GEOTRACES Arctic Cruise Planning Meeting
June 2009, Delmenhorst, Germany

Workshop Report

Written by workshop participants

Contents

General Introduction

GEOTRACES is an international research programme focused on understanding the cycling of trace elements and isotopes (TEIs) in the oceans. The *GEOTRACES science plan* was published in 2006 and can be downloaded, together with additional information about the programme, at http://www.geotraces.org.

The first GEOTRACES Scientific Steering Committee (SSC) meeting was held in December 2006 in San Francisco. At that meeting, the SSC decided to run four workshops during 2007 to advance the planning of implementation of the programme. One of these, held in Germany in September 2006, brought together modelers and observationalists with interests in ocean chemistry to discuss the role of ocean modeling within GEOTRACES. The other three workshops were designed to plan the ship tracks and justification for the ocean sections that will form the back-bone of GEOTRACES and focused on the Atlantic, Pacific and Indian ocean basins. Reports from these workshops are available from www.geotraces.org/ GEOTRACESPlanningWorkshops.html. When these workshops were organized, the International Polar Year (IPY) had started and several GEOTRACES expeditions were already underway. It was therefore decided to organize a similar workshop for the polar oceans after the completion of the IPY. Because the scheduling of Arctic expeditions was considered most urgent, a workshop was first held to discuss plans for the Arctic Ocean. This document reports discussion and recommendations arising at the Arctic cruise planning meeting, held in Delmenhorst, Germany in June 2009.

The meeting was divided into three sections. During the first day of the meeting reviews were presented of our present knowledge of water masses and tracer distributions in the Arctic Ocean. Results of recent expeditions and ship schedules for the near future were presented. In advocacy talks, the participants had an opportunity to present what they considered key scientific issues. All presentations are available on the GEOTRACES Web site. The participants then set out on Day 2 to formulate, in smaller groups, the key scientific questions to be answered. The meeting then reconvened to discuss these scientific issues. In the last part of the meeting, participants divided into a second set of breakout groups to sketch the optimal locations for future expeditions, justify these choices, and put them in the context of past and planned work. The reports of the breakout groups form the basis of this workshop report.

This report presents the opinions of participants at the workshop regarding the important processes for trace-element cycling in the Arctic Ocean, the regions in which these processes should be studied, and suggestions for appropriate ocean sections to sample these regions in an efficient manner. This report will be considered by the GEOTRACES SSC in November 2009 and will be included with the reports of the 2007 ocean basin workshops to draw a global map of proposed GEOTRACES ocean sections. It is also expected that material in this report will provide useful justification to those seeking funding for the planned research in the coming years.

Michiel Rutgers van der Loeff
Per Andersson
Kristin Orians
Hein de Baar
June 2009

Arctic Change and the significance of the IPY for the GEOTRACES program

The Arctic Ocean constitutes less than 3 % of the global ocean area and about 1% of the volume, but is truly unique in several ways. About 10% of the global river run-off is delivered to the Arctic Ocean and about 30% of the world's soil carbon is estimated to be stored in northern ecosystems within the Arctic catchment area. Effects due to a warming climate may have profound impact on the Arctic permafrost, resulting in increased export of organic carbon and sediments to the Arctic Ocean. Arctic shelves constitute about 25% of the global ocean shelf area and are among the shallowest in the world acting as an important regulator of the river export of organic carbon and TEI to the central Arctic Ocean.

During the IPY, which began in 2007 and officially ended in March 2009, the conditions in the Arctic Ocean were very different compared with most of the twentieth century, with record low summer ice extent in the Arctic Ocean during 2007. The rapid and extreme changes that now appear to be happening in the Arctic with less ice coverage during the summer and decreasing permafrost both on land and in shelf areas, such as the East Siberian Sea, are crucial indicators of changes in the Arctic ice-ocean-atmosphere system.

A goal of the IPY was to make major advances in polar knowledge and understanding and the GEOTRACES cruises carried out as part of the IPY have certainly contributed to that. But another major goal of IPY was to leave a legacy of many subprojects, including marine sciences, which will contribute offspring in the years to come (Fig. 1). The vast experience gained and the collaboration built during the IPY will thus be important in shaping future directions of tracer (GEOTRACES) studies in the Arctic.

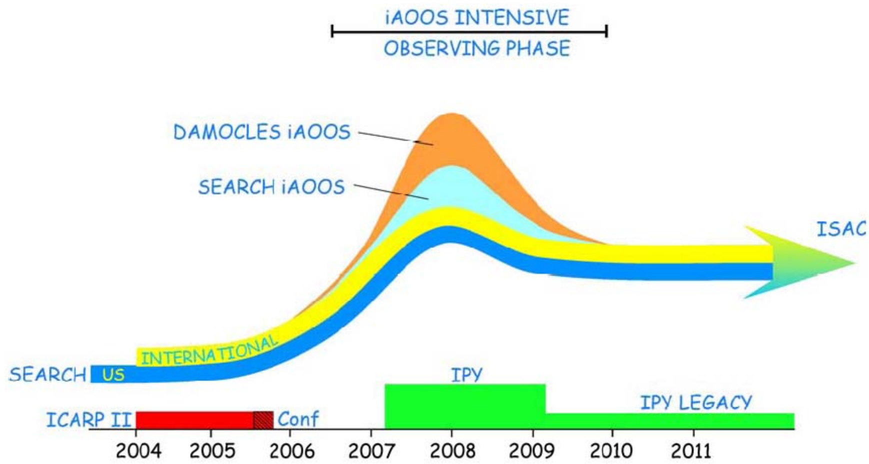


Fig. 1. The integrated Arctic Ocean Observing System (iAOOS) in relation to ICARP, IPY, and the multidecadal SEARCH and ISAC studies of Arctic change, showing the aim to leave a legacy of high observation activities after the intensive phase of the IPY.

Presentations

Introductory presentations

As introduction to the scientific questions to be addressed in future Arctic studies there were four presentations on Arctic hydrography and tracer chemistry

Ursula Schauer (Alfred-Wegener Institute for polar and marine research, Germany)
  Warming and freshening of the Arctic Ocean in the 2000s
Peter Schlosser (Lamont-Doherty Earth Observatory, USA)
  Circulation patterns, mean residence times and freshwater components in the Arctic Ocean
John Smith (Bedford Institute of Oceanography, Canada)
  Applications of Radionuclide Tracers to Process Studies in the Arctic Ocean
Leif Anderson (Dept of chemistry, Göteborg University, Sweden)
  The Arctic Ocean Carbon Cycle in a Changing Environment

Overview of past IPY expeditions

LOMROG Oden 2007	Leif Anderson
Polarstern 2007	Hein de Baar, Michiel vd Loeff
Hesperides 2007	Antonio Tovar Sanchez
Smirnitskyi 2008	Per Andersson

Other recent activities that were mentioned, but not discussed, were the Japanese expeditions with R/V *Mirai* and Chinese expeditions with the icebreaker *Xuelong*.

Cruise Planning and long term ship schedules

Canadian expedition 2009	Kristin Orians and Roger Francois
Russian ships of opportunities: 2009 and 2010	Igor Semiletov
Oden	Per Andersson
Polarstern	Michiel vd Loeff

Advocacy talks

Some participants used the opportunity to present some issues considered particularly important for future Arctic research:

Lars-Eric Heimbürger	Mercury in the Arctic
Ala Aldahan	Iodine as a geotracer
David Kadko	Be-7 measurements in the Arctic
Billy Moore	Marine Groundwater Discharge
Mark Baskaran	Interaction of ice-rafted sediments and surface seawater using short- & long-lived nuclide tracers
Bill Landing (poster)	Aerosol and Rainfall Sampling and Analysis for GEOTRACES

Note: most presentations are available on the GEOTRACES website

Breakout groups 1: Scientific Questions

In a first series of breakout groups we discussed the scientific questions to be addressed in the Arctic Ocean.

1.1 : Sea ice

Participants: Ana Aguilar-Islas (Chair) Patricia Camara Mor, Michiel van der Loeff, Christa Pohl, Mark Baskaran (Rapporteur)

Introduction

The areal extent of summer sea ice cover in the Arctic Ocean has decreased by more than 25% over the past three decades and yet, the role of sea ice in the biogeochemical cycling of TEIs remains poorly understood. Past major international geochemical research efforts (such as the Geochemical Sections (GEOSECS) project in the 1970s and the Joint Global Ocean Flux Study (JGOFS) in the 1980s and 1990s) were not conducted in the Arctic Ocean. Thus, the GEOTRACES program provides a unique opportunity to study sea ice and to establish baseline geochemical data for the rapidly changing Arctic Ocean.

Key Questions

A. Inputs of TEIs into sea ice

Sea ice can serve as a platform for retaining and transporting TEIs incorporated from various sources. Sources of TEIs to the sea ice include ice rafted sediment (IRS), wet and dry atmospheric deposition, as well as dissolved and suspended particulate constituents incorporated into brine channels during ice formation. The relative importance of these inputs for the different TEIs has not been quantified. Entrained sediment in sea ice is commonly observed in the Arctic Ocean. This sediment likely provides a dominant source of TEIs for ice formed over the Arctic shallow shelves. However, organic compounds within sea ice can act as ligands for TEIs, and might play an important role in the accumulation of sea ice TEIs at the ice-water interface. Additionally, radionuclides deposited from the atmosphere (e.g. ^{7}Be and ^{210}Pb) might serve as indicators of atmospheric input. Studies that address the mechanisms of incorporation of TEIs into sea ice are required. Examples include:

- Characterization of sea ice organic ligands
- Exchange of TEIs between surface seawater and sea ice
- Rates of dissolution of particulate TEIs in brine channels
- Effect of seasonality: Thawing and freezing cycles, biological activity, atmospheric deposition

B. Transport of TEIs by sea ice

The distribution of TEIs in the Arctic Ocean is affected by sea ice movement and processes (e.g. Darby, 2008; Pfirman *et al.*, 1997). It was shown earlier that the regions with the highest dissolved Al, Fe and ^{232}Th values appear to coincide in many cases with the presence of high concentrations of ice-rafted sediments (Measures, 1999; Trimble *et al.*, 2004). Most of the sediments are usually incorporated in shallow water depths (particularly over the vast, shallow Siberian shelves) during episodes of frazil ice formation. These coastal sediments are derived from different source rocks bordering the coastal areas and the watersheds for the major arctic rivers and hence the isotopic composition of key tracers (such as ^{143}Nd/^{144}Nd and ^{87}Sr/^{86}Sr) of the weathered detrital material are likely different. Measurements of these nuclides in the coastal sediments and sea ice sediments will yield insight on the sediment source and the transport (Tütken *et al.*, 2002). The sea ice transport of key TEIs has not been constrained. To accomplish this, the residence times of TEIs in sea ice and the transport time scales must also be constrained. Further, inputs due to ice melting must be distinguished from other fresh water inputs. Stable oxygen isotope composition, nutrients and dissolved Ba concentrations of surface waters have been used as tracers to differentiate freshwater inputs in Arctic waters. Increased flux of particulate material to the water column could be expected as a result of increased ice melt. A change in quantity and quality of sedimentation flux has the potential to affect TEI scavenging towards the seafloor. Additionally, release of biologically required TEIs (such as Fe and Zn) during the melting of sea ice in seasonally ice-covered areas could potentially influence the spring bloom.

C. The role of sea ice algae in the biogeochemical cycling of TEIs in the surface waters

The organic carbon content of IRS ranges from <2 % up to 15%, and this large range is attributed to the presence of sea ice algae. Some of the exopolymeric substances released from sea ice algae could significantly affect the biogeochemical cycling of TEIs in the surface waters.

D. The role of sea ice in the cycling of TEIs in the Central Arctic Ocean

In view of the dramatic decrease in sea ice cover in the summer in the central Arctic Ocean the question arises what will happen to the primary productivity and export production. At present the export production in the central Arctic Ocean is very low and the community is highly regenerative (based on sediment trap, sedimentation rate and ^{234}Th/^{238}U disequilibrium data). Ice melt means more light to the water column but it is not clear whether nutrient supply is sufficient for additional export. How much additional nutrients can wind mixing bring to the surface water? Could the extent of regeneration (the export ratio) change?

Key TEIs for the Arctic Sea Ice Research:

In addition to the Key TEIs identified in the GEOTRACES Science Plan, the following TEIs also should be added to study the sea ice in the Arctic Ocean: Ba, REE, ^{234}Th, ^{228}Th, ^{210}Po, ^{210}Pb, ^{7}Be, ^{10}Be, ^{143}Nd/^{144}Nd, ^{87}Sr/^{86}Sr, ^{239}Pu/^{240}Pu and ^{18}O/^{16}O ratios.

1.2 Rivers and shelves

Participants: Don Porcelli, Billy Moore, Martin Frank (Rapporteur), Igor Semiletov, Jing Zhang and others.

Objective A. Riverine inputs to the Arctic

What are the fluxes and characteristics of TEIs to the margin of the Arctic Ocean, and how are these fluxes modified in estuaries that are located on the unique environment of the broad intermittently ice-covered shelves?

A dominant input of TEIs onto the shelves is from river water, which is strongly modified by estuarine processes. The resulting concentrations and isotopic compositions then provide fingerprints of waters moving into the ocean basin. To understand this, the fluxes of freshwater, organic matter, and nutrients, which affect estuarine processes, must also be constrained. Further, how can such inputs be distinguished from ice melting processes? Within estuaries, complex interactions due to a number of processes occur in the environment of strong salinity gradients, including removal of trace components onto particles and within flocculating materials, release of TEIs from underlying sediments due to weathering and redox reactions, biological activity, photochemical reactions, and exchange with underlying sediments. These influence the concentrations, speciation, and bioavailability of TEIs, as well as the isotopic characteristics of water mass tracers such as Nd. The water fluxes and concentrations of TEIs vary within rivers seasonally, and among rivers, and so studies focused on rivers are also required. Other efforts to accumulate discharge and major element data include the PARTNERS Programme, although there is little data available on TEIs.

Specific objectives include

- Seasonal collection and characterisation of river waters to obtain the fluxes during different shelf conditions and to obtain average annual fluxes.
- Collection and analysis of waters, suspended particles, and colloids across the salinity gradients and to the shelf edge for analysis of TEI concentrations and speciation, as well as nutrients, organic compounds that serve as ligands for TEIs, and markers of biological activity that affects TEI cycling.
- Collection and characterisation of underlying sediments using short cores to determine chemical processes occurring near the sediment-water interface.

Objective B. Groundwater inputs to the Arctic shelves

What is the importance of submarine groundwater discharge on the TEI distribution in the Arctic Ocean?

Groundwater discharges to coastal regions have been found to be important in various areas of the world. In the Arctic, groundwater flow is complicated by permafrost, which can restrict recharge on shore and discharge offshore, where submerged permafrost is present. Discharges may occur throughout the shelves, where components can interact in the shelf environment, as well as from the shelf slope into the open ocean. Groundwater discharges can be a major source of waters and TEIs onto shelf environments. In the Arctic, the flux of submarine groundwater has not been quantified. Short-lived Ra isotopes and Ba are indicators of groundwater discharge; in addition, areas of high methane fluxes in regions of underlying permafrost might serve as indicators of high flow through the underlying drowned permafrost on the shelves. In addition to TEIs, the fluxes of organic compounds, which may serve as metal ligands, and nutrients, which promote biological activity, should be targeted. Since groundwater discharge is expected to change considerably with the thawing of permafrost, the aim is to provide a baseline study in a changing environment. Specific objectives include:

- Sampling of waters across the shelves and onto the shelf slope, in particular submarine canyons associated with paleoriver channels. Analyses would include Ra and Ba as specific indicators of groundwater discharge. On-board measurements of methane can guide sampling locations.
- Sampling under winter conditions when river discharges are minimized and when groundwater inputs can be most clearly perceived in river plume areas.

Objective C. Shelf processes

What mechanisms control TEI characteristics on the shelves away from major estuaries?

The distinctly broad continental shelves of the Arctic provide extensive environments for modification of shelf waters, including waters entering the Arctic from the Pacific and Atlantic oceans. Several processes control TEI addition, removal, and bioavailability; for example, interaction with suspended sediments, porewater reactions, interactions with suspended biological material, association with colloids, and changes in speciation. In addition, changing sea ice cover affects the supply of freshwater, interactions with the atmosphere, biological activity, and wind-driven mixing.

An additional source of sediments and terrestrial organic matter is coastal erosion. The highest rates have included regions where permafrost outcrops, and so large amounts of organic material may be released. Specific objectives include

- Collection and analysis of waters, suspended particles, and colloids across the salinity gradients and to the shelf edge for analysis of TEI concentrations and speciation, as well as nutrients, organic compounds that serve as ligands for TEIs, and markers of biological activity that affects TEI cycling.

- Collection and characterisation of underlying sediments using short cores to determine chemical processes occurring near the sediment-water interface.
- Sampling during conditions of minimal ice cover, during highest biological productivity, and during winter conditions.

Objective D. Dense brine formation
What are the TEI characteristics of dense brines formed on the shelves that supply deep waters?

The highly modified TEI compositions from the shelves are transported from the shelves to the open ocean not only in surface waters that can be traced in the open ocean (see other section) but also into deep waters. This is a potentially important mechanism for controlling TEIs in the deep ocean. Such waters might be found in depressions along the shelf, descending the slope, or mixed into the deep waters at the foot of the slope. Specific objectives include

- Sampling of shelf brines where encountered on the shelf, or (less likely) descending along known regions of deep water formation.
- Sampling of deep ocean waters at the base of the slope in areas of deep water formation, and analysis not only of TEIs but also indicators of young waters, including CFCs.

1.3: Aerosols and atmospheric deposition

Participants: Antonio Tovar Sanchez (Chair and Rapporteur), Martin Frank, Marie Boyé, Angela Milne, Lars-Eric Heimbürger and David Kadko.

What is the importance of atmospheric deposition in the Arctic?

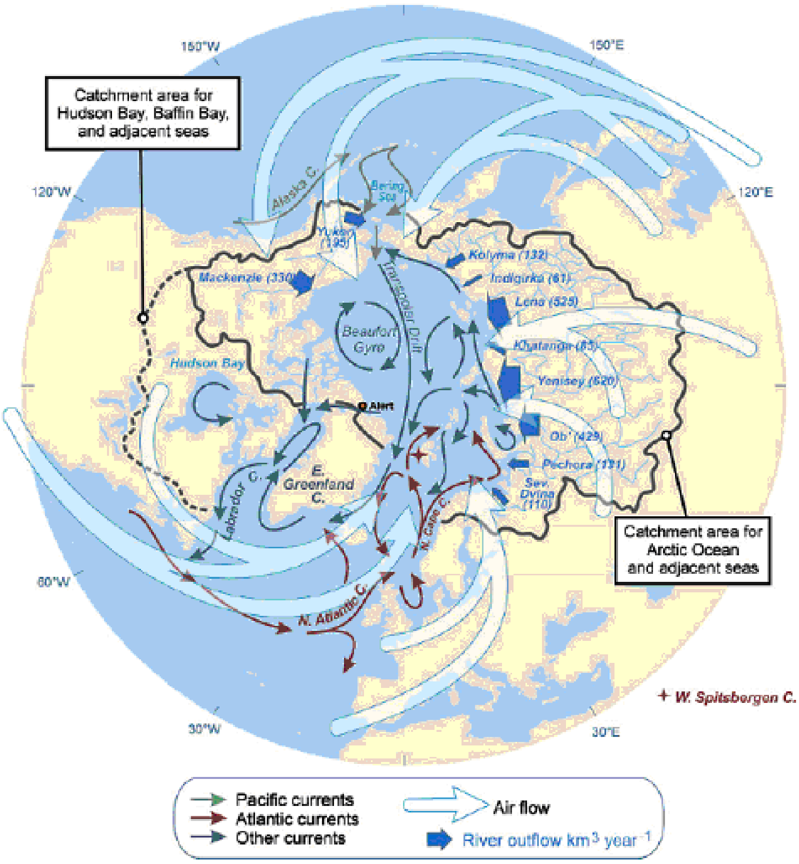


Fig. 2 Major physical transport pathways (wind, rivers and ocean currents) bringing contaminants into the Arctic Ocean (Macdonald *et al.*, 2005; Outridge *et al.*, 2008)

Key questions:

1. What is the seasonality and what are trends of atmospheric deposition?
2. What are the seasonal changes of the partitioning between the different compartments (i.e. atmosphere, surface water, snow, ice and biota) and also the subsequent effect on ocean chemistry and the ecosystem?
3. What are the geographical regions and sources (anthropogenic and natural) of atmospheric particles?
4. What is the effect of atmospheric deposition on the water column?

Strategies to tackle these questions:

1. To investigate the seasonal changes in atmospheric deposition:
    a. 2-3 years survey of atmospheric deposition (dry and wet) from land stations.
    b. Are there any trends (older measurements or time series)?
    c. AMDE (Atmospheric mercury depletion events) – rapid Hg deposition

2. Sampling simultaneously (i.e. same cruise) the partitioning into different environmental compartments (i.e. atmospheric deposition, surface water, snow, ice and biota).

3. Identify sources
   a. Trace element ratios (tracer examples)
   b. $^{7}Be/^{210}Pb$ of aerosols (terrestrial *vs* ocean)
   c. Pb isotopes as a tracer of origin

4. In order to study the effect on the biogeochemical process in the water column:
   a. Characterize size fractionation and quantify the leachable fraction of the different trace elements (bioavailability of key elements).
   b. Coordinated incubation experiments on board: Determine the response of primary production to ice and atmospheric deposition additions
   c. Sampling the surface microlayer as an air-water interface where transfers and exchanges of materials and gases occur.
   d. Development of tracers for transport and partitioning processes (e.g. ^{7}Be).

1.4 Exchange with Atlantic and Pacific

Participants: Leif Anderson, Per Andersson, Hein de Baar, Roger Francois (Rapporteur), Christa Pohl, Peter Schlosser, John Smith, and Jing Zhang

The same discussion group met twice to discuss (1) the Arctic throughflow from the Pacific to the Atlantic and (2) the Arctic "choke points". Here we report the overarching questions; in the chapter "breakout groups 2" we report the actual proposed sections with their justification.

The Arctic Ocean connects the Pacific and Atlantic oceans and, as such, plays a crucial role in global ocean circulation and climate. In particular, it is the main pathway whereby water vapor transported from the Atlantic to the Pacific by atmospheric circulation is returned to the Atlantic, potentially influencing the sites and rates of deep water formation in the North Atlantic and therefore the strength and climatic impact of the ocean thermohaline circulation. As Pacific waters transit through the Arctic, they are also chemically altered by biological processes, river input and interactions with continental shelves and sea ice. These processes impart unique geochemical fingerprints to Arctic waters that can be used to trace the impact of Arctic outflow on North Atlantic circulation and biogeochemical cycles.

The Arctic Ocean is unique in having only narrow connections (i.e. "choke points") with its neighboring ocean basins (Fig. 3). Shallow Pacific waters enter the Arctic Ocean through the Bering Strait while deeper Atlantic waters enter through Fram Strait and the Barents Sea shelf. Likewise, seawater exits the Arctic Ocean and enters the North Atlantic through Fram Strait and Davis Strait. It may therefore be relatively easy to establish a partial budget in the Arctic Ocean for most TEIs (i.e. input from the Pacific + input from the Atlantic – output to the Atlantic) which could inform us of the less easily quantifiable but potentially important terms of the Arctic's TEI budgets, that is, aeolian, river and groundwater input, shelf exchanges, and biological removal.

Constraining TEI budgets for the Arctic Ocean may not only elucidate processes affecting their cycling in the Arctic Ocean but could also have important implications for understanding the biogeochemical cycling of TEIs in the North Pacific and North Atlantic oceans. For that reason, it will be important to connect and coordinate the Arctic sections with those already planned for the Atlantic and Pacific oceans. For instance, it has been estimated that addition of nitrogen-depleted water from the Pacific to the Atlantic through the Canadian Archipelago may sustain a significant fraction of the relatively high rates of nitrogen fixation in the North Atlantic. River input and/or shelf interactions in the Arctic Ocean could likewise affect the input of important micronutrients from the Arctic and therefore influence ecosystem structure and productivity in the North Atlantic. We might also expect little scavenging of particle reactive elements, such as ^{230}Th and ^{231}Pa, under permanent ice cover, which could result in a net export of these TEIs from the Arctic to the North Atlantic. The ratio ^{231}Pa/^{230}Th measured in Atlantic sediments has been used to evaluate past changes in the rate of the Atlantic Meridional Overturning circulation. Input of these two nuclides from the Arctic modulated by sea ice extent could potentially affect the interpretation of this paleoceanographic tracer. The Arctic throughflow also connects water masses with the most extreme ε_{Nd}. The ε_{Nd} of North Pacific water is very radiogenic, reflecting Nd input from young volcanic rocks, while seawater in the North Atlantic have very negative values, reflecting input from old cratons (Andersson *et al.*, 2008; Porcelli *et al.*, 2009). The resulting systematic variations in the Nd isotopic ratio of seawater potentially provide a water mass tracer which is recorded in the authigenic phase of marine sediments for the reconstruction of paleocirculation. The mechanisms which impart different Nd isotopic signatures to seawater are not well understood, but seem to mainly involve river discharge and isotopic exchange with shelf sediments, two processes that can profoundly impact the chemistry to seawater in the Arctic Ocean. By following the evolution of the Nd isotopic composition of Pacific water from its point of origin, through the Arctic Ocean and to the Labrador and Nordic seas, we will be able to better document the role of these processes in imparting the isotopic signature of seawater and to better assess the limit to which ε_{Nd} can be considered a conservative tracer, a key assumption for its use as a water mass tracer in paleoceanography. These questions, among others, could be addressed by monitoring the flow of TEIs at the Arctic choke points and by following the evolution of the chemical and isotopic composition of the different water masses of the Arctic Ocean (Polar mixed layers, Pacific waters, Atlantic water, Polar Deep Water) as they enter in, transit through and exit from the Arctic Ocean.

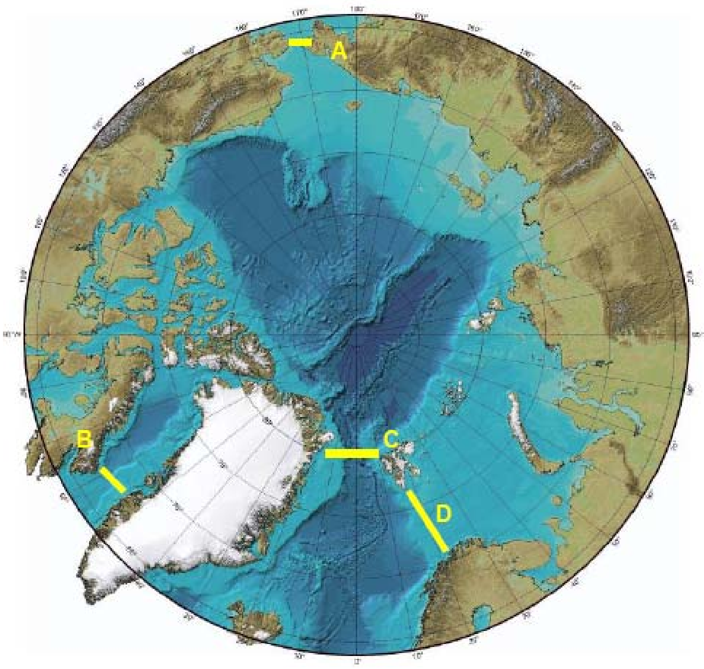


Fig. 3. Arctic "Choke Points": A = Bering Strait; B = Davis Strait; C = Fram Strait; D = Barents Sea Shelf

Breakout groups 2: Sections and Process Studies

In a second series of breakout groups we discussed the ideal locations of future process studies and sections in the Arctic, taking into consideration

- the scientific questions defined before (breakout groups 1)
- existing data of past programs
- motivation of the selected location
- preferences for timing or season
- possible links to ongoing projects

As an example of the availability of historic data, Figure 4 shows cruise tracks of a selection of expeditions and stations for which CFC/SF_6 data are available. (Tanhua *et al.*, 2009)

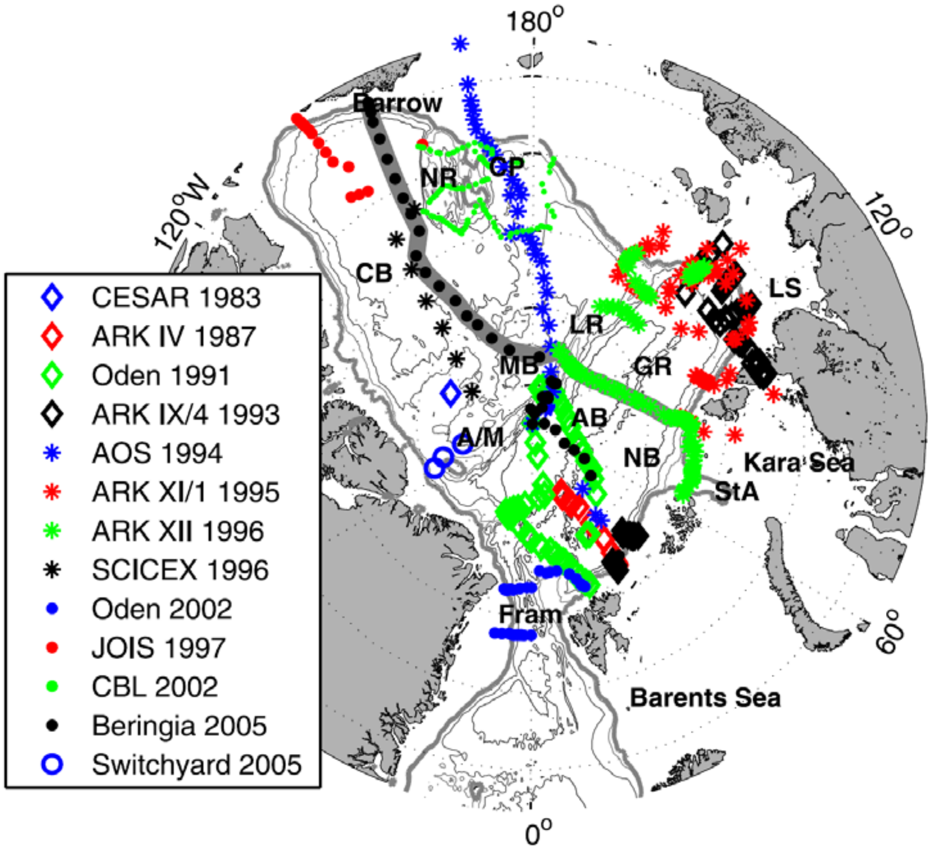


Fig. 4. Map of the Arctic Ocean with cruise tracks of earlier oceanographic expeditions. Here a selection of expeditions and stations for which CFC/SF_6 data are available. (Tanhua *et al.*, 2009).

2.1: Choke points and Nordic Seas

Participants: Leif Anderson, Per Andersson, Hein de Baar, Roger Francois (Rapporteur), Christa Pohl, Peter Schlosser, John Smith, and Jing Zhang

<u>Estimating the flux of TEIs through the Arctic Ocean "Choke Points"</u>

The task of establishing TEI budgets for the Arctic Ocean would be greatly facilitated by collaborating with existing programs which use instrumented moorings to monitor the variability in water, heat and salt transport at each of the "Choke Points" (Fig. 3).

For instance, the Bering Strait is only ~ 50 m deep and ~ 85 km wide. Bering Slope and Bering Shelf waters join the Alaska Coastal Current through this narrow passage to enter the Chukchi Sea and eventually the Arctic Ocean (Fig. 5). The Bering Strait throughflow has been monitored on the eastern side (U.S. EEZ) since 1990 and since 2004 a Russian-US team has deployed an array of 8 moorings to measure velocity, temperature and salinity across the entire strait (http://psc.apl.washington.edu/HLD/Bstrait/bstrait.html). Monitoring the concentration of TEIs on the same transect would provide a direct means of quantifying the input of TEIs to the Arctic from the Pacific.

A combination of moorings and seagliders (Fig. 6) is used across Davis Strait to monitor the integrated Canadian Archipelago throughflow modified by terrestrial inputs and oceanic processes during its southward transit through Baffin Bay (http://iop.apl.washington.edu/projects/ds/html/overview.html). One of the principal goals of this program is to estimate freshwater input into the Labrador Sea in relation to fluctuations in atmospheric circulation to better assess its impact on the formation of Labrador Seawater. Monitoring TEIs concentrations across the strait would provide quantitative information on one of the main outflows of TEIs from the Arctic into the Atlantic.

A similar mooring program across Fram Strait (http://arctic-roos.org/Members%20of%20AROOS/awi) complemented by annual cross sections (Fig. 7) monitors the inflow of Atlantic water into the Arctic and the return flow off Greenland. Collaboration with this program is also imperative to close the Arctic TEI budget.

The Barents Sea is another important pathway whereby Atlantic waters enter the Arctic Ocean. This inflow is also monitored by an array of moorings deployed between Norway and Bear Island (Fig. 8). At present the mooring program has funding until 2012. This mooring program is designed to capture the Atlantic inflow, the deep outflow in the Bear Island Trench, and most of the outflow on the slope south of Bear Island.

Finally, several programs investigate the transport between the Nordic Seas and the Atlantic:

a- Between Greenland and Iceland: Denmark Strait

At the Denmark Strait (DS) sill, moored ADCPs have been deployed since 1996 in the framework of the VEINS, ASOF-West, SFB460 (IfM Kiel), and THOR programs. Transport and bottom temperatures (since 1999) and salinity (since 2005) of the dense DSOW are monitored. At present, the array is maintained by IfM Hamburg (Contact: Detlef Quadfasel) and the Icelandic Marine Research Institute (Contact: Hedinn Valdimarsson, Reykjavik). Regular hydrographic transects across DS sill are made by the Marine Research Institute, Reykjavik (Contact: Hedinn Valdimarsson). About 600 km downstream of the DS sill, the Angmagssalik array, monitoring EGC and DSOW with current meters, is maintained by CEFAS, Lowestoft UK (Contact: Stephe Dye).

b- *Between Iceland and Norway:*

In 2005, a bottom-mounted ADCP was deployed at the Iceland-Faroe Ridge for IfM Hamburg southeast of Iceland (Contact: Detlef Quadfasel). The Faroe Bank Channel is continuously monitored since ~1995 by a single bottom-mounted ADCP of FRS, Thorshavn, Faroes (Contact: Bogi Hansen).

These hydrographic programs would provide the current velocity fields needed to estimate the importance of these pathways for the Arctic budget of TEIs. Considering the interannual variability observed in the physical data, it is clear that these relatively short cross sections will have to be repeated as often as possible to evaluate the interannual variability of the TEIs concentration fields.

Using the estimated fluxes of TEIs through the Arctic "Choke Points" to constrain the other terms of the Arctic TEI budgets

TEIs can be added into Arctic water by aeolian dust, run off, sea ice or remobilization from shelf sediments. On the other hand, they could be removed by biological uptake, scavenging or shelf interactions. Significant imbalances between TEIs input through the Bering Strait, Fram Strait and Barents Sea and output through Davis Strait and Fram Strait would indicate significant net addition or removal within the Arctic Ocean by either of these processes.

Pacific waters that enter the Arctic Ocean through the Bering Strait may have already been modified by processes in the Bering Sea (biological uptake, shelf interactions). Similar processes in the Chukchi Sea may also affect the TEI composition of Pacific waters before they enter the deep Arctic basins. The importance of these processes could be assessed by implementing two additional transects bordering the Bering and Chukchi shelves (Fig. 5). If significant changes in TEI concentrations are found between these transects, they should be complemented by process studies in the Bering and Chukchi Seas to identify the mechanisms producing the observed changes.

Atlantic water entering the Arctic Ocean through the Barents Sea may be similarly affected by processes occurring in the Barents and Kara Seas. In particular, the effect of shelf exchange and biological removal in the Barents and Kara Seas could be documented by measuring the concentration of TEIs along a transect between Svalbard and Severnaya Zemlya (Fig. 9).

The Nordic Seas

The Nordic Seas are a critical transition zone between the Arctic and Atlantic oceans and one of the main sites of deep water formation where freshwater input from the Arctic modulates the strength of the ocean meridional overturning circulation, with global climatic consequences. There is a clear need to examine seawater TEI concentrations in this region to develop paleoproxies documenting past changes in the site and rate of deep water formation and to document the geochemical processes which tag this important water mass end-member with its TEI signature.

The two transects across Fram Strait and the Barents Sea shelf described above will quantify the exchange of TEIs between the Arctic Ocean and the Nordic Seas. To fully document the TEIs' mass balance in the Nordic Seas, we should also measure the exchange rates of TEIs between the North Atlantic and the Nordic Seas (Fig. 10). This could be achieved by measuring TEI seawater concentrations across Denmark Strait and between Iceland and Norway in association with the mooring programs described above that would provide information on the flux of water and salt through these choke points. In the boundary region between the Nordic Seas and the Atlantic, a number of standard sections have been established (Fig. 11). On these sections, the hydrographic properties have been monitored for a long time by regular research vessel cruises and quasi-permanent mooring arrays have been established on some of the sections since the 1990ies. Based on these measurements, time series are generated for the properties and fluxes of all the three inflow branches of Atlantic water to the Nordic Seas. The standard sections also cover some, but not all, of the overflow branches of dense water back into the Atlantic. (Bogi Hansen, pers. comm.). Including measurement of TEIs on some of the regular cruises could allow estimates of import from the

Atlantic to the Nordic Seas and would give some information on export. Repeat stations in each of the basins of the Nordic Sea would also document changes in the TEI field in relation to variability in deep water convection and freshwater input from the Arctic Ocean.

<u>The Arctic Ocean "throughflow"</u>

In addition to the cross sections described above, which will effectively establish input/output of TEIs into and from the Arctic Ocean, we will still need sections passing through the choke points and crossing the Arctic Ocean to document the gradual evolution of water masses as they transit through the Arctic Ocean, in relation to river input, shelf interactions, sea ice cover and aerosols fluxes, thereby documenting the internal processes that control the Arctic TEI budgets. These cross sections should also be connected to the network of sections planned for the Pacific and Atlantic Oceans to create points of intersection between sections proposed by different countries which could be used for intercalibration among different national programs.

Transects documenting the non-conservative behavior of targeted TEIs in Pacific and Atlantic waters as they transit through the Arctic Ocean would be particularly informative. Pacific waters entering through the Bering Strait exit to the North Atlantic partly through the Canadian Archipelago and Davies Strait and partly through Fram Strait, in the East Greenland Current. Water flowing through the Canadian Archipelago has been shown to be mostly of Pacific origin. Building on the IPY program "Canada's Three Oceans (C3O)", the transect shown in Fig. 12 would fulfill the need to connect the Arctic GEOTRACES program to its Atlantic and Pacific counterparts and would document the effect of a wide range of processes (Fig. 13) on the TEI content of seawater. A transect along the East Greenland Current would connect the proposed TEI studies in Fram Strait and the Nansen/Amundsen Basin with the already scheduled sections in the North Atlantic along the pathway of NADW starting at Denmark Strait.

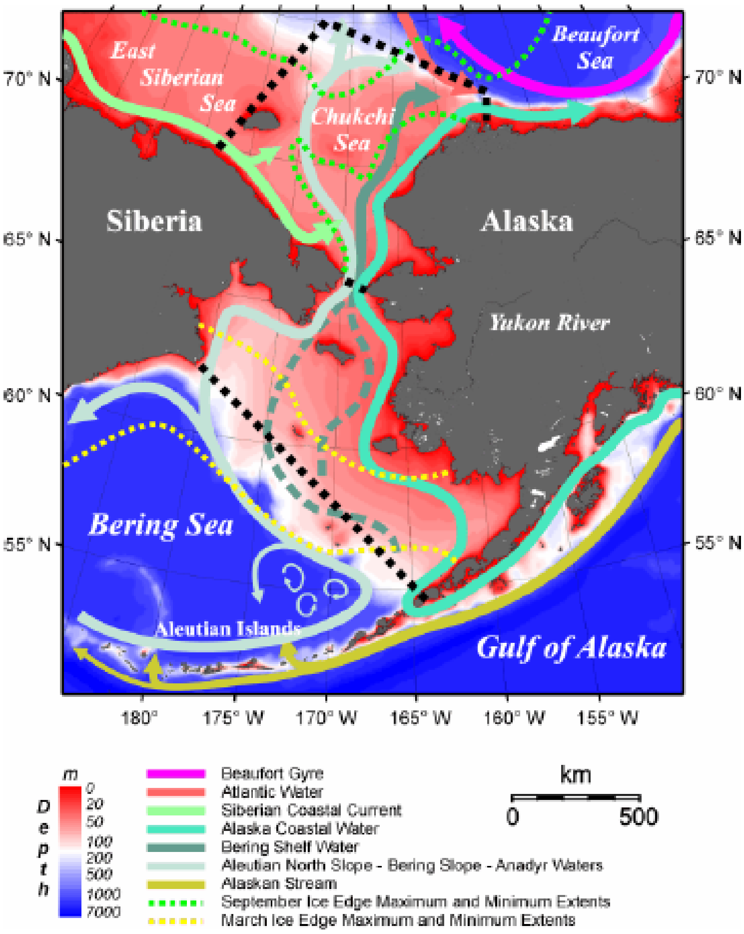


Fig. 5. Inflow of Pacific water through the Bering Strait. Black dotted lines are the proposed sections.

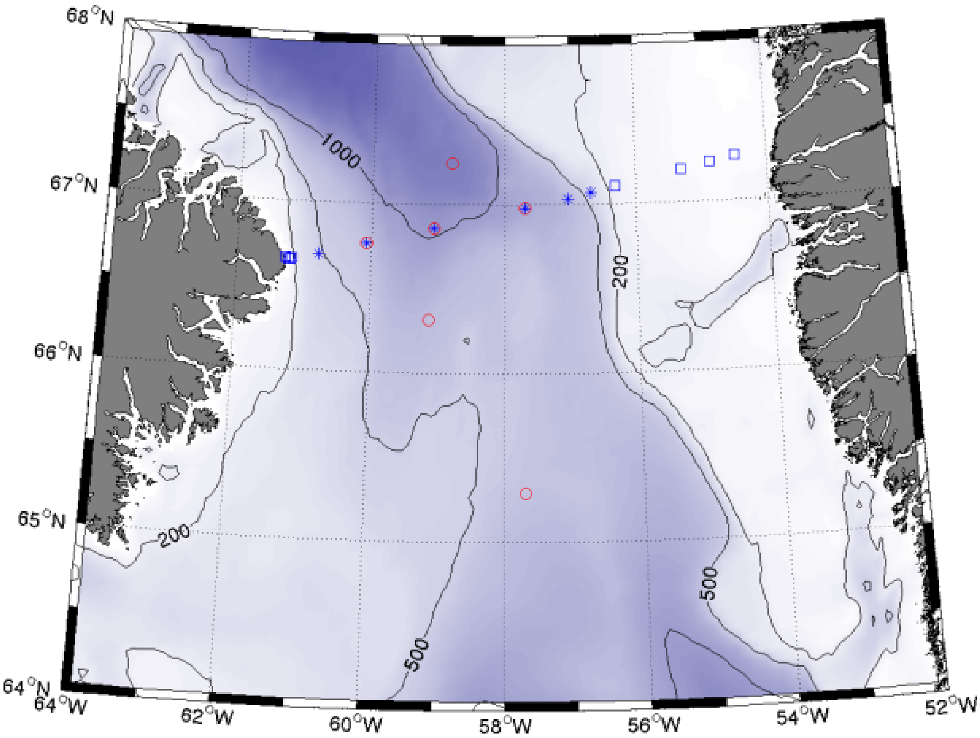
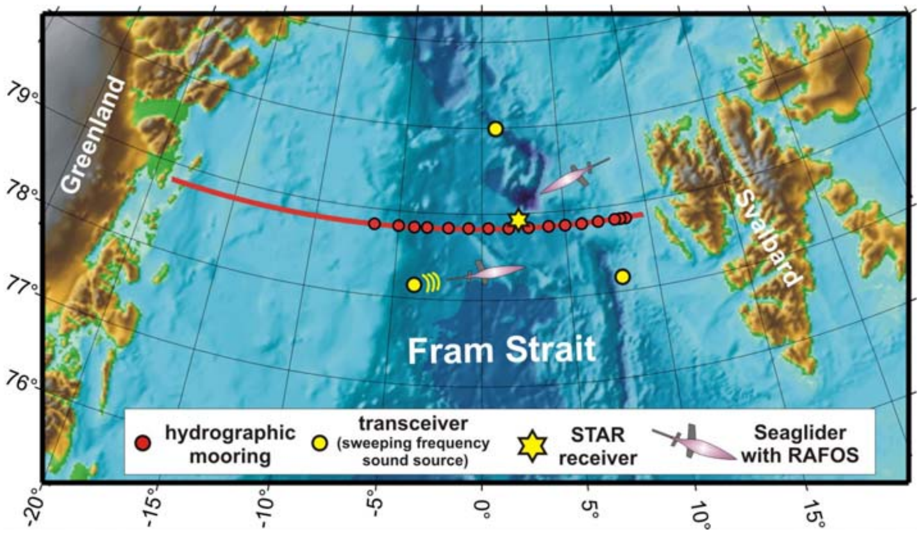


Fig. 6. Monitoring stations across Davis Strait (http://iop.apl.washington.edu/projects/ds/html/overview.html)



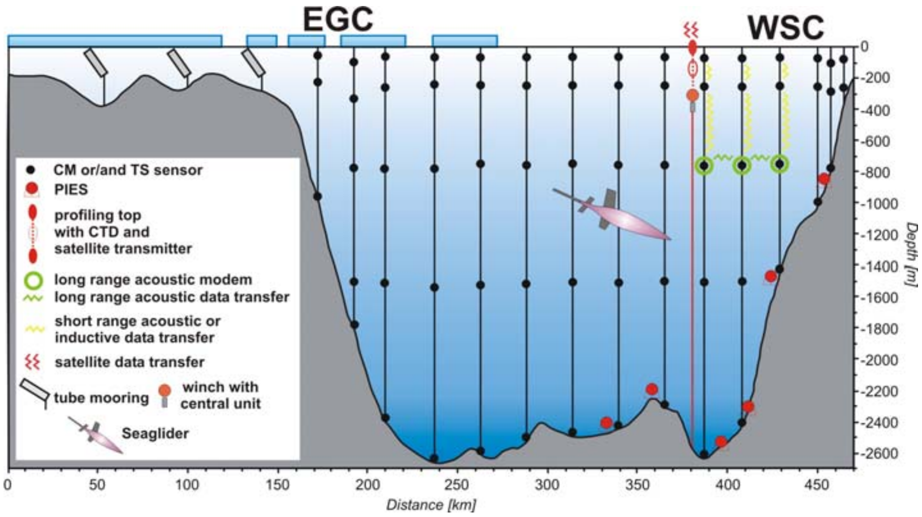


Fig.7. Moorings across Fram Strait (http://arctic-roos.org/Members%20of%20AROOS/awi)

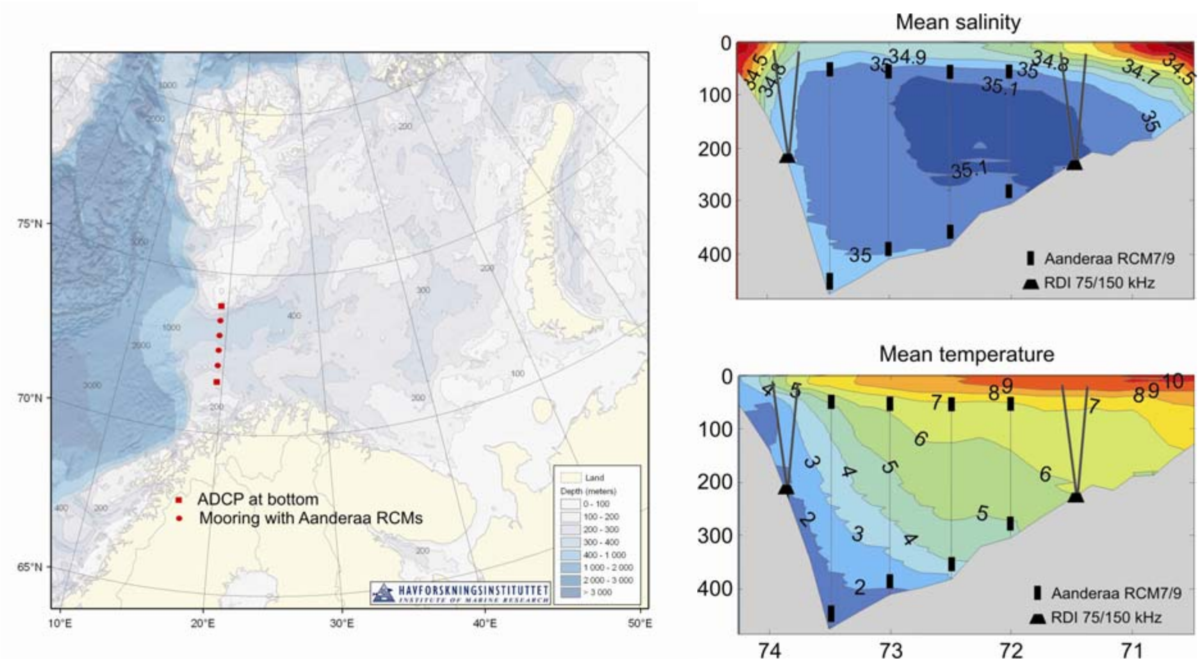


Fig. 8. Mooring array monitoring the inflow of Atlantic water into the Barents Sea (left). Mean salinity and temperature and mooring details for the period July 2008-July 2009 (right). Data obtained from Randi Ingvaldsen, Inst. Mar. Res. Norway.

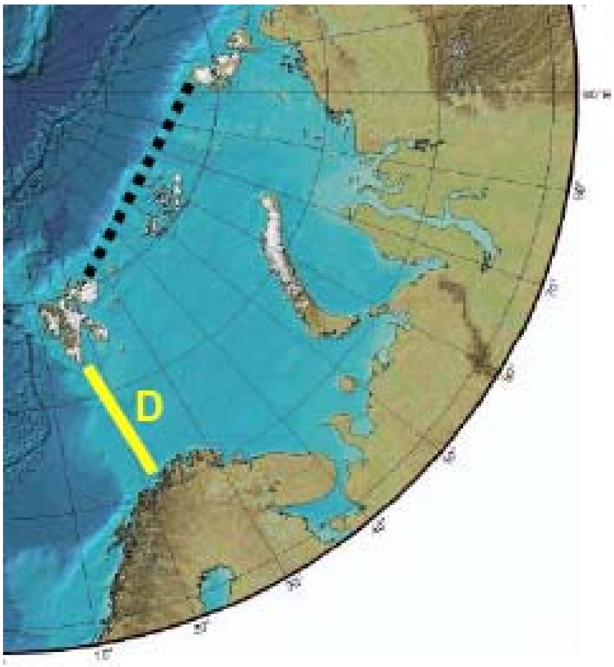


Fig. 9. Proposed transect to document TEI concentration changes in Atlantic water crossing the Barents Sea

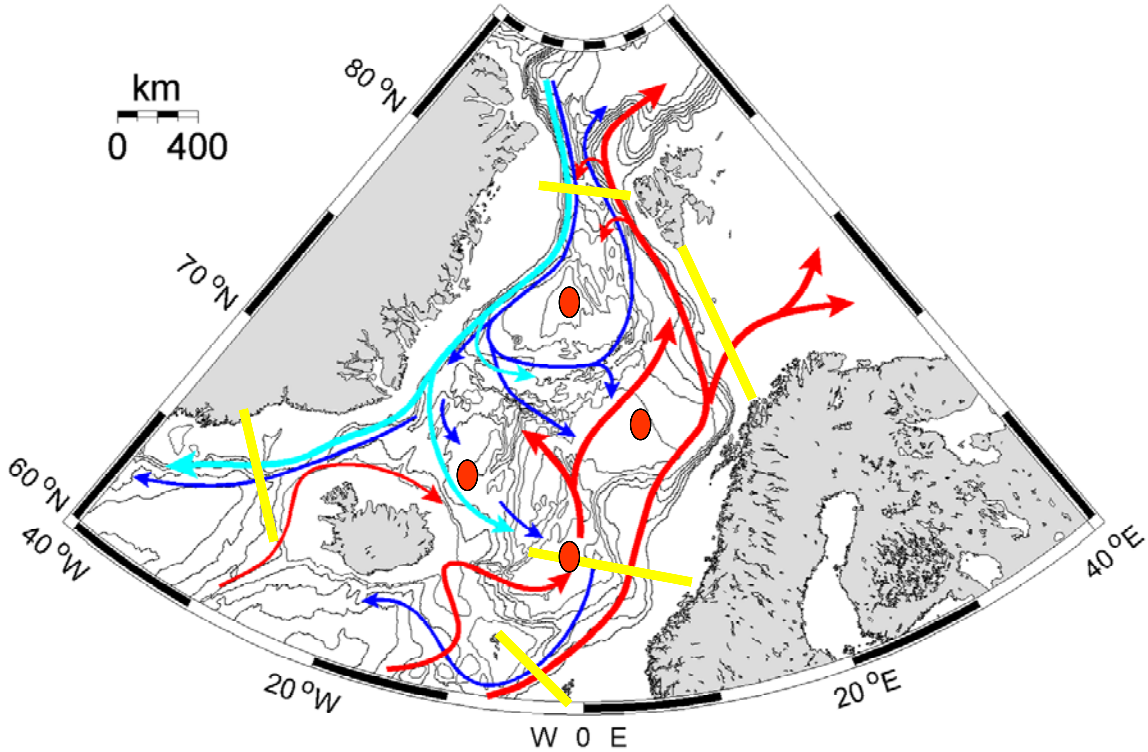


Fig. 10. Proposed transects and repeat stations in the Nordic Seas

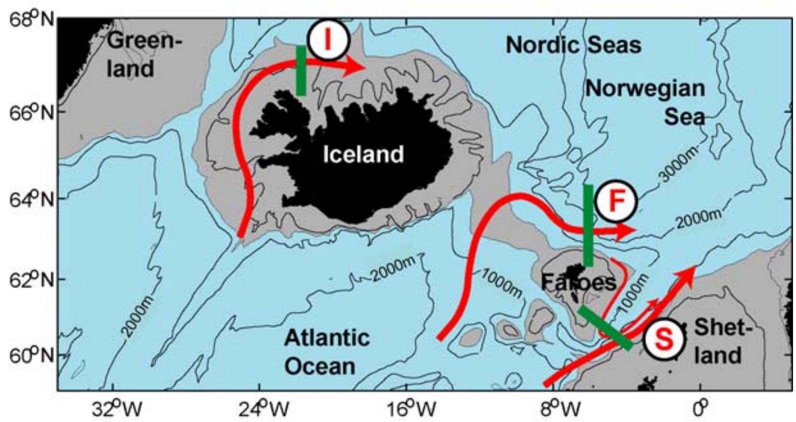


Fig. 11. On sections I, F, and S, the hydrographic properties have been monitored for a long time by regular research vessel cruises. Quasi-permanent mooring arrays have been established on some of the sections since the 1990ies.

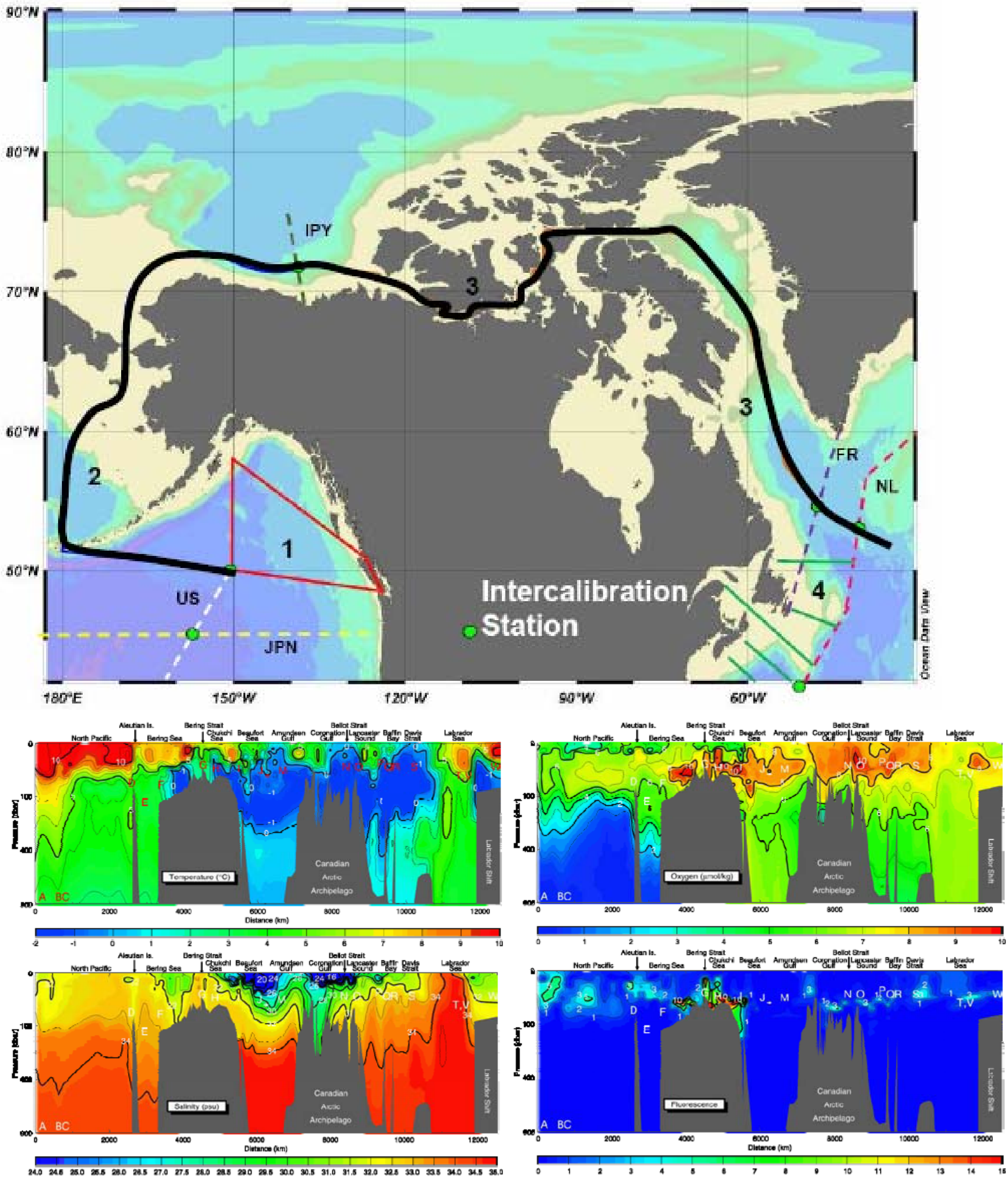


Fig. 12. Transect from the Pacific to the Atlantic through the Canadian Archipelago and hydrographic data obtained by the C3O program during IPY.

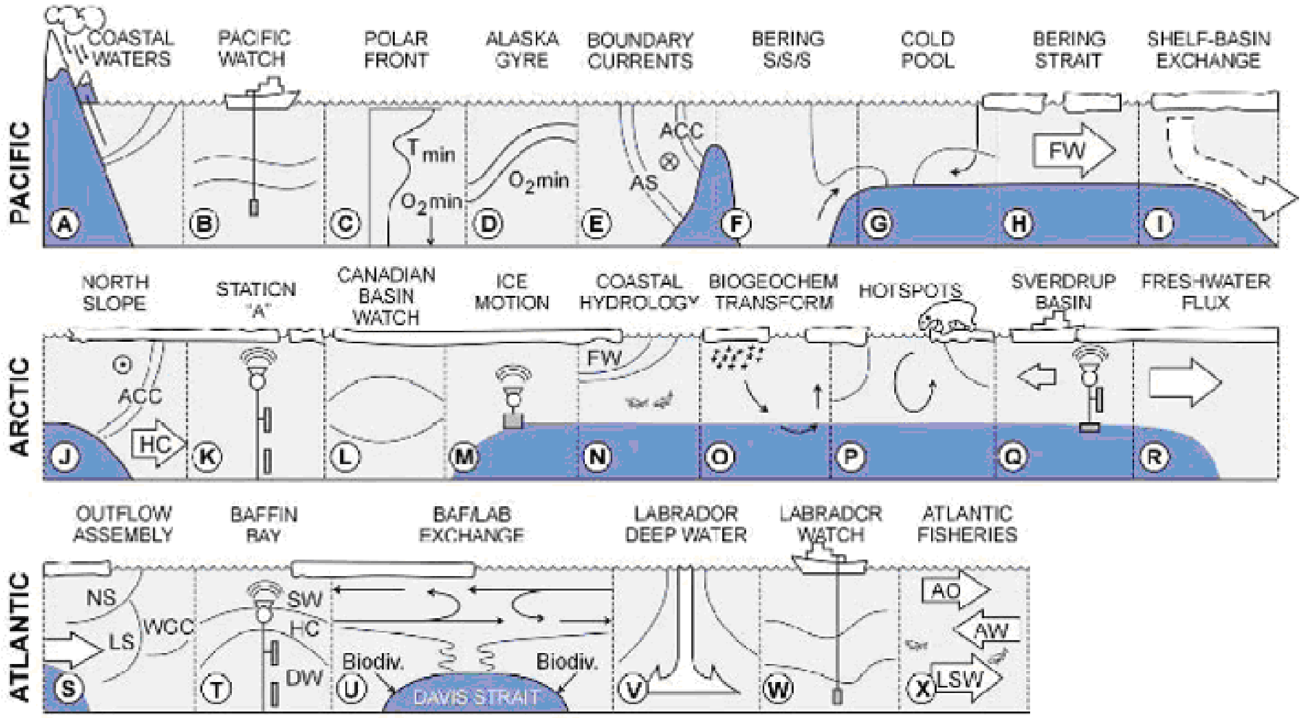


Fig. 13. *Cartoon showing regional benchmarks along the C3O transect from the Pacific to the Atlantic via the Arctic (Cartoon and description below are taken from Carmack et al., PICES_press; v16_n2; pp_22-25)* **A** identifies British Columbia coastal waters, an important habitat for Pacific salmon; **B** passes near Ocean Station "P", an icon of long-term time series; **C** crosses the Polar Front into **D**–the Gulf of Alaska gyre, characterized by a shallowing of the pycnocline, nutricline and hypoxic waters; **E** crosses the Alaskan Stream (AS) and Alaska Coastal Current (ACC), major freshwater (FW) transport corridors; **F** follows the flux of FW from the Pacific into the Bering Sea and the upwelling of nutrient-rich waters onto the slope and shelf; **G** crosses the Bering Sea shelf and near-bottom 'cold pool'; **H** is Bering Strait, the gateway of low-salinity Pacific water into the Arctic Ocean; **I** is the Chukchi Sea, a site for production of cold halocline waters (HC) that drain into the Arctic Ocean via Barrow Canyon; **J** is the Alaskan North Slope coastal current connecting U.S. and Canadian coastal ecosystems; **K** is Arctic Ocean Station "A", a times series maintained off and on since 1987; **L** is the Beaufort Gyre, the FW flywheel of the Arctic Ocean, in support of the Beaufort Gyre Exploration Project (BGEP); **M** denotes the ongoing monitoring of ice thickness and drift on the Canadian Beaufort Shelf; **N** is the coastal hydrology of the Canadian Beaufort Shelf and Arctic Archipelago, including lake and river characteristics; **O** represents physical and biogeochemical changes as ice and seawater (residence time ~ 5–10 years) transit the Canadian Arctic Archipelago; **P** represent various biological 'hotspots' *en route*, such as Bellot Strait, Gulf of Boothia and Barrow Strait, where physical processes produce and concentrate food for top predators; **Q** is the transit north across the poorly explored Sverdrup Basin; **R** is Arctic FW outflow through northern archipelago passages in support of CATS (Canadian Archipelago Through-flow Study) and ASOF (Arctic–Subarctic Ocean Fluxes) objectives; **S** is the "assembly" in northern Baffin Bay of Arctic outflow waters from Nares Strait (NS), Lancaster Sound (LS) and the West Greenland Current (WGC); **T** is Baffin Bay and its isolated deep water; **U** is Davis Strait and the bifurcations in the Baffin/Labrador and West Greenland currents, and the export of Arctic outflow waters; **V** is deep convection in the Labrador Sea; **W** passes near Ocean Station "B", another time-series icon; **X** represents the influence of arctic-derived waters on the physical habitat of the North Atlantic fisheries.

2.2: Rivers and shelves

Participants: Don Porcelli, Billy Moore, Martin Frank (Rapporteur), Igor Semiletov, Jing Zhang and others.

Sampling strategy for process studies and sections on riverine inputs and shelves

In order to cover the most important processes supplying TEIs from the Arctic rivers and those modifying and supplying TEIs on the shelves before they are transported into the open Arctic Ocean a strategy is proposed that includes investigations of two major rivers, the Mackenzie and the Lena. The main difference between the two rivers besides the difference in lithologies and the environmental setting in the hinterland is the width of the shelves, which will have different consequences for modification of TEI composition and distribution. Both river studies will, however, have to include a detailed investigation of the processes on the shelves away from the riverine inputs. Near the Lena delta this could happen near the coast in the western Laptev Sea, whereas the narrow shelf regime near the Mackenzie could be covered in the Amundsen Gulf.

Laptev Sea – Lena Delta (serving all mentioned objectives)

A transect from the Lena River mouth across the shelf break during **August/September** is proposed, which will allow the monitoring of the TEI supply of the Lena river and subsequent modification on the wide shelf (exchange, scavenging, redox-driven inputs, submarine groundwater discharge). This should include detailed sampling across the shelf edge down the slope including high-resolution bottom sampling to include dense brines if present. One option would then be to go east across the Lomonosov Ridge and back onto the shelf edge for some investigation of the transport of TEIs within the boundary current and the processes associated with the shelf edge.

Then one possibility would be to turn into the Indigirka Canyon, which is a location with a large potential for investigation of groundwater discharge, erosional inputs from the melting permafrost and dissociating gas hydrates, in addition to the Indigirka plume.

Further east the transport of TEIs and nutrients within the Lena plume could be followed along the east Siberian shelf to meet a cruise track across the Chuckchi Sea and Bering Strait including an investigation of the productivity, transport on the shelf, and the presence of remnant water bodies on the east Siberian Shelf.

All these activities can only be realized in close cooperation with and involvement of Russian partners and their local expertise and would build on established collaborations between, for example, Swedish or German groups and Russia.

These activities should be complemented by separate sampling expeditions of the Lena freshwater end member during the high discharge period (late **May/June**) and one during low discharge (most likely **April**, expedition on ice from Tiksi?). Any further samples of the river waters collected during other times of the season would be good.

This sampling could be combined with water sampling of the fresh riverwater end member of all other Siberian rivers (possibly linking with a program such as PARTNERS to get samples of different seasons from all the major rivers).

Laptev Sea shelf to be combined with the Lena delta study **(serving objectives B and C)**

The western Laptev Sea shelf near the coast is not strongly influenced by the Lena river discharge. Investigations would focus on shelf exchange and modifications of TEI distributions, including melting submarine permafrost underneath.

Other projects to potentially link with:
PARTNERS
SBI Shelf Basin Interaction Program
ISSS International Siberian Shelf Study
NABOS
NPEO
SHEBA

Mackenzie Delta (serving all mentioned objectives)
A section from the mouth of the Mackenzie River into the open Canadian Basin across the narrow shelf will be part of the Canadian Cruise in **September** 2009, which represents a low discharge period. An additional sampling expedition in **May/June** during the high discharge period should complement this effort.

One possibility for further activities would be to follow the Mackenzie plume westward in order to monitor modification of the TEIs (building on data of Canadian and U.S. studies). This could be linked/combined with a cruise going across the Bering Strait into the Canada Basin.

Further activities could include a study on the shelf in the vicinity of the **Amundsen Gulf**, which would represent a situation that is largely unaffected by the Mackenzie River plume and at the same time is a narrow shelf environment. Sampling areas should include the shelf and the continental slopes.

Other projects to potentially link with:
CASES
CFL Circumpolar Flaw Lead Study
Is there an ongoing program monitoring the Mackenzie to link to for sampling activities?
Further away in the North of Greenland: Switchyard program with limited capabilities for TEI sampling.

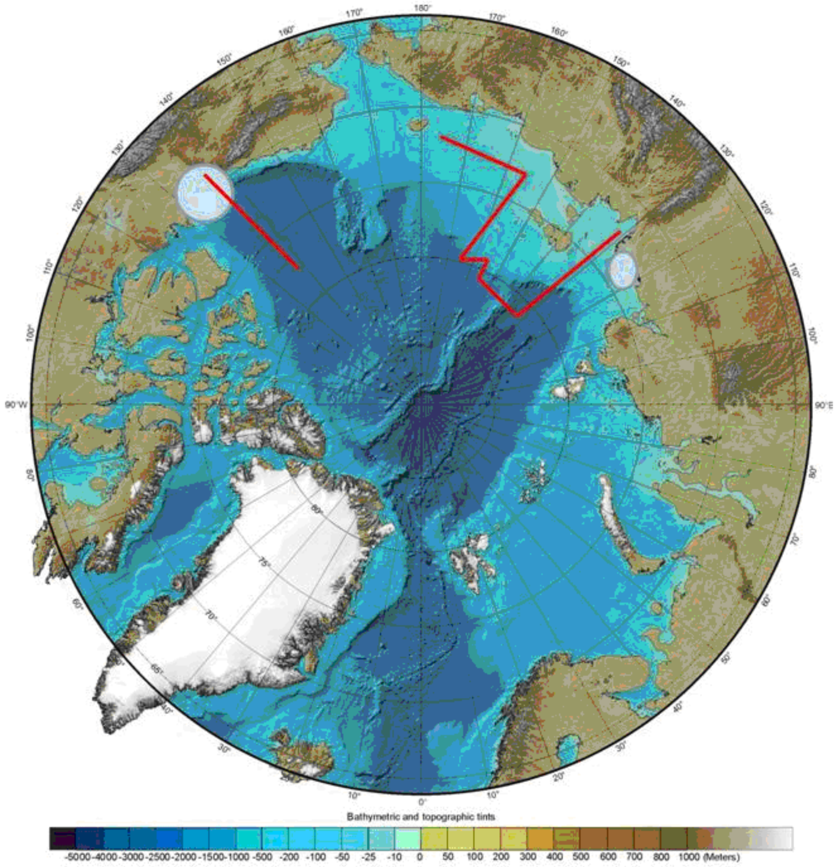


Fig.14. Proposed sections (red lines) and locations for process studies (light circles on Laptev and Mackenzie shelves) for studies of rivers and shelves. The zigzag on the edge of the Makarov Basin indicates study of shelf-edge processes and TEI transport in the boundary current.

2.3: Deep basins and hydrothermal input

Participants: Ana Aguilar-Islas (Rapporteur) Patricia Camara Mor, Michiel van der Loeff (chair), Christa Pohl, Lars-Eric Heimbürger, Mark Baskaran, Marie Boyé

2.3.1- Cross Basin

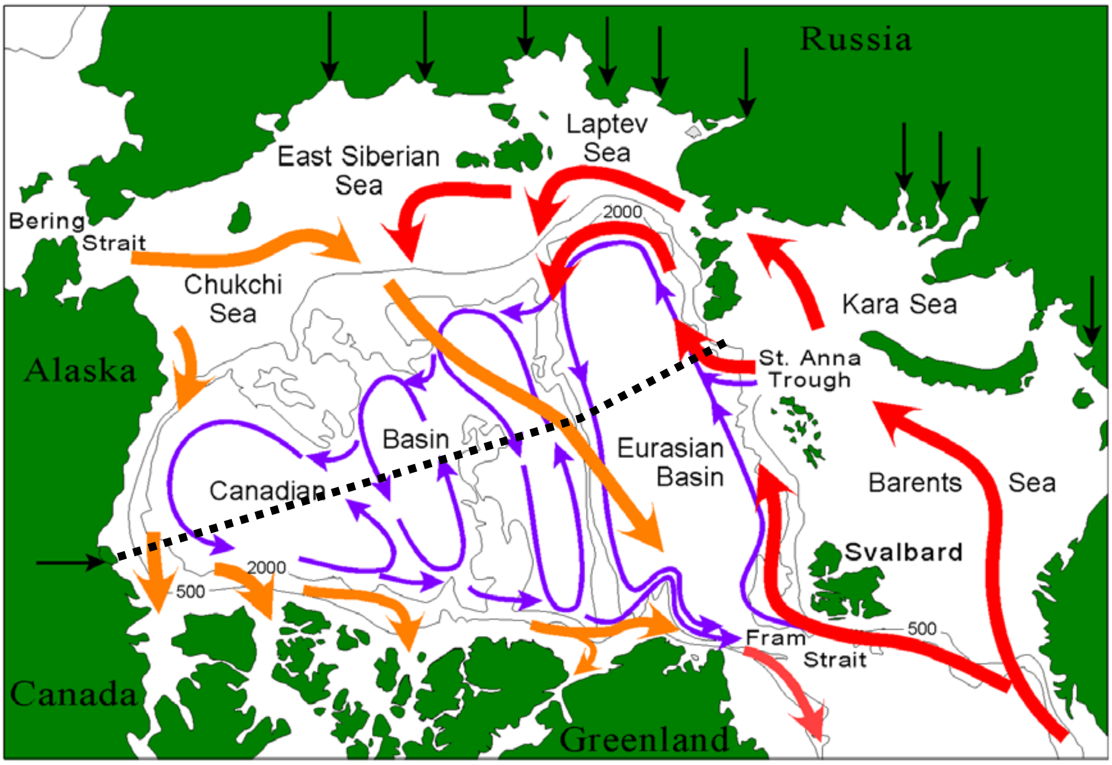


Fig.15. Schematic diagram of surface Atlantic (red), Pacific (orange) and deep water (blue) circulation after Rudels, Jones, Anderson, with suggested cruise track for cross basin section (broken line).

A long cross-basin transect should start in the Kara Sea, pass through the North Pole and end at the McKenzie River. Transecting through the North Pole is of interest in order to interface with the existing North Pole Station (Station A). The rationale for this transect is to increase our understanding of the behavior of the TEIs in the general circulation of the deep basins and to investigate the transition between Atlantic and Pacific water masses and the exchange between basins. Process stations and ice stations can be incorporated into this transect to investigate the role of sea ice in biogeochemical cycles, and the transport of TEIs by sea ice. This is the longest and presumably most expensive section and the logistics would be easiest during the summer.

Motivation.

- TEI transport in the transpolar drift
- Pass through center of the Beaufort Gyre (BG) (end member, with longest residence time, and also the oldest ice, important fresh water storage basin)
- Exchange between transpolar drift and BG
- Pass through North Pole Station A
- Atmospherically transported TEIs from different source regions
- Acquire new data on residence time of particles and deep water masses
- Address questions of boundary scavenging in the Arctic

Historic and existing programs:
This section will build on many earlier hydrographic expeditions to the various Arctic basins, on tracer data collected throughout the Arctic with submarines and on two previous full transarctic hydrographic and tracer sections: AOS 1994 and Beringia (Oden/Healy), 2005.

Existing programs to link with
NABOS
LOMROG
Japanese expeditions (?)
Korean expeditions (?)
Historical sampling at North Pole as basis for establishment of time-series station

2.3.2- Gakkel Ridge
Series of cross-sections over the Gakkel Ridge to investigate potential locations of hydrothermal plumes along the ridge. Sampling during these sections should concentrate on deep water. The time of year is not important, but summer might be best logistically.

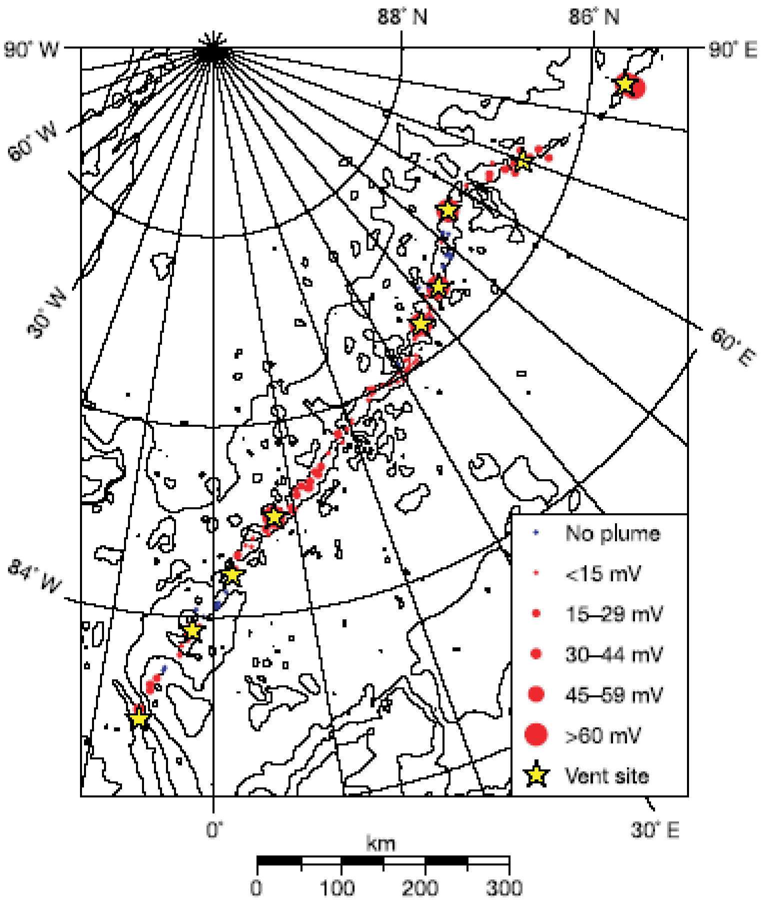


Fig. 16. Hydrothermal activity at Gakkel Ridge (Edmonds *et al.*, 2003)

Motivation

- The role of hydrothermal inputs on the budget of TEIs in deep waters
- TEI flux from a ridge with exceptionally low spreading rate

Ancillary Material
Hydrothermal activity at the Gakkel Ridge was described by Edmonds *et al*. (2003), and studied in more detail by the AGAVE expedition 2007 while in the same year Fe, Mn and temperature anomalies were also found during the Polarstern expedition ARK XXII/2 (Schauer, Klunder, Middag).

2.3.3- Lena to Deep Admundsen Basin
Cross-shelf transect starting at the Lena River Delta and ending in the deep Amundsen Basin.
Seasonality could be addressed by conducting this section in spring and summer.
This transect is the seaward extension of the transect suggested by the shelf/river group

Additional motivation:
- Crossing the boundary current near the Laptev Sea
- Exchange of TEIs from shelf to deep basin
- Transport of TEIs by sea ice
- Atmospheric transport of TEIs from different source regions

Links to previous and ongoing programs:
Historical data from many Russian, German/Russian and Swedish/Russian expeditions in this area. Ongoing programs are NABOS, ISSS.

Ancillary Material
For atmospheric transport see Fig.2.
For water circulation see Fig. 15.

2.3.4- East Siberian Shelf to Deep Makarov Basin
Cross-shelf transect starting at the East Siberian Shelf and ending in the deep Makarov Basin.
Seasonallity can also be addressed with this short transect. This transect can be linked with one proposed by shelf/river group.

Motivation
- Crossing the boundary current near the East Siberian Sea
- Transition zone between Atlantic/Pacific waters
- Beginning of transpolar drift
- Exchange of shelf with Makarov Basin
- Transport of TEIs by sea ice
- Atmospheric transport of TEIs from different source regions

Links to previous and ongoing programs:
In this region historical data are much more sparse, but the study should make use of data from further west (Laptev Sea) and east (Chukchi Sea)
Ongoing programs are NABOS, ISSS, BEST, SBI.

Ancillary Material
For atmospheric transport see Fig.2.
For water circulation see Fig. 15.

2.3.5- Deep Water formation
We know from TS and tracer distributions that occasionally brines produced on the shelves must make it to the deep sea. Actual cascading water masses have never been observed. Most promising are measurements of intermediate nepheloid layers and of chemical and physical

signals of the penetration of dense shelf waters. An example are the signals in Al, Si, and Ba observed during the *Polarstern* expedition 2007 in the deep Nansen and Makarov basins (Fig. 17), which may help to identify deep water renewal pathways.

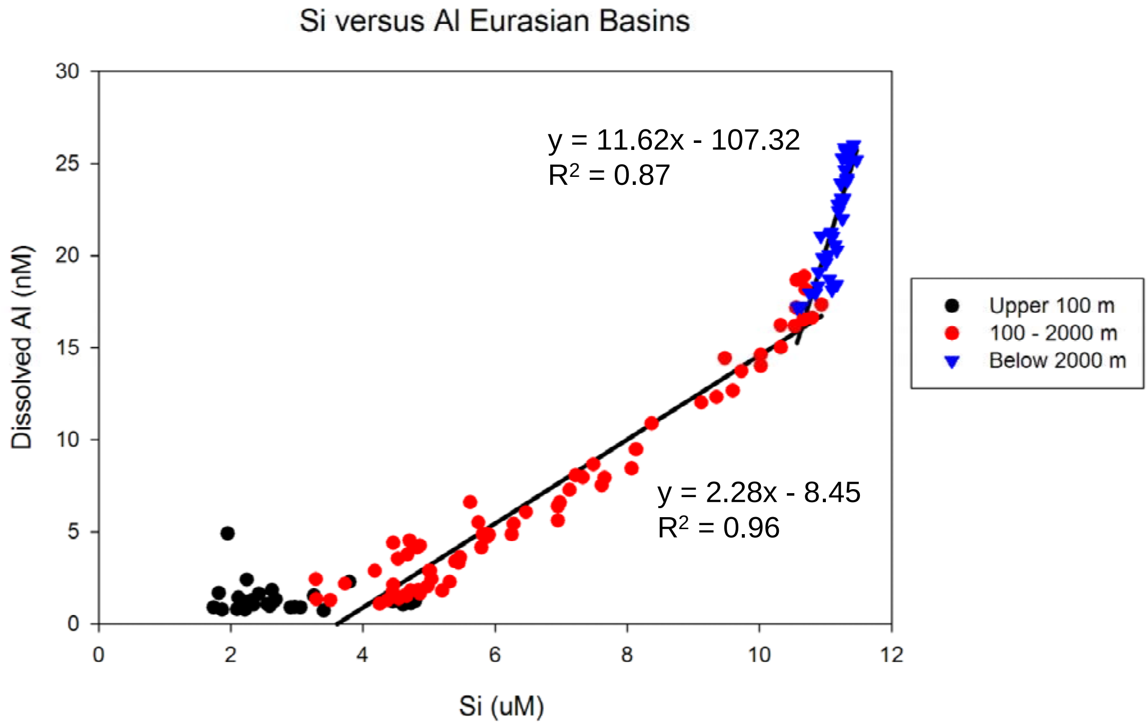


Fig. 17. The relationship between Al and Si in the deep Nansen Basin shows a deviation that may be related to shelf water input (Middag *et al*., *Mar. Chem.*, in press). A similar relationship was found for Ba and Si by Roeske *et al.* (in prep.).

Most promising area for cascading shelf waters is the St. Anna Trough. The sampling period for such a study should depend on the period of brine formation. If this study takes place during ice formation, it can be linked to process studies of the inclusion of TEIs into sea ice during its formation.
The process study could include shelf areas where dense brine is formed, such as Storfjorden on Svalbard (Schauer, 1995).
For studies on shelf processes sea also section 2.2. “Rivers and shelves”.

2.3.6- Sea Ice Processes

Location:
Offshore location off the Siberian shelf
One location for this study should be in an area where Atlantic and Pacific waters interact to allow the investigation of the effect of different N:P ratios on productivity when the ice melts.
The search for suitable samples of “dirty ice” and the deployment of short-time sediment traps under ice floes will require the use of helicopters.

Timing:
This study must include various stages of ice melt, primary production and export flux and must extend over the full Arctic summer.

Motivation

- The influence of the presence (or absence) of sea ice on primary productivity
- To use seasonality (or interannual variability) as a way to predict possible future changes due to climate change
- How changing areal ice cover will affect the input of atmospherically derived TEIs into the deep basins
- Partitioning of atmospherically derived TEIs into snow, sea ice, and water, and how this affects the distribution of surface TEIs and the ecosystem
- The effect of sea ice on the biogeochemical cycle of TEIs controlled by the carbon cycle… (or TEIs that control the carbon cycle)
- Incorporation and transport of TEI’s
- Release of sea ice TEIs by the melting of sea ice

Ancillary Material

Fig. 18. Left, a picture of *melosira arctica* with a diver to show the size. Melosira falls may be an important aspect of under-ice particle and elemental flux. Right, melting dirty ice, a major pathway of transport of terrigenous material towards the central Arctic.

Links to other programs

DAMOCLES
SBI
BEST
ISSS
NABOS

Synopsis and concluding remarks

In this workshop 35 scientists from 11 countries discussed the future strategy for sampling in the Arctic Ocean in the framework of the GEOTRACES program. In breakout groups we discussed themes that were considered most important for future studies. We formulated themes in four categories: Sea Ice, Rivers and Shelves, Aerosols and Atmospheric Deposition, and exchange with Atlantic and Pacific Ocean. In a second series of breakout groups we formulated suggestions for future cruises and process studies. In a final plenary session we agreed on the following summary map of recommended sections and process studies.

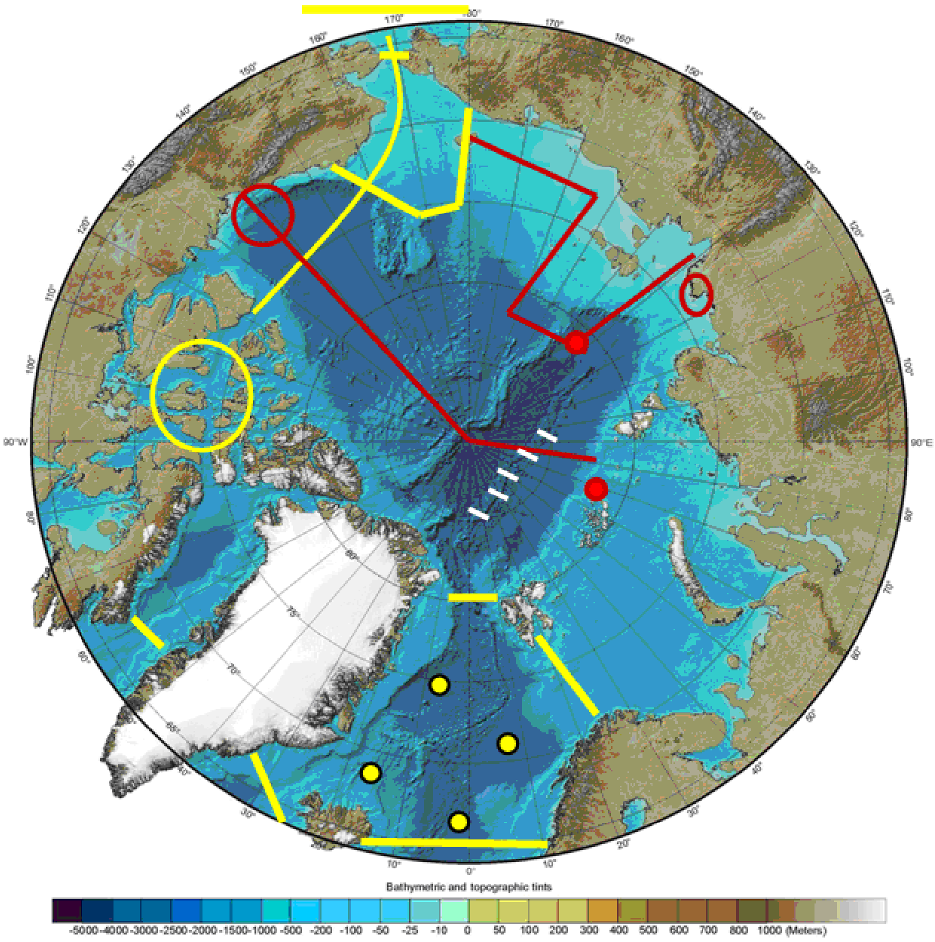


Fig. 19. Summary map of recommended sections and process studies. Yellow: sections and areas considered essential to define the TEI exchange between Arctic and adjacent ocean basins. Red lines and circles: regions for study of river and shelf processes and inputs, Red dots: process studies in the central Arctic (Role of ice cover on biogeochemical cycles) and St Anna Trough (deep water formation/cascading shelf waters). White bars: hydrothermal inputs at Gakkel Ridge.

We did not identify countries or persons to take the lead in expeditions to any of these favoured tracks and regions as we did not want to make claims at this stage. We wanted to encourage initiatives to propose and organise expeditions along the lines of our recommendations and with regard to the high costs do not expect that competition for cruise tracks in the Arctic will be an issue.
We expect that the map can be used as a basis for future cruise proposals for GEOTRACES expeditions

Acknowledgements
We thank Doris Meyerdiercks and Marion Wachholz-Logemann from the Hanse Wissenschaftskolleg for hosting the meeting. The meeting was supported financially by the European COST action ES0801, the Hanse Wissenschaftskolleg, US-GEOTRACES and the U.S. National Science Foundation grant to the Scientific Committee on Oceanic Research (SCOR).

Appendices

A1 - Workshop Announcement
A2 - List of participants
A3 - Workshop program
A4 – Programs and acronyms

A1 - Announcement GEOTRACES Arctic cruise planning workshop

December, 2008

Dear Colleague,

GEOTRACES will host a planning workshop to define the scientific objectives, and to develop a strategy to achieve those objectives, for the Arctic Ocean. The workshop will be held at the Hanse Institute for Advanced Study, Delmenhorst (near Bremen), Germany, on 8-10 June, 2009.

The goal of the workshop is to refine the scientific objectives developed in the GEOTRACES science plan (available from www.geotraces.org), and place those objectives into a framework of specific ocean sections and process studies. An important aspect of the workshop is to identify nations that are prepared to take the lead in carrying out specific cruises as elements of the broader basin-scale plan. Individuals who are prepared to organize research cruises and to secure funding to support those cruises are particularly encouraged to participate.

Workshops focusing on the Atlantic, Pacific and Indian basins were held in 2007. Reports are available from www.geotraces.org/GEOTRACESPlanningWorkshops.html. By then the international polar year (IPY) had started already and several expeditions with GEOTRACES programs were already underway. It was therefore decided to organize a similar workshop for the polar oceans after the completion of the IPY. We now plan to hold an Arctic GEOTRACES Workshop in Bremen in June 2009. The emphasis of this workshop will be on the planning of Arctic expeditions, but ideas on future expeditions in the Southern Ocean can also be discussed.

This workshop will produce a set of recommendations that will be used by the GEOTRACES Scientific Steering Committee, in conjunction with other input, to develop a coherent global plan for the GEOTRACES program.

The Scientific Committee on Oceanic Research can offer funds to assist with travel expenses of participants coming from developing nations. We also expect that the travel expenses of a fair number of participants from countries that have signed COST Action ES0801 ("The ocean chemistry of bioactive trace elements and paleoclimate proxies") and of a few participants from other countries can be covered from the COST Action.

If you wish to participate in the Arctic planning workshop or would like additional information about it, send an e-mail to mloeff@awi.de. If you wish to be kept informed about general GEOTRACES planning activities, then send an e-mail to geotraces@ldeo.columbia.edu indicating your interest.

Best wishes,
Michiel Rutgers van der Loeff, AWI, local organizer
Bob Anderson and Gideon Henderson, Co-chairs, GEOTRACES SSC

A2 - **List of participants**

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A3 – Workshop Program

GEOTRACES Arctic Cruise Planning Meeting
8 to 10 June 2009
HWK, Delmenhorst, Germany

7 June evening arrival of participants

8 June
08:45 registration
09:00 (5min) Welcome, schedule, practical details (Michiel vd Loeff + HWK)

Session chair: Roger Francois
09:05 (45min + 5min) plenary talk Ursula Schauer:
    Arctic Hydrography
09:55 (45min + 5min) plenary talk Peter Schlosser:
    Circulation patterns, mean residence times and freshwater components in the Arctic Ocean
10:45 (30min) Coffee

Session chair: Hein de Baar
11:15 (45min + 5min) plenary talk John Smith:
    Applications of Radionuclide Tracers to Process Studies in the Arctic Ocean
12:05 (45min + 5min) plenary talk Leif Anderson:
    The Arctic Ocean Carbon Cycle in a Changing Environment
13:00 Lunch

Session chair: Pere Masque
14:30 Roundup of Arctic IPY cruises

Oden 2007	Leif Anderson
Polarstern 2007	Hein de Baar, Michiel vd Loeff
Hesperides 2007	Antonio Tovar Sanchez
Smirnitsky 2008	Per Andersson

16:00 Coffee
16:30 long term ship schedules

Canadian expedition 2009	Kristin Orians and Roger Francois
Russian ships of opportunities: 2009 and 2010	Igor Semiletov
Oden, Polarstern, other ships?	

18:30 welcome drink
19:00 Dinner at HWK

9 June

Session chair: Don Porcelli and Martin Frank
08:30 Advocacy talks, including:

Lars-Eric Heimbürger:	Mercury in the Arctic
Ala Aldahan:	Cosmogenic isotopes
David Kadko	Be-7 measurements in the Arctic
Billy Moore	Marine Groundwater Discharge
Mark Baskaran	Sea Ice
Bill Landing	poster: Aerosols

10:15 Coffee
10:45 Breakout groups
Suggested themes:

sections:
- separate discussions for sections in the Eurasian and Canada basins
- sections through the Greenland-Norwegian Sea to connect to the Atlantic sections

pathways and process studies:
- the fate of river water and processes on the shelves
- hydrothermal inputs
- aerosols and atmospheric deposition
- ice rafted transport

12:30 Lunch
14:00 Breakout groups continued

Session chair: Per Andersson
15:00 Meet in plenary and present breakout groups results
15:30 Coffee
16:00 Plenary meeting continued
18:00 Taxi to hotel, possibility to spend evening in Bremen

10 June

08:30 Breakout groups start finalizing group reports
10:15 Coffee

Session chair: Michiel van der Loeff
10:45 Synthesis of the meeting, distribution of tasks and responsibilities for writing of meeting report
12:30 Lunch
Afternoon work on report and
Finalize report
15:30 Coffee
people start leaving late afternoon

A4 – Programs and acronyms

BEST	Bering Ecosystem Study Program
CASES	Canadian Arctic Shelf Exchange Study
CFL	Circumpolar Flaw Lead System Study
C3O	Canada's Three Oceans
DAMOCLES	Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies
ICARP	International Conference on Arctic Research Planning
IPY	International Polar Year
ISAC	International Study of Arctic Change
ISSS	International Siberian Shelf Study
LOMROG	Lomonosov Ridge Off Greenland
NABOS	Nansen and Amundsen Basin Observing System
NPEO	North Pole Environmental Observatory
PARTNERS	Pan-Arctic river transport of nutrients, organic matter, and suspended sediments
SBI	Shelf Basin Interaction
SEARCH	Study of Environmental Arctic Change
SHEBA	Surface Heat Budget of the Arctic Ocean

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