs of the communities around the Bering Sea that have a strong personal and cultural investment in the past, present, and future of the environment, and who can contribute important knowledge about Bering Sea natural and social system dynamics.

7. On the Future of ASOF (*Chair: J. Meincke*)

With the funding of the ASOF-West component running out in 2006, the future of ASOF was perceived as an important issue to address during this meeting. Jens Meincke was in charge of coordinating several inputs from the ISSG members as response to the following questions:

- Is the ASOF mission statement still valid?
- Will there be enough ASOF components continued to keep ASOF in real existence? Who will be the drivers?
- Is it advisable to bring ASOF to a formal end with the Faroe conference in June 2006 and the ASOF book?
- Are there “parents” among the longer-term existing organizations / programmes to adopt / absorb ASOF if felt necessary / useful?

It was recognized that several elements of ASOF-East will continue under the IPY initiative and the EU FW5 project DAMOCLES. While some other components of the ASOF monitoring system will be supported by national institutions till new funding opportunities will arise.
Given that almost all the elements of ASOF will remain in place for several more years it was decided that the ASOF SSG should continue providing the coordination of the monitoring system and meeting annually.

7.1 The Integrated Arctic Ocean Observing System (iAOOS): an AOSB-CliC Observing Plan for the International Polar Year

Following its review of about 1150 Expression of Interest (EoI) the ICSU-WMO Joint Committee for the IPY undertook the task of identifying certain proposals (about 228) which were thought to have sufficient scope to act as “clustering projects” for a range of other submissions. The iAOOS was provisionally identified as one of these, with the potential to act as lead project for a range of EoIs dealing with the Arctic Ocean Circulation. AOSB and Clic boards were invited to further develop their submission into one that might formally be recognized as an IPY Core Project.
The iAOOS aim is to describe the ocean-atmosphere-cryosphere system of high northern latitudes working as a complete system. For the first time, thanks to new observing techniques, we are in prospect of being able to measure almost any key variable at almost any place and time. So it now seems feasible that by filling gaps in our spatial coverage and extending the available series in time, we may be able to view the ocean-atmosphere-cryosphere system of high northern latitude operating as a complete system.

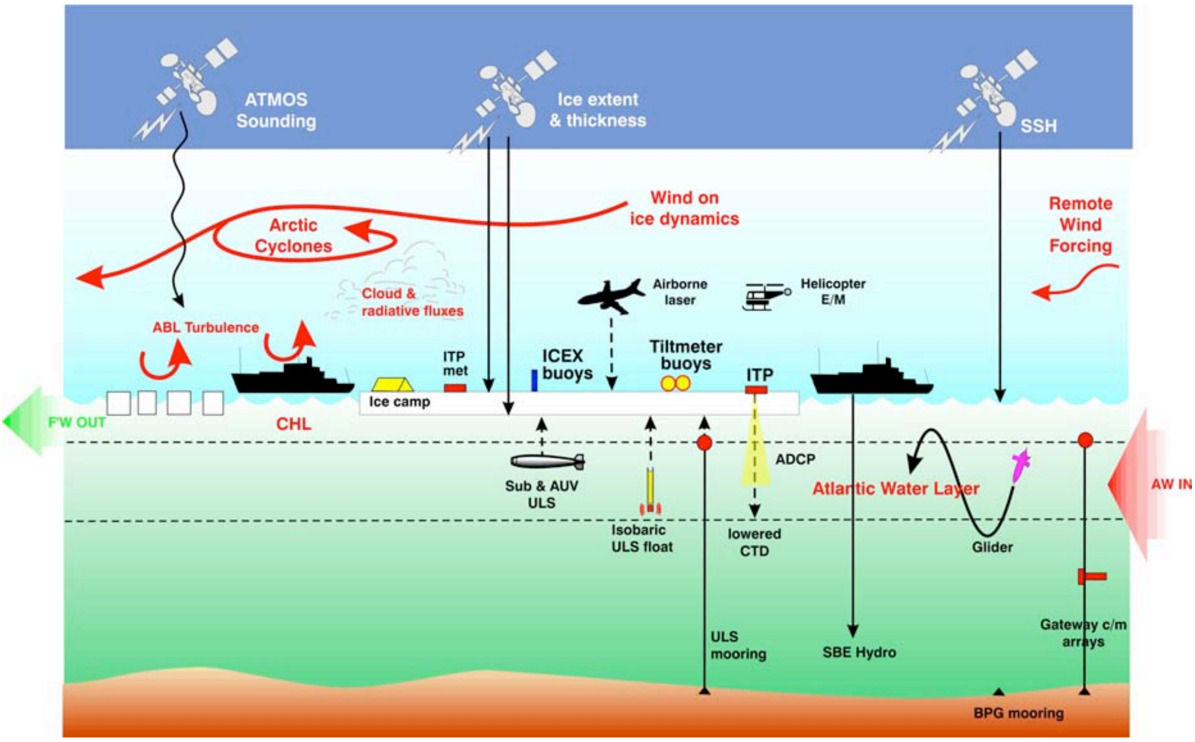

Figure 2. Schematic of the vertical stack of observations from satellites to seabed that would be necessary to inform an iAOOS study focused on the present state and future fate of the Arctic perennial sea-ice.

Figure 2 shows the vertical stack of the iAOOS with its most innovative elements. The ocean observing efforts in iAOOS spread far beyond the Arctic Ocean itself to include the subarctic seas. It is now demonstrable that a substantial component of Arctic variability originates in Nordic Seas and is further altered in crossing the circumarctic shelves before being introduced along the Arctic Ocean boundary. In turn we would expect the major climatic and societal impacts of Arctic change to take effect via ocean transfers south through the Canadian Arctic Archipelago and western Nordic Seas. This objective envisages maintaining and expanding the present ASOF arrays, but with the new purpose of identifying and predicting the mixing of local and remote forcing that controls the flux of warmth and salt to the Arctic Ocean. An ability to predict the warmth of the main inflows to the Arctic is so central to the aims of iAOOS as to justify maintaining the three main ocean flux arrays concerned as (Faroe-Shetland Channel or Svinoy, Barents Sea Opening and Fram Strait) as “observatories”. New cutting-edge observing techniques will complement the conventional moored arrays in both the Atlantic and Pacific gateways.
In the iAOOS it is proposed to study the transformations and mixing of the various source watermasses as they cross the broad circumarctic shelves and enter the circumarctic boundary current. This will be done by using a mix of observational and modelling techniques: 1) a scatter of shelf moorings and shelf-exchange moorings to be set by US-SEARCH in a bread arc from the Barents Sea to Alaska; 2) Complete circumarctic coverage of the Arctic Ocean Boundary Current through the enhancement of the present NABOS array into an international Mooring-based Arctic Ocean Observational System coordinated by IARC Fairbanks; 3) Standardised ice-breaker-based hydrographic transects across the shelf-basin boundary into the central basins

The final element of the iAOOS ocean programme addresses the time-varying processes by which the signals of Arctic change are transferred through subarctic seas to lower latitudes.
iAOOS will take place under the aegis of AOSB and CliC drawing its research science partly from an enhanced subset of US-SEARCH, partly from DAMOCLES and partly from the Chinese, Korean and Japanese scientists of the Pacific Arctic group. It will be sustained for 4 years but it will be set in the context of the much longer-term research efforts that are currently getting underway in the Arctic (fig. 1)

7.2 Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies: DAMOCLES

It is well accepted that the Arctic sector is one of the most sensitive areas to climate change. Mean sea-ice draft decreased by 1.3m in the deep-water portion of the Arctic Ocean. We are not sure what changes in the Arctic heat fluxes would cause the observed change in sea-ice thickness:

- A 4W/m^2 increase in ocean flux as heat advected by the Atlantic layer and/or by the cold halocline layer?
- A 13W/m^2 increase in poleward atmospheric heat transport as heat advected by storms and changes in storm track?
- A 23W/m^2 increase in downwelling shortwave radiation and/or increase in length of the melting season?

These changes are significant but they are the threshold of our actual observational capabilities and yet field experiments performed in the Arctic in 2004 documented one more step toward a warmer Arctic.

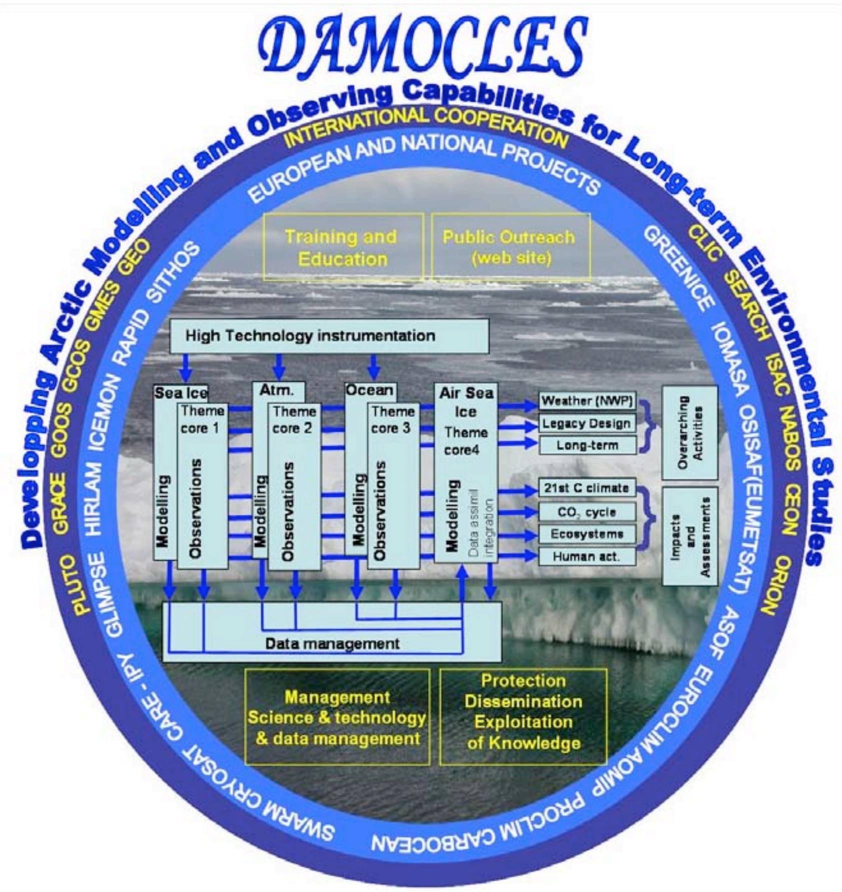

Figure 3. Schematic representation of DAMOCLES activities.

DAMOCLES is a 4 years project funded by the EU 6th Framework program "Global Change and Ecosystems". The specific objectives of DAMOCLES are:

- Determine the processes responsible for the variability and changes in the Arctic climate system
- Improve our capabilities to predict Arctic climate changes in particular extreme events
- Design optimal components of a long-term integrated monitoring and forecasting system for the Arctic Ocean
- Assess impacts of an extreme climate event such as the disappearance of the Arctic perennial Sea-Ice

About 45 partner institutions and 8 SMEs participate in DAMOCLES which officially started in December 2005. DAMOCLES consists of 8 Work Packages (see Fig. 3):

1) Sea Ice. To measure the variability of sea ice thickness with the tiltmeter ice thickness buoys, a network of floats equipped with upward sonar, satellite altimetry, autonomous underwater vehicles, submarines, laser profiling from airborne missions and airborne EM thickness profiling by helicopter from ships and land/ice bases. To determine the effect of dynamics on the sea-ice thickness distribution. To quantify the role of thermodynamic sea-ice processes to construct historical time series.
2) Atmosphere. Observation and process modelling of dynamics and occurrence of mesoscale cyclones; physical processes in the atmospheric boundary layer (ABL); interaction of clouds, radiative fluxes, surface albedo and snow/ice thermodynamics
3) Ocean. To develop and implement the improved observational system with capabilities to monitor the input of mass and heat to the Arctic Ocean; To document and understand the variation of the exchanges with the North Atlantic by observing fluxes through the major gateways; To observe and understand processes important for the interaction between the shelves and the deep basins, including the transformation of water masses and the variability in the strength and properties of the boundary current; To assess the heat flux from the Atlantic layer in the central Arctic to the ice and atmosphere; To observe and understand the variability of the arctic circulation and properties of fresh surface mixed layer in relation to large scale atmospheric patterns; To observe the propagation of the Atlantic-derived sublayer in the central Arctic; To identify the "switchgear" that determines whether Arctic freshwater will pass directly to the Atlantic "conveyor" or recirculate in the Nordic Seas; To assess the scale and extent of changes associated with ocean freshwater fluxes, and their impact on the AMOC.
4) Integration by Modelling. To progress the understanding of the fate of sea ice and its interaction with ocean and atmosphere by means of observation-supported model improvement and sensitivity studies; To develop assimilation methods with the goal of producing fields of key arctic variables for the DAMOCLES period that combine information from observations and models; To quantify the effects of improved understanding and process description or assimilation techniques on simulation capabilities
5) Overarching Activities. Improvement of numerical weather, ocean and sea ice prediction: short –medium range prediction assessment: *workshops on assessment of forecast quality improvements (especially polar lows);* Interaction between observations and models in DAMOCLES and its

optimization on climate time scales including the design of a legacy phase: *workshops on evaluation of sampling strategy, evaluation of model performance, evaluating the sensitivity of the arctic environment;* The production of 4D gridded analysis and reanalysis fields; Documented sets of analyzed atmospheric, oceanic and sea ice fields
6) Impact Activities. Arctic climate scenario based on improved regional models and GCM scenarios; Impact on CO2 cycle and phytoplankton production; Climate impact on marine ecosystems; Changing conditions in the Arctic Ocean: Impact on human activities and assessment of their adaptation and vulnerability to changes
7) Knowledge Dissemination. Summer Schools; Public outreach
8) Innovative Technological Developments. Ice Tethered Platforms ITP; Upward Looking Sonars ULS (Floats, AUVs, Moorings, Subs); Tiltmeters (Sea Ice Thickness); Moored CTD Profilers and Currentmeters; Tomography (Fram Strait); Sea Gliders operating under Sea Ice ; ADCPs ; Ice Mass Balance system

A specific Support Action for the period 2007-2009, has been submitted to the 4th call of the 6th EU FW program in order to support a joint EU-US initiative for the development of Arctic Ocean Long-term observing and forecasting systems, infrastructure and data management. This initiative would explore opportunities and potential benefits to co-ordinate large research programmes such as SEARCH (US) and DAMOCLES (EU) and to organize common workshops and international conferences

7.3 Bipolar Atlantic Thermohaline Circulation (BIAC)

Sein Østerhus presented a Norwegian proposal for IPY called BIAC. The role of the thermohaline circulation as driving force for the ocean circulation, and therefore the global climate, is well acknowledged. The majority of the deep-bottom water production takes place in the Atlantic sector. The densest water ventilating the world ocean abyss is produced in the northern and southern extremes. When the dense water is cascading towards great depths, it mixes with surrounding water masses to produce the various brands of bottom water. The replacement of surroundings water is believed to be an important driving force for the global THC. The BIAC concentrate on all aspects related to bottom water formation and THC in the past, present and future. Modelling and remote sensing are important tools as well as in situ measurements that will require adequately equipped icebreakers and moorings.
The aim of the proposed project is to study mechanisms, manifestations and impacts of bottom water formation on the bipolar Atlantic ocean shelves. Key areas are the Barents Sea and the southern Weddell Sea. The main objectives are:

- Identify locations where dense water is formed (open ocean, shallow shelves)
- Study dense water formation processes; cooling, ice formation, convection
- Identify dense water pathways on shelves and in semi-closed basins
- Study the cascading of dense water towards the deep ocean
- Define physical and biogeochemical controls on ocean carbon biogeochemistry
- Investigate relationships between variability in deep-water formation CO2 uptake rates and large-scale natural or anthropogenic climate forcing
- Obtain paleo-records of dense-water formation rates

The role played in the climate system by the interaction between the ocean and Antartic ice shelves is a key issue regarding future climate changes. To establish a long term (several decades) observation in the southern Weddell Sea, a monitoring station on the Filchner-Ronne ice shelf will be proposed under BIAC

8. Science Talks

8.1 Advances in Modelling the Canadian Arctic Archipelago Throughflow *(David Greenberg)*

A finite element model covering the CAA domain has been set up for running at different horizontal resolutions. An early result of the model runs concerned tides and barotropic mean flows. The simulated values at selected surveyed areas, like Nares Strait, Jones Sound etc…, have been compared with observations. The same model was also used to make the first computation of freshwater transports.
The latest development in modelling the CCA throughflow is a set up of a 3D finite volume unstructured ocean model with generalized vertical sigma coordinates and z-levels, semi-implicit time integration for the external mode, no horizontal diffusion in the tracer equation, with thermodynamic/dynamic ice and atmospheric forcing. The goals for these experiments are:

- Study the effect of tidal mixing on the mean circulation
- Explore the sensitivity of the mean circulation to the closing of the passages
- Study flow seasonality
- Applications to biology

The boundary conditions were provided by the pan-Arctic modelling experiments using AIM, an ocean model forced with 50 years NCEP reanalysis data and with climatological precipitation, humidity, runoff and OBCs.
The model results show that the freshwater transport tends to be equally split between Nares and Barrow Straits. The closing of passages has little impact, the large scale still dominates. Z-level yields a better representation than sigma coordinate (too much advection/diffusion along the sigma layers).

8.2 Canadian Arctic Archipelago Initial Results *(Humfrey Melling)*

ASOF needs to estimates with known accuracy the fluxes of freshwater (including ice) and their seasonal and interannual variations and understand the forcing and controls on magnitudes and variability of these fluxes. In order to achieve this, some technical challenges and theoretical issues are to be addressed:

- measurements of current and salinity within 40m of the ice canopy
- reliable access to remote, ice choked areas of the Archipelago
- reliable and cost-effective retrieval of mooring from beneath thick old ice
- measuring freshwater flux via a narrow, meandering flow in a wide channel
- differences in sea level between ocean basins
- rotating flow in channels of realistic geometry
- stress at the seafloor and the ice canopy in tidal channels
- buoyant boundary flow through a maze of wide connected channels
- lagrangian aspects of mixing in channels
- flow (and blocking) of pack-ice in channels of realistic geometry
- dynamical interactions between flows of air, ice and water in channels

Table 2 shows the flux estimates at several areas of the CCA.

Area	Volume	Freshwater
Nares Strait current	0.8 Sv [snap shot]	29 mSv [snap shot]
Nares Strait ice drift		3 mSv [guess h]
Hell Gate/ Cardigan	0.3 Sv [rough]	
Lancaster Sound	0.7 Sv	48 mSv
Lancaster S. ice drift		1.3 mSv [guess h]
Baffin Bay ice		33 mSv [guess h]
Davis Strait current		100 mSv
Davis Strait ice drift		35 mSv [guess h]
Bearing Strait (inflow)	0.8 Sv	80 mSv

Table 2. Volume and freshwater flux estimates.

The table include new data from 2002-2005 mooring deployment in Cardigan Strait. The measurements of freshwater flux in the same area is still an unresolved challenge due to large amplitude variation in T-S structure caused by internal tides. Strong currents preclude observations of T-S profiles.
In Lancaster Sound the I-Cycler reveal appreciable freshwater flux above 30m depth in summer.
Changes in heat and salt in Baffin Bay are identified as a warming at the Atlantic inflow (0.18±0.07 degC/10y at 700m) with interannual temperature variance coherent with NAO index (30%) and freshening at the Arctic inflow (-0.086±0.04 psu/10y at surface)

8.3 Davis Strait Freshwater Exchange *(Craig Lee)*
The Davis Strait presents the integrated modifications of terrestrial inputs and oceanic processes of CAA throughflow during its southward transit. The waters exiting Davis Strait directly influence the Labrador Sea deep convection sites. The Davis Strait is also well positioned for investigating how the Arctic freshwater system modulates deep-water formation and influences the associated meridional overturning circulation. During the hydrography survey carried out in September 2004 when the mooring array were deployed, an average 0.96 degC temperature and 0.15 salinity above climatology were observed. The greater westward extent of warm, saline waters indicates their Irmiger origin. The volume and freshwater transports are consistent with previous estimates 2.5Sv and 130mSv respectively. In 2005 the mooring array was serviced. Data were retrieved from landers and moorings. The ADCP "bottom tracking" shows the ice decreasing eastward. MicroCAT coupled with ADCPs can give a crude estimate of ice draft. Possible improvements for future deployments include:

- Stiffened subsurface moorings against knockdown events
- One ICECAT over each shelf
- Replace deeper landers with short moorings
- Need large, capable vessel for difficult operating conditions
- Two Mk2 ULSs over west side
- Possible open water year-round on east side may provide flexibility for glider operations.

In September 2005 the seagliders with under-ice acoustic navigation were tested in Davis Strait and data will be used to develop navigation algorithms and autonomy.

8.4 Warming Events and Heat Flux Variability in Fram Strait *(Agnieszka Beszczynska-Möller)*

The array of moorings in Fram Strait was first deployed in 1997. It is a continuous time series that spans from 10m above seabed to ca. 50m below surface and from the eastern Greenland shelf break to the western shelf break of Spitsbergen along 78°50'N. The time series reveals that there have been two strong increases of heat flux in 1997-99 and 2003-2004, both increases of heat flux are related to warm anomalies in Fram Strait and increase of the volume flux. The extra input of net heat flux through the Strait changes the flow structure mostly in the recirculation area. The warm anomalies are advected from the Svinoy section with time lag of about 1.5 year and travel to the Arctic Ocean with a delay of a few years.

8.5 Upper Ocean T-S Variations in the Greenland Sea *(Sirpa Hakkinen)*

The data used are the NODC hydrographic data base, ICES data base, NCEP/NCAR reanalysis and NOAA weather Station data (SLP). The focus is in the upper layer as the data reveal episodes of high density (high salinity). The high salinity Atlantic water abundance seems linked to positive NAO phase on interannual time scales. The strong heat loss from the Atlantic waters at low NAO index phase is one mechanism that explain the dense upper ocean but advection also plays an important role. Weak NAO reduces inflow of Arctic water to GIN Seas and a there is a westward Ekman transport of Atlantic waters.

An updated altimetric SSH and geostrophic velocity field EOF1s have been performed using the data of TOPEX/Poseidon and Jason-1 for the period from October 1992 to March 2005. The SSH and velocity at any location is obtained by multiplying the value of the spatial pattern with the time series value (first principal component).

8.6 Covariance Between the Three Branches of Atlantic Inflow and the Two Branches of Overflow; Some New Results *(Svein Østerhus)*

The flux of warm and saline Atlantic water flows northward toward the Arctic in three different branches:

- The Iceland branch / Irminger current, west of Iceland
- The Faroe branch / current, over the Iceland-Faroe Ridge
- The Shetland branch, continental slope current, through the Faroe-Shetland channel

The total Atlantic volume flux for the period Jan 1999 – Dec 2001 is 8.5 Sv with a maximum is October and a seasonal amplitude variation of 0.4 Sv. The average temperature is 8.5 degC and salinity is 35.25 with a total heat flux of 313 TW and salt flux of 303 kT/s. The Shetland branch is negatively correlated with the Faroe and Iceland branches. By adding the new data and recalculating the volume transport for the period 1995-2005 the total Atlantic inflow is 8.6 Sv.

As part of a work package of MOEN, an ensemble hindcast study was performed for the meridional overturning exchanges with the Nordic Seas for the period 1948-present. The main objective of this study is to quantify the impact of increasing Arctic river discharges on modelled exchanges and watermasses composition. The modelling strategy consists of:

1) Spin up MPI-OM1 model with restoring of SSS (1/180 days) until the drift in exchanges and water mass properties of the Atlantic are insignificant (800 years)

2) Diagnose the monthly mean restoring flux on SSS from the spin up (average of year 650-850)
3) Continue from the spin up state (year 800) and perform an approx. 1000 year long control simulation with annually repeated (static) restoring flux on SSS
4) Pick app. 20 initial conditions for ensemble simulations from the control simulation separated by 50 years
5) Perform two ensemble hindcast simulations from 1948-2002 differing only in the applied Arctic river discharge
The total simulated Atlantic inflow is 8.7 Sv, in good agreement with observations. The model also performs well in reproducing the overflows.

8.7 Some Recent Current Measurements in Norwegian Waters *(Harald Loeng)*
Preliminary results from bottom mounted ADCPs in the Fugloy – Bear Island were presented. Temperatures, salinities and currents were recorded for the period Aug 2004 Aug 2005. The data of the moorings deployed within the ASOF-North project were also presented for the period Aug 2003 – May 2005. The current vectors together with the recorded temperatures reveal episodes of Atlantic inflow pulses. The Argo floats deployed in Aug 2003 in the area 68-70N and 0-5E are giving insightful data.

8.8 The Warming of the Abyss, 1970-date *(Bob Dickson)*
Since the mid 80s, the deep water of the Greenland Sea has been observed to warm rapidly. The Greenland Sea Deep Water (GSDW) is the coldest and freshest of the three deep waters (Norwegian Sea DW and Arctic Ocean DW). It is assumed that the cooling of GSDW reflects the increased vertical exchange with the surface (convection), and its warming reflects the increased lateral exchange with the Arctic Ocean through Fram Strait. Some evidences show that the recent warming of GSDW reflects a change from vertical (strong doming of isopycnals, convection to bottom) to horizontal (shallow convection, import of AODW) exchange in the Greenland Sea:

- Since 1982 the properties of GSDW started to move away from those of GSSW and towards those of AODW
- The isopycnals have deepened in the Greenland Sea reflecting the collapse of the dome
- Silicate increased in the deep Greenland Sea reflecting an increased import from the (silicate-rich) Arctic Ocean
- Oxygen decreased reflecting less contact with the (oxygen-rich) surface waters and more input from the (oxygen-poor) AODW

The NSDW is partly made of GSDW and it began to warm too, the density of both deep basins has decreased to the point of crossover. The sense of the deep exchange between the Greenland Sea and Norwegian Sea was observed to reverse in the Jan Mayen Channel. If the GSDW continues to warm at present rates, it is predicted that the deep properties of the Greenland Sea will match those of the Arctic Ocean in 20 years time.

9. ASOF Workshop on Tracers (Chair: *M. Karcher*)

The workshop attracted a range of key contributors from the international community (see agenda Appendix B). Their contributions are going to appear in the ASOF Newsletter issue #5, which will be available on the ASOF website [http://asof.npolar.no].

APPENDIX A. LIST OF PARTICIPANTS

Beszczynska M. A.	AWI Bremerhaven, GERMANY	abeszczynska@awi-bremerhaven.de
Boscolo R.	IIM-CSIC Vigo SPAIN	rbos@iim.csic.es
Dickson R.	CEFAS, Lowestoft UK	r.r.dickson@cefas.co.uk
Falkner K.	OSU, Corvallis USA	kfalkner@coas.oregonstate.edu
Gascard J.C.	LODYC, Paris FRANCE	jga@lodyc.jussieu.fr
Greenberg D.	LEGOS, Toulouse FRANCE	David.Greenberg@legos.cnes.fr
Hakkinen S.	GSFC-NASA, Greenbelt USA	sirpa@polaris.gsfc.nasa.gov
Haine T.	EPS-JHU Baltimore USA	twnh@stommel.eps.jhu.edu
Hansen B.	FFL Faroe Islands	bogihan@sleipnir.fo
Harms I.	IfM Uni. Hamburg GERMANY	harms@ifm.uni-hamburg.de
Jones P.	BIO Dartmouth CANADA	JonesP@mar.dfo-mpo.gc.ca
Karcher, M.	AWI Bremerhaven GERMANY	mkarcher@awi-bremerhaven.de
Kershaw P.	CEFAS, Lowestoft UK	P.J.Kershaw@cefas.co.uk
Lee C.	APL-UW, Seattle USA	craig@apl.washington.edu
Loeng H.	IMR Bergen NORWAY	harald.loeng@imr.no
Masque P.	Uni. Autonoma Barcelona SPAIN	pere.masque@uab.es
Meincke J.	IfM Uni. Hamburg GERMANY	meincke@ifm.uni-hamburg.de
Melling H.	IOS Sidney, B.C. CANADA	mellingh@pac.dfo-mpo.gc.ca
Newton B.	LDEO, U. Columbia USA (LDEO)	bnewton@ldeo.columbia.edu
Svein Østerhus	Uni. Bergen NORWAY	svein@gfi.uib.no
Rudels B.	FIMR Helsinki FINLAND	Bert.Rudels@fimr.fi
Tanhua T.	IfM-Geomar, Kiel GERMANY	ttanhua@ifm.uni-kiel.de
Ukita J.	LDEO, U. Columbia USA	jukita@ldeo.columbia.edu
Zhang Y.	MBARI, Monterrey USA	yzhang@mbari.org
Yashayaev I.	BIO Dartmouth CANADA	yashayaevi@mar.dfo-mpo.gc.ca
Watson A.	Uni. East Anglia, Norwich UK	a.watson@uea.ac.uk

APPENDIX B. AGENDA

Day 1. Wednesday, November 16th

09:00 Welcome Remarks and Housekeeping (*B. Dickson, R. Boscolo*)
- Special welcome from a representative of the hosting institution (*P. Nival*)

09:15 Introduction to the ASOF ISSG meeting (*B. Dickson*)

09:30 Updates on ASOF-EC(N) (*A. Beszczynska*)

10:10 Updates on ASOF-MOEN (*B. Hansen*)

10:30 Coffee Break

11:00 Updates on ASOF-EC(W) (*B. Dickson and J. Meincke)*

11:30 Brief reports on two Bergen Workshops: the SeaGlider workshop in September 2005; The workshop on the relationships between Atlantic inflow branches October 2005 (*S. Østerhus*)

11:50 Brief report on the recent ODEN cruise *(B. Rudels*)

12:15 Update on ASOF WG7 (*M. Karcher*)

12:30 Relations with ESSAS—the GLOBEC/ICES Ecosystem Study of SubArctic Seas *(H. Loeng).*

12:45 Lunch

14:00 Status and Prospects in the Subpolar Gyre; plans for spilljet project *(T. Haine)*

14:45 Update on ASOF-West activities *(H Melling, C. Lee and I. Yashayaev)*

16:00 Coffee Break

16:30 Discussion Session on the Future of ASOF (*Chair: J. Meincke*).
- DAMOCLES *(Jean-Claude Gascard)*
- iAOOS *(B. Dickson)*
- Norway-IPY proposal: Bipolar Atlantic Thermohaline Circulation (*S. Østerhus)*

18:00 Adjourn

Day 2. Thursday November 17th

09:00 Advances in modelling and observing the CAA throughflow *(D. Greenberg)*

09:30 Initial results from the Smith Sound & Hell Gate arrays *(H. Melling)*

09:55 Initial results from the Davis Strait and progress towards under-ice sampling by glider (*C. Lee*)

10:15 The warming events in the Fram Strait (*A. Beszczynska*)

10:40 Coffee Break

11:10 Upper ocean T-S variations and convection in the Greenland Sea, together with an update on the slowdown of the subpolar gyre (*S. Hakkinen*)

11:30 Covariance between the three branches of Atlantic Inflow and the two branches of overflow; some new results *(S. Østerhus)*

11:50 First results from bottom mounted ADCPs in the Fugloya-Bjornoya section *(H. Loeng)*

12:15 Warming of the abyss, from 1970 to date *(B. Dickson)*

12:45 Lunch

Tracers Workshop (Chair: *M. Karcher*)

14:00 From Russian Rivers to Polar Seas using trace elements and their isotopes *(M. Rutgers van der Loeff and P. Masque)*

14:30 Tracers west of Greenland *(K. Falkner)*

15:00 Tracing fresh water inside the Arctic Ocean and exported from it (*P. Jones*)

15:40 Coffee Break

16:10 Arctic Ocean to subpolar seas using Delta O-18 observations (*B. Newton)*

16:40 Modelling the signals of Delta O-18 and Tc-99 through Arctic to Subarctic Seas *(M. Karcher)*

17:10 Brief recap on the Tc signal *(P. Kershaw)*

19:30 Dinner and Celebration for Bogi's 60th birthday

Day 3. Friday November 18th

09:05 Greenland Sea to overflow; tracking the SF6 signal *(A. Watson)*

09:45 Recent use of high resolution dispersion modelling to trace sources and pathways of water masses in Denmark Strait *(I. Harms)*

10:15 Formation of DSOW and its hydro-chemical composition (*T. Tanhua and A. Olsson)*

10:45 Coffee Break

11:15 DSOW structure and origin from a multi-tracers analysis combined with T/S and currents observations (*J. C. Gascard*)

11:50 129-I as tracer of DSOW through the abyssal Labrador Sea and south to Bermuda (*J. Norton Smith and P. Jones*)

12:45 Lunch

14:00 T-S tracing of the overflows in the North Atlantic *(I. Yashayaev)*

14:30 Deep transport and recirculation in the Subpolar Gyre *(T. Haine)*

15:00 Synoptic chemical sampling with distributed mobile systems: a possibility? (*J. Bellingham and Y. Zhang)*

15:45 Coffee Break

16:10 ASOF Conference: registration and funding *(B. Dickson*)

16:30 Web and newsletter products from the meeting (*R Boscolo).*

17:00 Adjourn (B Dickson)