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

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Rationale and background: To many investigators, the polar reservoirs of ice and freshwater (including the ice-mass of Greenland) represent the key to the polar role in climate[414,546]. And the climatic impact of Arctic change[133,134] is still centred on the fate of the Arctic sea-ice and the climatic and social effects of its disappearance. Many state-of-the-art climate models predict that the perennial sea-ice of the Arctic Ocean will disappear in late summer within a few decades or less. Important questions remain as to whether this expectation is justified[607,644], and if so when this change will take place and what effect it will have on climate on a regional-to-global scale[546,811]. Such a dramatic physical affront to the ocean-atmosphere-cryosphere system in high northern latitudes, corresponding to a change in surface albedo from more than 0.8 to less than 0.3 over a surface larger than Europe, is bound to have radical effects on human activities with immediate impacts on the indigenous inhabitants of the circum-Arctic region and the ecosystem on which they depend, and with widespread effects on socio-economic activity on a hemispheric scale.

Since the mid 1990s, observational programs such as EC-VEINS and the pan-Arctic ASOF and US-SEARCH programs have shown clearly enough that large-scale coherent changes have been passing through northern seas on a time scale of decades. Though patchy in both space and time, these studies from the Arctic Ocean and subarctic seas have by now provided records of sufficient length and scope to show that a whole complex of inter-related changes are involved, to glimpse the regional drivers of these variations at annual-to-decadal scales and to hint at their climatic importance. At the same time, new and vital observing techniques have been emerging so that for the first time we are in prospect of being technically able to measure almost any of the key variables, at almost any place and time, that we need to describe the ocean-atmosphere-cryosphere system of high latitudes[67,129]. So it now seems feasible that by filling gaps in our spatial coverage and extending the available series in time[54,179], we may be able to view the ocean-atmosphere-cryosphere system of high northern latitudes *operating as a complete system* for the first time. And improving our understanding of that system and testing its predictability does seem to be a most direct way of extending the ability of society to mitigate for or adapt to its changes. That at any rate is the rationale behind the integrated Arctic Ocean Observing System (iAOOS), and the upcoming International Polar Year (IPY) provides the necessary stimulus for piecing together the available PIs, gear, ships and funding on the pan-Arctic scale that seems necessary to making the attempt.

Purpose: In the IPY planning process, there is both a general and a specific purpose to this iAOOS project submission. Following its review of the >950 ‘expressions of interest’ (EoI) to the IPY Project Office in January-May 2005, the ICSU-WMO Joint Cttee for the IPY undertook the task of identifying certain proposals which were thought to have sufficient scope to act as ‘clustering projects’ for a range of other submissions. In late March, the iAOOS submission (EoI #80) was provisionally identified as one of these, with the potential to act as lead project for a range of EoIs dealing very generally with the Arctic Ocean Circulation, and the AOSB and CliC Boards were invited to further develop their submission into one that might formally be recognised as an IPY Core Project. This re-submission is the result, with a dual purpose; first to describe a further refinement of the iAOOS proposal itself, and second to form a pan-Arctic context for the broadest range of EoIs that share the iAOOS focus on the fate of the Arctic ice. From the full list of 954 EoIs on 26 May 2005, a total of 86 were identified as relevant to this primary focus of iAOOS, and a possible context for each is identified [in superscript] in the present text. Clearly, in the space of a few pages, it will not be possible to refer to more than a handful of these 86 in any detail but that in any case is not the purpose of this re-submission. Its purpose is to describe the varied observational components that *might* realistically be pieced together during the IPY to attempt the focus question on the fate of the Arctic ice. Thus this is emphatically *a* scheme for iAOOS rather than *the* scheme for iAOOS, put forward to illustrate to interested parties (funding agencies and PIs mainly) what sort of intensive pan-Arctic observing plan might be possible if the available resources of funding, shiptime, gear and PIs are brought to bear. The extent to which this iAOOS plan may come to resemble any actual future international observing effort will not of course be known until the decisions of national and international funding agencies for IPY funding are individually determined and disclosed. Only then will the 86 Expressions of Interest that we have considered be of *actual* relevance; however in the meantime, the complete listing of ‘iAOOS-relevant EoIs’ is appended below as the basis for this illustration.

IAOOS Project Description: Any attempt to describe the full complexity of an observing system as comprehensive in its intended goals as iAOOS is liable to become choked with detail. Very few types of measurement will be *unimportant* and it will always be possible to slice the observing plan in a number of different ways in order to describe its elements. Here, we attempt to describe both a vertical and a horizontal ‘transect’ through iAOOS, hopefully without too much redundancy. The ‘vertical transect’ we describe is for the High Arctic, where the iAOOS primary focus on the fate of the perennial sea-ice necessarily involves a vertical stack of observations from satellite to seabed; this section will also serve to make the point that iAOOS is not just an ‘ocean’ program. The ‘horizontal transect’ through iAOOS that follows *will* largely be concerned with the ocean but in spanning the Arctic and subarctic seas, will make the equally valid point that iAOOS cannot just concern the Arctic. As the US-SEARCH and ASOF programs have clearly demonstrated, change may certainly be imposed on the Arctic Ocean from subarctic seas, and the signal of Arctic change is expected to have major climatic impact by reaching south through subarctic seas to modulate the Atlantic thermohaline circulation[51].

Transect 1. Observing the Arctic Ocean from satellites to seabed. As the newly-funded EC-DAMOCLES project points out, there is a primary need to improve the observations and modelling of the **Arctic atmosphere**. Current climate models, global as well as regional, are more unreliable in the Arctic than in most other regions, so that the inter-model spread in scenarios for future climate is larger in the Arctic than elsewhere. There are many reasons for this. Some stem from the inability of models to handle mesoscale synoptic disturbances (even the present-day observational network is incapable of detecting all mesoscale cyclones). Some are related to an insufficient understanding of the several important local feedback mechanisms that appear to be special to the Arctic. Some of these processes are sub-grid scale in climate models and need to be parameterised; many deal directly with the energy transfer at the surface, and are therefore directly relevant for the melting of the sea ice. In prioritising its observational coverage of the Arctic marine atmosphere, the EC-DAMOCLES component of iAOOS therefore focuses on the following processes, to be sensed by a mix of systems including satellite soundings[158,206,501], surface ships, manned ice camps[54,120,124,421], autonomous ice-tethered platforms (ITP) and IABP/ICEX buoys[120,139] (illustrated schematically in Fig 1):

I. Dynamics and occurrence of mesoscale cyclones[167]. Mesoscale cyclones, such as Polar lows, are common particularly in the marginal ice zone. The strong winds associated with the cyclones have a major influence on sea ice dynamics[618], and are supposed to make a large, but insufficiently known, contribution to the lateral transport of heat and moisture into the Arctic atmosphere[807].
II. Physical processes in the atmospheric boundary layer (ABL)[164,408]. The Arctic ABL is usually stably stratified, and numerical models typically suffer from the largest errors in such conditions. An additional difficulty is the localized convection over leads[687] and coastal polynyas, which makes the ABL heterogeneous in the grid scale of models.
III. Interaction of clouds, radiative fluxes, surface albedo, and snow/ice thermodynamics[325]. Polar clouds may have different optical properties compared with lower latitudes[212,566,757]. The interaction processes are extremely complex, and involve strong feedback effects, above all the surface albedo feedback.

Thus the ‘atmospheric’ objectives selected by DAMOCLES are to better detect Arctic cyclones; to improve modelling of their interaction with sea ice; to quantify the contribution of the cyclones to the transport of heat and moisture; to understand and model boundary-layer processes over the Arctic Ocean; to develop improved parameterizations of turbulent fluxes in the atmospheric boundary layer (ABL) over the Arctic Ocean; to understand and model the formation and life cycle of Arctic clouds; and to understand and model radiative transfers through the Arctic atmosphere and their interaction with the snow/ice surface albedo.

Observing the **sea-ice** itself forms the second fundamental component of iAOOS. Recently we have seen strong indications of radical changes in the Arctic sea ice (eg Comiso, 2002; Serreze 2003; Rothrock et al 2003), including the thinning of the Arctic ice-pack from more than 3m on average to less than 2m over a large part of the central basin of the Arctic Ocean, and among the most disturbing modelling results are those predicting the disappearance of the Arctic perennial ice during this century. However the processes are far from clear. The iAOOS strategy, shared by EC-DAMOCLES, is to address these knowledge gaps by large-scale, long-term observations at high resolution, aiming to achieve a sufficiently synoptic coverage of the Arctic Ocean to detect time- and space-scales in the variability of sea ice thickness, extent, concentration, type and drift, while measuring also the essential climate parameters that control these variables[185,537]. Ultimately, the intention is to form a new and more dependable picture of the future of the Arctic by establishing a more rational basis for predicting the reduction to disappearance of its perennial sea-ice.

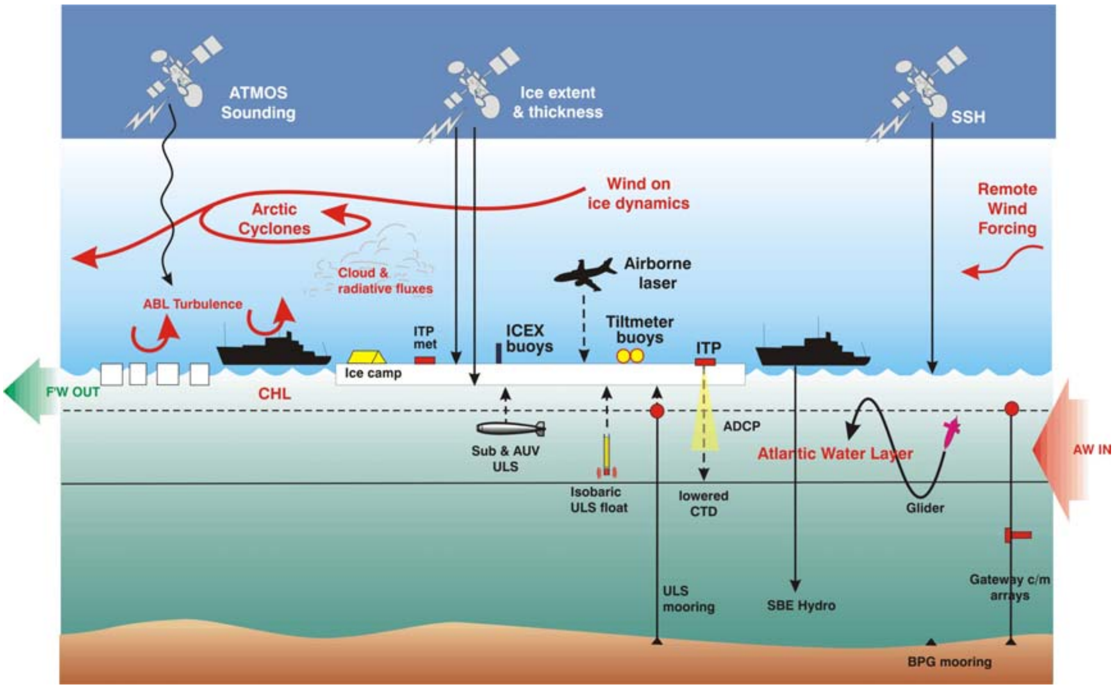

Figure 1. Schematic of the vertical stack of observations from satellites to seabed that would be necessary to inform an iAOOS study focused on the present state and future fate of the Arctic perennial sea-ice.

This program element will by necessity be one of the most innovative in iAOOS (see Fig 1). Our ability to map the changes in sea ice cover on a pan-Arctic scale has already benefited from the arrival of passive AMSR multi-channel reconstructions at 5-85 GHz. The satellite radar altimetry which has been used to provide estimates of ice thickness from direct measurements of ice freeboard (Laxon et al 2003), sea surface height (SSH) and potentially other[590] retrievals even in these ice covered regions (Peacock and Laxon, 2004) has so far suffered from two drawbacks. First its geographical coverage has hitherto been limited to latitudes south of 81.5N leaving a large part of the central Arctic without cover; that will be remedied in 2005 with the arrival of CRYOSAT which will extend cover to 88N[501,921]. A lack of ground truth has posed a second more fundamental problem for the validation of ice-thickness and SSH estimates alike. That can now change, using a broad range of new techniques[185,324,363]. Deployed across the ice-surface, a network of a dozen or so tiltmeter buoys[904] (Figs 1, 2c), developed under the EU's SITHOS and GreenICE projects, will measure the power spectrum of flexural-gravity waves propagating through the ice to provide their own new and independent measures of ice thickness; processing will be accomplished on board with transmission of spectra or raw data by low-orbit satellite (Iridium), and as the network moves around the Arctic, the distribution of modal sea ice thickness is mapped in time and space. Above the ice, airborne laser[594] will provide accurate local calibration and validation of satellite-derived ice-freeboard measurements [see also 350]. Beneath the ice, AUV[373,578] and floats operating accurately at constant pressure will carry Upward Looking Sonar (ULS) to further validate satellite estimates of ice-thickness, while a small scatter of bottom pressure gauges (BPGs) moored across the Arctic deep basins[436,940] (Fig 2b) will provide the necessary ground truth to derive estimates of the Arctic Ocean circulation from remotely sensed measurements of sea surface height. Though all these systems are new, all exist or are in immediate prospect, and by their use, for the first time, direct measurements or validated estimates of the circulation, stratification and ice-volume[855] of the Arctic Ocean will be possible with monthly-to-seasonal resolution.

Transect 2: Observing change in the circulation and properties of Arctic and subarctic seas. In describing the ocean observing effort in iAOOS, it is convenient to switch to the horizontal ‘plane’ since the appropriate boundaries for ocean observing must 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. The ocean programme of iAOOS is defined by all of these elements (inputs, shelves, boundary, deep-basins and outputs) and together they define its domain. The remainder of this submission takes the form of brief tour through this domain, with the dual purpose of summarising the component tasks and of illustrating further the technical developments that could make iAOOS possible. We begin with the Arctic Ocean itself as the central ‘hub’ of the program before describing the observational elements that are designed to cover its exchanges to and from subarctic seas[20,666,770].

Arctic Ocean circulation: As just mentioned, the perennial ice-cover of the Arctic Ocean and its fate forms a primary focus of iAOOS. The central Arctic Ocean is also where the inflows from Atlantic and Pacific[804] and the products of the shelves merge and are redistributed. Here, the fresh surface layer of Arctic river runoff[67,223] (10% of global total runoff) and its associated cold halocline layer (CHL) normally act to isolate the sea-ice cover from the warm Atlantic-derived layer below (see Fig 1), though a change in the location of freshwater storage in the Arctic Ocean coupled with a more extensive spread of Atlantic water has recently (1990s) allowed contact between this warm sub-layer and the surface.

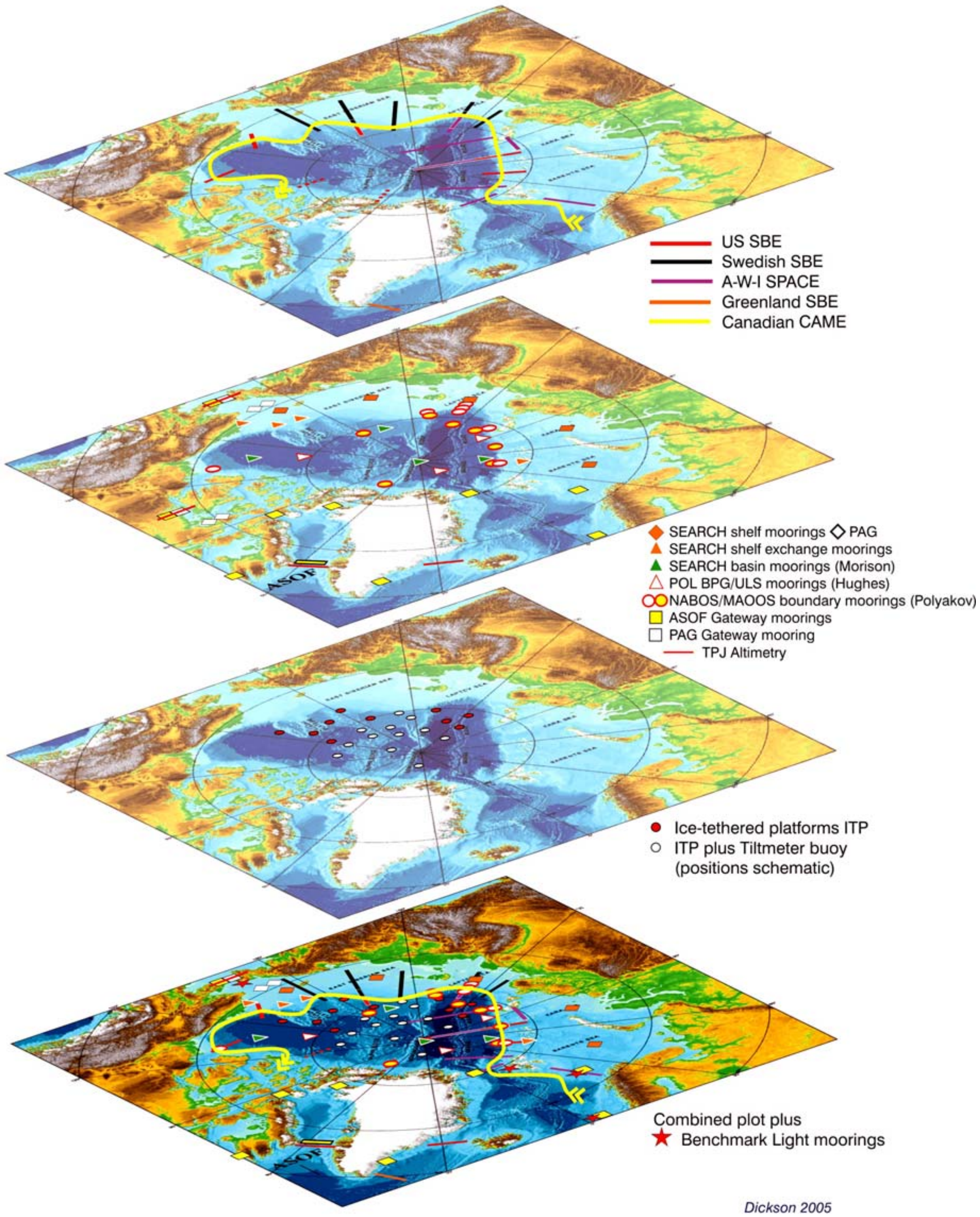

Figure 2. The elements of an integrated Arctic Ocean Observing System showing a) the ship-based Shelf Basin Exchange transects, b) the proposed mooring system for Shelf, Slope, Basin and Gateways c) grids of Ice-Tethered Platform and Tiltmeter Buoys (positions figurative) and d) the full combined deployment.

Thus year-round monitoring of the surface water properties *and* the Arctic circulation[63,241,329,385,832] are both needed to identify their roles in the development of the Arctic ice-cover[86,185]. In turn, changes in freshwater distribution and atmospheric circulation jointly control the 'switchgear' (Steele et al ?) that determines the amount and preferred path of the freshwater flux southwards to the Atlantic thermohaline 'conveyor' (see below). Under the EC-DAMOCLES component of iAOOS, an extensive integrated scheme of floats[485] & gliders (Fig 3) will make subsurface profiles throughout the upper watercolumn of the Arctic Ocean (emphasis on the upper 800m but with excursions to 2 km depth), thus exploring and describing both the variable CHL and the variable Atlantic-derived sublayer[578,731], communicating their data to satellites and receiving measurement-control and navigation information via a net of ice-tethered platforms (ITPs; Fig 2c).

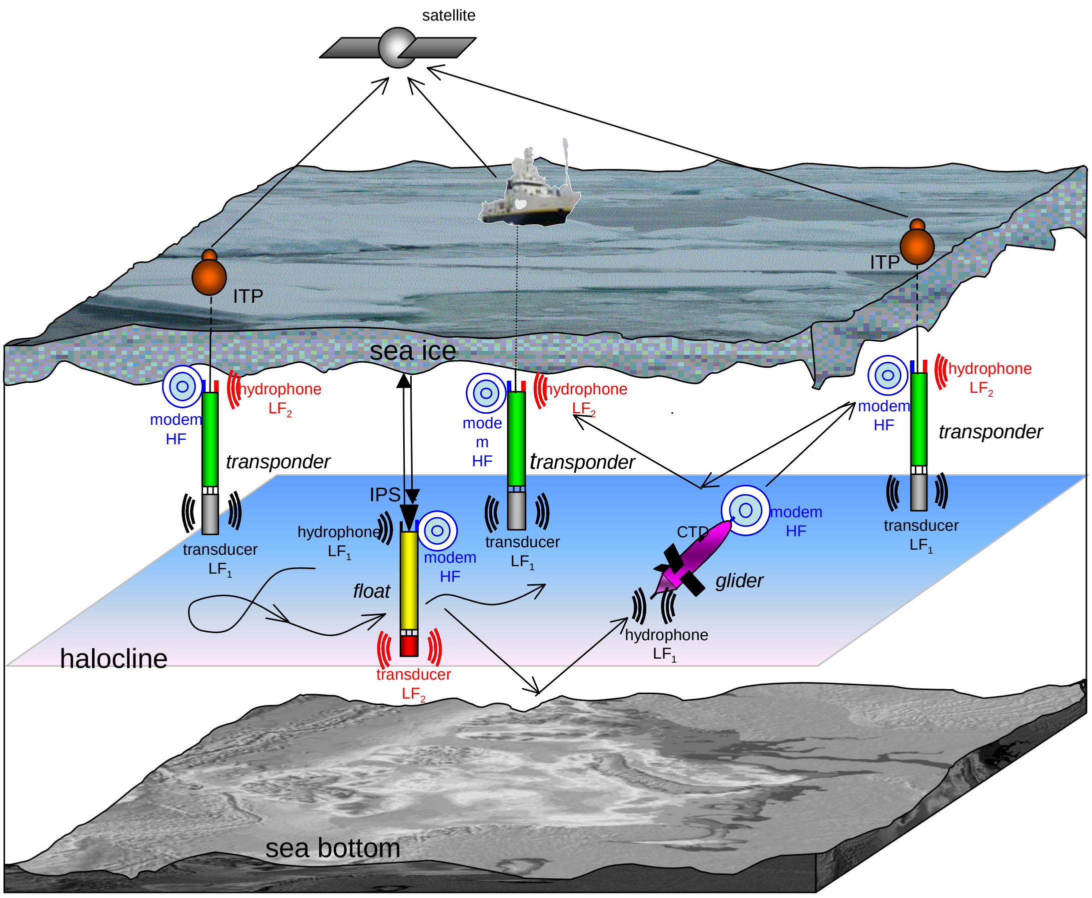

Figure 3. The ocean observing scheme proposed for the Arctic Ocean by the DAMOCLES Integrated Project of EC-FP6. The proposed network of tiltmeter buoys for ice-thickness measurement is not separately shown but would be laid in close proximity to the ITPs. A combined ULS and bottom pressure program by US-SEARCH and EC-DAMOCLES would complete the system.

The ITPs themselves (proposed variously by EC-DAMOCLES, US-SEARCH[916], NOAA, and WHOI[905]) will deploy profiling CTDs through the upper watercolumn[932] and will monitor the vertical structure of ocean currents using ADCPs, while also fulfilling their conventional role of collecting meteorological data at the ice surface. Because of the limitations of sound propagation in shallow waters, the DAMOCLES float & glider programme will be confined to the Arctic deep basins, but the exchanges between Arctic shelves and the deep basins will be addressed by the addition of dedicated hydrological sections----extensions of selected Shelf Basin Exchange (SBE) transects (see below and Fig 2a)---- with a heavy reliance on tracers such as $^{129-}$I, $^{18-}$O, Barium etc. Individually or in combination, these tracers will allow us to calculate the precise advective time-scales of all tracer-laden water masses[45,269].

Inputs from subarctic seas: The northward flux of heat by the ocean, estimated at 260TW where it crosses the Greenland-Scotland Ridge to enter the Nordic Seas (Hansen and Østerhus 2000, revised 2004 pers comm) is of major importance to the climate of Europe. In recent decades we have been aware that the flow of Atlantic water northwards to the Barents Sea and into the Arctic Ocean has become warmer, stronger and probably narrower (eg Quadfasel et al 1991; Morison et al 1998; Polyakov et al 2005 submitted). Only recently however have we learned that the spread of warmth to the Barents Sea and Arctic might be attributable to a mix of both local and remote forcing (Orvik and Skagseth, 2003) conveying the possibility of prediction. An ability to predict the warmth of the main inflows to the Arctic[114] is so central to the aims of iAOOS as to justify maintaining the three main ocean flux arrays concerned (Faroe-Shetland Channel or Svinoy, Barents Sea Opening and Fram Strait[20,42]; yellow squares in Figure 2b and d) as iAOOS 'observatories', using them to test and develop our predictive skills, and where these predictions fail, to determine which factors (eg diversions or short-circuits of flow and their drivers) have caused them to fail. Thus this objective envisages the maintenance of the present ASOF arrays, but for the new purpose of identifying and predicting the mix of local and remote forcing that controls the flux of warmth and salt to the Arctic Ocean. Continuation of the long-established gateway moorings in the Bering Strait, maintained since 1990 by Aagaard's UW group[367] (yellow square Fig 2b), will supply the corresponding coverage of the variable Pacific inflow to the Arctic Ocean, perhaps reinforced in the western Strait by the additional moorings proposed for the IPY by the Pacific Arctic Group[157;see also 98] (John Calder NOAA, pers comm. 2005; white square labelled PAG in Fig 2b).

New cutting-edge observing techniques will complement the conventional moored arrays in both the Atlantic and Pacific gateways[91]. In the EC-DAMOCLES component of iAOOS, a Norwegian NERSC initiative for monitoring the transports of heat and mass through Fram Strait by acoustic tomography will cover the highly variable flows in the deepest part of the Strait as well as the important fluxes along either boundary by installing two transmitters either side of the Strait with a single receiver in mid-Strait. A simplified Yo-Yo system attached to the top of the receiver mooring will surface every other day to transmit the data to satellite in close to real time. A system of SeaGliders (Craig Lee, University of Washington) is under consideration both for primary data collection and backup data retrieval. While in open water in the eastern Strait, mission control might be achieved by Iridium communication via satellite; in the ice-covered west, RAFOS beacons would be used for glider navigation and data recovery. In the case of the Bering Strait, a Canadian proposal (Cherniowsky's group[691]; IOS Sidney) will add Topex-Poseidon-Jasin altimetry support (1992-2012 expected) to the existing UW *in situ* observations of Bering Strait throughflow (Aagaard and Woodgate), providing east-west gradients in sea level every ~1.5 days in the ice-free season (June–November).

Shelf-Basin Interactions: In crossing the broad circumarctic shelves, the saline Atlantic-water streams are separated into fresh water and brine-enriched end members by the freeze/melt cycle (Midttun, 1985), and the drainage of these brines plays an important role in the ventilation and renewal of the deep and intermediate waters of the Arctic Ocean. Recent results (Skogseth et al., 2004) confirm that annual estimates of total brine rejection can be made from model-assisted interpolation of satellite and in situ data, that the variability can be linked to atmospheric forcing and source-water salinity, and that the dominant mixing and entrainment processes occurring on the way to the shelf break can be understood. Using these techniques, interannual variability and trends in the export of brine-enriched shelf waters would be studied through the IPY.

More generally, the transformations and mixing of the various source watermasses as they cross the broad circumarctic shelves[860,896,902] and enter the circumarctic boundary current contribute substantially to the modification of water masses throughout the whole Arctic water column. In iAOOS, it is proposed to study this sensitive zone and its highly non-linear processes of watermass transformation[145] using a mix of observational and modelling techniques: (i) A scatter of shelf moorings and shelf-exchange moorings to be set by US-SEARCH in a broad arc from the Barents Sea to Alaska (Fig 2b; positions defined in the SEARCH Science Plan), supplemented by shelf moorings of the Pacific Arctic Group immediately to the north of Bering Strait (ii) 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 (MAOOS[915]; Fig 2b) coordinated by Polyakov's Group at IARC Fairbanks. (iii) Standardised icebreaker-based hydrographic transects across the shelf-basin boundary and into the central basins to distinguish temporal from spatial changes and deduce local interactions with the shelves along the flow-path of the boundary current. As shown in Fig 2a, these transects would form an internationally-coordinated circumarctic 'Snapshot' of Shelf-Basin Exchange (SBE) processes during the IPY, with Grebmeier's Shelf-Basin Exchange (SBE) study[522] contributing around 8 icebreaker- or aircraft-based transects and EC-DAMOCLES contributing a further 6 to 9 icebreaker transects through Anderson's Swedish SBE lines[562] plus the A-W-I Synoptic Pan-Arctic Climate and Environment (SPACE) study[18] (Schauer). At intervals, these would be tied to the MAOOS mooring network where they cross the boundary current (see Fig 2d) and each of the radiating SBE lines would be connected in azimuth by the circumarctic hydrography of Carmack's Canadian Arctic Margin Experiment (CAME[681]) and Shimada's Pan-Arctic ocean Circulation Experiment (PACE[832]). (iv) Ocean circulation models combined with detailed process models will cover the atmosphere-ice-ocean system with high temporal and spatial resolution[811].

The combination of these approaches will permit 4 results of global importance --- the provision of a regional heat and freshwater budget, the provision of physical and biogeochemical boundary conditions for basin wide studies of the Arctic Ocean, an understanding of how ocean-climate signals propagate around and into the Arctic deep basins, and a 'benchmark' synoptic assessment of a rapidly-changing and climatically-important system.

Output to impacts: 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 where they are anticipated to have their main societal or climatic impact.

The 1st main objective of this sub-task addresses the issue of how much fresh water passes south from the Arctic to the N Atlantic, what might control the changing balance of flow either side of Greenland, and (in a little more detail) what might promote the episodes of diffluence of freshwater from the E Greenland Current (EGC) back into the Nordic Seas[35]. State-of-the-art freshwater flux arrays (yellow squares Fig 2b) have already been established under the ASOF Programme in Lancaster Sound (Prinsenberg, BIO Canada[682; also 241,688,712]), in the Kennedy Channel (Falkner, OSU; Melling IOS Sidney) and in Hudson Strait (Straneo and Pickart, WHOI), and coverage west of Greenland has now been completed by the establishment of a SeaGlider-based monitoring program for the Davis Strait by Craig Lee, UW (see Fig 2b) following their first successful use in operational survey there by Eriksen and Rhines. The continuation of these technically-advanced arrays & systems into iAOOS has yet to be negotiated. East of Greenland, it is planned to maintain and augment the existing ice & freshwater flux arrays in the western Fram Strait (7-moorings maintained by Hansen, NPI Tromso;[see also 86]), midway along the E Greenland shelf at 74N (University of Hamburg SFB 520), and south of Denmark Strait (ASOF-EC) to provide for the first time a continuing measure of the gross and net freshwater flux for comparison with changes in the regional windfield and ocean circulation. Here, the A-W-I NAOSIM model will be employed as the main interpretative tool. The fact that this model has been able to simulate the remarkable events of 1994-5, when the largest volume flux of ice yet measured through Fram Strait (e.g. Widell et al 2003) was substantially redirected eastwards into the Greenland Sea (Karcher and Gerdes, pers comm 2003), justifies our reliance on this technique. Newly developed autonomous moored water samplers (Truls Johannesen and Watson) coupled with hydrographic analysis (Mauritzen 1996, Rudels et al 2002; Jonsson & Valdimarsson, 2004), will provide the tracer data necessary to identify the source and continuity of these flows while moored profilers and other techniques will study their influence on the processes of vertical exchange in the adjacent Greenland Sea[35,343].

The 2nd objective of this task addresses the fundamental question of whether the influence of ocean fluxes on the MOC is likely to take effect through processes of local (overflow), regional ('hosing' the NW Atlantic) or global (worldwide salinity redistribution) scale, individually or in combination. The DAMOCLES component of iAOOS intends to address this by setting up an interactive 2-way linkage with the UK-NERC 'RAPID' project led by Keith Haines of Reading University to assimilate all N Atlantic datasets for the past 40 years[see also 223], including those from high latitudes, into a high quality ocean circulation model with the aim of expanding our view of the space-time evolution of major ocean-climate anomalies on a larger scale than can be tackled in iAOOS or DAMOCLES alone. Since this part of iAOOS directly addresses the efficiency with which the Arctic communicates with the Ocean's thermohaline 'conveyor', it may yet prove to be the component of greatest importance to the Earth's changing climate system.

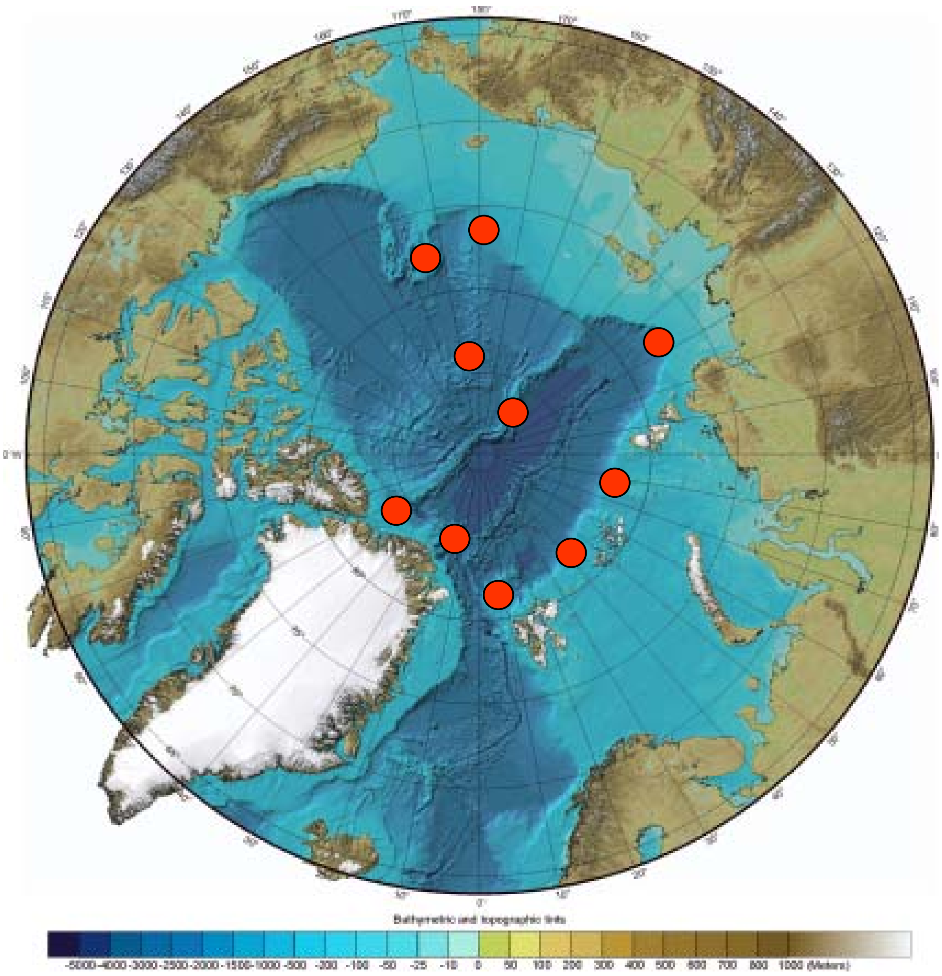

Figure 4. Key coring sites at points of relatively high sediment accumulation needed to set modern observations into the longer-term context of Arctic change (Mikkelsen, pers com 2005).

Establishing a paleo-context for present Arctic change: Arctic change is nothing new; during most of the Cenozoic the Arctic Ocean will have exchanged water with the Atlantic, the Pacific and surrounding continents, and the variability of these fluxes and of sea ice extent and thickness will be identifiable in the marine sediment record, thus providing multicentury time-series as a context for our present brief instrumental series (ARCUS 1999; APPG 2003; Kristofferson and Mikkelsen, 2004). In particular, scientific coring of marine sediments provides a window onto the shorter and long-term natural variability of the Earth system ---its rates and spatial patterns----prior to human interference. Making such paleoclimatic reconstructions will rely on the use of high-resolution (i.e. decadal to centennial) well-dated proxy records from sites of high sedimentation, and 10 such sites are suggested in Figure 4 (Naja Mikkelsen, pers comm.). As shown, the most promising potential sites are suggested to include the continental slopes of the Laptev, Barents[403] and Kara Seas and the Chukchi Borderland, which would potentially comment on the varying influx through both the Atlantic and Pacific gateways, the terrestrial signals from the major Russian rivers as well as the changes of the Arctic Basins themselves. In addition, the Yermak Plateau[91] and Morris Jessup Rise are marginal plateaus where sediments will contain a record of Arctic and Atlantic Ocean exchange[54] through the Fram Strait. The three sub-parallel ridge systems and topographic highs of the Arctic Ocean (the Gakkel Ridge, Lomonosov Ridge and the Alpha-Mendeleev Ridge) also afford suitable conditions for high sedimentation and thick sediment drift deposits; the successful drilling of the Lomonosov Ridge in 2004 by the International Ocean Drilling Program (IODP) provided a 450 meter long record spanning the last 60 mio years. By contrast, since the deep Arctic Basins are dominated by turbidite sequences these areas have low priority for high resolution coring.

The iAOOS 'legacy phase' and the longer term observational context: iAOOS will take place under the aegis of the AOSB and the Climate and Cryosphere programme (CliC) of WCRP, drawing its research science partly from an enhanced subset of US-SEARCH[916], partly from the DAMOCLES Integrated Project of EC Framework Programme 6 (recently awarded) and partly from the Chinese, Korean and Japanese scientists of the Pacific Arctic Group. None of these efforts is small. DAMOCLES, for example contributes the integrated efforts of 47 European research institutions including 10 Small and Medium Enterprises (SMEs) distributed among 12 European countries. If the funding round permits anything like the scale of scientific effort proposed here, it will certainly be the largest and most intense collaborative research effort ever devoted to the Arctic Ocean and to the variability of its physical environment.

Even so, this level of effort hardly seems excessive for the tasks of (1) observing the ocean-atmosphere-cryosphere system of high northern latitudes *operating as a complete system* for the first time, (2) from that, identifying and understanding the changes occurring in the perennial sea-ice of the Arctic Ocean and in the whole gamut of atmospheric, riverine and oceanic processes across the Arctic/subarctic domain that are collectively responsible for forcing these changes, (3) using that understanding to improve the realism by which these changes are simulated in models, thus extending the lead-time prior to the onset of extreme climate events and (4) determining appropriate adaptation strategies for a range of anticipated socio-economic impacts following the disappearance of the perennial sea-ice.

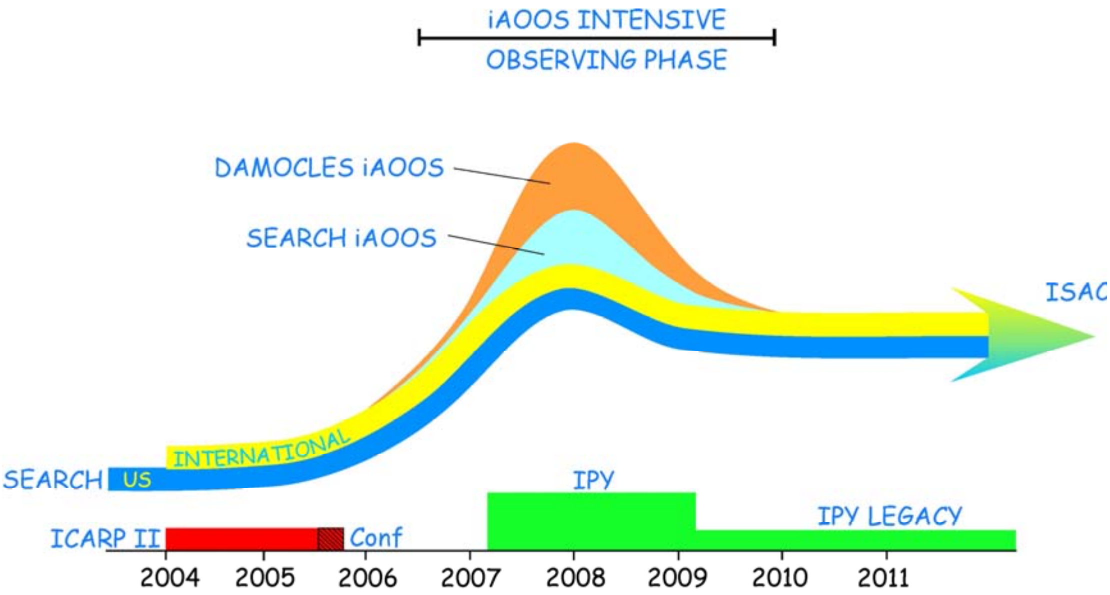

Figure 5. The integrated Arctic Ocean Observing System (iAOOS) in relation to ICARP, IPY, and the multidecadal SEARCH[916] and ISAC[620] studies of Arctic change.

Though this intense focus on the science of the polar regions and on the human dimension of polar change seems appropriate to these tasks and is of a scale appropriate to the importance and potentialities of a 4th International Polar Year (IPY), it could not be sustained at such high intensity and complexity beyond the 4-year study envisaged here. The paradox is of course that the climatically-important changes underway in the Arctic Ocean and in its sea-ice are expected to work themselves through on decade-to-century time-scales. The solution must lie in setting iAOOS into the context of the much longer-term research efforts that are currently getting underway in the Arctic which share many of the goals of iAOOS; Figure 5 attempts to do so. Supplementing the existing full US Study of Environmental Arctic Change (SEARCH[916]; blue bar) with a correspondingly large and complete major international effort (yellow bar), the new International Study of Arctic Change ISAC[620], led by Leif Anderson of Goteborg University, will coordinate a multi-decadal and multi-disciplinary pan-Arctic effort to understand, explain and identify the socio-economic impacts of change at high northern latitudes; ISAC will be organised under the aegis of the non-governmental Arctic Ocean Sciences Board (AOSB) and International Arctic Science Committee (IASC). ArcticNet will have similar stamina in the Canadian Arctic[673], and it is possible -----even likely----that other large component parts of iAOOS such as DAMOCLES will develop a 'legacy phase' of their own in due course. Further details of the AOSB-CliC

Plan for the IPY can be accessed at http://asof.npolar.no, while the corresponding Plan for the Southern Ocean by Steve Rintoul of CSIRO Marine Laboratories, Hobart, Tasmania is at http://clivar.org/organisation/southern/documents/SOIPY.pdf .

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Table of the Expressions of Intent that are identified as important or relevant components of iAOOS.

IPY#	Title	Lead Contact
18	Synoptic Pan-Arctic Climate and Environment Study	Ursula Schauer
20	Polar Ocean Gateways: The keys to understanding long-term global change	Karsten Gohl
35	Long term variability of the hydrographic structure, convection and transports in the Greenland Sea	Gereon Budéus
42	The West Spitsbergen Current dynamics – in situ observations versus numerical modelling.	Jan Piechura
45	Synoptic transects of trace elements and their isotopes in the Arctic Ocean. A contribution to the international GEOTRACES program	Michiel Rutgers van der Loeff
51	Bipolar Atlantic Thermohaline Circulation	Tor Gammelsrød
54	Mapping the present state and past history of the Arctic ice cover at critical locations by two international ice stations	Peter Wadhams
63	Ocean Exploration in Polar Regions	Jeremy Potter
67	The Arctic Regional Integrated Monitoring System.	Charles Vorosmarty
86	Detecting Oceanic Changes through Arctic Sea Ice Coring	Stephanie Pfirman
91	SEDARC: Arctic Gateways, high latitude thermohaline circulation, sediment transport pathways and ice sheet dynamics, Fram Strait (74ºN-85ºN)	John Howe
98	Alaska Ocean Observing System	Molly McCammon
114	Variability in Transport of Atlantic Water in the Norwegian Slope Current in Response to Wind: Teleconnections between the Atlantic and the Arctic.	Vigdis Tverberg
120	The Transpolar Drift system in the Arctic Ocean	Vladimir Pavlov
124	Multi-disciplinary environmental investigations in high-latitudinal regions of the Arctic on the basis of research drifting stations “North Pole” during the IPY 2007/2008.	Ivan Yevgenievich Frolov
129	CANADA #139:Enhanced Northern Environmental Observations for IPY	Barry Goodison
133	Climate of the Arctic and its role for Europe	Ola Johannessen
134	Improvement of Arctic regional climate models by coordinated model intercomparison and measurements	Klaus Dethloff
139	The International Arctic Buoy Programme: Expanding Arctic Observations for the International Polar Year	Ignatius Rigor
145	A study of the water mass transformation north of Svalbard	Detlef Quadfasel
157	Causes and Impacts of Recent Changes in the Pacific Arctic	John Calder
158	Impact of Aerosols on the Arctic Hydrological Cycle	Judith Curry
164	International Sea Ice Summer School 2007	Peter M Haugan
167	Local and long-range interactions of polar mesocyclones	Suzanne Gray
179	Arctic System Reanalysis	John Calder
185	Assessing, understanding, and conveying the state of the Arctic sea ice cover	Don Perovich
206	Atmospheric Data Assimilation and Targeting in Polar Regions at ECMWF	Philippe Bougeault
212	The Arctic Summer Cloud-Ocean Study	Michael/Caroline Tjernström/Leck
223	The response of the Arctic Ocean to increasing river discharges	Douglas Clark
241	Western Arctic Currents Measurements	Waldemar Walczowski
269	GEOTRACES: An international study of the biogeochemical cycles of trace elements in the Arctic and Southern Oceans	Robert Anderson
324	An Arctic Ocean Mobile Observatory (AOMO) and related Cyberinfrastructure	Max Coon
325	Maritime Arctic Radiation and Cloud Observations: POlynyas, Leads, and Over ice	Peter Minnett
329	Physical and ecological environment of the Arctic Ocean north of Greenland	Leif Toudal
343	Modes of Convection in the Greenland Sea	Peter Wadhams
350	Airborne Hydrographic Sampling of the Polar Oceans	James Morison
363	Assessment of the global change manifestation in the Arctic Ocean and sea ice	Ivan Frolov
367	Measuring the Pacific Input to the Arctic via the Bering Strait	Rebecca Woodgate
373	The New Polar Explorers of the 21st. Century: Autonomous Vehicles	James Maslanik
385	Transport pathways and circulation within the Canadian Basin of the Arctic Ocean.	Rebecca Woodgate
403	POLARSTERN expedition “Nordic margin” in the framework of the EU project HERMES “Hotspot Ecosystem Research on the Margins of European Seas”	Michael Klages
408	Experimental investigation of atmosphere-surface interaction in polar regions	Yuri Volkov
414	Hydrological cycle in Arctic Region	Tetsuo Ohata

421	International North Pole Drifting Station	Vladimir Gruzinov
436	North Pole Environmental Observatory	James Morison
485	Circulation and heat, salt, and oxygen budgets in the polar marginal sea-ice zone	Kevin Speer
501	Polar Hemispheric Acquisition of Remote Observations of the Environment by Satellites	Mark Drinkwater
522	Integrated ARCTIC OCEAN OBSERVING SYSTEM -2 "Shelf-Basin Exchanges (SBE)"	Jacqueline Grebmeier
537	Interaction of sea ice decline and upper ocean warming, and associated climatologic and ecological processes	Jinping Zhao
546	Arctic's role in climate change	Cecilie Mauritzen
562	A Nordic Land-Shelf-Basin Interaction Study along the Siberian Shelf Seas	Leif Anderson
566	Polar clouds and the ozone layer in changing climate.	Niels Larsen
578	AUV-based measurements and modelling of heat flux from Atlantic water in the Arctic Ocean	Timothy Boyd
590	Tidal Influences on Polar Processes (TIPP): Fieldwork, Theory, and Modeling	Laurence Padman
594	Capturing Large-Scale Change in the Arctic Ocean and Cryosphere from Aircraft	Vicki Childers
607	The State and Fate of the Polar Cryosphere	Jeffrey Key
618	Arctic Weather Extremes	Erik Kolstad
620	International Study of Arctic Change	Leif Anderson
644	CANADA #98: Variability and Change in the Canadian Cryosphere	Ross Brown
666	CANADA #79: Development of Ocean Modelling Capacity for Simulating the Canadian North, and Arctic-Atlantic Links	Paul Myers
673	CANADA #135:The Canadian Research Icebreaker Amundsen: opening the Canadian Arctic to international collaboration for the IPY and beyond	Louis Fortier
681	CANADA #91:The Canadian Arctic Margin Expedition	Eddy Carmack
682	CANADA #102: Freshwater Flux in the Canadian terrestrial and oceanic polar regions.	Simon Prinsenberg
687	CANADA #96: The Circumpolar Flaw Lead (CFL) system	David Barber
688	CANADA #92:Canada Ocean Monitoring Experiment	Eddy Carmack
691	CANADA #166:Ocean transports across 66N from satellite altimetry, numerical models and in-situ observations	Josef Cherniawsky
712	CANADA #126:Ocean Fluxes and Flows	R.W Macdonald
731	Complex Researches of the Environment Condition at the high latitudes of the Arctic ocean on the board "Academic Fedorov"	Ivan Frolov
757	Climatic Changes of Clouds and Main Atmospheric Parameters over Polar Regions	Irina Chernykh
770	Inter-Ocean Exchange	Sergey Gladyshev
804	Complex investigation of natural environmental conditions within the frames of the Joint Russian-American Long-term Census of the Arctic (RUSALCA).	Ivan Frolov
807	CANADA #211:The structure and evolution of the stratospheric polar vortices during IPY and its links to the troposphere	Norman McFarlane
811	Simulated IPYs: International Collaboration in Arctic Change Studies Based on Numerical Modeling	Andrey Proshutinsky
832	Pan-Arctic ocean circulation experiment	Koji Shimada
855	Sea Ice Mass Budget of the Arctic (as part of an international Arctic Ocean Observing System iAOOS)	Jennifer Hutchings
860	Comprehensive investigations of the Kara Sea in the interactions with adjacent regions of the Arctic - the coastal areas, the continental slope and the basin.	Sergey Pisarev
896	Frontal zones in the Barents Sea and adjacent waters	Oleg Titov
902	Biological fluxes and climate variability in the European Arctic Seas: local production vs. advective biomass	Paul Wassman
904	Measuring basinwide Arctic ice thickness by the use of air-dropped tiltmeter buoys	Peter Wadhams
905	An Array of Ice-Tethered Profilers to Observe the Arctic Ocean	John Toole
915	MOORING-BASED ARCTIC OCEAN OBSERVATIONAL SYSTEM	Igor Polyakov
916	Study of Environmental Arctic Change	Peter Schlosser
921	Sea Ice from Space for IPY	Harry Stern
932	Sea Ice Mounted Oceanographic Profiler	David Meldrum
940	Ocean Pressure in the Arctic Derived from Satellite Gravity Observations and In Situ Pressure Measurements	James Morison