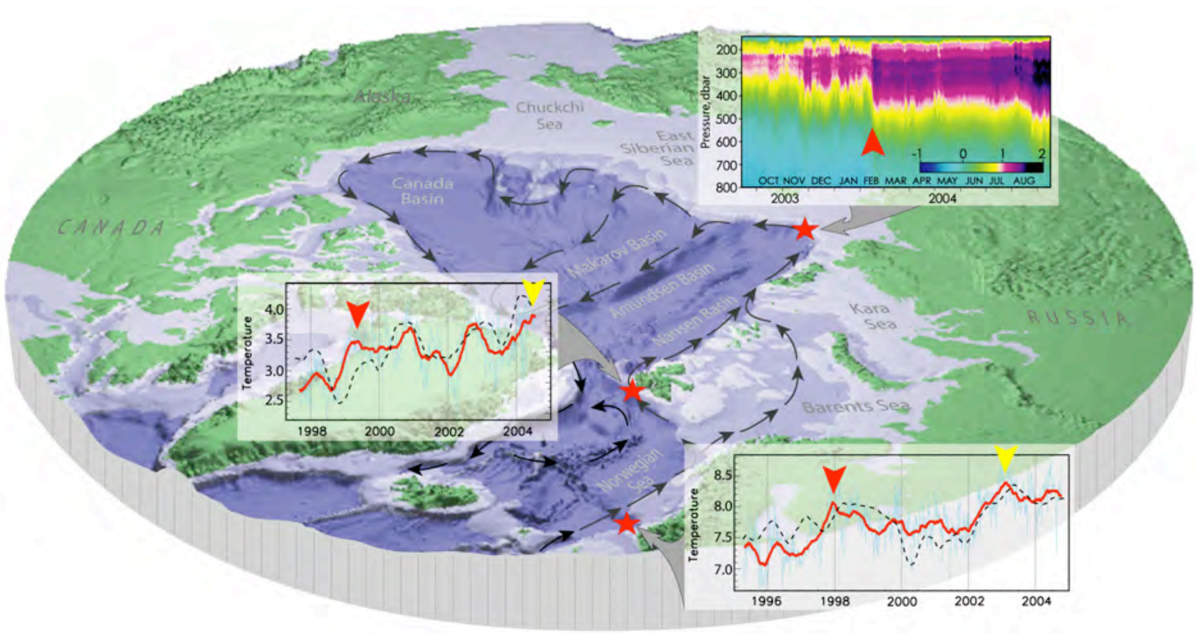
S4D-NABOS Workshop
“Near-slope observations in the Arctic Ocean”

March 6-7, 2009, Paris

R e p o r t



Organizers:

- International Arctic Research Center, University of Alaska Fairbanks, USA
- SEARCH for DAMOCLES (S4D), Europe & USA
- Arctic and Antarctic Research Institute, Russia

Report on the S4D-NABOS Workshop
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Preamble

This workshop was held to coordinate scientific activities and future field experiments (including coordination of plans for ships, manpower, scientific instrumentation, and targeted regions) in the near-slope area of the Arctic Ocean. This area is a critically important scientific and political route for developing an understanding of the Arctic that is so important to the global community. In this time of rapid environmental and political changes and global financial crisis, there are urgent needs to enhance international cooperation and foster synergy and interdisciplinary dialog. The meeting was sponsored by the International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF) and the S4D International Project. The workshop was held at the Pierre and Marie Curie University (PMCU), which provided excellent facilities.

The two-day meeting opened with welcome addresses by Dr. Jean-Claude Gascard (leader of DAMOCLES) and Dr. Igor Polyakov (leader of NABOS). Following these, the meeting consisted of lectures during the first day and the morning of the second day and a wrap-up session during the afternoon of the second day. It was broken up into three sessions dealing with a) the current state of Arctic Ocean research, b) research plans for 2009 and beyond, and c) a roundtable discussion on perspectives on coordinated research in the Arctic.

Current State of Arctic Ocean Research

Vladimir Ivanov and *Co-authors* presented preliminary scientific results from the NABOS-2008 cruise. Under severe conditions of the Arctic winter and polar night, the cruise program was successfully fulfilled. Five moorings were recovered and two new ones were deployed. New unique scientific data were collected along the Eurasian continental margin. Joint analysis of AWI mooring records in Fram Strait and NABOS data suggests that warming in the Atlantic Water (AW) layer in the Laptev and East Siberian seas will resume in 1–1.5 years. Strong seasonal variability in the AW layer evident from 2004–2007 NABOS data is confirmed by the newly obtained time series near Severnaya Zemlya.

Igor Polyakov and *Leonid Timokhov* presented the eight-year-long history of the NABOS project. Scientific results produced by the project were essential for understanding ongoing changes in high-latitude regions, particularly, reduction of arctic ice. Some of the important milestones of the observational program are the following. In 2003–04 NABOS observations captured the exceptional warming which entered the Eurasian Basin in 1999. Observations in 2007 documented strong warming of the very uppermost layer in the ice-free area of the eastern Eurasian and Makarov basins. The magnitude of this warming is unprecedented in the history of regional instrumental observations. The unique strength and spatial distribution of this warm surface anomaly suggest the important role of oceanic heat in shaping this summer's substantially reduced Arctic Ocean ice cover. Mooring-based NABOS observations were instrumental in detecting a strong seasonal signal in the Arctic Ocean interior. Oceanographic cross-sections were used to demonstrate propagation of the AW heat through halocline. NABOS has become an important element of the IPY by enhancing international cooperation, resulting in shared research infrastructure, updated databases, and fostering of synergy and interdisciplinary dialog. NABOS was instrumental in extensive biochemistry and turbulence observations carried out by our partners in previously inaccessible areas of the Arctic Ocean.

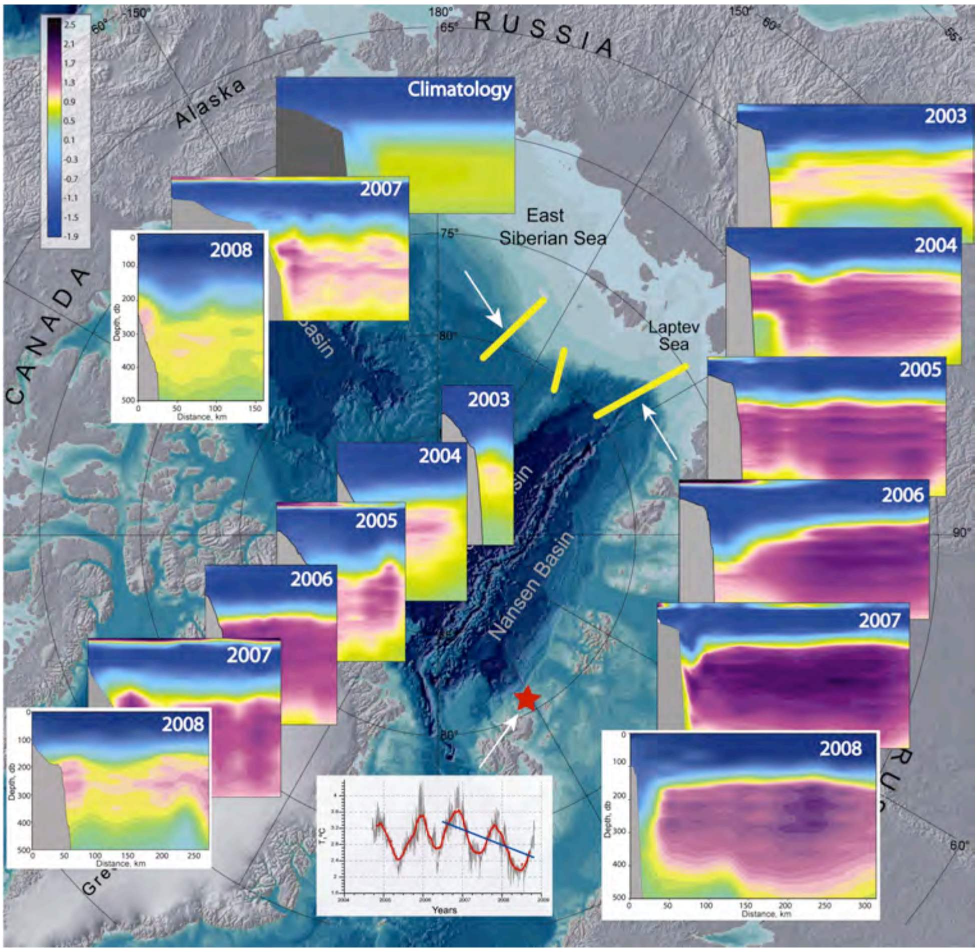


Figure IP1. Cross-sections of water temperature (o°C) measured during 2003–08 scientific cruises and mooring-based time series of water temperature (°C) from the vicinity of Svalbard. These observations provide evidence that the unprecedented warming of the Arctic Ocean observed in the 2000s is shifted toward its cooler phase in the Eurasian Basin.

Leonid Timokhov and *Co-authors* discussed temperature and salinity anomalies observed in the Arctic Ocean in summer 2007 and 2008 and factors that caused these anomalies. Various expeditions carried out during the International Polar Year provided invaluable information about unique arctic processes which shaped the Arctic Ocean state in summer 2007 and 2008. Anomalous atmospheric conditions caused warming and freshening of the upper Canadian Basin of the Arctic Ocean with temperature anomalies up to 3°C whereas temperatures in the Eurasian Basin were close to normal (Figure LT1) and salinities were somewhat higher. The Atlantic Water layer was warmer over the entire Arctic Ocean in 2007. However, in 2008, observations showed some cooling, but the temperatures were still higher than normal. The reason for these changes is hidden in the variable supply of Atlantic Water into the Arctic Ocean interior through Fram Strait.

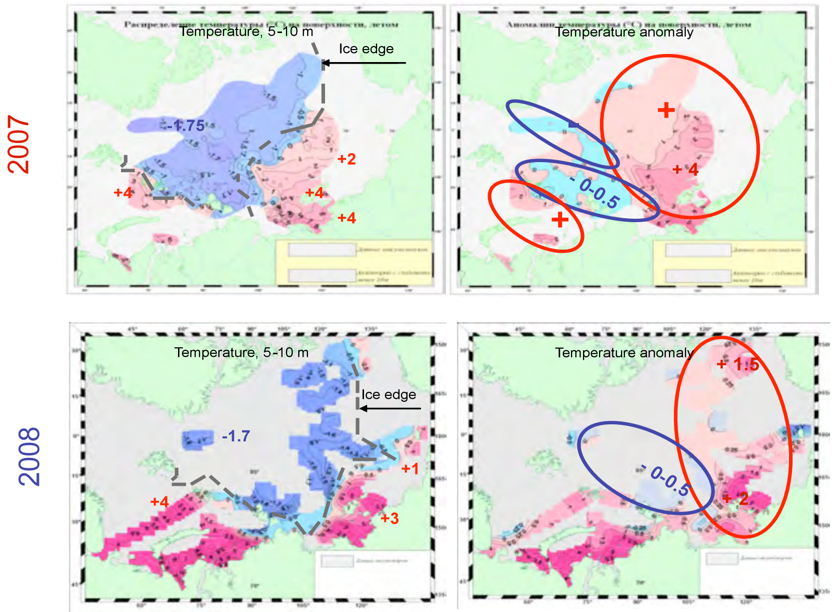
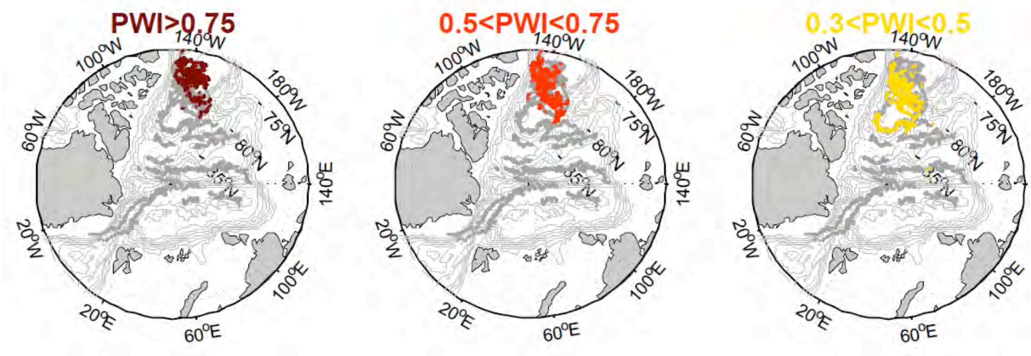


Figure LT1: Temperature (left) and temperature anomaly (right) of the surface layer (5–10 m) in summer 2007 and 2008.

Pascaline Bourgain, _Cecilie Mauritzen_ and _Jean-Claude Gascard_ presented PWI (Pacific Water Influence) and AWI (Atlantic Water Influence) indices which detect the presence and intensity of summer Pacific water and Atlantic water respectively. The PWI index is the difference between the shallow temperature maximum and the minimum of the two temperatures between the mixed layer bottom and the pressure level, deeper than the Pacific water core, where the potential temperature gradient reverses. The AWI index is the difference between the Atlantic water core potential temperature and the top of the thermocline potential temperature. The indices were applied to the ITP 2004–09 data. The indices were successful in mapping the extent and circulation of the two water masses in the central Arctic Ocean. The AWI index has been recognized to be missing Atlantic water processes with surface processes. The method will be refined; in particular, the AWI index will be modified in order to take into account only Atlantic water processes. The method will thereafter be applied to more data in order to investigate temporal evolution.



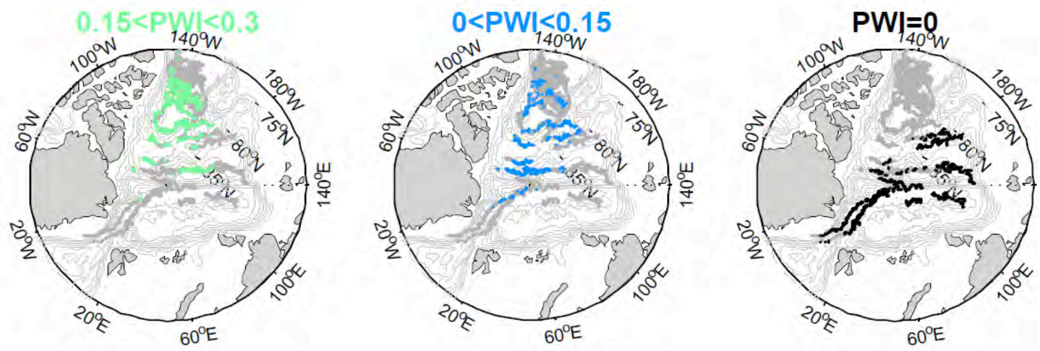


Figure PB: Spatial distribution of PWI index groups applied to ITP data (2004–2009). The higher the PWI, the more summer Pacific water.

<u>*Sergey Kirillov*</u> and <u>*Leonid Timokhov*</u> reported their analysis of intrusive thermohaline structures in Atlantic intermediate waters near the Severnaya Zemlya continental slope. The recorded thermohaline intrusive structures in the Atlantic Waters core (AWC) are the evident signature of the intensive lateral mixing over the continental slope northeast of Severnaya Zemlya. These structures have been traced over the entire water column and were the most developed over the depth range of 170–400m (Figure SK) in our one-year-long series of measurements. The upward heat fluxes due to the double-diffusive mixing in the upper thermocline intrusions were estimated to be within the range of 0.5–4.0 W/m^2 with moderate values from the beginning and more sizable values from the end of recording period. These rates are rather small to cool the AWC by ~2.0–3.0°C between Fram Strait and the Severnaya Zemlya region. Authors speculate that lateral heat exchange through interleaving is a more effective mechanism of the AWC ventilation than vertical heat flux.

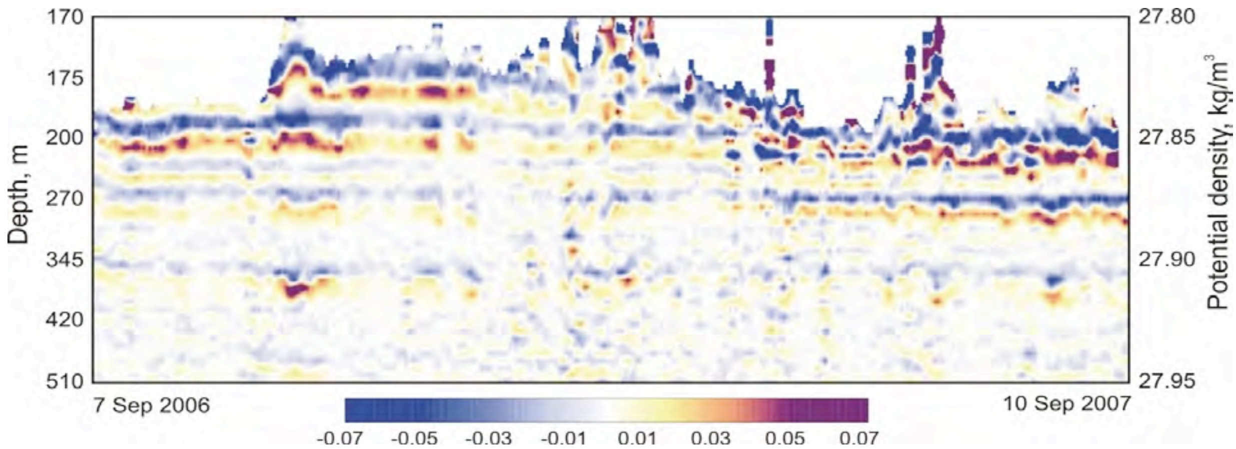


Figure SK. The evolution of the water temperature anomalies (°C, relative to the 20m mean) recorded by the MMP mooring profiler.

<u>*Sheldon Bacon*</u> presented an overview of the UK *Arctic Synoptic Basin-wide Oceanography* (ASBO) project, which is a UK Arctic-IPY consortium project funded by the UK Natural Environment Research Council. Its main aim is to contribute to the understanding of the Arctic Ocean and sea ice circulation, fluxes, and exchanges with surrounding oceans. The six consortium partners all have specific roles. These are: (i) University College London, responsible for sea ice remote sensing and modelling; (ii) the National Oceanography Centre, Southampton: providing chemical measurements (nutrients and dissolved oxygen) during the

fieldwork, and (physical oceanography) assembling an Arctic Ocean climatology and inverse models of the circulation; (iii) British Antarctic Survey: analysis of freshwater sources, and coordinating measurements of oxygen isotope anomaly ($\delta^{18}O$) and barium; (iv) Bangor University: marine turbulence measurement and analysis; (v) Reading University: running and analysing an Arctic Ocean assimilation model; and (vi) the Scottish Association for Marine Science: deploying ice-tethered ocean profilers with surface meteorology packages and ice mass balance sensors. Additionally we collaborate with the UK Hadley Centre, intending later in the project to compare Arctic Ocean circulation and fluxes as derived form inverse, assimilation and diagnostic modeling with Hadley climate model performance in the region. We contributed to the 2007 and 2008 field seasons through participation in the NABOS cruises in both years, and in the 2008 Beaufort Gyre expedition. Two papers derived from 2007 fieldwork results have already been published (Lenn et al., 2009; Abrahamsen et al., 2009).

Igor Dmitrenko and Co-authors analyzed observational mooring data collected at the northeastern Laptev Sea continental slope in 2004–2007 and documented a hydrographic seasonal signal in the intermediate Atlantic Water (AW) layer, with generally higher temperature and salinity from December-January to May-July and lower values from May-July to December-January. At the mooring position, this seasonal signal dominates, contributing up to 75% of the total variance. Our data suggest that the entire AW layer down to at least 840m is affected by seasonal cycling (Figure ID), although the strength of the seasonal signal in temperature and salinity reduces from 260 m (±0.25ºC and ±0.025 psu) to 840 m (±0.05ºC and ±0.005 psu). The seasonal velocity signal is substantially weaker, strongly masked by high-frequency variability, and lags the thermohaline cycle by 45–75 days. We hypothesize that our mooring record shows a time-history of the along-margin propagation of the AW seasonal signal carried downstream by the AW boundary current. Our analysis suggests that the seasonal signal in the Fram Strait Branch of AW (FSBW) at 260m is predominantly translated from Fram Strait, while the seasonality in the Barents Sea branch of AW (BSBW) domain (at 840m) is attributed instead to the seasonal signal input from the Barents Sea. However, the characteristic signature of the BSBW seasonal dynamics observed through the entire AW layer leads us to speculate that BSBW also plays a role in seasonally modifying the properties of the FSBW.

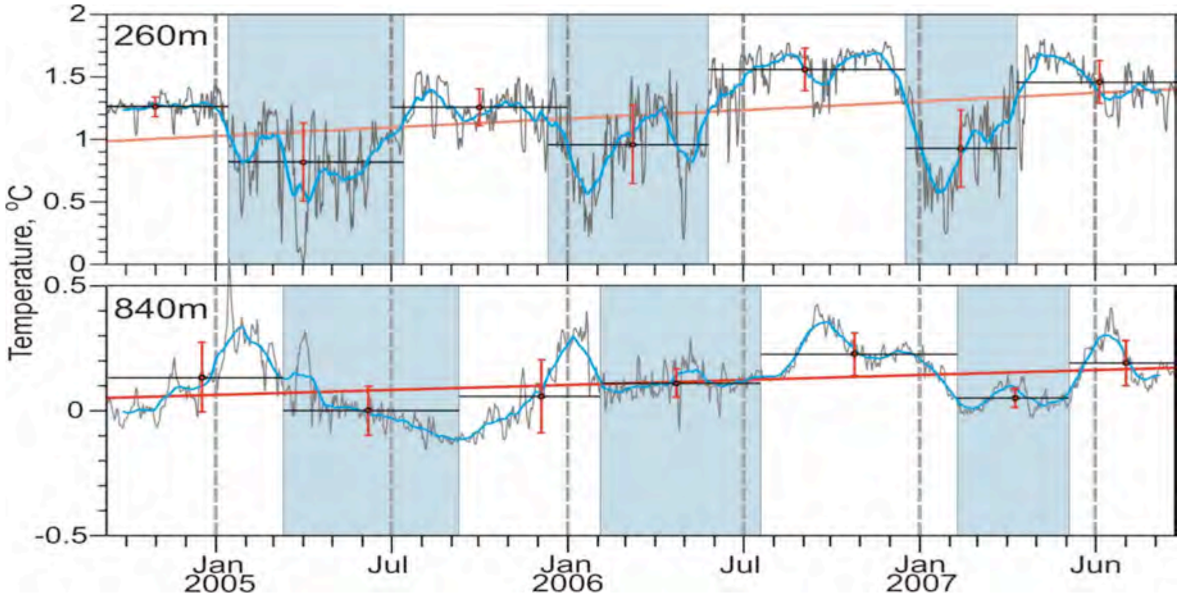


Figure ID: The 3-year-long daily mean time series of temperature (°C) for the FSBW layer (top) and the BSBW layer (bottom). Note that for the BSBW, the temperature and salinity seasons shown by shading are lagged relative to the FSBW core seasons by ~50 days. The seasonal mean is depicted by horizontal lines. Error bars show ± one standard deviation of the seasonal mean. The linear trends are shown by bold red lines.

Jan Piechura and Ilona Goszczko presented observational results on changes of temperature and salinity at the slope of Severnaya Zemlya in 2006–08 and hypothesized a possible connection of these changes to warming/cooling of Atlantic Water carried by the West Spitsbergen Current. They reported strong seasonality of temperature, salinity, and currents speed time series at 100 and 880m observed at this location of the Arctic Ocean (Figure JP). The most dynamic periods were winters 2006/2007 and 2007/2008 when a strong current up to 28cm/s along the slope in a south-east direction was recorded (Figure JP). At that time, the highest temperature 2.5–3.2°C and salinity were recorded at about 100m depth, which presents some evidence of Atlantic Water lifted up close to the surface.

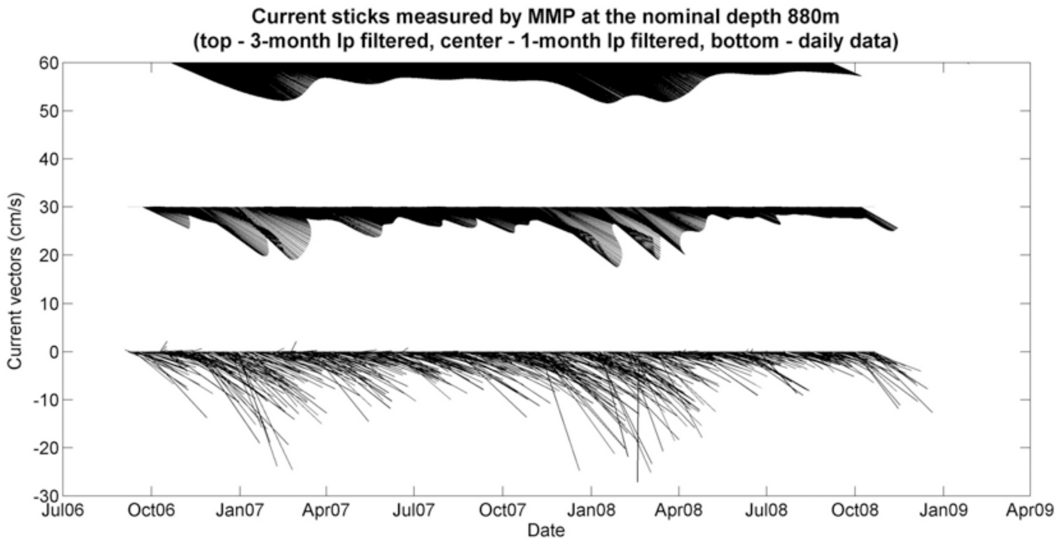


Figure JP. Currents recorded by the mooring profiler MMP at 880m near Severnaya Zemlya in 2006–2009.

Vladimir Alexeev presented results of a comparison of recent atmospheric trends from different reanalysis products and radiosonde data. Disagreement between different reanalysis datasets is quite substantial, even at the surface. "Hotspots" of disagreement at the surface are located in the East Siberian, Chukchi and Beaufort seas. NCEP-1, NCEP-2, and NARR datasets do not confirm the so-called "elevated" tropospheric polar amplification found in ERA-40. Radiosonde data also do not exhibit faster warming aloft. Most of datasets indicate that the recent arctic warming originates from the surface.

Elena Maksimovich and Jean-Claude Gascard presented results of analysis of a climatic change signal in the arctic atmosphere from NCEP reanalysis data. They used NCEP reanalysis temperatures from the lowest sigma level and introduced an index based on Freezing Degree-Days (FDD) in an attempt to explain ice extent variability. Maps of FDD index show a maximum in the Canadian Arctic. Freezing intensity decreases in time. For example, FDD loss was ~40 days/year over the last decades for the central Arctic. For shelves, the situation is different. Minimum ice extent is well correlated with freezing intensity.

Cecilie Mauritzen reported that *iAOOS-Norway: Closing the loop*, has been an IPY project to coordinate and improve many of the routine ocean measurements performed by the Norwegian institution (and to utilize the data in operational ocean forecasting). Relevant to the NABOS experiment, iAOOS-Norway measures both upstream (Svinøy, Station Mike, Barents Sea opening, Fram Strait – one mooring east of the AWI array) and downstream (western Fram Strait) conditions. Sea gliders have been put in operation at Station Mike and at Svinøy, and presently we receive temperature, salinity, and velocity measurements of the Norwegian Atlantic Current (actually down to 1000m) every 8 hours (see Figure CM). Each transect takes approximately 20 days to complete.

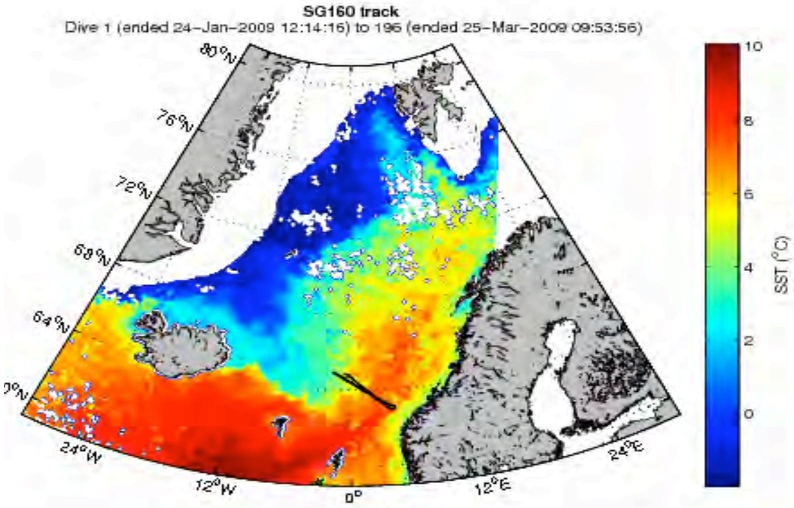


Figure CM: Sea surface temperature in the Nordic seas March 25, 2009, with sea glider track at Svinøy superimposed. Acknowledgement: Frode Høydalsvik and Steinar Eastwood, *met.no*.

Ursula Schauer presented an analysis of oceanic heat flow through Fram Strait and Eurasian Basin warming. Computation of oceanic heat transport through Arctic passages, like Fram Strait, is possible only with very crude assumptions since the net throughflow is not zero. Given this caveat, heat transport of the West Spitzbergen Current has been derived from 10 years of transport measurements using a stream tube approach (Figure US). The heat transport through Fram Strait varied between approximately 30 TW from 1997 until 2002 and approximately 40 TW thereafter. Observations in the Eurasian Basin in 2007 showed that about 60% of the heat corresponding to the additional 10 TW for 4 years is stored in the Eurasian Basin.

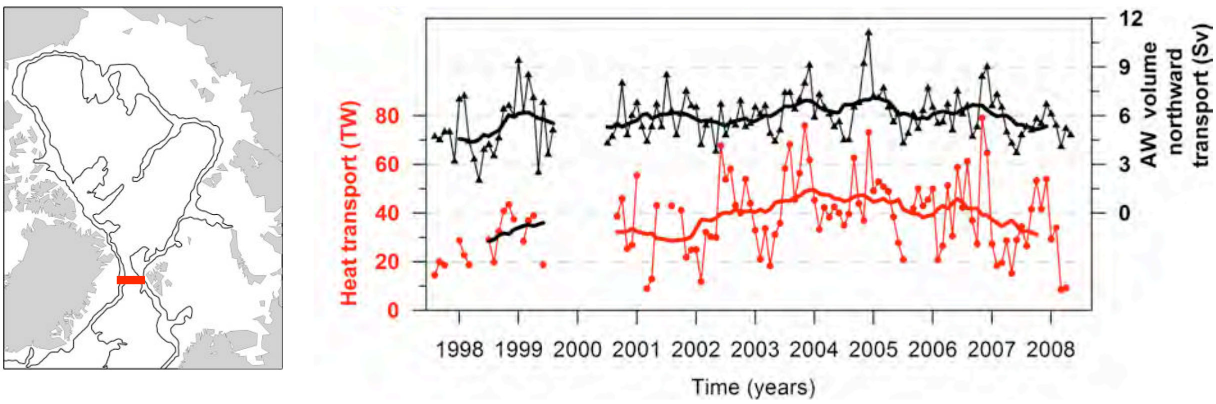


Figure US: (Left) Location of a 10-year mooring array. (Right) Volume (black line) and heat (red line) transports of the Atlantic Water in the West Spitsbergen Current. Only water warmer than 1°C is considered (updated after Schauer et al., 2008).

Igor Ashik, Vladimir Sokolov and Leonid Timokhov reported recent thermohaline conditions at the continental slope area of the Arctic Basin. They noted that in the upper 10m layer of the Eurasian Basin of the Arctic Ocean, there were positive temperature anomalies and negative salinity anomalies. At the continental slope, there was wide-spread cooling in the core of the Atlantic Water layer and reduction of the layer thickness compared with 2007, however the Atlantic Water is still warmer compared with climatology (Figure IA). Observations also showed an increase of water temperature in the deeper layer beneath the Atlantic Water layer. Over the north-western part of the Laptev slope, observations showed meandering of the major stream of the Atlantic Water with secondary jet-like and eddy-like structures.

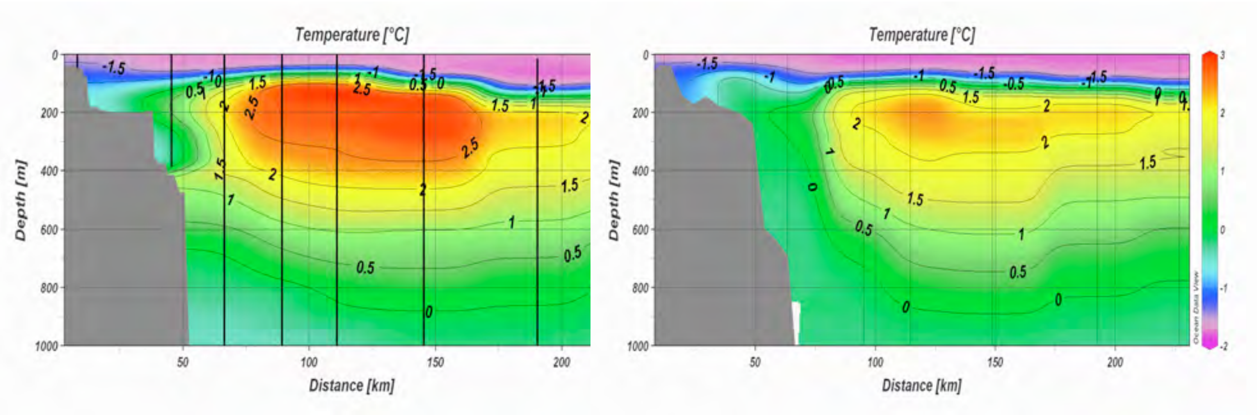


Figure IA. Cross-sections of observed water temperatures for the northern part of the Severnaya Zempla region in 2007 (left) and 2008 (right).

Tatiana Alexeeva and Sergey Frolov presented methods of visual sea ice observations, carried out during the NABOS expeditions. The shipborne data, derived onboard the icebreaker *Kapitan Dranitsyn*, allowed them to analyze the distribution of important sea ice parameters in the Laptev Sea: total ice concentration, sea ice thickness, hummocks and ridges concentration, snow depth, etc. Some preliminary results of comparison of the visual shipborne data with satellite images were shown. A new system of sea ice information support was developed in the AARI; it was proposed to provide expeditions by current and forecast sea ice maps and recommended routes of navigation.

Irina Repina, Alexander Smirnov, Dmitry Chechin and Boris Ivanov presented results of recent field studies of air-ice interactions in the Arctic Ocean. In summer, mean heat balance at the surface is dominated by radiation balance. However, under specific conditions at the surface, the contribution of turbulent fluxes could be compatible with net radiation balance. For example, heat flux over polynyas is about 10 times larger than over the other surfaces. The major effect of ice concentration on the magnitude of heat flux is reflected in the high correlation between these parameters. Spatial distribution of sensible heat flux over the Laptev Sea shows wide scattering over space and time (Figure IR). Exchange coefficients calculated using direct measurements do not correlate with any single meteorological parameter, but rather depend on a variety of factors, which are usually difficult to estimate. Calculation of turbulent fluxes in the confined area with irregular underlying surface requires careful selection of the method of calculation and types of parameterization of coefficients.

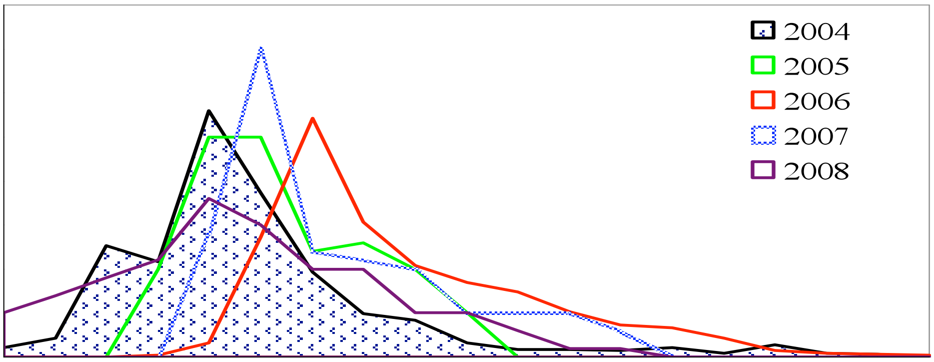


Figure IR: Relative occurrence of the sensible heat fluxes (H) from the measurements taken over the Laptev Sea in the summer for different years.

Yueng-Djern Lenn focused her presentation on results from the 2007 field season in which the microstructure turbulence, temperature, and salinity measurements showed that the turbulent mixing is negligible in the arctic boundary current upper thermocline where double diffusive convection dominates. The double diffusive convection heat flux was found to O(1 W/m^2) which is too small to account for the along-stream cooling of the upper thermocline observed. This strongly suggests that lateral exchange, either due to current divergence or an exchange with the shelf regimes, is more important for the modification of the Atlantic water core carried in the boundary current. One important caveat is that the significant inter-annual and seasonal variability seen in the boundary current needs to be better resolved before the heat budget can be properly and accurately estimated. Nonetheless, our results confirm conclusively that the vertical mixing is weak in the boundary current and imply that energetic mixing must take place elsewhere. Preliminary results from a 10hr time-series of measurements taken in the Laptev Sea shelf during the 2008 field season were also presented. These show a period of enhanced turbulent dissipation ($>10^{-4}$ W/m^3) along the bottom that may be associated with the tide. More surprisingly, there was an order of magnitude higher episode of strong turbulent dissipation at about 20m depth. We speculate that that is associated with the period during which the wind-driven ice-drift was in opposition to the barotropic tidal current, resulting in greater friction and greater turbulent dissipation.

Jens A. Hölemann and Co-authors discussed seasonal and interannual variability of bottom water temperatures on the Laptev Sea shelf. According to the authors, methane, in a solid icy form called methane hydrate, is trapped in submarine permafrost. If the temperature at the seabed rises a few degrees, it could initiate decomposition of these hydrates, releasing methane to the atmosphere. This process is of particular importance at the northern limit of the submarine permafrost distribution because a small increase in seafloor temperatures can produce a significant southward shift of this boundary. The record of bottom water temperatures at the moorings deployed in the central Laptev Sea close to the shelf edge at 60m water depth demonstrates that the thermal energy from the Atlantic intermediate water is advected onto the Laptev Sea shelf (Figure JH). Based on observations of bottom water temperatures in the south-eastern Laptev, Sea we hypothesize that the “warm” water reached the recurrent winter-polynya near the delta of the river Lena during the winter of 2007/2008.

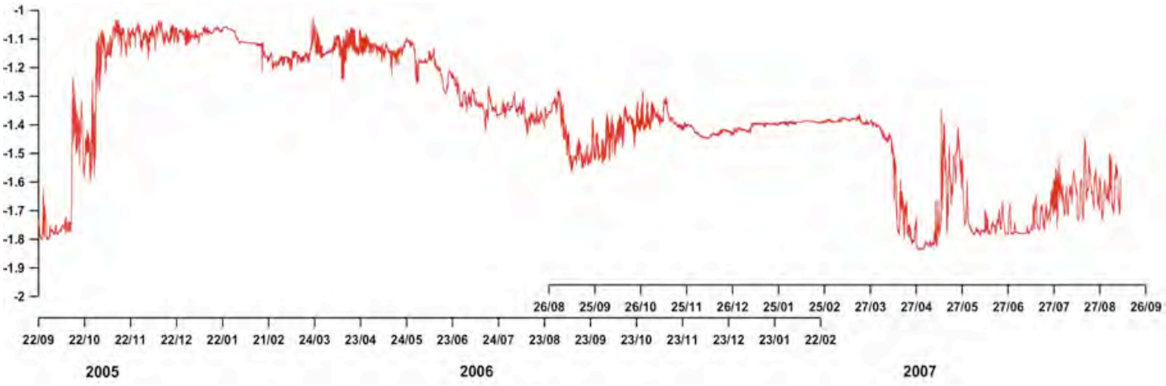


Figure JH. During the deployment from 2005 until 2007, a period of unusual high bottom water temperatures was observed on the outer shelf of the Laptev Sea (60m water depth). These results indicate that thermal energy from the Atlantic intermediate waters was advected onto the shelf, and that the exceptional warming that entered the Arctic Ocean in 1999 also has an impact on the stability of submarine permafrost.

Rebecca Woodgate and Co-authors presented results from a new technique of “finger-printing” the Atlantic Water boundary current by temperature-salinity (T-S) structures. Both the Fram Strait Branch Waters (FSBW, usually tagged as the temperature maximum at salinities of ~34.85psu) and Barents Sea Branch Waters (BSBW, usually tagged as an inflexion in T-S space around sigma-0 values of 28 kg/m^3) show small-scale intrusions in temperature and salinity. These features, nicknamed “zigzags” because of their form on a T-S diagram, are a large-scale manifestation of molecular scale physics and relate to double diffusive exchange of heat and salt. Prior work by other authors has considered formation mechanisms of these zigzags. Woodgate et al. suggest that the structure of the zigzags gives information about the parent water masses from which the structures form, and thus can be used to extract information about time-variability of the FSBW and BSBW. Moreover, a detailed study of the Mendeleev Ridge and Chukchi Borderland Region supported by hydrographic CFC and oxygen data, suggests that these structures can be used to track water pathways. Figure RW presents the pathways obtained from such an analysis for data from 2002.

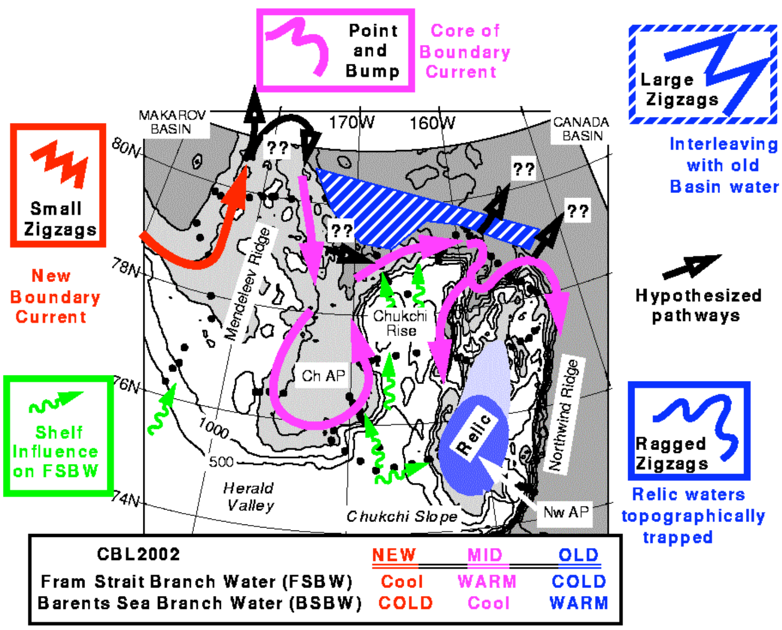


Figure RW: pathways obtained from zigzag T-S structure analysis for data from 2002 (reproduced from Woodgate, R.A., K. Aagaard, J.H. Swift, W.M. Smethie, Jr., and K.K. Falkner (2007), Atlantic water circulation over the Mendeleev Ridge and Chukchi Borderland from thermohaline intrusions and water mass properties, *J. Geophys. Res.* 112, C02005, doi:10.1029/2005JC003416).

Göran Björk reported results of an expedition under the international Siberian Shelf Study (ISSS) project carried out in 2008 on the Siberian shelves. This was a collaborative project between Russian and European (mostly Swedish) scientists. Funding for the project came from a private foundation and funding agencies of Russia, Europe, and Sweden. R/V *Yakob Smirnitsky* was used for this cruise. Ice conditions did not allow the team to fulfil the cruise plans in full. For example, all but one deep-water cross-sections were cancelled. There was a lot of sampling, particularly chemical sampling. For example, temperature and salinity measurements demonstrated a clear demarcation line for the area of Pacific influence with higher temperatures and salinities. There was a special Harold Canyon study with a series of cross-sections. Results are similar to those obtained by R. Pickart. The northernmost section showed traces of vigorous mixing. The deepest section showed traces of dense-water flows.

Takamasa Tsubouchi reported progress of historical data collection and inverse modeling in the Arctic Ocean. As iAOOS is getting established, we could enclose the Arctic Ocean by Fram, Davis, and Bering straits and the Barents Sea opening during a certain period (Figure TT). This situation would enable us to adjust estimated fluxes along each strait by applying inverse modeling. The preliminary result of calculated initial mass imbalance was presented. The necessity of further modification of the initial imbalance was discussed.

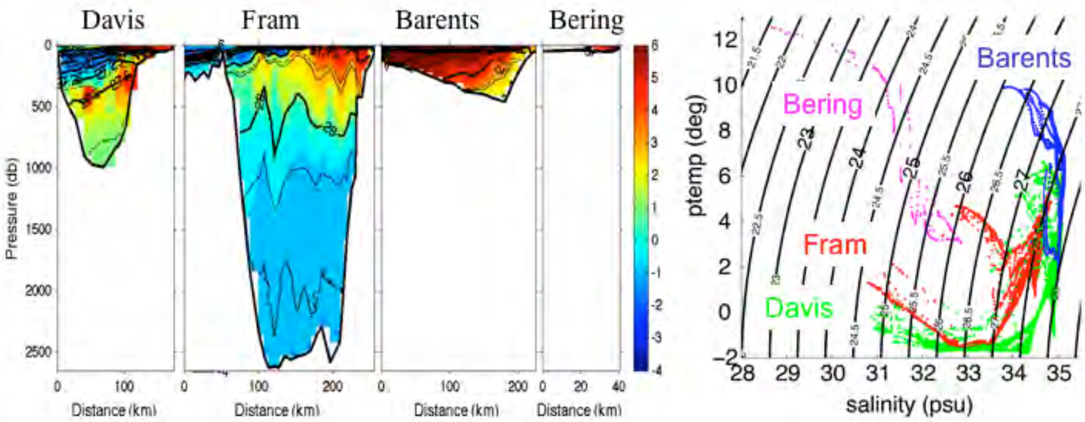


Figure TT: Temperature section and TS figure along the Fram Strait, Davis Strait, Barents Sea opening section and Bering Strait during summer 2001-2004.

Research plans for 2009 and beyond

Leonid Timokhov presented plans of the Arctic and Antarctic Research Institute (AARI) for 2009 and beyond. Plans for 2009 include supply of the NP-36 drifting station and, depending on the situation, organization of a new NP-37 station (Figure LT2, left), deployment of six moorings in the Kara Sea and to the north off Severnaya Zemlya (Figure LT2, right). For 2009, the German-Russian expedition is planned in the southern part of the Laptev Sea (Figure LT2, right, yellow square). Partners now are discussing ways to collaborate with the NABOS expedition.

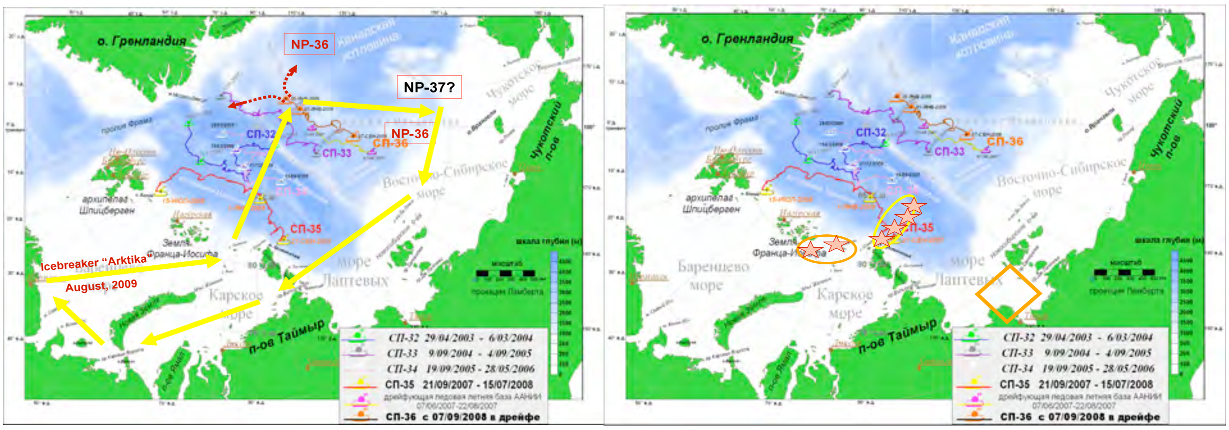


Figure LT2: AARI plans for summer 2009 field work.

Igor Polyakov presented plans for NABOS for 2009 and beyond. For 2009 these plans include servicing NABOS moorings near Svalbard and the Laptev slope, including recovery of two moorings and deployment of four or five depending on funding. Strategy of the future mooring experiment includes maintenance of several climatologic moorings as shown in Figure IP2. These are conventional moorings heavily equipped with CTD sensors (including several above major flotation for measurements in the upper ocean layer), ADCPs, and sea-level meters. MMP moorings will be used for process-oriented experiments around climatologic moorings when a cluster of MMP moorings is moved from one climate-mooring location to another one on an annual basis. Plans for CABOS for 2009 and beyond include maintenance of CABOS moorings for as long as possible.

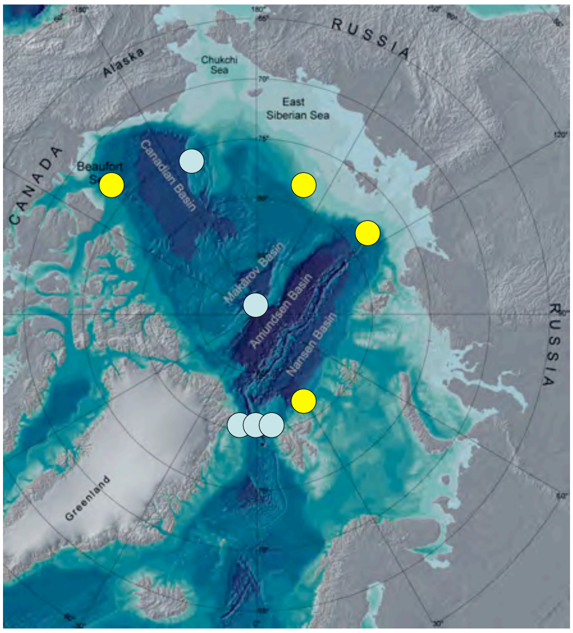


Figure IP2. Locations of moorings for the Arctic Ocean Observational Network for 2009 and beyond. Yellow dots show NABOS mooring locations, blue dots show mooring locations of other programs.

Sheldon Bacon reported that the UK is changing the way it funds environmental science. Research programs are delivered through seven research "Themes" (Earth System Science, Climate, Biodiversity, etc.), each of which is managed by a Theme Leader. The Theme Leader decides annually on Theme Action Plans (TAPs), and TAPs deliver funds to targeted subject areas. Relevant to arctic science are Announcements of Opportunity, derived from recent TAPs, on Ocean Acidification (containing an explicit arctic component) and the Methane Network (relevant to gas hydrates). Additionally, a "scoping study" on terrestrial glaciology has recently been completed, with a view to possible future glaciology funding. The UK arctic science community is pressing for further arctic science to be included in a near-future TAP, and it is to be hoped that there may soon be funds delivered to enable further study of (maybe) the Arctic Ocean, atmosphere, sea ice, biology / ecology, and climate. Also relevant is the recently signed UK-Canada Memorandum of Understanding, which aims to initiate bilateral sharing of polar logistics.

John Calder presented two activities that may affect the future of ocean observations in the Arctic. In September 2009, the OceanObs09 conference will bring together an international group of oceanographers to review the current state of global ocean observing and provide insight on future directions. The result of the conference will be a publication that will include the invited plenary presentations and all of the submitted "community white papers" that discuss various aspects of ocean observing. The conference results will be influential in the coming update of the GCOS Implementation Plan. At least four of the expected 130 white papers will have an arctic focus. Dr. Calder provided copies of the white paper he is organizing and invited the group to comment on it. Over the past 18 months an arctic-wide effort has been made to gain insight on the current state of arctic observations of all types and identify an approach for sustaining many of the observing projects undertaken during the International Polar Year 2007-2009. This effort is known as the Sustaining Arctic Observing Networks (SAON) process. It is anticipated that the Arctic Council and the International Arctic Science Committee will continue this process over the next two years, with the aim of presenting recommendations to funding agencies and national leaders that would enhance the continuation of critical environmental observations in the Arctic.

Jean-Claude Gascard presented a view of post-IPY arctic research. Before IPY, we knew that the arctic environment is changing fast. However, over the last two IPY years we have learned, for example, that ice drifts approximately two times faster in recent decades than before, and ice thickness has been reduced by half. When we started DAMOCLES, it was assumed that the models capture speed of drift and other major features of arctic ice. However, last year presented a new challenge. The vessel *TARA* drifted two times faster than expected, and we realized that old statistics are no longer valid. Results of simulations of ice decline using a cluster of IPCC GCMs in comparison with observations do not look very promising. However, some models are capable of simulating tendencies of ice decline. At the start of DAMOCLES, we planned to utilize modern technologies such as ARGO buoys, POPs, MOPs, and mooring platforms. This approach combining Lagrangian and Eulerian methods of observations should be adopted by NABOS. Various buoys provide invaluable information about the state of the ocean, ice, and atmosphere. We need to continue our cruises as well. The frame for the future should adopt several directions, including analysis of changes in arctic cryosphere and their impact on the global climate system and study of the high-latitude ecosystem. International cooperation should not be cosmetic but should become an important conduit for arctic research.

Ursula Schauer presented the German Polarstern cruise plan in the Arctic for the next three years (Figure US2). It includes work in Fram Strait, the central Arctic Ocean, and in the Laptev Sea in 2009 and 2011.

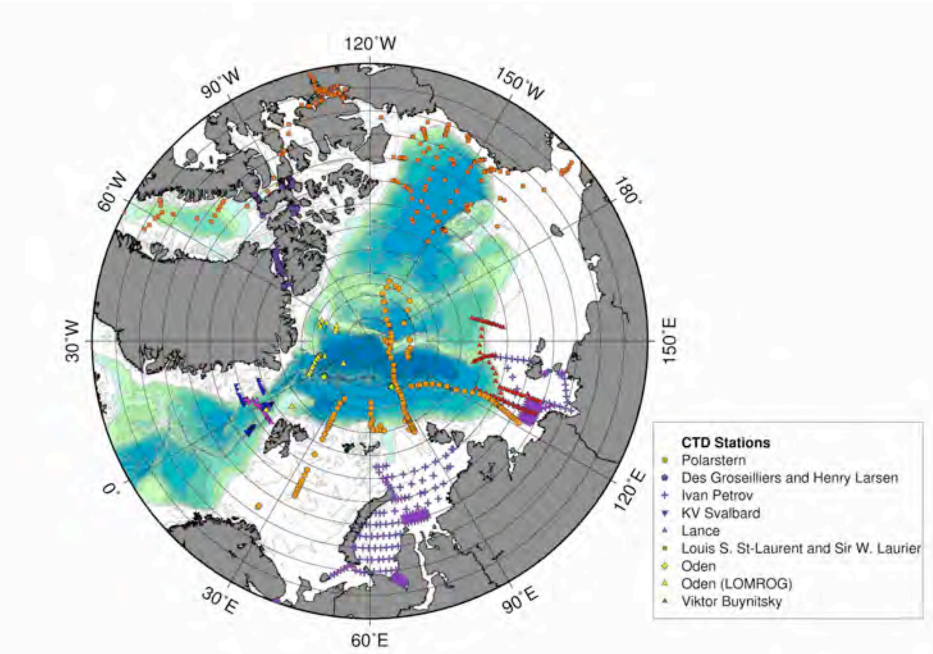


Figure US2: German Polarstern cruise plan in the Arctic for the next three years.

Takashi Kikuchi described the cruise plans for R/V *Mirai* in 2009 and beyond. To quantify ongoing changes of arctic meteorological, bio-geochemical, and physical environmental factors in the Arctic Ocean, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) plans to conduct an arctic cruise in 2009, 2010, and hopefully 2012. The main target area is the western Canada Basin and the Makarov Basin. In 2009 the R/V *Mirai* arctic cruise (MR09-03) will start on September 7 in Dutch Harbor, Alaska, USA, and will end on October 15 in Dutch Harbor. Depending on ice conditions, MR09-03 will include an oceanographic cross-section across the major basin and fixed-point observations for several days at locations marked by stars (Figure TK).

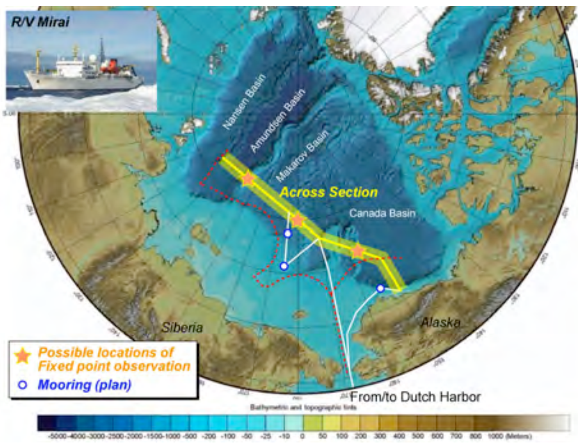


Figure TK. Arctic cruise planned for R/V *Mirai* in 2009 (MR09-03).

Jens A. Hölemann presented plans for deployment of moorings on the inner and outer shelf of the Laptev and Kara seas in 2009 and beyond. At present, four shallow water moorings are deployed in the central and eastern Laptev Sea. The deployments were conducted within the framework of the research projects NABOS and "System Laptev Sea" / Barkalav. It is planned to recover the moorings in August/September 2009 and to redeploy them for the period of one year in the central Laptev Sea (outer shelf and north of the Lena delta) and the western Laptev Sea to study the shelf-basin interactions and the evolution and dynamics of the Laptev Sea polynya.

Jan Piechura reported on research plans of the Institute of Oceanology, PAS for 2009 and beyond. In 2009, IOPAS plans to continue hydrography at the dense grid of stations at the West Spitsbergen Current and Storfjordrenna. Plans also include re-deployment of the MMP mooring in Fram Strait and two moorings at the slope of the Svalbard shelf in the vicinity of Hornsund Fjord.

Jean-Claude Gascard presented information about deployment of the MOPS mooring on Yermak Plateau and Storfjord. The mooring deployed in 2007 on Yermak Plateau at ~680m depth consisted of long-range 75Hz ADCP placed near the bottom and mooring CTD profiler. The latter was essentially a version of ARGO float. Justification for this deployment came from experiments carried out in 1988. Twenty years ago, several floats were launched at ~300m depth (AW core) near Svalbard. These floats were tracked by listening stations. Several of these floats were trapped over Yermak Plateau. A new mooring deployment targeted mechanisms for this trapping. Unfortunately, the CTD profiler did not work properly, refusing to go along the line as planned. However, the ADCP provided the full year record of currents for ~500m depth range. The major feature of the record is the bursts of strong (>50cm/s) diurnal tidal currents. The next deployment is planned soon from Vagabond in one of Svalbard's fjords. This new deployment will test the CTD profiler, targeting brine rejection during ice formation.

Round table: Perspectives of coordinated research in the Arctic

Dr. *Sheldon Bacon* led this session. Three major topics were suggested for discussion. The first one is possible publication as a result of this workshop. The second topic is a contribution to the white paper presented by J. Calder (NOAA). And the last one is "Perspectives of coordinated research in the Arctic."

Joint publication:
I. Polyakov proposed a joint publication summarizing results of this workshop. BAMS may be a good target for this publication. This publication may include a description of our findings, which include a strong seasonal cycle in the ocean interior, cooling phase of the Arctic Ocean, upward heat fluxes from Atlantic waters, and biochemical changes. S. Bacon stressed that it is important to define whether we target a research or review article, and a geographical region. I. Polyakov suggested that it should be a review article with possible focus on the slope area of the Eurasian Basin with upstream extension. The structure of the article may follow our Eos 2007 paper, which included a summary of achievements and future plans. U. Schauer expressed concern that it is rather difficult to formulate a focus of such a paper with no clearly stated outcome of the meeting. J. Piechura expressed strong support for linking Arctic Ocean changes to upwind processes. C. Mauritzen suggested that we prepare a meeting report as the first step for the review paper. S. Bacon suggested,

however, that a short article may be used as a meeting report. Careful selection of materials for the paper is required.

<u>Contribution to white paper</u>:

Prior to the workshop, J. Calder invited contributions to the white paper "An Integrated International Approach to Arctic Ocean Observations for Society (A Legacy of the International Polar Year)" to be submitted to the OceanObs'09 meeting. The paper was written by a committee led by J. Calder. The goal of the paper is to describe our vision for the future of the Arctic Ocean observing system and to clearly address the major needs of society. J. Calder stressed that the time schedule is very tight, and the present size of the draft precludes lengthy additions. Contributions, therefore, should be short and precise. More than 100 white papers have been accepted, and only four among them are devoted to the Arctic. S. Bacon suggested that the contributors become contributing authors of the paper. U. Schauer wondered whether the committee will include contributions from German scientists, and J. Calder responded positively.

<u>*Perspectives of coordinated research in the Arctic:*</u>

I. Polyakov began this discussion by asking for comments and advice on the future of NABOS and on possible ways to enhance the program and international cooperation in Arctic Ocean exploration (Figure IP2 was shown). *J.-C. Gascard* stressed the importance of a combination of Lagrangian and Eulerian methods of observations. *R. Woodgate* suggested that the structure of boundary currents should be clarified, and for this purpose mooring cross-slope sections suit best. *Y.-D. Lenn* suggested that the oceanographic cruises should be complemented by measurements of turbulence using available modern techniques (such as ship-based ADCP).

I. Polyakov asked for comments on the locations of the existing moorings (Figure IP2), which are proposed to remain the same in the future. He argued that, according to NABOS observations, these locations are good for climate monitoring because they are well away from sites with strong local dynamics (like Severnaya Zemlya). Two moorings deployed in 2009 on the slope of the Laptev and East Siberian seas may serve as a prototype for these climate-oriented moorings. Each mooring includes several ADCPs, microcats, and sea-level meters. Instead of annual cruises and single-year mooring deployments utilized in the previous years, biannual cruises and 2-year mooring deployments were proposed. Thus, these climate-oriented moorings will extend the established time-series. The MMP-based movable array of four process-oriented moorings will be used to study processes around climatologic sites. *R. Woodgate* supported the general idea and noted that maintaining the mooring locations is the key. She mentioned that an additional good site for mooring-based climate monitoring may be off the Alaskan coast. *L. Timokhov* stressed the importance of using at least two moorings at each site. This would help avoid problems with interpretation of the records. *S. Bacon* supported this idea, referring to previous experience gained from mooring deployments in Denmark Strait. *I. Dmitrenko* stressed the importance of mooring-based experiments in St.-Anna Trough planned for 2009. *U. Schauer*, *L. Tomokhov,* and *C. Mauritzen* expressed strong support for this experiment.

I. Polyakov expressed concerns about the future of NABOS funding and asked for help from the workshop, particularly when communicating with funding agencies (including in proposals). *L. Timokhov* expressed strong support for the program, emphasizing the strong standing of NABOS in the Russian polar community. Including NABOS in the agreement between two federal agencies (U.S. NOAA and Russian RosHydroMet) is a clear sign of recognition of the program. *C. Mauritzen* congratulated the NABOS team for their achievements and wished them good luck in the future. *I. Polyakov* asked *U. Schauer* about possible use of Polarstern for future activities related to NABOS, and the answer was positive.

J.-C. Gascard stressed that polar oceanography is in transition from an extensive field campaign carried out under the auspice of the IPY, and we need to find ways to use that momentum in the future. He invited participants of the workshop to take part in a symposium to be held November 17–19, 2009, in Brussels, where the IPY legacy will be discussed. *J.-C. Gascard* stressed that NABOS should be a part of this legacy. The major frame for the future observational system is created, and we may need to add several details to this scheme. There will be problems in the future. For example, exploration of the bottom floor using an icebreaker is planned by many countries, and resources from physical oceanography may be needed. We need to continue what we started under the IPY. For example, NABOS moorings are in place, and various Lagrangian drifters have been deployed. *J.-C. Gascard* thanked all participants of the workshop for their contributions and stressed that this meeting became an important element of a series of post-IPY meetings which help evaluate its legacy and put forward perspectives of coordinated research in the Arctic. *I. Polyakov* also thanked workshop participants for help in strategizing future Arctic Ocean exploration. With this, the meeting was adjourned.

Acknowledgements. We would like to thank NSF, NOAA, and Shell for providing financial support for the meeting and UPMC for hosting us and providing tea/coffee/lunch/dinner.

Igor Polyakov, 20 April, 2009

Annex 1 – Agenda

AGENDA: S4D Workshop
"Near-slope observations in the Arctic Ocean"

March 6-7, 2009
Universite Pierre et Marie Curie
4 place Jussieu 75005 Paris, France (metro Jussieu line 7 and 10**)**
location **ATRIUM** (the orange building on University campus)
look at **S4D** sign posted on the campus from the entrance
at the street intersection between Rue Cuvier & Rue Jussieu

March 6, 2009, Friday

Breakfast: 8.30 – 9:00.
Welcome from Hosts: Jean-Claude Gascard, Leonid Timokhov and Igor Polyakov

Morning Session: 9.30 – 12.30. (Chair: Dr. Cecilie Mauritzen)

I. Current State of Arctic Ocean Research

1. Vladimir Ivanov, Igor Polyakov, Sergey Kirillov, Igor Dmitrenko and Leonid Timokhov "*NABOS-2008 cruise - preliminary scientific results*."
2. Igor Polyakov and Leonid Timokhov – "*Eight years of NABOS*"
3. Leonid Timokhov, Igor Ashik, Alexander Danilov, Igor Dmitrenko, Jens Hoelemann, Vladimir Ivanov, Sergey Kirillov, Alexander Novikhin, Igor Polyakov, Vladimir Sokolov – "*Summer 2007 and 2008: the temperature and salinity anomalies in the Arctic Ocean and the affecting factors*."
4. Pascaline Bourgain, Cecilie Mauritzen and Jean-Claude Gascard – "*Pacific and Atlantic water pathways across the Arctic Ocean"*
5. Sergey Kirillov and Leonid Timokhov – *"Intrusive thermohaline structures in Atlantic intermediate waters near Severnaya Zemlya continental slope: the rates of double-diffusive heat and salt fluxes."*

Coffee break 10.45 – 11.15

6. Sheldon Bacon – "*An overview of UK ASBO project.*"
7. Igor Dmitrenko, Vladimir Ivanov, Sergey Kirillov, Rebecca Woodgate, and Igor Polyakov – "*Upstream conditioned seasonal modification of the Arctic Ocean intermediate water layer over the Siberian continental margin*"
8. Jan Piechura and I. Goszczko – "*Notes on changes of temperature and salinity on the slope of Sieviernaja Ziemla in 2006 - 2008, and possible connection to warming/cooling of AW carried by the WSC*"
9. Vladimir Alexeev – "*Looking for climate change signal in the arctic atmosphere: local or remote?*"
10. Elena Maksimovich and Jean-Claude Gascard *"Looking for climatic change signal in the Arctic atmosphere from NCEP reanalysis"*.

Lunch: 12.30. – 13.30.

Afternoon Session: 13.30 – 17.00. (Chair: Dr. L. Timokhov)

I. Current State of Arctic Ocean Research, (Continued).

11. Cecilie Mauritzen – "*Highlights from the IPY project iAOOS-Norway*"

12. Ursula Schauer – "*Oceanic heat flow through Fram Strait and Eurasian Basin warming*"

13. Igor Ashik, Vladimir Sokolov and Leonid Timokhov – "*The recent thermohaline conditions at the continental slope area of Arctic Basin.*"

14. Tatiana Alexeeva and Sergey Frolov – "*Visual sea-ice observation in the NABOS cruises and the ice-navigation support.*"

15. Irina Repina, Alexander Smirnov, Dmitry Chechin, Boris Ivanov – "*The experimental study of the air-ice-sea interaction in the Arctic seas"*

Coffee break 14.45-15.15

16. Yueng-Djern Lenn – "*Processes influencing the modification of the East Siberian Arctic boundary current."*

17. Jens A. Hölemann – "*Seasonal and interannual variability of bottom water temperatures on the Laptev Sea Shelf*"

18. Rebecca Woodgate, Knut Aagaard, J. H. Swift, W. Smethie, and K. K. Falkner, "*Fingerprinting Atlantic Water in the Chukchi Borderland.*"

19. Göran Björk – "*ISSS-08 cruise on the Siberian shelves*"

20. Takamasa Tsubouchi – "*Progress of historical data collection and inverse modeling in the Arctic sea*"

Discussion 16.30-17.00

Dinner (19.00 – 21.00 p.m.). on board a boat along the Seine river.

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March 7, 2009, Saturday

Breakfast: 8.30 – 9.00.

Morning session: 9.00. – 12.30. (Chair: Dr. I. Polyakov)

II. Research Plans for 2009 and beyond

1. Leonid Timokhov – "*US-Russian cooperation in research of the northern Laptev Sea and adjacent Arctic Ocean in 2009 and beyond*"
2. Igor Polyakov – "*Planning NABOS for 2009 and beyond*"
3. Sheldon Bacon – "*Planning Arctic study from UK*"
4. John Calder – "*Efforts in the Arctic Council and other aspects regarding international coordination of Arctic observations.*"
5. Jean-Claude Gascard "*Post IPY Arctic research"*

Coffee break. 10.30-11.00

6. Ursula Schauer – "*Polarstern cruise plan 2011*"
7. Takashi Kikuchi – "*R/V Mirai cruise plan in 2009 and beyond*"
8. Jens A. Hölemann – "*Deployment of moorings on the inner and outer shelf of the Laptev and Kara Seas: 2009 - ?*"
9. Jan Piechura – "*Research plans of Institute of Oceanology, PAS*"
10. Jean-Claude Gascard. "*MOPS moorings on Yermak Plateau and Storfjord*"

Lunch: 12.30 p.m. – 13.30 p.m.

Afternoon Session: 13.30 – 17.00 p.m. (Chair: Dr. Sheldon Bacon)

Round Table: Perspectives of coordinated research in the Arctic, joint publications

Coffee Break 14.45- 15.15

Note: All presentations are limited to 15 minutes including immediate questions.

Annex 2

LIST OF PARTICIPANTS
S4D Workshop
"Near-slope observations in the Arctic Ocean"
Paris, March, 6 (Friday) -7 (Saturday), 2009.

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