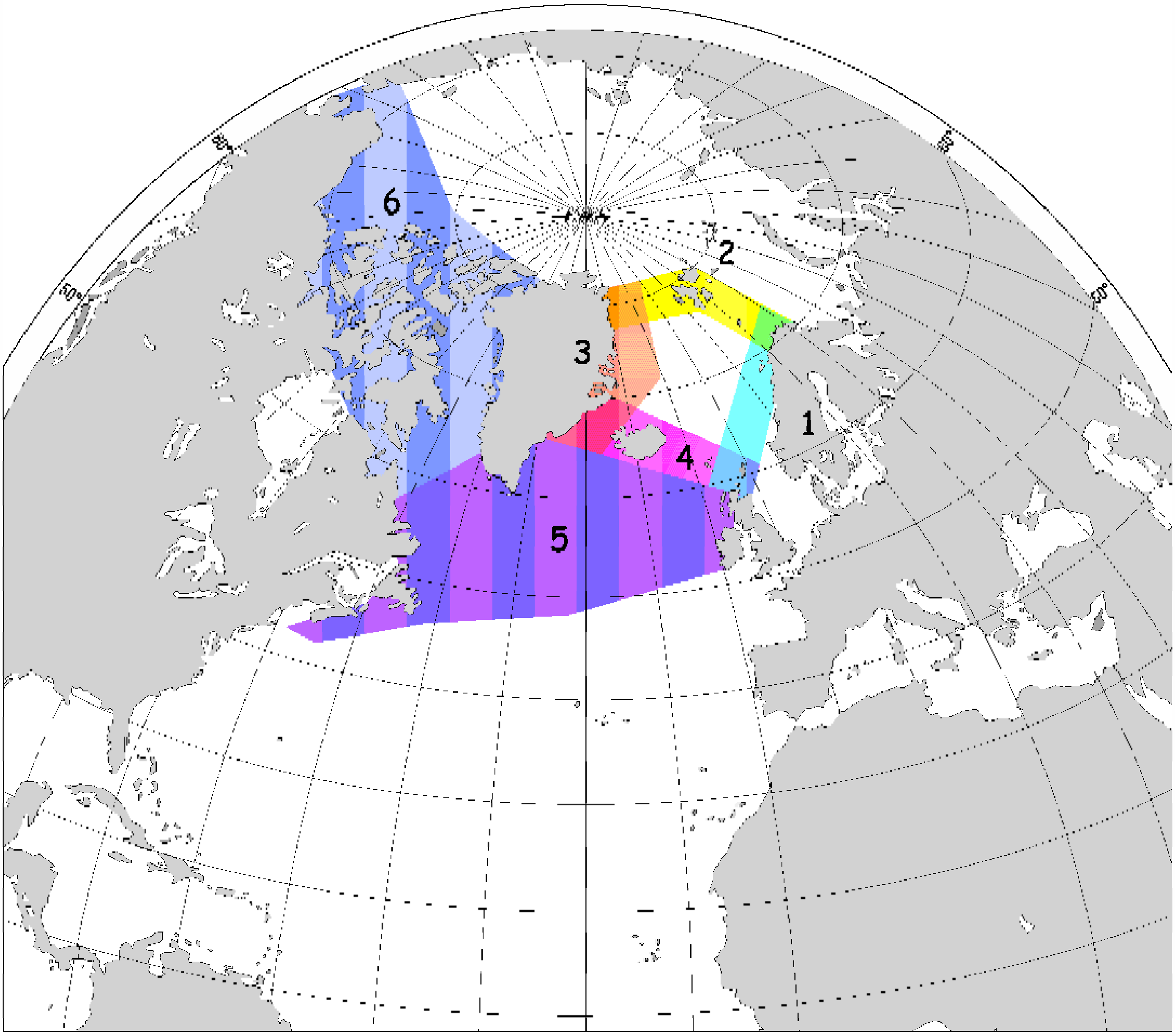
ARCTIC - SUBARCTIC OCEAN FLUX STUDY (ASOF)



IMPLEMENTATION PLAN

Draft Version 1.0 April 2002

Corresponding authors :

ASOF Chair
Bob Dickson EQ CEFAS; Centre for Environment, Fisheries and Aquaculture Science (CEFAS), The Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 OHT England. tel: (44) 1502-524282, fax: (44) 1502 513865, e-mail: r.r.dickson@cefas.co.uk

Deputy Chair ASOF-East
Prof. Dr. J. Meincke; Institut für Meereskunde, Universität Hamburg, Troplowitzstr. 7, D-22529 Hamburg, Germany phone: +49 (0) 40 - 42838-5985, fax: +49 (0) 40 - 5605724, e-mail: meincke@ifm.uni-hamburg.de

Deputy Chair ASOF-West
Peter B. Rhines Prof. of Oceanography and Atmospheric Sciences, Box 357940, University of Washington Seattle, Washington, 98195. tel: 206-543-0593, (212 ORB-1..office) fax: 206-685-3548 (209 OTB..GFD lab). Web sites: www.ocean.washington.edu/research/gfd/gfd.html, and www.ocean.washington.edu (=> Faculty => Rhines). e-mail: rhines@ocean.washington.edu

http://www.asof.npolar.no

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1. ASOF Aim Restated

The overall objective of ASOF was chosen with some care: *'To measure and model the variability of fluxes between the Arctic Ocean and the 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'.*

Several points are implicit in this statement.

First, in keeping with a number of other current research efforts, we assume that the role of the high-latitude ocean in decadal climate variability will take effect primarily through its influence on the Atlantic thermohaline circulation [THC or Meridional Overturning Circulation (MOC)]. Most projections of greenhouse gas induced climate change anticipate a weakened MOC in the North Atlantic due to increased freshening and warming in subpolar seas[1-3] and the supposition is that this climate signal will be transferred to the deep ocean via the two overflows. However lest ASOF be seen as too-narrowly concerned with the study of ocean fluxes *per se*, we should add that the measurements we plan will also support the study of local or regional effects on climate arising from watermass- and circulation- changes within the subarctic seas, and ASOF will be equally alert to these.

Second, it is an underlying assumption of ASOF that, in planning to make the first measurements of the principal oceanic fluxes that connect the Arctic Ocean and North Atlantic through subarctic seas, the point of doing so is 'decadal'. In other words, the final objective would not be met until our shorter term research "snapshots" can be set into the context of decadal change.

Third, our aim suggests there is point to making these measurements in a coordinated way so far as possible. As just one example, a simulated increase in either of the main freshwater outputs that connect the Arctic Ocean with the Atlantic (via the Canadian Arctic Archipelago and along the East Greenland Shelf) seems capable of effecting a slowdown of the MOC [4,5], and advanced coupled models already indicate that these two main freshwater inputs may have a shared time-dependence [6]. It therefore makes sense to investigate this finding through simultaneous, rather than successive, measurement if at all possible.

The ASOF Science Plan ("Strawman 3") describes in detail the science and rationale behind these assumptions. It can be found in pdf form on the SEARCH and NPI websites [http://www.psc.apl.washington.edu/search/ASOF and http://www.asof.npolar.no/].

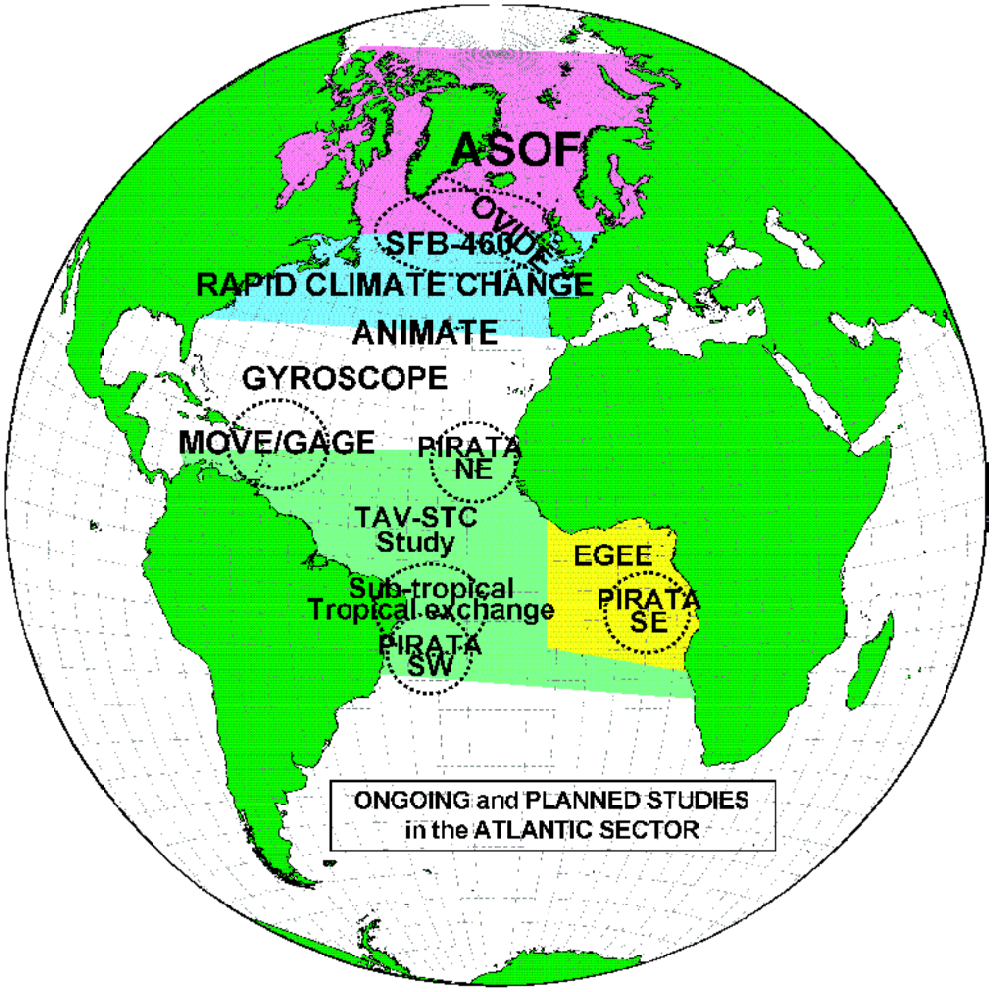
2. Purpose and Contents of Implementation Plan

Implementation plans can vary widely in their content and assumptions. This plan is intended to be a more fluid document than the Science Plan it supports, so if new techniques or circumstances arise, the plan can be adapted to make optimum use of these. As this plan is so updated each version will be numbered to keep the Reader current.

The ASOF Implementation plan is almost bound to be non-standard. Unlike the more normal circumstance, where a single funding agency or institute issues an announcement of opportunity (AO), the tasks of ASOF have such wide geographic scope (Bering Strait to Faroe-Shetland Channel) that a diversity of funding on two continents is bound to be involved, each with detailed and different chronologies, stipulations and deadlines. Describing this web of funding will be an important part of this Plan. Even where present funding exists, it will typically be of 3-5 years duration so that in most cases, thought will need to be given to its continuation to decadal scale.

3. The ASOF Domain

The ASOF domain may be described in four ways. The global figure (Fig. 1) is that adopted by the International CLIVAR Project Office (ICPO). It is designed to define the ASOF domain in its broad outline in order to set ASOF activities into the context of ongoing and planned studies in the Atlantic sector. It defines the primary ASOF focus to be the belt of subarctic



ASOF: Arctic Subarctic Ocean Flux Array
RAPID CLIMATE CHANGE: (UK)
SFB-460: Subpolar North Atlantic Study (Germany)
OVIDE: Observation of the Interannual and Decadal Variability of the Subpolar gyre in the N. Atlantic (France)
ANIMATE: Atlantic Network of Interdisciplinary Moorings and time series for Europe (EU)
GYROSCOPE: ARGO funded by EU
MOVE: Meridional Overturning Variability Experiment (Germany)
GAGE: Guyana Abyssal Gyre Experiment (USA)
PIRATA Extensions: SE, SW, NE
EGEE: Study of the Oceanic Circulation and its Variability in the Gulf of Guinea (France)

Figure 1. The ASOF domain

seas that connect the Arctic Ocean with the northern North Atlantic, and makes the point also that many other activities overlap with ASOF in both motivation and geographical area.

Figure 2 defines the ASOF domain in terms of its six main regional tasks, which are briefly summarised in the caption. Successful completion of these tasks would meet the ASOF goal of measuring the key ocean exchanges between the Arctic Ocean and subarctic seas, their transformation on passing through the subarctic seas, and their arrival and impact on the overturning circulation of the Northern North Atlantic, though in practise, the number and delineation of these regional tasks may yet change on advice from the ASOF ISSG. In many ways these tasks form a successor study to EC-VEINS (1997-2000), but now include efforts

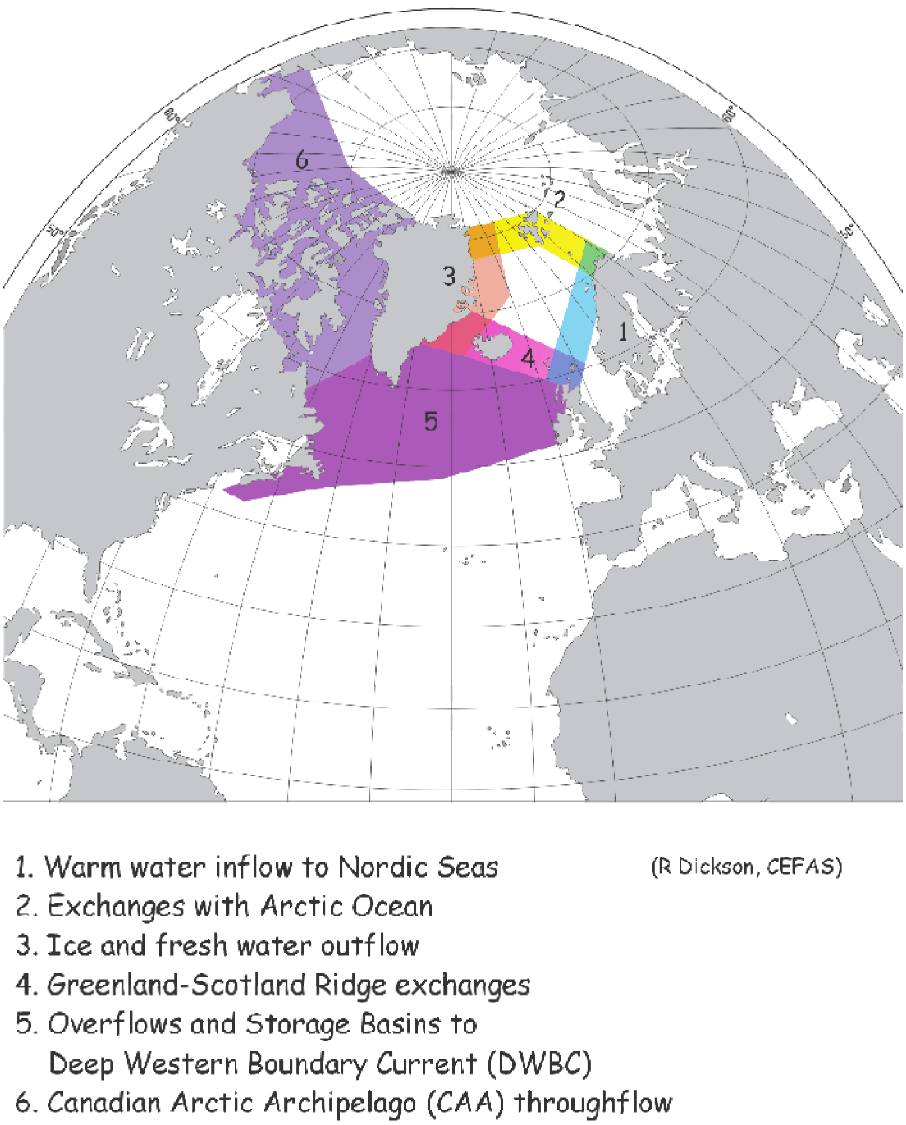


Figure 2. ASOF tasks by region

to measure both of the freshwater fluxes through northern seas —— arguably the most important but least tractable component of exchange.

Implementing this distributed system of measurements will require the expertise, access and funding of scientists and agencies from both North America and Europe, and common funding calls on both continents have been agreed for these sorts of tasks. Thus thirdly, in order to organise research to match the available funding on either side of the Atlantic, the ASOF domain and its Steering Group are also organised into “ASOF-East” and “ASOF-West” groupings as a practical measure. News of recent funding bids will be described below under the ASOF-East and ASOF–West subheads.

The final subdivision of ASOF, its tasks and domain, is to describe progress towards implementation of the full range of activities — region by region ——that will contribute to each ASOF task. Some of these activities will be directly funded as “ASOF” (for example the measurement of the freshwater flux passing SE Greenland under ASOF-EC). Others will stem from existing nationally or internationally funded efforts that are also of central relevance to ASOF aims and objectives (for example the long-term measurement of the ice and freshwater flux through western Fram Strait by Norsk Polarinstittut———a major source of the freshwater that will be observed off SE Greenland). As in the example just given, it is important that we know of all of the main relevant activities in planning the appropriate deployment of effort to meet a given ASOF task.

4. ASOF Project management structures and their evolution.

The changes in the ASOF domain just described have already been reflected in the way in which the ASOF Project is managed and further changes are envisaged. Initially, while formulating the content of the ASOF Science Plan, the issues were extremely broad (ie has slowdown of the MOC happened before? Is it likely to recur? What systems need to be put in place to observe such changes? What are the key unknowns? etc). Thus, at an early stage in the life of the Project, the Science Plan was driven forward by the widest possible range of informed opinion, gathered through international discussion meetings and correspondence.

Later, as ASOF has moved from Science Plan towards Implementation, the main management issue has moved from being *what to do* to *how to do it and fund it*. For this reason the International Science Steering Group set up to administer and advance this stage of the Project in 2001-2 was deliberately structured into an ASOF-West and an ASOF-East group, each with an experienced and practical Deputy Chair, to reflect the expected breakdown in further planning and the funding by continent. That administrative structure continues.

However once the circum-arctic pattern of ASOF activity was resolved into its component regional tasks (Figure 2), it became clear that there was much less point in continuing to meet collectively at one location and much more point to furthering the implementation of each task through a series of local workshops. In each of these, local experts might focus on, debate and solve the problems of implementation in whatever detail they might occur yet be reasonably assured that their solution would collectively also meet the larger-scale purposes of ASOF. The setting up of regular Project Workshops is in any case a key feature of Project Management by the EC. This final organisational step has yet to be taken by the ISSG through the selection of Chairmen and Teams for each regional task, but once these are agreed it is likely that the ISSG itself would continue to cover the largest overarching scale of ASOF project management by correspondence. Thus the management and coordination system for ASOF would be matched to the overall needs of the program, as well as to the needs of the regions.

5. Regional Breakdown of Tasks

In this Section of the plan we attempt to give a brief synopsis of change for all six of the ASOF regional tasks. Tasks 1-4 include and extend familiar aspects of the VEINS measurement programme under EC MAST-3, but ASOF will add new aspects to these tasks which VEINS was not able to accomplish. We give a more extensive account of what is intended in the case of tasks 5 and 6 since these are both quite new. In each case we try to identify the most likely source of funding and any ancillory external effort that may be underway.

In doing so it is necessary to distinguish between ASOF Programmes funded directly for the purpose and two other categories – ASOF-Associated and ASOF-Relevant. The former (ASOF-associated) are "external" programmes which specifically intend to devote part of that project effort to making an ASOF contribution. An example would be the Norwegian NOClim Project which is distinct from ASOF in being chiefly occupied with process studies in Northern Seas but whose Tasks 6 and 7 (on long hydrographic time-series in Arctic Seas) are very similar to the interests and activities of ASOF in the north. The latter category, (ASOF-Relevant) are more independent programs which may have been funded and in existence prior to ASOF, but whose results are of primary significance to one or other task of ASOF. Examples might be Aagaard's ONR-funded long-term measurements of fluxes through the Bering Strait, or the IFM Kiel MOVE array at 16N already designed and deployed to measure the meridional overturning circulation of the N Atlantic and its changes.

Task 1. Warm water inflow to Nordic seas: The arrays which successfully made the first measurements of Atlantic Water and heat to the Nordic Seas [7] will continue under ASOF-EC (E) (see funding model 7a below). These arrays thus cover most (>90%) of the warm water inflow to the Arctic Mediterranean. On the Svinoy Section further north, Orvik et al [8] were able to use the VEINS data-set to describe a three-way response of the inshore (long-slope) branch to NAO forcing—warming, narrowing and strengthening as the NAO amplified.

The largest remaining problem will lie in quantifying the unconstrained offshore branch and we envisage a new research role for OWS Mike at 66N 2E to meet this purpose. In addition to acting as our atmospheric $C0_2$ monitor, the long hydrographic time series at Mike already prescribe the changing hydrographic character of Faroe-Shetland Overflow further south, and the depth of the σt=28.0 isopycnal at Mike, slowly deepening with time, is the factor which determines the strength of that cold deep outflow [9].

Now, we add a research role which will exploit the Weathership's location, overlying the free offshore branch of Atlantic water, to begin the task of observing its mean state, variability and dynamics as it passes north through the Norwegian Sea. To EC FP-5 and possible continuation funding in FP-6 we may thereby attract Norwegian input from NOClim and from the new Polar Climate Research initiative of the Norwegian Research Council for this important purpose. The latter initiative intends in its 3rd objective, to provide *"Technology and methods for Earth observations and measurements in the deep ocean"* and is expected to be funded at a total of NOK 110 million over the period 2002-2006.

Task 2. Exchanges with the Arctic Ocean: from the comparison of our longest hydrographic time-series, we are aware that the signal of interannual variability can pass poleward along both Atlantic inflow branches (via Fram Strait and Barents Sea) to drive changes in the character and extent of the Atlantic-derived sublayer in the Arctic Ocean. The resulting dislocation of the mutual boundary between Atlantic and Pacific influences across the High Arctic over recent decades is the factor which provided much of the original impetus to the Study of Environmental Arctic Change (SEARCH), currently being spun-up to implementation by the Polar Science Center at the University of Washington, Seattle.

In addition large-scale changes originating within the climatically-sensitive Arctic Ocean can pass south to affect subarctic seas. Thus Arctic-subarctic exchanges remains a priority topic in ASOF. For most of this Century, our knowledge of the variability of these exchanges was derived largely from standard hydrographic sections worked over many decades but at very infrequent intervals throughout the year. Thus the first continuous direct measurements of flow in EC-VEINS proved something of a surprise, demonstrating that measuring the flux through either boundary was likely to involve capturing a small throughflow in the presence of a large and time-dependent recirculation. This is the principal problem to be solved in this task of ASOF. The funding model is largely ASOF-EC (N) but with additional input from NOClim tasks 6 and 7 (i.e. 7a, 7d, 7e below).

Task 3. Ice and freshwater outflow: Despite their decisive influence on the overturning circulation in many coupled climate models, neither of the main freshwater fluxes from the Arctic Ocean to the North Atlantic has been measured. These two flows, passing south under the ice of the East Greenland Shelf and through the ice-covered passageways of the Canadian Arctic Archipelago, are seen as the central unknown of ASOF. Study of these flows is thus the top priority for advancing our understanding of the role of the high-latitude ocean in rapid climate change. However, these are also the most intractable of the ASOF tasks.

Advances have been made, or are in prospect: (a) Since 1990 the Norwegian Polar Institute (NPI) has monitored the ice thickness and ice transport through Fram Strait. Most years, these measurements have employed two moorings but since 2000, a total of four NPI moorings combining a Christian Michelsen Institute ES300 ULS and an Aanderaa DCM 12 acoustic doppler current profiler has been deployed as part of a 14-Mooring A-W-I & NPI VEINS array. These moorings have provided a valuable direct measure of ice thickness and annual ice transport through Fram Strait since 1990 [10] and all four of the existing ULS Moorings in the western Fram Strait will continue under the ASOF-EC (N) proposal. Such moorings, however, are not designed to measure the liquid part of the freshwater transport which remains the major unknown. It is a major advance, therefore, that ASOF-EC (N) will add a 5th "freshwater mooring" on the East Greenland shelf at 10 W in which an inverted CTP profiler will be combined with ULS and ADCP to add the first regular sub-ice salinity and temperature profiles to the existing measurements of ice thickness and flux (see annex 1).

(b) Though we believe evidence exists that the peak ice flux through Fram Strait in 1994-5 was able to reach and influence the abyssal hydrography of the Labrador Sea [11], and hence potentially the Deep Western Boundary Current, the amount of the Fram Strait freshwater flux which reaches the North Atlantic as a function of time is a further large unknown. The IFMH-CEFAS joint array that is being extended across the SE Greenland shelf off Angmaggsalik is a major new initiative being developed for ASOF-EC (W), with input from the NOAA Global Change Consortium on the Ocean's Role in Climate:Abrupt Climate Change Studies (CORC-ARCHES). Additional freshwater flux arrays further south at C. Farewell are currently the object of bids to the first funding call of the UK-NERC RAPID Thematic. Though the present array depends on allowing knockdown of the array by ice, later arrays from C. Farewell to Fram Strait are expected to rely on the use of the cheap fishing-reel-based HOMER CTD profiler of the POL laboratory Bidston; development of this system will rely on the Small Business Research Initiative (SBRI) of NERC RAPID Thematic. Thus the funding model of this 3rd regional task of ASOF is a mix of ASOF-EC

(N), [perhaps with additional input from Polar Climate Research initiative?], ASOF-EC (W), CORC-ARCHES and NERC RAPID, i.e., 7a, c, d, and e, below.

Task 4. Greenland-Scotland Ridge Exchanges: Most of the overflows which cross the Greenland Scotland Ridge have been measured during VEINS and have already begun to provide evidence of long-term variability. In addition to describing the time-dependent recipe for the source waters which feed the Denmark Strait Overflow, we now know that freshwater passing south along the East Greenland shelf, thus bypassing the sill, may yet attain a high enough density to drain downslope and recruit locally to the descending plume——a quite new result by Rudels, since confirmed by others. We know or suspect that the changing hydrographic character of the deepening plume may reflect events in the Fram Strait, far upstream, and that these changes may affect the trajectory of the descending plume along the Slope; that the thickness of the overflow layer seems, from direct acoustic measurements, to be a function of its speed, etc.

In the case of the eastern overflow (above), we have the startling result that a slow deepening of the σt=28.0 isopycnal at OWS Mike appears to have brought about a 20% decrease in the coldest and densest part ($t < 0.3°C$, $\sigma t > 28.0$) of the overflow since 1950. All of these VEINS arrays will continue in ASOF-EC. However a quite new and unifying task will be to monitor the net balance of all exchanges across the Ridge using satellite altimetry and hydrography. The hydrographic and current structure over the Greenland-Scotland Ridge can with some simplification be viewed as a three layer system: deep overflows, inflows of Atlantic Water and outflow of Polar surface water. The first order dynamics of the exchanges are then governed by geostrophy and hydraulic control. The near surface flows of Polar and Atlantic waters are geostrophically balanced and are associated with certain slopes of the sea surface and of the interface to the overflow water. The mean height of the interface depends on the production and availability of dense waters in the Nordic seas north of the Ridge.

To determine the fluxes in the different layers, the mean height of the interface and the slope of the sea surface have to be known. The latter can be obtained from satellite altimetry, such as from the TOPEX/Poseidon and ERS missions, and, when the sea level difference between Iceland and the Faroese shelf is plotted, there is seen to be strong variability on timescales of months to years and also a trend. The decrease of 5cm over about ten years corresponds to a change in surface velocity of 0.01 m/s, or a transport decrease of almost 0.5—the same order as the decrease of overflow transports in the Faroe-Bank Channel reported by Hansen et al. [9]

The mean interface height over, and north and south of the respective sills can be determined with a seasonal resolution from the standard hydrographic sections, occupied by the respective laboratories on Iceland, the Faroe Islands and Scotland. In addition higher resolution interface time series are available from the inverted echo sounders moored in the eastern part of the section. One might want to add direct water level measurements on the East Greenland Shelf using tide gauges, since there the satellite data are likely to be contaminated by ice floes. The funding model for this ASOF Task is a mix of ASOF-EC (W), ASOF-EC (E) plus a pending bid to the Danish National Science Foundation for the satellite work.

Task 5. Overflows and Storage Basins to Deep Western Boundary Current (DWBC): The overall objective of Task 5 is to identify, understand, and monitor the transfer of climate signals from the Nordic Seas and the Canadian Archipelago into the subtropical North Atlantic. We already believe we can see evidence of such large-scale multi-decadal signals passing through. first, an apparent weakening by 25% in the transport of the cold, dense overflow through Faroe-Bank Channel since 1950, based on a mix of direct and proxy evidence [9]; and second, the recent evidence from long hydrographic records that the entire system of overflow and entrainment that ventilates the deep Atlantic has changed steadily in character over the past four decades resulting in a sustained and widespread freshening of the deep and abyssal ocean [11].

The basins of the subpolar North Atlantic Ocean - Iceland Basin, Irminger Basin, Labrador Sea, and Newfoundland Basin - are the last reservoirs for storage and mixing of the northern overflows. Vigorous water-mass conversion occurs there before the final products are discharged south into the Deep Western Boundary Current as North Atlantic Deep Water. These waters also represent the main receiving volumes for the main flows of ice and freshwater that pass south from the high Arctic to the North Atlantic. Key processes therefore include: descent and entrainment of overflowing waters through Denmark Strait, Faroe Bank Channel, and across the Iceland-Faroe Rise; deep and abyssal flow through Charlie-Gibbs Fracture Zone, past Flemish Cap, and the Tail of the Grand Banks; diabatic transformation via deep convection in Labrador and Irminger Seas; shelf-slope interaction along the Greenland and Labrador shelves; storage of property anomalies in recirculations and exchange with boundary currents; sea ice formation, transport, and melting; and, interaction between southbound overflow waters and northbound subtropical waters.

The relative importance of these mechanisms for the propagation of climate anomalies, via advection or waves, is unclear. But they motivate the following urgent questions for ASOF science to address:

(1) What is the variability in large-scale stratification and circulation in these basins and how does it relate to changes upstream? What processes control this variability and how predictable are they?

(2) What is the variability in fluxes of freshwater, ice, and heat through the region? How is this variability controlled? What compensation is there between anomalies from the Nordic Seas and the Canadian Archipelago?

(3) How is dissolved material exposed to, and sequestered from, the troposphere and what is the variability in these processes?

(4) How are stratification and property anomalies modified and transmitted through the subpolar North Atlantic? How do they propagate into the deep western boundary current? What are the mechanisms involved?

(5) What are the critical quantities to measure at which critical places to monitor the meridional overturning circulation? How can ocean general circulation models be used to synthesize the data from a long-term observing array?

To address these issues ASOF will implement a diverse bespoke field program (see Fig. 4, Annex 2). [Though funding is incomplete, Figure 4 does contain elements supported or expected under funding models 7a (EC), 7b (NSF) and 7c (NERC RCC) below, together with a range of other initiatives already funded from existing institutional/national sources, most notably the important long-term observations at key locations currently being provided under SFB 460 of IFM Kiel]. Together with independent observing efforts already in place, the key elements in the subpolar ASOF observatory will include:

(1) Timeseries stations in the principal western boundary currents, in the stable recirculating watermasses and at critical topographic passages: overflows through Denmark Strait, across the Iceland-Scotland Ridge, through Charlie-Gibbs Fracture Zone, and through the Newfoundland Basin and its seamount chain, and shelf currents on the Greenland, Labrador, and Newfoundland shelves. New advances in mooring and float technology promise significant new capabilities: to take in-situ tracer timeseries samples (e.g., nutrients, CFCs, SF6, ^{129}-I); to make hydrographic measurements using low-cost autonomous vehicles that can navigate intelligently; and, to operate under ice or in areas with high fishing pressure.

(2) Repeat hydrographic and tracer transects that characterize the large-scale stratification and circulation frequently enough to monitor variability and track propagating anomalies. The continuation of select WOCE WHP sections for CLIVAR is an important contribution. But more frequent reoccupation of select transects is necessary (e.g., seasonal transects across topographic sills and continental shelves with variable sea-ice coverage). In some cases moored or drifting instruments will be most effective. A plan that begins to capture the three-dimensional structure of the water-masses and deep and shallow boundary currents, fig. 6, extends from the subpolar continental shelf of Maritime Canada, through the Labrador Sea and Baffin Bay and continues farther northward to the Arctic Basin. Distinct contributions will be made by, (a), ship-based CTD casts with a full (~ 36 bottle) water sampler; (b), fast, high resolution ship-based CTD sections with Moving Vessel Profiler or sea-soar technology and (c), sections through basin-interior water masses and boundary currents with autonomous glider technology, dense in space and time.

(3) Assembly and analysis of remotely-sensed data products that monitor the physical state of the region and its variability. These variables include sea surface height, sea surface temperature, ocean color, sea level wind, and sea ice characteristics. Other sources of air/sea buoyancy and gas flux data may include meteorological analysis products and in-situ instrumentation.

This observing network must provide data in near real time to address the key ASOF science goals for the subpolar North Atlantic. Two further components are essential for successful implementation: First, the changes seen in this region must be related to upstream changes in the Canadian Archipelago, and Nordic Seas. Equally, downstream changes in North Atlantic Deep Water must be monitored as signals pass along the western boundary into the subtropical and equatorial Atlantic. We note (a) that the long-established Canadian (BIO and St Johns Newfoundland) AZMP array of repeat hydrographic lines, worked normal to their eastern shelf to the 3000m isobath approx., would be a most effective monitor of these changing signals, particularly if augmented to reach down into deeper water and (b) that the proposed WHOI Woods Hole - Bermuda moored array (Figure 5, Annex 2) would be well-placed to describe these changes as they pass south through the southern boundary of the ASOF domain, particularly if present prototype moored whole-water samplers can be developed sufficiently in reliability for use on the array. Second, high-resolution circulation models must be developed to capture the key dynamic and thermodynamic processes. Their primary purpose is to synthesize data from the disparate ASOF observing array in a dynamically consistent framework using data assimilation. The model fields, constrained by measurements, must then be used to infer quantities and processes that cannot be observed directly (e.g., the total fluxes of heat, mass, and freshwater through the area, and the net diabatic conversion processes). Accurate models should also be used to design and optimize the observing network. Only if these two additional components are successful - setting the subpolar observations in a regional context and synthesizing them using dynamical circulation models - can the ASOF scientific questions be resolved in a deep and coherent way.

Task 6. Canadian Archipelago, Baffin Bay and North Continental Slope. West of Greenland, the Arctic communicates with the Atlantic through the Canadian Archipelago and Nares Strait. Baffin Bay acts as another recirculating basin, leading through Davis Strait to the Labrador Sea. Movement of Arctic waters to the Atlantic is not a simple transit, but involves continuous mixing, freezing/thawing and interaction with the atmosphere. We describe here in a northward progression the observations that will cover this region.

Arctic outflows involve low-salinity water concentrated in the upper few tens of meters, often in company with sea ice and icebergs. The near-surface circulation is sensitive to wind-forcing, convection, and is seasonal. Strong fronts, small horizontal length scales and strong tidal velocities are common. Sampling requirements with respect to time and space are severe, and new technologies are being applied to deal with this extreme environment. A wide variety of techniques is available, including remarkable chemical tracers. Transient tracers like Iodine-129 and tritium, and steady-state tracers like phosphate/nitrate and oxygen isotopes provide articulate determination of pathways of circulation, freshwater transport and river input.

(a) *Davis Strait.* The water masses in Davis Strait (sill depth 650m) have relatively simple structure, with warm, saline Irminger Sea Water and low-salinity West Greenland Current water heading north, on the east side of the Strait. Extending from the middle of the strait to the west side, a low-salinity core moves southward through the Strait. Apparently no waters denser than about σ_θ = 27.65 pass southward through Davis Strait (or through Hudson Strait). These passages produce no deep or abyssal water masses in the Atlantic, but interaction with the Irminger Sea Water does occur.

In this region instrumented moorings, patterned after the work of C. Ross in the 1980s, will monitor the water-mass movements and sea-ice. Ross' estimate from three years occupation with a 5 mooring array is a net of about 2.4 Sverdrups southward (3.1 Sv moving southward, minus 0.7 Sv. northward). These numbers are very tentative, and there is a significant seasonal cycle to deal with. Yet they are in accord with estimates made within the Archipelago. This line (fig. 6) is also a repeat hydrographic section. When ice-free, the hydrography of the Strait can be measured with glider sections, which can resolve well the upper ocean low-salinity layer, and sharp fronts, as well as providing repeated crossings. They will act as a high-resolution, often-repeated extension of ship-based hydrography.

(b) *Baffin Bay.* Extensive mooring deployments were carried out in the 1980s by the Bedford Institute group and with 9 moorings during 1997-98 by Institute of Ocean Sciences. Baffin Bay receives warm, saline water from the south, and low-salinity water from the Arctic (with a strong contribution of water from the Pacific). Wind driven ice covers much of the Bay in winter, but an ice bridge at the north forces wind-blown open water known as the North Water Polynya, with its remarkably active biology. Repeat hydrography in the region (e.g., fig. 6) can be carried out using icebreaker transits.

Three aspects of circulation south of the ASOF passages are particularly challenging. First, the intense seasonality of circulations and deep convection in this region argue for sampling more frequently than once per year. Second, the low-salinity Arctic outflows are concentrated in the upper 100m of the water column, with fine vertical scale and frontal horizontal structures, and are often ice-covered. Third, the shallow continental shelves make important contribution to the ASOF fluxes, yet they can be iceberg scoured, inaccessible sites that are hostile to moored instrumentation.

(c) Canadian Archipelago. The Canadian Archipelago is virtually an inland sea with 2.5 x 10^6 km^2 of continental shelf amounting to 20% of the Arctic Ocean. Transport is crudely estimated as about 0.6 Sverdrup through each of 4 passages that open onto Baffin Bay (Bellot Strait, Barrow Strait/Wellington Channel, Cardigan Strait/Hell Gate, Kennedy Channel/ Nares Strait) (fig. 7). Sill depths range from a mere 24m (Bellot Strait) to about 220m (Kennedy Channel) [14]. Canadian oceanographers from both Bedford Institute of Oceanography and Institute of Ocean Sciences have developed sites for moorings and hydrography to measure Arctic through-flows, at first in Barrow Strait and Cardigan Strait/Hell Gate. For example, 9 moorings with ADCPs, CTD units and upward looking sonar were deployed in 2001 in Barrow Strait, by the Bedford Institute group in a program begun in 1998. In the northern passages, mooring deployments are now in the fourth year of a six-year program by the Institute of Ocean Sciences group. These mooring programs (and tide gauges) clearly show extreme seasonality, with summer transport maxima of both volume and freshwater. Nares Strait, at Kennedy Channel is a key future site for both fresh water and nutrient transport. New technology is essential, with the channels covered by land-fast ice and stable ice arches much of the year. The ICYCLER is a profiling ctd newly designed for this environment, and planned for its first high latitude deployment in 2003. Further technological development, for example with autonomous ctd vehicles working under the ice over the winter, are contemplated.

The fresh-water transport in the Archipelago occurs both as low-salinity water and as ice. The channels range from 10 to 50 km wide, well exceeding the Rossby deformation radius, so that surface waters from the Arctic are banked up on the south side of the channels. The north sides see Atlantic water penetrating from Baffin Bay a considerable difference westward and northward. A strategy involving high-resolution observations of a single passage may provide the structural understanding of the flows and their seasonality, which will aim at more efficient measurement of the four-passage system. Tide gauges located at intervals in the Archipelago have shown a significant seasonal pressure gradient across the Archipelago, and with modern pressure gauges this technique is promising for the future. We hope to have moorings in place, in all of the key passages, as a key component of ASOF.

Extensive hydrography/tracer sampling is anticipated in the Archipelago, as mooring work develops and science time on icebreakers becomes more available. Access is available using Canadian icebreaker transits to the Arctic, and may be improved with new or reprogrammed vessels dedicated to science.

(d) *Continental slope north of Canadian Archipelago.* The continental slope north of the Canadian Archipelago is the site of a strong boundary current, which brings water of Pacific origin to the head of the passages, both east and west of Greenland. The water masses and gyres of the Arctic Basin itself, are likely to be influential in directing the pattern of outflow to the Atlantic. Mooring measurements are currently being made in the Beaufort area of the slope by Weingartner and Pickart. ASOF will establish moorings and hydrographic lines between there and Greenland.

Three open problems motivate the proposal to deploy oceanographic moorings along the Arctic Ocean shelf slope poleward of the Canadian Archipelago. First, recent work by Rothrock et al [16] suggests a decline of more than 40% in the average thickness of Arctic sea ice in the SCICEX region of the Arctic Ocean. Accounting for this ice loss is critical. Polyakov and Johnson[15], & Holloway and Sou[13] show decadal and longer patterns of ice redistribution from the central Arctic to the periphery which may help account for the observed sea ice loss. In any case, the sea ice must melt, be redistributed, or both. The A1-A7 moorings would be equipped with upward-looking sonars to build a record of ice thickness and identify patterns of variability.

The second problem is determining the role the large-scale circulation of the Arctic Ocean may play in driving flow through the Archipelago. Varying wind regimes (for example related to the Arctic/North Atlantic Oscillation) have decadal time-dependence, which could drive along-shore pressure gradients that could be sensed by instruments located at A1-A7. The net pressure difference between these gauges would be compared with tide gauges and other records within the Archipelago describing the through flow. The pressure data collected would help evaluate the dynamic link between the large scale Arctic Ocean and flow through the Canadian Archipelago.

The third issue concerns the amount and variability of the freshwater transported by the boundary current that flows along the slope break. Current meters and T&S recorders would provide a record of the variability of this current and allow some estimate of its freshwater content. Some of the freshwater comes from the Beaufort Gyre which may store and release freshwater as its circulation strengthens and relaxes at the decadal scale, some comes from the Mackenzie River, and some comes from the Pacific Ocean via the Bering Strait.

All three of these issues can be addressed by deploying and recovering oceanographic moorings at several or all of the locations shown in fig. 8, as resources permit. Emphasis will be on bottom pressure, sonar ice draft measurement, and the temperature/salinity/velocity structure of the boundary current. There is a strong symbiosis with programs in the Beaufort slope and interior Arctic Basin. Indeed, the shifting gyre structure of the Arctic circulation may be capable of controlling the sites of southward flow to the Atlantic. While the logistic issues for this mooring plan are daunting, they are not insurmountable. Moorings with bottom pressure gauges and upper-looking sonar for ice draft, and temperature-salinity-velocity recorders will be developed to the extent that resources allow.

An aircraft based hydrography/tracer program is planned for this region, with 500 km long sections extending north from the continental shelf (fig. 8). This, in combination with moorings and pressure gauges, should give a reasonably complete picture of the gyre and boundary current structure of the Arctic Basin in the region most relevant to ASOF. New sampling bottles suitable for lowering through small holes in the ice have been designed for this work.

Other tasks?: It will be for the ASOF ISSG to determine whether and when to institute further sub-groups to manage cross-cutting tasks, for example a Numerical Experimentation Group, or one concerned with Technical Development (e.g. top-down & bottom-up sub-ice profilers and their comparative trialing, deeper ocean-gliders or those capable of making excursions under ice, the substitution of bottom pressure gauges for conventional current meter moorings in areas of predominantly barotropic flow, the development of reliable moored whole-water sampling systems for tracer capture etc). Though some of these items may be specific to a task, there may be others of more general application, and if only in order to minimise costs in such an (intended) long term program, ASOF is likely to have a continuing need to identify, develop and deploy more efficient technologies.

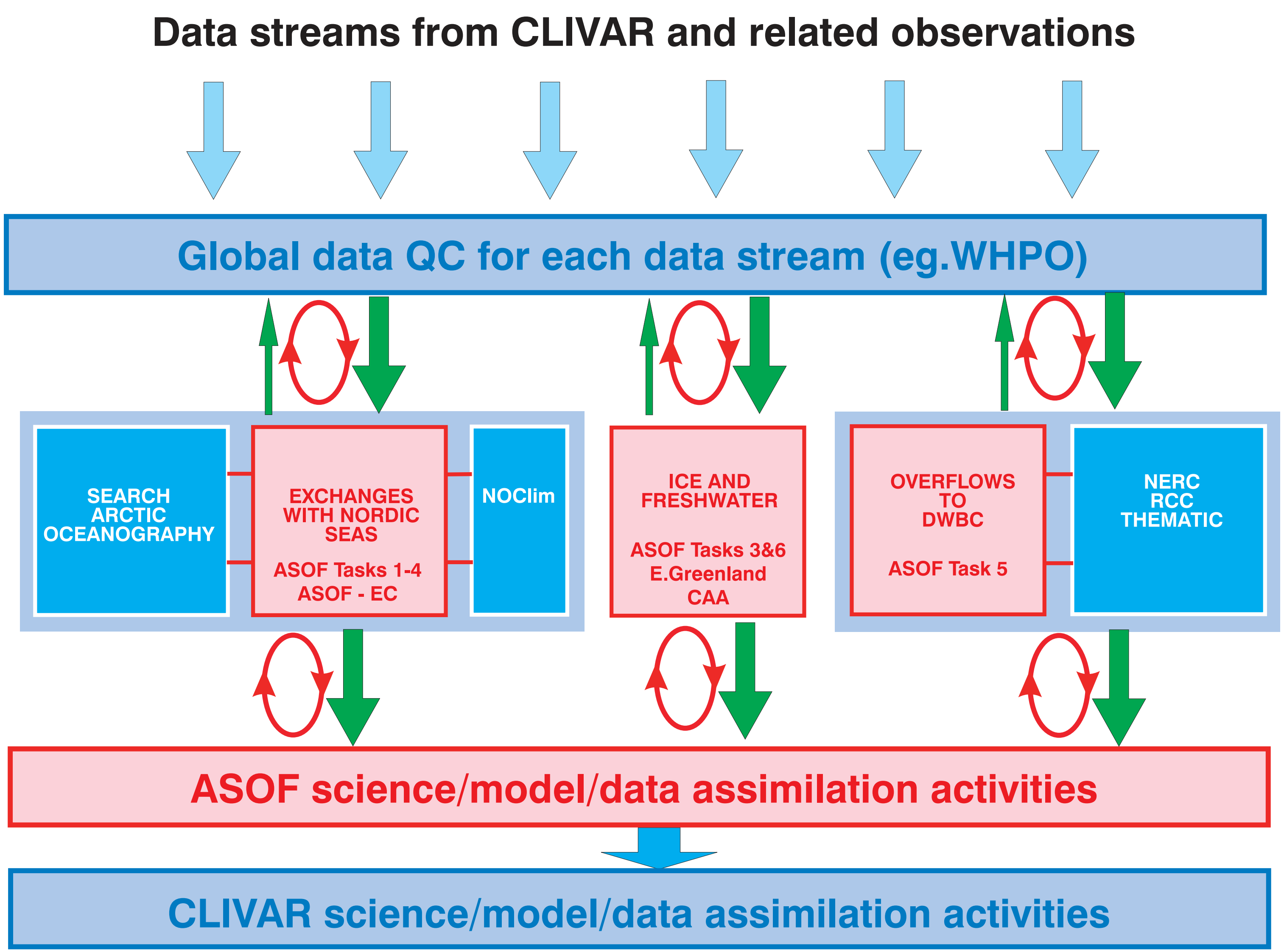


Figure 3. Suggested ASOF data management scheme to conform with CLIVAR model

6. Data Management

ASOF intends to conform to the data management model for CLIVAR. The most important reasons for doing so are ***first*** to ensure that ASOF can access the multidisciplinary data sets that will be generated by CLIVAR and its related activities. ***Second***, to ensure that the data sets generated by the individual regional tasks of ASOF will be of maximum use to the wider community, and be directed smoothly into the CLIVAR data stream following any period of confidentiality that might apply.

The justification is simply that although ASOF is principally an ocean-observing program, its tasks (data analysis, interpretation, synthesis and modelling activities) cannot effectively be carried out in isolation but will require access to a multiplicity of external data sources:

- Terrestrial data (hydrology, river flow, data on changing land use)
- Atmospheric data (probably not in real time but certainly atmospheric analysis products), temperatures, cloud cover, circulation, precipitation.
- Other ocean data (again most likely not in real time but from the high quality delayed mode data sets on which quality control has been carried out by individual PIs and by data centres)
- Paleo data (setting the present climate regime in a long term context).

In CLIVAR, data systems already exist to deal with all of these streams, though each has a different level of maturity. The first two above are largely handled through operational agencies, the latter two reside with the research community, (paleo data through the IGBP PAGES project, ocean data largely through CLIVAR and GOOS/GCOS).

The CLIVAR delayed-mode data system is evolving from that used during WOCE. In WOCE each data stream (hydrography, current meters etc) was submitted to a dedicated Data Assembly Centre (DAC) in standard format. Each DAC carried out quality control (the rigour varying from centre to centre) and then made the data sets available to the user community. In CLIVAR by contrast it is thought that regional task- or experiment-based data centres may assemble relevant data sets from DACs and other sources for the use of their scientists. This model of “Regional Application Centres” (RAC) would be similar to those adopted by Projects of the EC Framework-5 Programme such as VEINS (Variability of Exchanges in Northern Seas).

Regional Application Centres do not necessarily have to be formed around the interests of a single research programme, however. In illustration of this (and for illustration ONLY at present); Figure 3, suggests the insertion of ASOF activities into the CLIVAR data management model as a component of three different types of RAC. One is “internal” to ASOF combining tasks 3 and 6 on ice and freshwater fluxes through the CAA and E. Greenland; the other two attempt to form practical groupings of common–interest tasks between quite distinct projects (for example, a two-project task concerned with the DWBC and its upstream influences, formed between ASOF 3 & 6, and NERC RCC). Or a hypothetical three–project grouping to tackle the long-term variability of exchanges to and from the Nordic Seas, in which ASOF tasks 1-4 might be linked with the SEARCH Arctic Oceanography subgroup, currently being formed, etc, and with certain tasks of the Norwegian NOClim project.

The criterion would be that the groupings are practical, ——that is, that the RAC thus formed would confer practical benefits without becoming so large as to be unwieldy.

For the present it is worth repeating that these groupings are illustrative only. The ASOF ISSG (and, of course, any other SSGs involved) will have the task of deciding which groupings of tasks into RACs best reflect the data management needs of the Programme, or simply the practicalities of meeting the stipulations of funders (as in VEINS). This decision will form an important task for the ASOF ISSG at its Hamburg meeting. Each of the RACs that is set up there will have an important role to play in e.g. identifying the 'external' data sets needed by ASOF researchers in a given regional task or RAC, ensuring that these sets meet ASOF standards in terms of quality and metadata and are available to ASOF researchers within an appropriate time frame. Conversely these RACs will play their own important role in maintaining the quality of data originating in their task and region, co-ordinating the data assimilation and modelling activities within the task or task-grouping, and determining appropriate conditions for the release of ASOF project data sets. Thus the way the ASOF RACs are structured will have an important influence on the overall effectiveness of ASOF and its relations with the broader activities of CLIVAR.

Policy on the data release is itself evolving. WOCE had a policy of data being in the public domain after two years. Elements in CLIVAR are pressing for immediate release of data. The appropriate data-release policy for ASOF to follow will be a second issue to be debated inter-sessionally by the ASOF ISSG and agreed at its 2nd Annual Meeting in October 2002 (any embargo period may well vary with task and parameter).

7. Funding summary

As already mentioned, the intended and necessary space- and time-spans of ASOF are such as to make a single funding model or a single implementation timetable unlikely. Here we describe the initial dates and deadlines of some of the main current funding lines likely to be instrumental in implementing ASOF (ie including "ASOF-associated" activities according to our earlier definition). The funding situation is improving significantly. We can expect the funding models shown to change with time and that other elements will be added. The following represents a snapshot of ASOF and ASOF-associated funding at the time of writing (April 2002).

7a. EC.

mid-October 2001	**Last call EC Framework Programme 5**
December 2001	**3-part ASOF-EC cluster bid awarded GO rating**
Feb 2002	**Funding confirmation expected from FP-5 programme Cttee**
March 2002	**Contract negotiation stage begins**
Early summer 2002?	**ASOF-EC programme begins under FP-5**
March-June 2002	**PI discussions begin on possible Large Scale Integrated Programmes bid as a successor ASOF project under EC FP-6.**
June 2002	**Deadline for receipt of Expressions of Interest for Large Integrated Programmes, EC Framework Programme 6, 2002-2006**
Summer 2004	**End of ASOF-EC project of FP-5**

EC implimentation timetable

7b NSF.

(i) Arctic Hydrology

February 2002	**Program solicitation by NSF OPP (NSF-02-071) for proposals on Arctic Freshwater Cycle: land/upper-ocean linkages; $30M 5 years, SEARCH-ASOF.**
June 3 2002	**Full proposal deadline at NSF**

(ii) Ocean Sciences (TBD).

7c NERC RCC.

17 January 2002	**1st science AO and monitoring system AO announced**
1 Feb 2002	**Town Meeting**
28 March 2002	**Closing date for outline bids**
30 April 2002	**SC meets to assess outline bids**
Early-mid may 2002	**Feedback to applicants**
15 July 2002	**Closing date for full bids**
mid-Nov 2002	**Assessment meeting (SC + coopted PRC)**
Early 2004	**Second AO**
TBD	**Third AO**

NERC RCC Implementation Timetable.

7d NOClim.

Dec 5-7, 2001:	**All Staff Fall meeting**
March 11, 2002:	**Scientific Steering Group(SSG)-meeting**
April 15, 2002:	**closing date registration NOClim Science meeting 2002**
May 13-15, 2002:	**NOClim Science meeting 2002 (Gardermoen, Oslo)**
June 20, 2002:	**SSG-meeting**
August 15, 2002:	**closing date for bid for NOClim II (to be confirmed)**
Dec 31, 2002:	**End of NOClim**
Jan 1, 2003 - Dec 31, 2004:	**Possible NOClim II**

NOClim Implementation Timetable

7e. In addition, a new ***Polar Climate Research initiative*** of the Research Council of Norway is expected to be funded at a total of NOK 110 million over the period 2002-2006, covering three main topics:

1. Marine climate in a polar area limited by the northern Norwegian Sea, including the Greenland Sea, the Fram Strait and the Barents Sea.
2. Ecological consequences of climate changes in the area.
3. Technology and methods for Earth observations and measurements in the deep ocean.

8. The ASOF Staffer

US Funding has been mostly been secured for work in support of the ASOF Project Office. Work will be half-time, and initially for two years at a location to be decided. Tasks and timetable will be to :

1. Amend and maintain Implementation Plan after approval by ISSG at its Hamburg meeting, October 2002. (First Draft will be tabled at the ASSW, Groningen, April 21-25)
2. Prepare ASOF Brochure July 2002.
3. Arrange and offer meeting support before, during and after the ASOF 2nd ISSG Hamburg October 2002
4. Prepare the ASOF Newsletter at regular intervals (2-4 times per year) and mail out as part of each CLIVAR mailshot.
5. Maintain the ASOF website.
6. Assist (if necessary) in the construction and submission of a large collaborative project for EC Framework Programme 6.
7. Attend meetings and describe ASOF aims, rationale and progress at meetings when ASOF Chair or Deputy Chairs cant be present and on their behalf.

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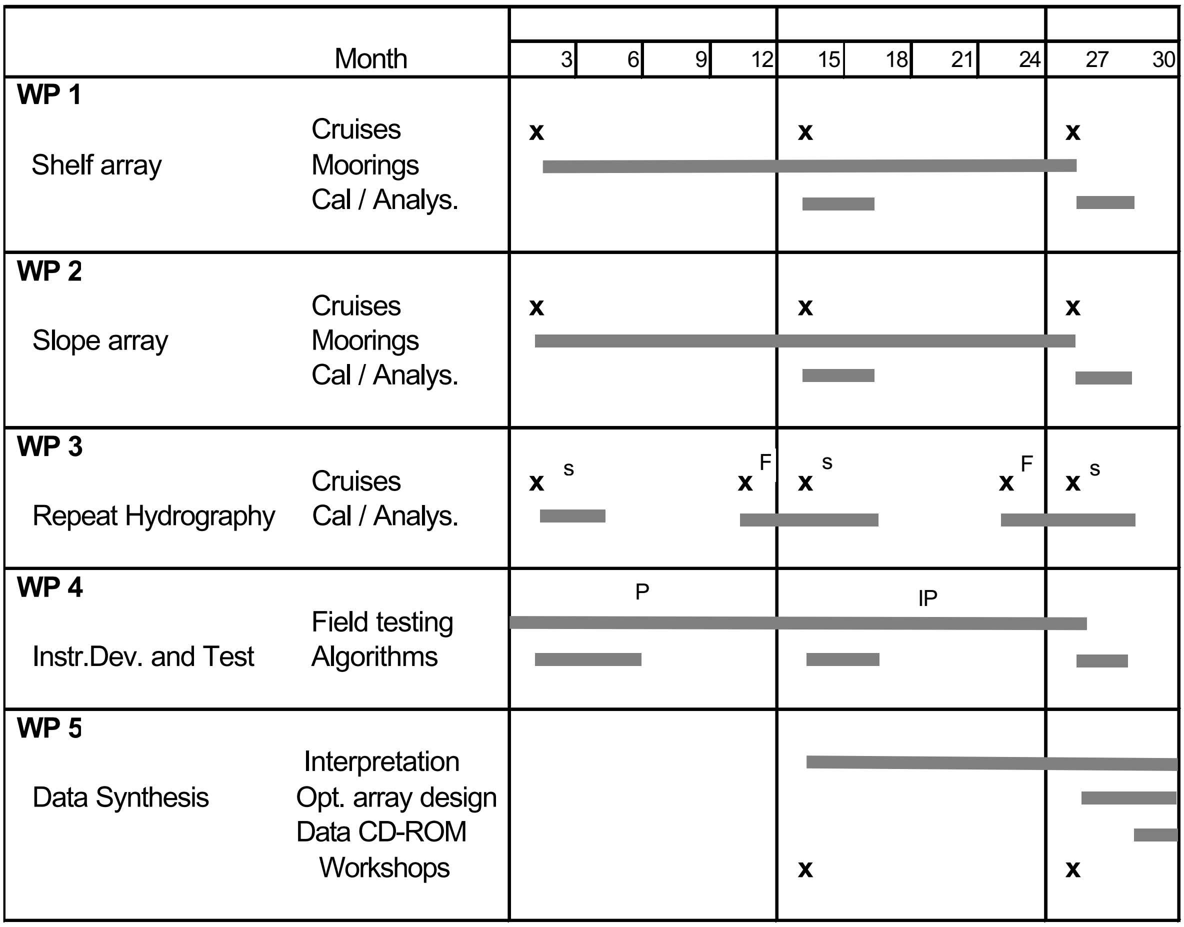
10. ASOF Calendar

Calendar for ASOF and ASOF-related events

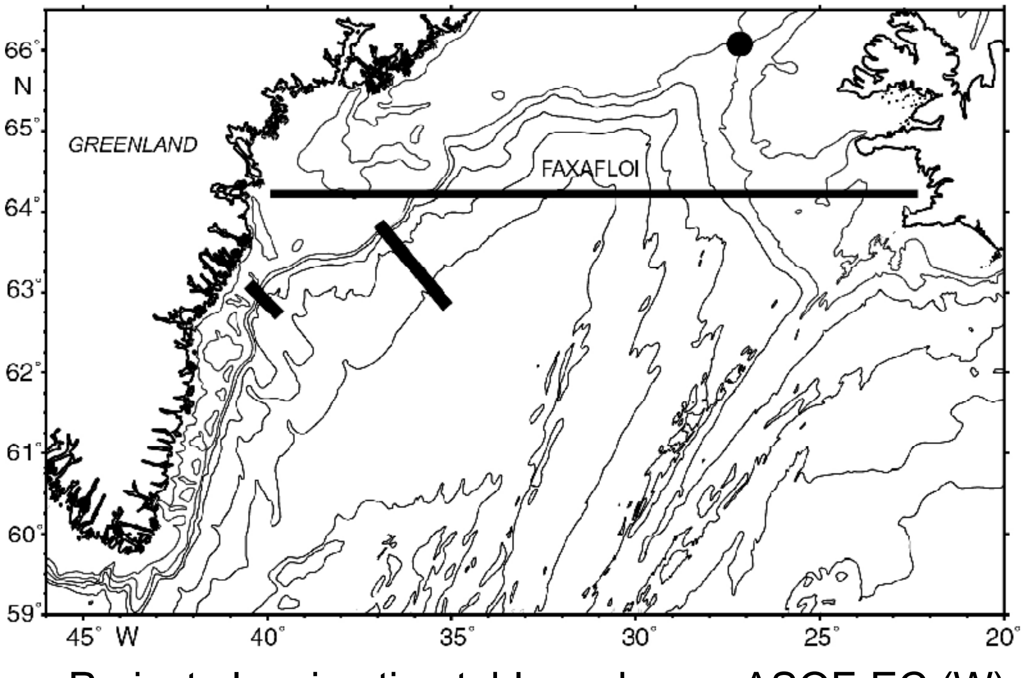
17-19 October 2002, Hamburg, Germany	2nd ASOF ISSG meeting, Institut für Meereskunde,Troplowitzstr. 7, D-22529 Hamburg, Germany
26-29 August 2002, Canada. www.mar.dfo-mpo.gc.ca/science/ocean/chapman/home.html	AGU Chapman Conference on High-Latitude Ocean Processes, L'Estérel, Québec, Canada
15 July 2002, UK www.nerc.ac.uk/funding/thematics/rcc/	Deadline for full proposals to the first AO of the NERC RAPID Thematic Programme.
10-12 July 2002, Bermuda, www.clivar.org/organization/atlantic	CLIVAR Atlantic Panel with focus on "MOC: theory and change mechanisms"
End June 2002, Canada www.innovation.ca	Canadian Foundation for Innovation to announce decision on Canadian Research Icebreaker proposal.
23-24 June 2002, Iceland www.rannis.is	North Atlantic Science Connections, US-Icelandic Science Day, re-arranged from September 2001. Reykjavík, Iceland.
June 2002 http://europa.eu.int/comm/research/nfp/networks-ip.html	Deadline for receipt of Expressions of Interest for Integrated Projects under EC Framework Programme 6
3 June 2002, USA www.nsf.gov/home/polar	Deadline for proposals to the NSF AO- Arctic Freshwater Cycle: Land/Upper ocean Linkages NSF02-071 www.nsf.gov/home/polar
13-15 May 2002, Norway www.noclim.org/	NoClim Science Meeting Clarion Hotel Oslo Airport, Gardemoenn, Norway.
30 April 2002, UK www.nerc.ac.uk/funding/thematics/rcc/	NERC RAPID SSC Meeting –Bid Assessment
21-26 April 2002, Groningen, the Netherlands www.aosb.org www.let.rug.nl/assw	Arctic Ocean Science Board and Arctic Science Summit Week, Groningen, the Netherlands.
17 April 2002, London, UK www.royal-met-soc.org.uk	Royal Meteorological Society meeting – Rapid Climate Change and the Thermohaline Circulation, Imperial College, London, UK.
28 March 2002, UK www.nerc.ac.uk/funding/thematics/rcc/	Deadline for NERC RAPID Outline proposals.
18-21 March 2002, Halifax, Nova Scotia www.ices.dk/committe/occ/wgohyd.htm	ICES Oceanic Hydrography Working Group including mini symposium on Arctic and sub-Arctic Oceanography, Halifax, Nova Scotia, Canada.
28 February 2002, EC	Funding confirmation expected for ASOF-East, EC programme committee.
22 February 2002, Lowestoft, UK	HOMER moored profiler meeting, CEFAS, Lowestoft, UK.
1 February 2002, London, UK http://www.nerc.ac.uk/funding/thematics/rcc/	NERC RAPID Town meeting, DTI, London, UK.

ANNEX 1

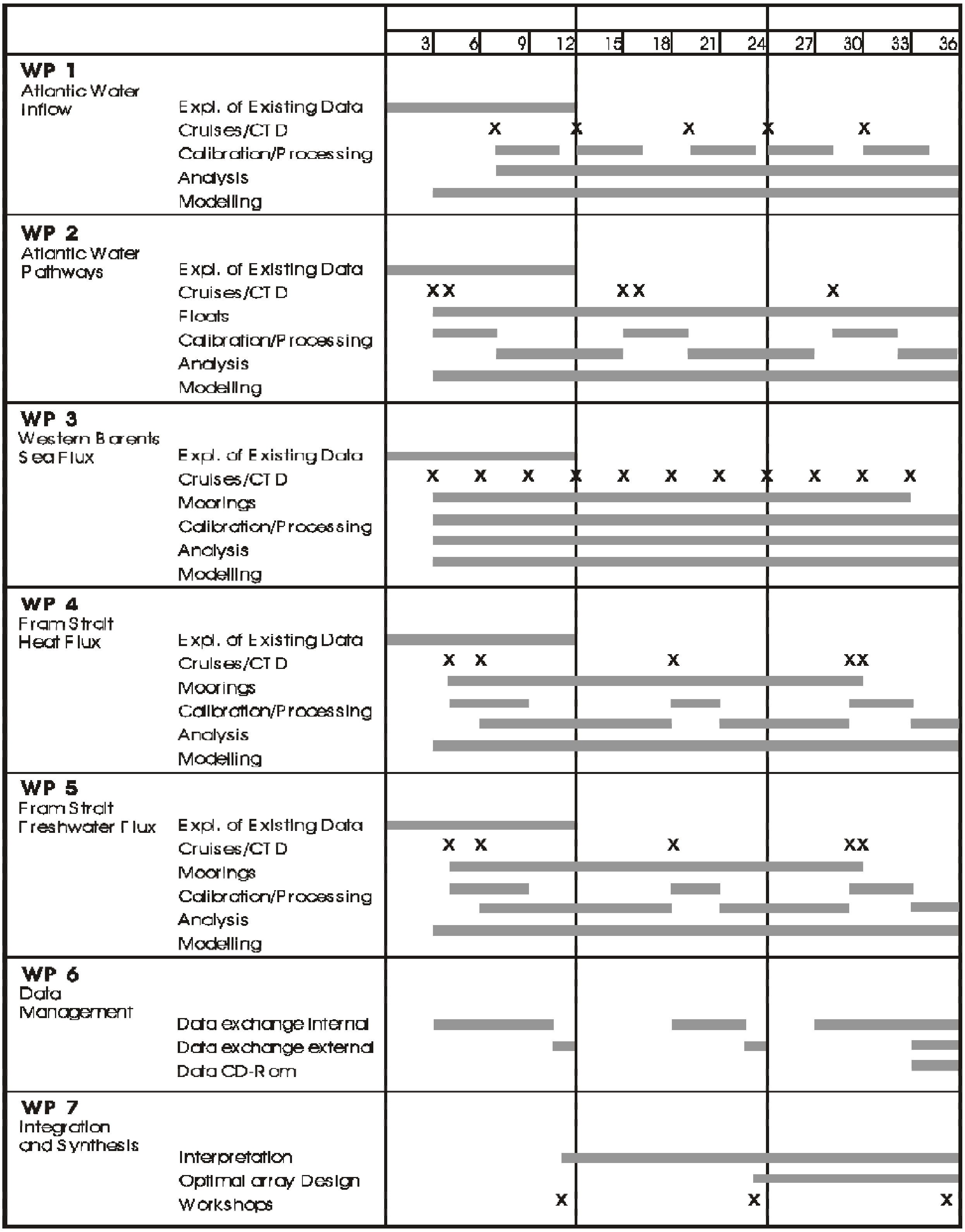
Project planning timetable and maps, ASOF-EC



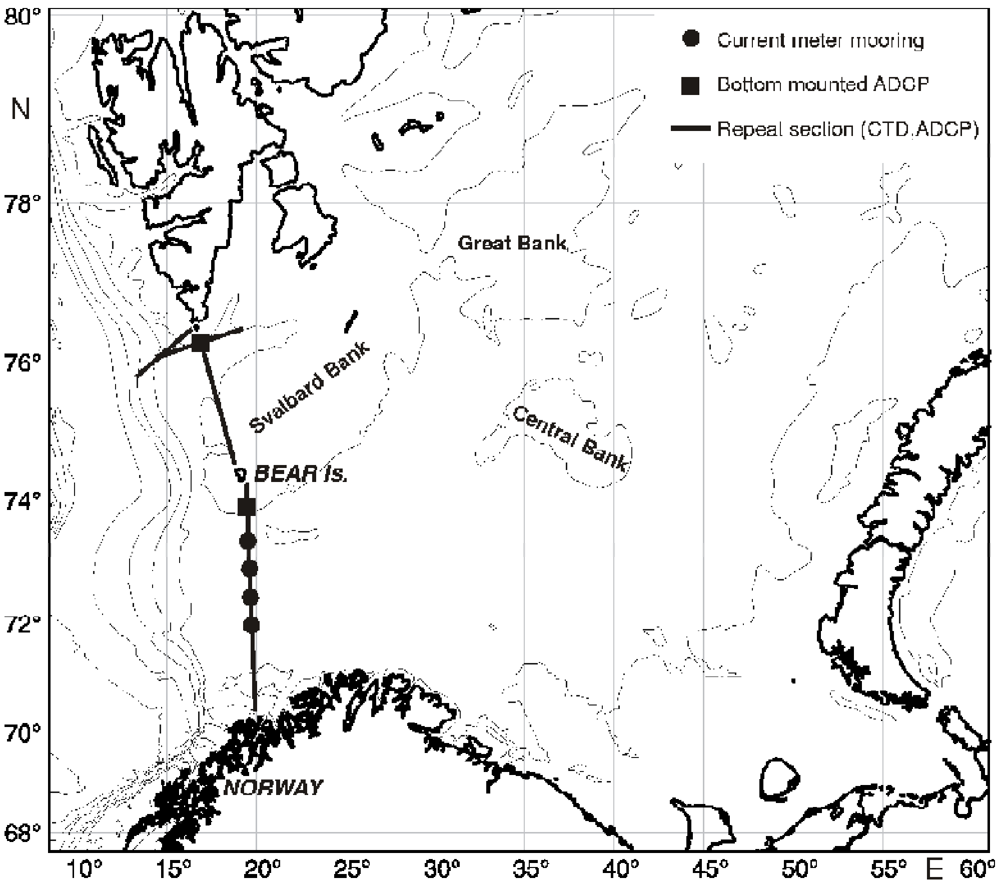
F = Faxafloi - standard section
S = Hydr. Sections along shelf and slope moored arrays
P = Prototype
IP = Improved prototype



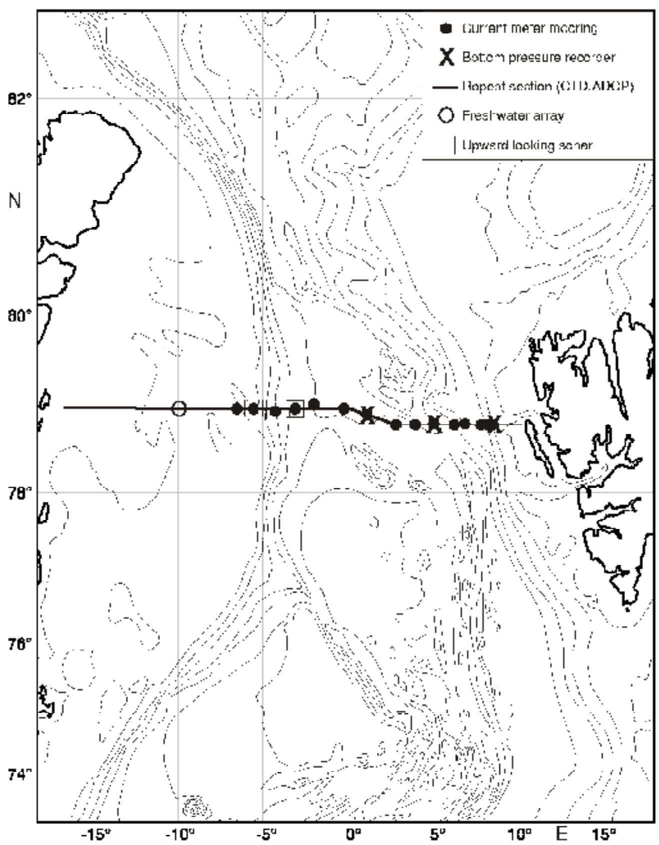
Project planning timetable and map, ASOF-EC (W)



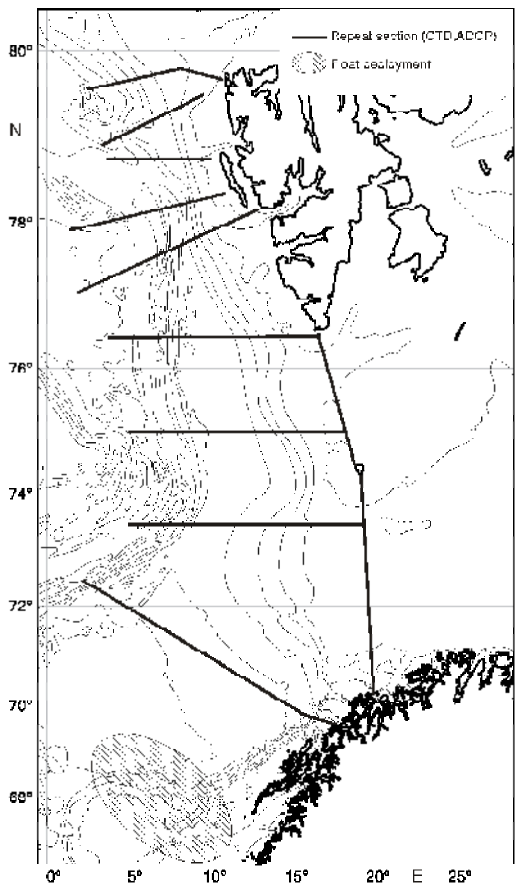
Project planning timetable and maps, ASOF-EC (N)



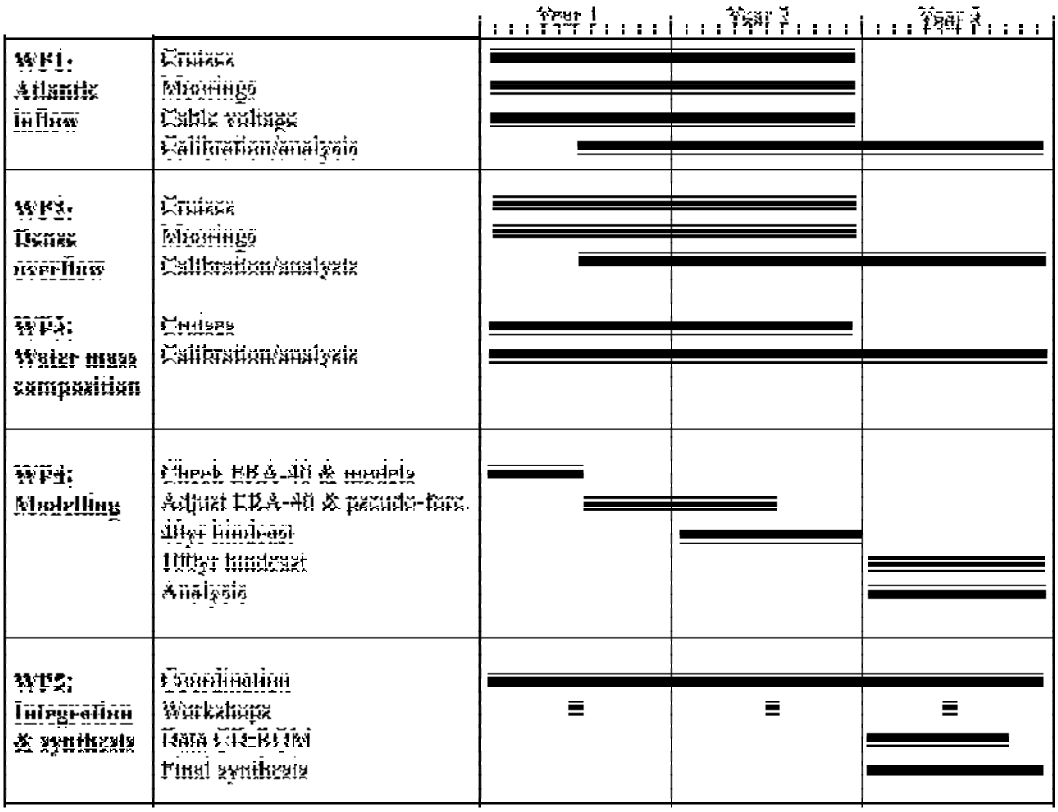
Current meter mooring
Bottom mounted ADCP
Repeal seclion (CTD,ADCP)
Great Bank
Svalbard Bank
Central Bank
BEAR Is.
NORWAY
N
E
80°
78°
76°
74°
72°
70°
68°
10°
15°
20°
25°
30°
35°
40°
45°
50°
55°
60°

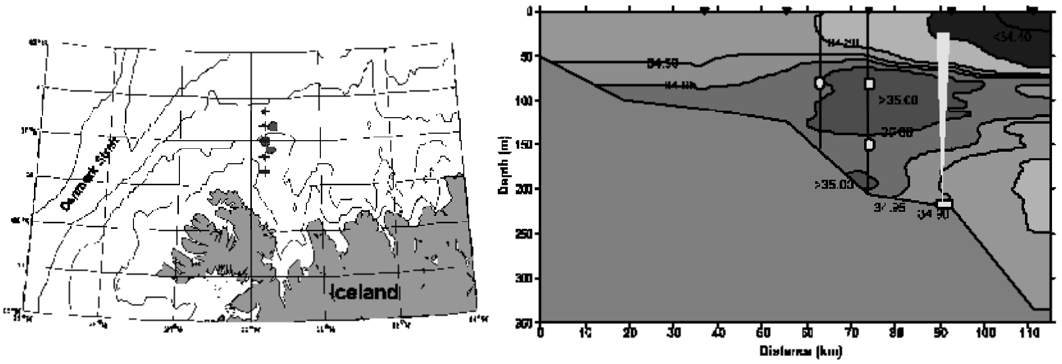


Current meter mooring
Bottom pressure recorder
Repeat section (CTD,ADCP)
Freshwater array
Upward looking sonar
N
E
82°
80°
78°
76°
74°
-15°
-10°
-5°
0°
5°
10°
15°

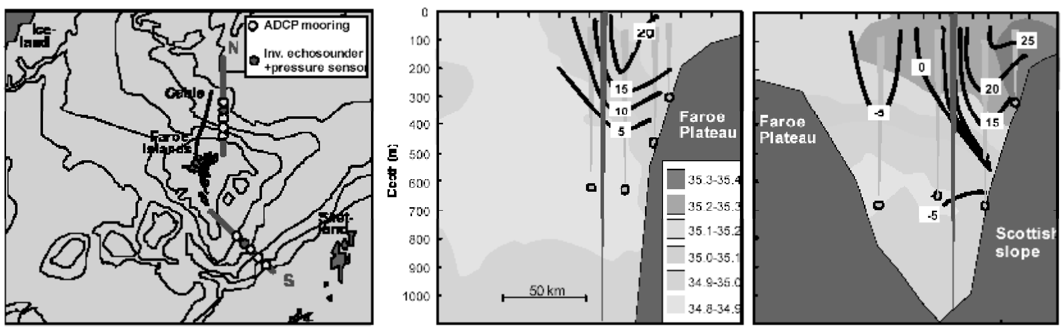


Repeat section (CTD,ADCP)
Float deployment
N
E
80°
78°
76°
74°
72°
70°
68°
0°
5°
10°
15°
20°
25°





Location (left panel) of planned current meter moorings (red circles) and CTD stations (blue +) north of Iceland. Sample salinity section (right panel) showing moorings lines with current meters and microcats (yellow circles) and bottom mounted ADCP (yellow box with sound beam illustrated by cone) in relation to a typical Atlantic core (red area).



Left panel: Location of ADCP moorings (yellow circles) and inverted echosounders combined with pressure sensors (green circles) in the Iceland-Scotland region. Thick red lines indicate CTD sections. Cable for voltage measurements is indicated by thick black line. **Middle and right panels:** Salinity, average velocity, and instrumentation on section N north of the Faroes (middle panel) and section S in the Faroe-Shetland Channel (right panel). Salinity is indicated by colour shading, and eastward velocity by thick isolines with numbers showing average velocity in cm/s. Yellow circles indicate moored ADCPs with sound beams (measurement range) indicated by yellow cones and green cones indicate echo sounders combined with pressure sensors.

Project planning timetable and map, ASOF-EC (E)

ANNEX 2

Project activity, ASOF-Task 5
Figures 4 and 5

Project activity, ASOF-Task 6
Figures 6-8.

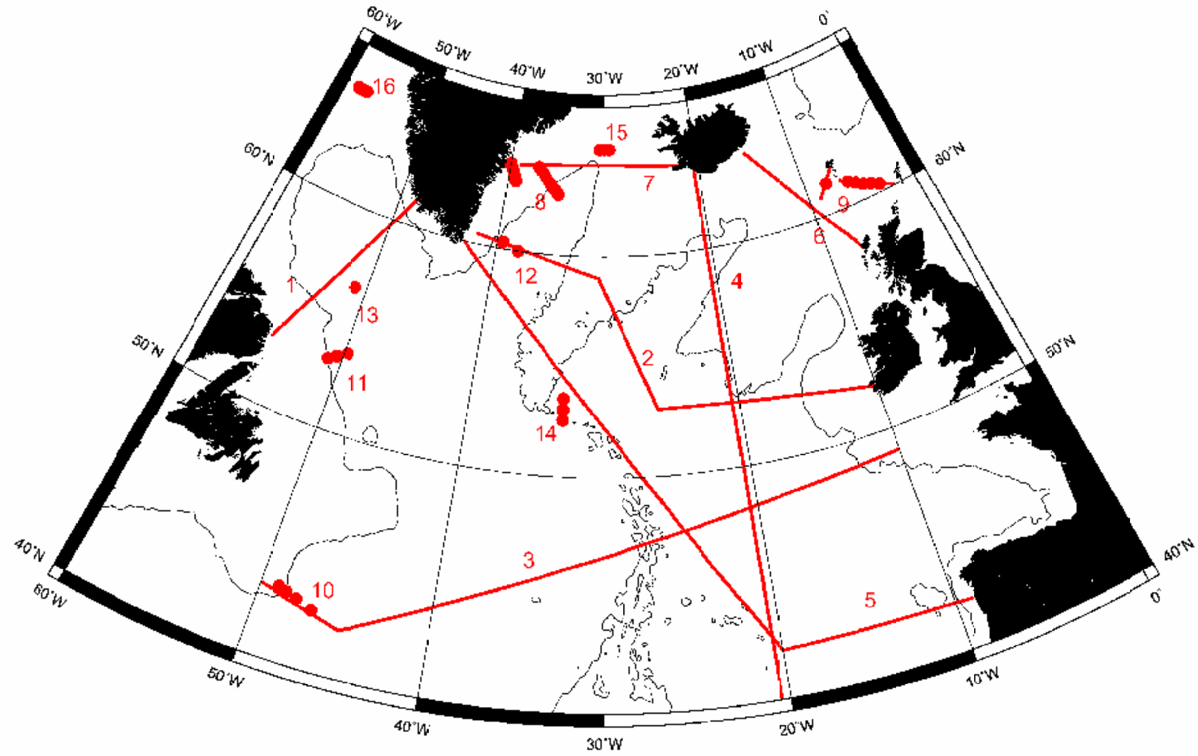


Figure 4. Map of funded and planned ASOF and ASOF-relevant fieldwork in the subpolar North Atlantic. 1-6 CLIVAR hydrographic transects (1. A01W, 2. A01E, 3. A02, 4. A16N, 5. A2, 6. Ellett line); 7. Icelandic Marine Institute Flaxafloi transect; 8-16 mooring stations (8. Meincke/Dickson, 9. Hansen/Turrell/Osterhus, 10. Schott, 11. Send, 12. Pickart/Heywood, 13. Clarke, 14. Watson, 15. Send, 16. Rhines). The 2000 m contour is shown.

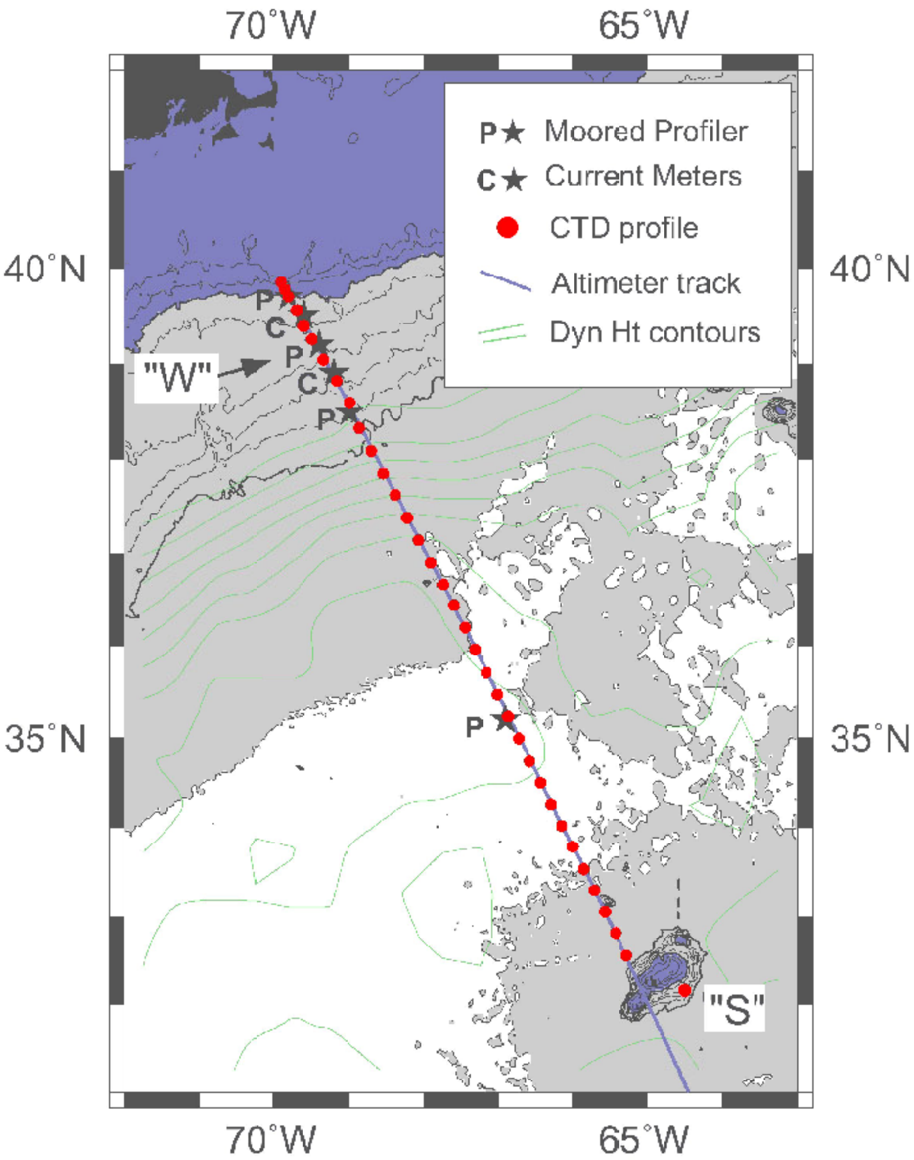


Figure 5. Proposed observing array between Woods Hole and Bermuda (reproduced by permission of John Toole), which is well-placed to observe changes passing south through the southern boundary of the ASOF domain in the Deep Western Boundary Current. As shown the array incorporates moored profilers and current meter moorings located along an altimeter track and might in due course incorporate whole-water samplers and other volunteer ASOF equipment.

Figure 6.

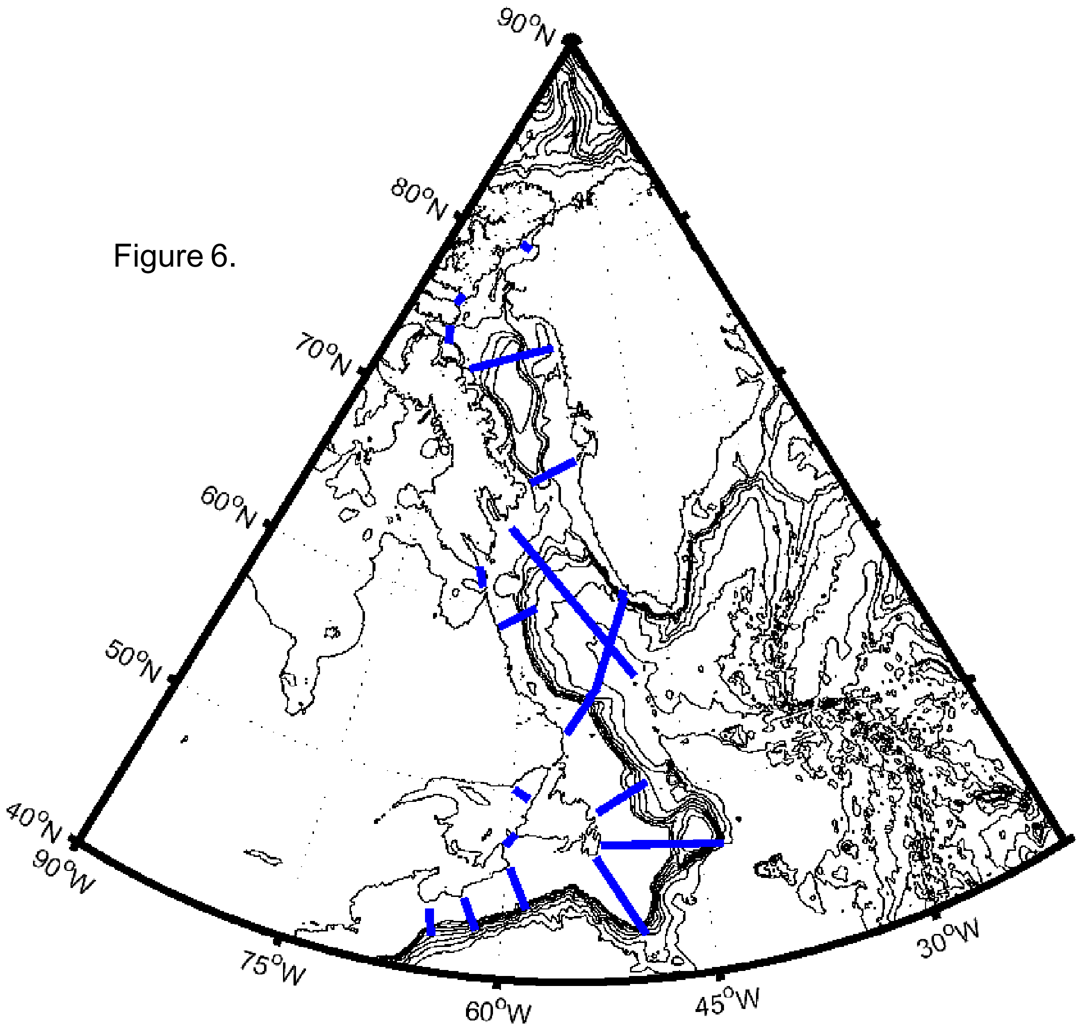


Figure 6. Key hydrographic and tracer lines for repeat measurement in ASOF-West, to be carried out by ships and, where possible autonomous gliders. The set of lines radiating across the Scotian Shelf, up to Labrador are the AZMP sections occupied by Canada 1 to 3 times per year.

Figure 7. Mooring sites in the Canadian Archipelago, for velocity, ice-draft and velocity, temperature and salinity measurements, with minimum sill depths (m) noted. Depth contour interval: 100m. Hydrographic and tracer observations will be made as densely and frequently as possible on transiting icebreakers.

Figure 8. Possible sites for moorings on the continental slope, in the Arctic boundary current, to measure pressure, ice draft, temperature, salinity and velocity. Hydrographic/tracer lines radiate into the Canada Basin from the Archipelago. Contour interval: 500m.

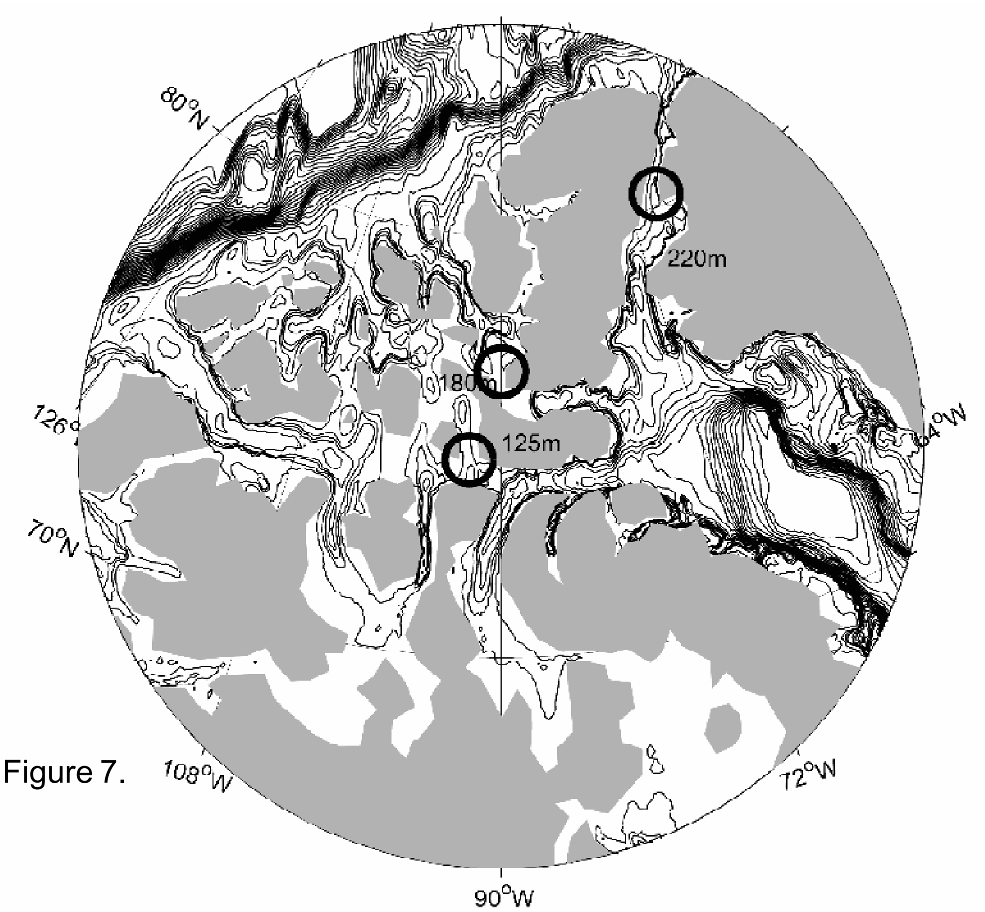


Figure 7.

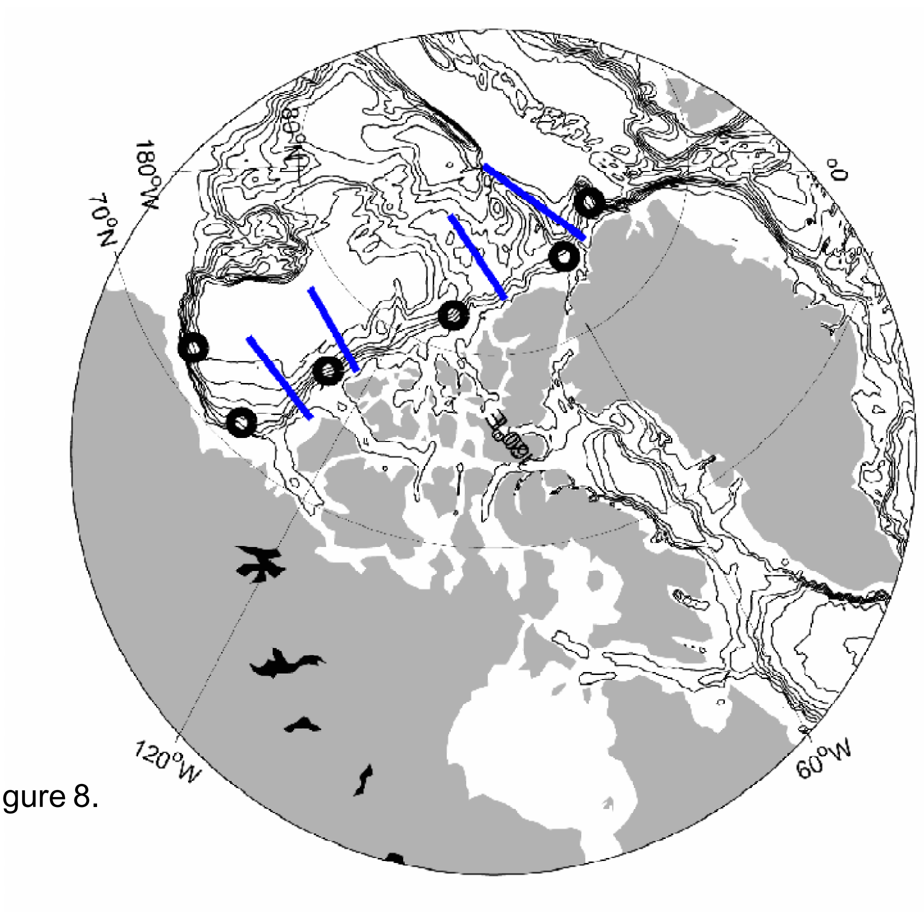


Figure 8.

ANNEX 3

Project map and tasks of the Norwegian NOClim Project. [ASOF-associated; (http://www.noclim.org/)].

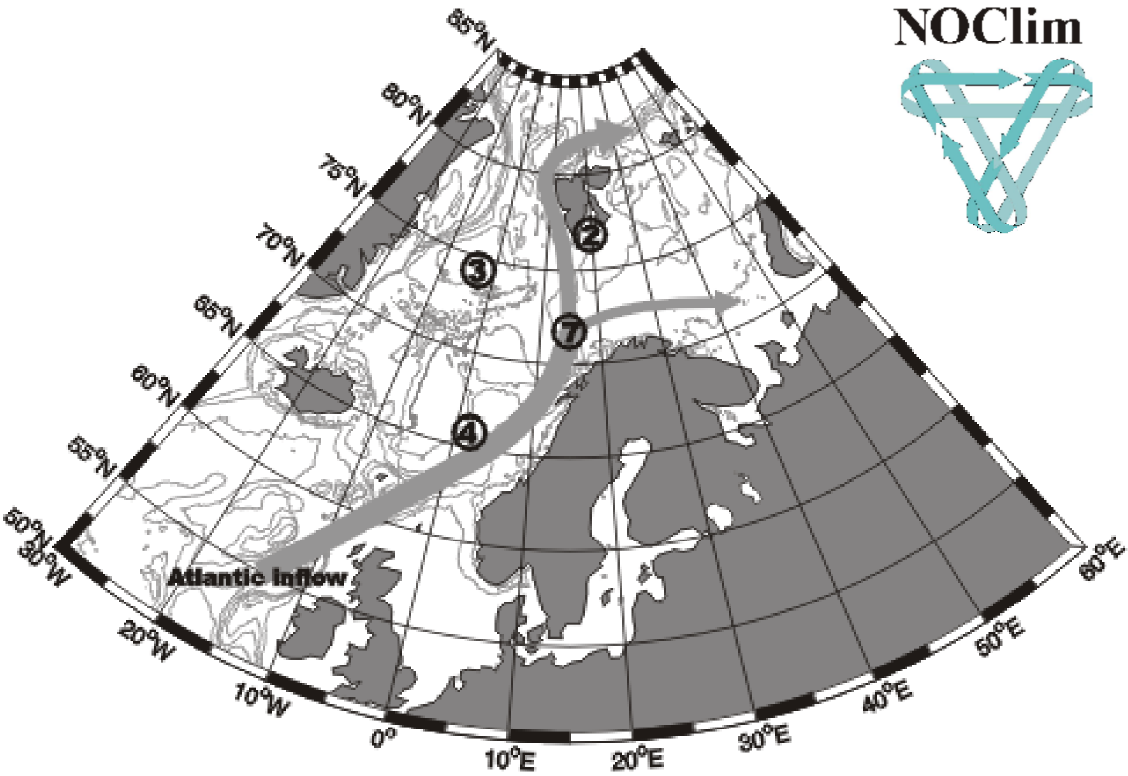


Figure 9. NOClim working areas and tasks.

- Task 1: Rapid and dramatic changes
- Task 2: Deep water ventilation from shelves
- Task 3: Deep water ventilation in the deep sea
- Task 4: Cross front exchange and formation of intermediate water
- Task 5: Variability and signal propagation from high resolution information
- Task 6: Coordinated analysis of long time series
- Task 7: Long term observations

ANNEX 4

NERC RAPID Thematic, 2002-6 (ASOF-associated).

[Under construction:- the activities, tasks and sites of the thematic programme will be described once the present expressions of Interest have been evaluated. At closing date for outline bids (28 March 2002), a total of 96 ‘standard funding’ applications and seven MOC monitoring’ applications had been received].

In US, a sub-project of the Study of Environmental Arctic Change (SEARCH)
In Europe, a project of EC Framework Programme V