International Arctic Research Center (IARC) and Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Annual Report

For the period of April 1, 2008 to March 31, 2009

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Introduction
By Larry Hinzman, IARC Director

The International Arctic Research Center at the University of Alaska Fairbanks is an international focal point for synthesis of our understanding of the Arctic System and the application of this understanding to prediction of the evolution of the Arctic System over the next century. IARC’s mission is to foster arctic research in an international setting to help the nation and the international community to understand, prepare for, and adapt to the pan-Arctic impacts of climate change. By acting in collaboration with researchers from Japan and throughout the world, we strive to improve comprehensive studies of the Arctic System. This represents a potential for scientific teamwork that would not otherwise be possible. We have conducted process studies and collected field measurements that provide the understanding needed to develop and validate models.

Research presented here includes improvements in marine ecosystem modeling based upon extensive measurements in the Bering Sea. The Bering Sea ecosystem has undergone profound changes in response to climate regime shifts in the past decades. These studies have provided more insight into the role of iron in this system and potential ecosystem responses to the loss of sea ice. There is much variability in the rate of sea ice growth and melt due to small-scale spatial heterogeneity in ice thickness, snow cover, and oceanic and meteorological conditions. Field studies have provided substantial ground truth on ice dynamics, useful for model verification and remote sensing analyses. The NABOS project continued to provide quantitative assessment of circulation and water mass transformation along the principal pathways transporting water from the Nordic seas to the Arctic Basin. Our terrestrial studies have focused upon gas fluxes from tundra and boreal forest soils and influences of environmental parameters such as snow cover. We have also strived to understand how atmospheric circulation has changed and how it has connected with the recently observed rapid changes in the arctic climate system and the extreme event of sea ice cover loss in 2007. We discovered rapid changes in the atmospheric circulation pattern are characterized by a numeric index that relates well to explain other environmental variations.

We at IARC sincerely appreciate the collaboration of our JAMSTEC colleagues, particularly at a time when changes in the Arctic and scientific understanding of the Arctic are evolving so rapidly. We must concentrate on problems where we can make substantive progress, and we must address issues to which we are in the best position to make the greatest contributions. We feel that we have selected worthy research topics and that we have made substantive progress in understanding the Arctic System.
Ocean Ecosystem Modeling and Observations

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2. Summary of Research Activities and Accomplishments
Marginal Ice Zone of the Bering Sea - Response of lower trophic level production to long-term climate change and the significance of water column nitrification
The Bering Sea ecosystem has undergone profound changes in response to climate regime shifts in the past decades. In Jin et al. (2009), lower tropic level production is assessed with a vertically 1-D coupled ice-ocean ecosystem model, which was applied to data collected by a National Oceanic and Atmospheric Administration (NOAA)/Pacific Marine Environmental Laboratory (PMEL) mooring from 1995–2005. The physical model is forced by sea surface winds, heat and salt fluxes, tides, and sea ice. The biological model includes coupled pelagic and ice algae components. Model results are validated with daily mooring temperature, fluorometer, and daily Sea viewing Wide Field-of-view Sensor (SeaWiFS) chlorophyll data. Figure 1 shows two distinct ocean conditions and phytoplankton bloom patterns are related to the Pacific Decadal Oscillation (PDO) Index regimes: warmer temperature and later warm-water
phytoplankton species bloom in PDO >1 years; colder temperature and earlier cold-water phytoplankton species bloom in PDO <-1 years. Productivity of different phytoplankton species changed dramatically after the 1976 climate shift, but the total annual net primary production (NPP) remained flat over the past four decades under similar nutrient regulation. Climate shift also affected the vertical distribution of lower trophic level production and energy flow to the upper ocean pelagic ecosystem or the benthic community. A long-term PDO regime shift occurred in 1976 and a short-term PDO reversal in 1998. Phytoplankton biomass responded promptly to both short- and long-term climate changes. Zooplankton biomass responded more to the long-term than to the short-term climate shift. The model results captured observed trends of zooplankton abundance changes from 1990s–2004.

![Figure 1](image)

**Figure 1.** Modeled monthly mean net primary production (NPP) in years of PDO Index > 1 subtracted by means in years of PDO Index < -1. D, F, Ai denote diatoms, flagellates, and ice algae, respectively.

Utilizing measurements of the specific rate of water column nitrification in our 1-D ice-ocean ecosystem model, we quantified the resupply of nitrate from nitrification in the middle shelf of the southeastern Bering Sea (Deal et al. 2008). Model sensitivity studies revealed nitrification rate as an important control on the dominant phytoplankton functional type, and the amount of nitrate in summer bottom waters and in the winter water column. Evaluation of nitrification using the model supports the hypothesis that increases in late-summer nitrate concentrations observed in the southeastern Bering Sea bottom waters are due to nitrification. Model results for nitrate replenishment exceed previously estimated rates of 20–30% based on observations (Whitledge and Luchin 1999). This study indicates that nitrification, potentially the source of up to ~38% of the springtime water column nitrate, could support ~24% of the annual primary production.

**Development of 3-D Coupled Ice-Ocean Ecosystem Model**

By implementing the IARC 1-D ice ecosystem model in the Los Alamos National Laboratory sea ice model, or CICE, we extended the ice-ecosystem model to a pan-arctic
scale (Deal et al. 2009). This early generation model includes an ocean mixed layer that supplies nutrients to the ice. Ice algal biomass expressed as Chlorophyll \( a \) (Chl \( a \)) concentration was simulated. The model also outputs ice algal primary production and dimethylsulfide concentrations. Polar plots of weekly (Figure 2) and monthly mean Chl \( a \) (mg Chl \( a \) m\(^{-2}\)) reveal spatial patterns of ice algal biomass accumulation consistent with observations. In particular, the vicinity of the Beaufort Gyre stands out as a region of low ice algal accumulation. The maximum value in the central arctic is around 15 mg Chl \( a \) m\(^{-2}\), while a significant portion of the surrounding regions exceeds 100 mg Chl \( a \) m\(^{-2}\). It should be noted that this model does not yet take into account a number of potentially significant processes, such as zooplankton grazing and sediments in sea ice. However, these model results may offer advantages over extrapolations based on sparse field observations alone.

![Polar map of base ten logarithm simulated mean ice bottom layer Chl a concentration (mg Chl a m^{-2}) for mid-May. The white line is the 15% ice edge contour, and the black lines are ice thickness contours of 1, 2, 3, and 4 m, working inward from the ice edge.](image)

**Figure 2.** Polar map of base ten logarithm simulated mean ice bottom layer Chl a concentration (mg Chl a m\(^{-2}\)) for mid-May. The white line is the 15% ice edge contour, and the black lines are ice thickness contours of 1, 2, 3, and 4 m, working inward from the ice edge.

We have focused our ecosystem model development on the Bering and Chukchi seas, where we have most of our observations for model validation and collaboration with JAMSTEC and JAXA observational scientists. Primary production in the Bering and Chukchi seas is strongly influenced by the annual cycle of sea ice. Ecosystem modeling of sea ice associated phytoplankton blooms has been understudied compared to open water ecosystem model applications. We are developing 3-D ecosystem models based on the 1-D coupled ice-ocean ecosystem model in the landfast ice in the Chukchi Sea and marginal ice zone of Bering Sea. The biological model includes both pelagic and sea ice algal habitats with 10 compartments: three phytoplankton (pelagic diatom, flagellates and ice algae: \( D, F, \) and \( Ai \)), three zooplankton (copepods, large zooplankton, and
microzooplankton: $ZS$, $ZL$, $ZP$), three nutrients (nitrate+nitrite, ammonium, silicon: $NO_3$, $NH_4$, $Si$) and detritus ($Det$). The coupling of the biological models with physical ocean models is straightforward with just the addition of the advection and diffusion terms to the ecosystem model. The coupling with a multi-category sea ice model requires the same calculation of the sea ice ecosystem model in each ice thickness category and the redistribution between categories caused by both dynamic and thermodynamic forcing as in the physical model (Jin et al. 2008).

**Figure 3.** Preliminary results from CICE-ecosystem model: Ice concentration and ice algal biomass at the bottom of sea ice on May 13, 1981.

_Bering Sea seawater iron and organic ligand distribution during spring_

Spring productivity in the Bering Sea is affected by the dynamics of its seasonal ice cover. Upon melting, sea ice can provide a source of iron (Fe) to the surface waters and influence the dynamics of the spring bloom. As shown in Figure 4, the surface water dissolved Fe distribution is influenced by the depth of the shelf and, in the outer shelf, by inputs from sea ice, where Fe concentrations also influence spring phytoplankton bloom (Aguilar-Islas et al. 2008). This result has implications to Bering Sea productivity resulting from expected future sea ice reduction. The additional input of Fe from sea ice is held in solution by excess concentrations of organic ligands with a high affinity for Fe.
**Figure 4.** Distribution of surface dissolved iron during April/May 2007.

*Gulf of Alaska Fe distribution*

Mechanisms controlling the high productivity of the continental shelf and slope of the northern Gulf of Alaska (GoA) are not well understood. Results from the US NEP-GLOBEC (Northeast Pacific Global Ocean Ecosystem Dynamics Program) studies show that Fe availability might be an important factor. Here we report the first data (Figure 5) on the cross shelf distribution of dissolved (<0.4 µm) and total weak acid dissolvable (unfiltered) Fe in the continental shelf and slope of the northern GoA during spring-summer. Large cross-shelf gradients of surface water Fe concentrations were observed in these productive coastal waters during both seasons. These Fe concentration gradients likely resulted from the influx of Fe by the enormous coastal freshwater discharge along the shelf margin that contains high concentrations of fine-grain, glacial-weathered particles.
Aerosol Fe dissolution – colloidal fraction, solubility and air mass trajectory

Atmospheric deposition provides a major source of Fe to the remote ocean. Only the portion of aerosol Fe that dissolves following its deposition on the surface ocean is thought to be bioavailable. In this paper, we estimate the portion of aerosol Fe that is soluble in seawater and determine that most of the aerosol Fe that dissolves in seawater is in the form of small Fe colloids rather than in truly soluble form. This is a new finding that provides useful data for marine ecosystem modeling involving Fe.
Pacific water transport in the Arctic Ocean in an eddy-resolving coupled sea ice-ocean model

The process of the Pacific water transport from the Chukchi shelf to the Canada Basin is investigated by using an eddy-resolving coupled sea ice-ocean model with realistic experimental design. The model used in this study is the Center for Climate System Research Ocean Component Model (COCO) version 3.4 developed at the University of Tokyo (Hasumi 2006). The model domain is the Chukchi Sea and the southern area of the Canada Basin. The horizontal resolution is about 2.5 km so that mesoscale baroclinic eddies are explicitly resolved.

The simulation result shows that a significant part of the Pacific water which passes through the Bering Strait during summer is transported by the northward currents following major features of bottom topography over the Chukchi Sea, and then flows into the Canada Basin by mesoscale baroclinic eddies over the Beaufort shelf break (Figure 7). The shelf-to-basin transport of the Pacific water reaches maximum during late summer and early autumn when the eddy activities are enhanced. Each eddy has a baroclinic anticyclonic structure and its horizontal and vertical scales grow up by being merged with other ones from August to October and then gradually shrink. Their maximum sizes reach about 50 km in the horizontal and 200 m in the vertical, respectively. The analyses of energetics and instability condition indicate that the eddies are generated and developed due to both baroclinic and barotropic instabilities of an intense and narrow jet through the

Figure 6. Percent fraction of soluble and colloidal Fe released from seawater leaching of aerosol samples collected from various locations shown in the x-axis.
Barrow Canyon and have a lifetime of several months. Comparison of the simulated eddies with those in other eddy-resolving model whose horizontal resolution is about 9 km (Maslowski et al. 2008) suggests the increasing of horizontal resolution clearly improves the representation of spatial scale of the eddies, although the scale still seems to be relatively large compared to some limited observations (Manley and Hunkins 1985). Further increases in horizontal resolution might continue to improve the representation of mesoscale eddies in this region. The pathway of each eddy is also one of important physical and biological concerns. Nishino et al. (2008) insist the distributions of nutrients and chlorophyll-\(a\) on both sides of a hydrographic front over the Chukchi Plateau could provide insight into spatial biological responses to sea ice reductions. The eddies simulated in our model travel northward along the Northwind Ridge, so a close relationship between primary production and the eddy-induced transport is suggested. Accumulation of more observational data which detect characteristics of the shelf break eddies is indispensable to validate the simulated eddy properties and to deepen understanding of mechanisms of the shelf-to-basin transport.

Simultaneously, we will proceed to implement a coupled sea ice-ocean-ecosystem model which accounts for interannual variations of sea ice extent, atmospheric forcing such as wind stress, downward shortwave and longwave radiation, and chlorophyll-\(a\) concentrations which are either derived from ship fields (e.g. R/V Mirai and T/S Oshoromaru cruises) and satellite data (e.g. Aqua/MODIS and Aqua/AMSR-E), in order to quantify the change in marine primary productivity induced by sea ice loss in the Arctic Ocean.

![Figure 7](image)

**Figure 7.** Vertically cumulate concentration of the virtual Pacific water tracer in October [m].
*New Methodologies for Estimating and Mapping Influential Parameters to Arctic Sea Ice Change*

*Age Structure of Arctic Sea Ice*

Previous studies of sea ice age by Rigor and Wallace (2004), Fowler et al. (2004), and Belchansky et al. (2005) used slightly different data and techniques, but were generally based on tracking ice parcels or particles through time. Particle tracking, however, is unable to resolve the role of deformation because particles have no area. We improved the currently available methods for estimating the age structure of sea ice, not only in the Arctic Ocean overall, but for each grid cell in particular. Unique to our new methodology is the maintenance of a dynamic age-class distribution function (ADF) that is attributed to each grid cell area.

Sea ice age was estimated and mapped using ice motion data to follow pixels of ice forward through time while maintaining an ADF within each pixel. During January 1979 to December 2006, ice motion vectors were applied to move the entire area of each ice-covered pixel at monthly time-steps for up to 121 months. After each time-step, new ADFs were rebuilt from a superposition of ADFs in cases of ice convergence, or a new age class was introduced to the ADF in cases of ice divergence and new ice formation.

Maintaining internal ADFs preserves a methodological precision by circumventing the need to assign a single age class to each pixel after each monthly ice-tracking iteration. Consistent with other studies of ice age based on ice motion data, our results show a substantial loss of old ice in the Arctic (Figures 1, 2). Internally quantifying the month-to-month dynamics of the ADFs provides additional information about the relative roles of dynamic and thermodynamic mechanisms that underlie ice extent changes.

The Northern Hemisphere is a closed system with respect to sea ice; there is no ice import or export across its boundaries. Our results indicate that each year, on average, 84% of the sea ice that is lost is due to melt and 16% is due to deformation. Within just the deep-water region of Arctic Ocean basin (an open system because ice import/export occurs across its boundaries), ice is lost due to melt (28%) and deformation (58%), as well as net ice export (16%).

Each year, on average, about 12.6×10^6 km^2 (100%) of new sea ice is formed in the Northern Hemisphere. Approximately 1.0×10^6 km^2 (7.9%) of the first-year ice extent is lost due to deformation and 9.5×10^6 km^2 (75.6%) is lost due to melt, while 2.1×10^6 km^2 (16.5%) survives the summer and ages to the perennial ice category. In the deep-water Arctic basin, annual ice growth averages about 1.9×10^6 km^2 (100%). The annual net export of first-year ice is negative and small (1.4%), but is an additional source of gain. About 0.2×10^6 km^2 (12.7%) and 0.3×10^6 km^2 (16.2%) of the first-year ice extent in the deep-water Arctic basin is lost due to deformation and melt, respectively, and 1.4×10^6 km^2 (72.5%) survives to become multiyear ice. Most of the multiyear ice that is recruited each year is originally formed in October. The insignificant net export of first-year ice from the Arctic basin suggests that the vast majority of ice flowing out of the Arctic basin is comprised of multiyear ice.
Figure 8. The fraction (%) of sea ice cover greater than 36 months old in September, 1982–2006.
Figure 9. Monthly extent (log scale) of 10 perennial sea ice age categories. The notable increase in extent of 2nd year ice in 1996 was due in part to a short melt season, and the notable loss of old ice in 1998 occurred primarily in the high-latitude Canadian Archipelago after an unusually warm summer.

**Summer Surface Albedo and Melt Pond Fraction**

We are developing a methodology that uses AVHRR visible, infrared, and thermal imagery with passive microwave satellite remote sensing data to estimate albedo and melt pond fraction at monthly intervals. AVHRR data are used to develop linear relationships between passive microwave brightness temperatures, air temperature, and ice concentration for estimating broadband albedo and melt pond fraction. By virtue of the long-term archive of SMMR-SSM/I passive microwave measurements, albedo and melt pond fraction are estimated Arctic-wide during the summers of 1979–2007.

Our results for the mid-summer month of July show negative albedo trends and corresponding positive melt ponding trends in the Chukchi Sea region (Figures 10C and 11C), consistent with this region’s well-established decline in summer ice cover. July 2007 albedo and melt ponding anomalies were widespread in the East-Siberian and Chukchi Seas sector of the Arctic (Figures 10D and 11D), also consistent with this region’s extensive ice loss that has been observed in recent years.
Our methods for estimating summer sea ice albedo and melt pond fraction over broad spatial and temporal scales using passive microwave remote sensing data show promising results. More validation data are needed to evaluate the methods and potentially fine-tune the a priori relationships we defined between melt pond proportion and surface temperature and albedo. Elaborating the methods to accommodating non-linear relationships with the passive microwave data might also improve model
accuracies. Nevertheless, even the linear models provide plausible insights into regional and interannual variability in albedo and melt ponding.

**Spatial and Long-Term Variability of Multi-Year Ice Distribution**

We have estimated a 30-year (1979–2008) record of January-March multi-year (MY) sea ice distribution, using a neural network analysis of SMMR-SSM/I passive microwave brightness temperatures (Belchansky et al. 2004, 2005). Preliminary results for January 2009 have been received.

Our results shows that since 2002, MY sea ice area has persistently decreased, with minimal values over the Arctic Ocean in 2007 ($2.50 \times 10^6 \text{ km}^2$), 2008 ($2.08 \times 10^6 \text{ km}^2$) and 2009 ($1.70 \times 10^6 \text{ km}^2$). Study area excludes 50 km near-shore zone and a hole around the Northern Pole with latitudes from $87.6^\circ \text{N}$ undetected by the SSM/I.

The most dramatic MY sea ice declines occurred in 2008 and 2009 (Figure 12). Average January 2009 MY sea ice cover shows substantial losses in the sector $150^\circ \text{E}$-$140^\circ \text{W}$ covering East Siberian, Chukchi Seas and adjacent parts of Arctic Ocean. The marginal zone of high interannual multi-year ice flux expanded northward eroding the central Arctic’s MY ice.

**Figure 12.** January MY sea ice concentration: long-term average 1979–2009; 2008 and 2009 distribution; trend; and 2008, 2009 anomalies. Shaded contours delineate significant ($S > 95\%$) slope.
Presentations

Seminars and Workshops Attended
Oct 1-9, 2008, Satellite monitoring of Arctic ice habitats under global climate change conditions. Third Russian-Polish scientific school for young ecologist. Zakopane, Poland, Invited speaker, Platonov, N.G.

Publications


Arctic Ocean Models and Observations

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2. Summary of Research Activities and Accomplishments

Jennifer Hutchings

Changes in the distribution of sea ice thickness, and hence arctic ocean-atmosphere fluxes, are controlled by ice growth, melt, advection, and deformation. There is much variability in the rate of growth and melt due to meter-scale spatial heterogeneity in ice thickness, snow cover, as well as oceanic and meteorological conditions. The meter-scale spatial heterogeneity is controlled by the super-position of thermodynamic response on an icescape sculpted by the mechanical redistribution of ice thickness. Mechanical deformation occurs abruptly, predominantly in winter, causing linearly organized regions of deformation which manifest as leads and ridges. To understand the impact of ice dynamics on sea ice mass balance, we require an accurate representation of how mechanics and thermodynamics relate to variability in boundary forces on the ice pack.

Jennifer Hutchings is leading observationally based investigations to validate sea ice redistribution models and understand how deformation affects sea ice mass balance. Collaborations, focused on joint buoy deployments, with JAMSTEC, CRREL and NPL are building a dataset with which the influence of sea ice deformation on ocean heat fluxes can be estimated. Sea ice deformation is only one of the mechanisms that influence sea ice mass balance, and IARC is contributing to the Arctic Observing Network to provide deformation observations for sea ice mass balance monitoring. Hutchings is also participating in a CliC working group to develop standards for pan-Arctic sea ice observations, which may lead to monitoring of the arctic sea ice mass balance. The IARC sea ice observation program has provided unique information with which to elucidate mechanisms controlling the end of summer ice extent in the Beaufort in 2006 and 2007. This data is used to validate satellite products that monitor the arctic sea ice pack.

During fiscal year 2008–2009 the sea ice observations group maintained and collected data from several sea ice deformation buoy arrays that were deployed in previous fiscal years. The International Arctic Buoy Program database was searched to identify historical buoy triads with which to monitor ice deformation in the Beaufort Sea. The ship observation program on the CCGS Louis S. St. Laurent, with a berth provided by the Institute of Ocean Sciences, was continued for a third year. This body of investigation resulted in a paper (Hutchings & Rigor, accepted pending revision). Data from previous campaigns, including the ISPOL drifting station in the Western Weddell Sea, continues to provide insight into the nature of sea ice deformation. Analysis of this data during 2008 is being prepared as a paper with co-authors Heil, Hibler, Worby, Steer, Haas, Lauianiai and Johansson. The paper is titled “Spatial variability of sea ice deformation in the western Weddell Sea during summer” and investigates transitions
between deformation regimes in the ice pack. Further work is underway, with the same collaborators, to independently verify deformation fractal scaling relationships identified by Weiss, Marsden, Stern, and Lindsay.

Collaborations with Jun Inoue and Takashi Kikuchi, JAMSTEC, are strengthening. During cruises in summer, 2008, Japanese and American parties deployed bridge ice cameras to develop an autonomous ship-based ice observation system. This data is being used in validation of passive microwave sea ice concentration. Undergraduate research assistant Alice Orlich, who is employed in this project, presented a satellite-ship comparison at the 2008 Annual American Association of Geographers meeting.

A collaboration with Bill Shaw, Naval Postgraduate School, to understand how sea ice deformation affects ocean-atmosphere heat flux from drifting buoy observations, highlighted the need for routine deployment of sea ice deformation buoy arrays around drifting ice stations. Plans were executed for a joint deployment of buoys with Takashi Kikuchi, JAMSTEC, and others at the North Pole Environmental Observatory in spring 2009. Pending successful deployment, a joint analysis of J-CAD ocean profiling and sea ice deformation data is anticipated for 2009–2011.

Hutchings attended a workshop on coordination of arctic sea ice observations, and has agreed to represent North America and be international coordinator for disseminating information regarding sea ice specific field campaigns throughout the Arctic. The aim of this CliC sponsored working group is to develop observation standards and archiving, to enhance international cooperation and collaboration in sea ice research. It is anticipated that the fledgling JAMSTEC-IARC ship observation program will become incorporated into an international pan-Arctic coordination of ship observations.

**Figure 1.** An example of the utility of a sea ice observation data base that is to be developed. Visual observations of ice concentration from four cruises (*Louis S. St. Laurent*, NABOS, Oden and Polarstern) were collated at IARC and compared to ice concentration estimated by the NASA Team algorithm. Difference between in-situ ship observation and near time coincident satellite estimate is plotted.
Ice Station POLarstern (ISPOL)

Sea ice drift and deformation in the Western Weddell Sea during December 2004 was characterized using in situ data from a meso-scale array of 24 drifting ice buoys. Horizontal GPS-derived position measurements are available from drifting buoys deployed as part of the Ice Station POLarstern (ISPOL) experiment for about 26 days during late November and December 2004, at various temporal resolutions and with different spatial accuracies. These data form the basis for sea ice velocity and deformation measurements across the meso-scale ISPOL array and at two remote sites. Analysis of the sea ice velocities reveals coherence for sea ice drift at separations of less than 70km, and a correlation length scale of 60km. No such coherence is obvious in the deformation field. Within the limits of the ISPOL array, at larger separations zonal ice drift remains correlated, while meridional ice drift becomes uncorrelated. This together with the east-west gradient in ice velocities indicate the influence of bathymetry, via tidal forcing, on local dynamic processes. Atmospheric forcing also contributed to the sea ice drift: About 40% of variability in the sea ice velocity is explained by changes in wind velocity, which is significantly less than other studies have found for the region during winter. Sea ice deformation was derived for the overall array and a set of sub-arrays with varying area between 10 to 2500 km². The net divergence of the ISPOL array was in excess of 30%, with the largest contribution to divergence from the southern section and along the eastern side of the overall ISPOL array. We observe considerable spatial variability in deformation rate components between sub-arrays. A log-log linear scale dependency between strain rate and area of buoy sub-array was identified. Sea ice deformation displays fractal behavior over the spatial scale resolved by the ISPOL buoy array, which indicates that ice pack deformation may be modeled with an identical rheological model across these scales, provided ice strength is appropriately scaled. Temporal variability for all deformation parameter is dominated by high-frequency (sub-daily) processes, namely tidal forcing and inertial response. Low-frequency (multiple days) processes, including atmospheric changes, played a secondary role in forcing sea ice deformation during ISPOL.
Validation of satellite passive microwave ice area products

Ship-board ice observation during summer cruises provide ice type, concentration and surface conditions (melt ponds, albedo information, roughness) to validate passive microwave satellite end of summer ice concentration products. This information, combined with satellite products and in-situ buoy data, provides a detailed description of the end of summer ice pack.

Hourly sea ice observations were recorded from the Canadian icebreaker CCGS *Louis S. Saint Laurent* during August and September, 2006 and 2007, closely following the ASPECT methodology with some deviations (see field reports for details). We have identified a $30\pm10\%$ low bias in the NASA Team Passive Microwave sea ice concentration in regions of young ice at an advanced stage of melt (Figure 1). Hourly observations are only useful in characterizing homogeneous regions of ice, and we do not sample sufficiently to identify errors in regions of $<60\%$ patchy ice.
Figure 3. (left & middle panel) Maps showing location of ice observations taken during Louis S. St. Laurent cruises in August/September 2006 and 2007. Ice concentration estimated visually minus SSMI NASA Team estimated ice concentration, observed on the same day, are plotted for both years. The two green boxed regions contained similar ice in both years: thin, >80% coverage consolidated young (first year or second year) pack that experienced stage 4/5 melt by the end of summer (>30% melt pond coverage, flooded ice). In 2007 the pack was still melting when we entered the region, and in 2006 we entered this region 2 weeks later, the surface had begun to freeze and there was near surface blowing snow. (right panel) Data is plotted for regions in the green boxes. 2007 is shown as crosses and 2006 triangles. SSMI Ice concentration was underestimated by 30% in 2007 compared to 10% 2006.

Mechanisms of recent sea ice change in the Beaufort Sea

Unusual Beaufort Sea ice conditions, in summers 2006 and 2007, were documented with a combination of in-situ and satellite observations. We show that the drift of sea ice into the Beaufort and divergence precondition recent summer ice conditions.

Intrusions of first year ice from the Chukchi Sea to the Northern Beaufort, and recent reduction in size of the Beaufort Gyre has led to reduced replenishment of older, multi-year ice in the western Beaufort, resulting in a younger, thinner ice pack in most of the Beaufort. However, during the winter of 2006, an anomalous southward, then westward push of MY ice formed an ice tongue that survived the summer melt season. To the north of this tongue of MY ice, there is a trend over the last decade towards increasing late winter pack divergence. This leads to 20-30% thin ice area of melting out earlier in summer, which may precondition the accelerated summer ice loss observed in recent years. Late winter opening in 2007 was two times greater than previously observed. Our results support the Perovich et al. (2008) hypothesis that summer 2007 thinning of MY ice was caused by an increase in solar absorption in the upper ocean due to lower sea ice concentration than normal, as the low ice concentration was partially driven by an anomalous opening event in the Beaufort Sea perennial ice pack in spring 2007.
Figure 4. Buoy divergence driven model of FY ice evolution during winter. Time series of open water and FY ice area is shown [top], and time series of mean FY ice thickness (bottom). Dotted lines show the date of melt onset according to the Maykut & Untersteiner (1971) growth/melt rate data set. Data is shown for buoy arrays that encompass the Beaufort Sea region. In this decade we observe greater opening in the Beaufort Sea perennial ice pack during winter, which results in a larger area and volume of first year ice compared to the 1990s.

Gleb Panteleev
Atmospheric reanalysis products play a major role in arctic system studies. They are used to force sea ice, ocean and terrestrial models, to analyze the climate system’s variability, and to explain the relationships among the system’s components and the causes of their change. Motivated by this success, I work on developing an integrated set of assimilation procedures for the ice-ocean system that is able to provide:
- gridded data sets that are physically consistent and optimally constrained to the observations of sea ice and ocean parameters (ocean reanalysis).
- operational hindcast/forecast of the circulation.
- optimal sampling strategy.

Developing a new version of the 4Dvar data assimilation model
A Semi Implicit Ocean Model (SIOM) was designed specifically to implement the 4D-var methods into the Arctic Ocean and regional models controlled by currents at the open boundaries and by surface fluxes. SIOM is a modification of the C-grid OGCM developed in Laboratoire d’Oceanographie Dynamique et de Climatologie (Madec et al. 1999). The new features of the SIOM are: a) implicit formulation of the diffusive adjustment; b) orthogonal curvilinear coordinates; c) hybrid (z and σ) vertical grid (these new features are important for the better approximation of the complicated coastline and topography); d) a tangent linear model obtained by direct differentiation of the forward model code; e) an adjoint code of the model built analytically by transposing the operator of the tangent linear model, linearized in the vicinity of the given solution of the forward model.
Developing a new version of the 4Dvar data assimilation approaches

A version of the reduced control space four-dimensional variational method (R4dVar) of data assimilation into numerical models is proposed. In contrast to the conventional 4dVar schemes, the method does not require development of the tangent linear and adjoint codes for implementation.

The proposed R4dVar technique is based on minimization of the cost function in a sequence of low dimensional subspaces of the control space. Performance of the method is demonstrated in a series of twin-data assimilation experiments into a non-linear quasigeostrophic model utilized as a strong constraint. When the adjoint code is stable, R4dVar’s convergence rate is comparable to that of the standard 4dVar algorithm. In the presence of strong instabilities in the direct model, R4dVar works better than 4dVar whose performance is deteriorated due to the breakdown of the tangent linear approximation. Comparison of the 4dVar and R4dVar also shows that R4dVar becomes advantageous when observations are sparse and noisy.

![Figure 5](image)

**Figure 5.** Relative reduction of the cost function $J/J_0$ for the experiments with the unstable and stable tangent linear and adjoint model.

Reanalysis of climatological circulation in the Bering Sea

During 2007–2008, I continued my work on the climatological reanalysis of the circulation in the Bering Sea. I reconstructed the mean spring and fall circulations. An analysis of these fields resulted in a qualitatively new estimate of the volume balance in the Bering Sea (Table 1) and qualitatively new reference sea surface height.

The new SSH reference together with satellite SSH anomaly give an estimate of total barotropic transport through the Aleutian passes. Our results indicate significant amplitude of inter-annual and seasonal variability through the Kamchatka and Near straits (Figure 6).
Currently I am working on the Regional Dynamical and Hydrophysical Atlas of the Bering Sea. Such a atlas will summarize the climatological seasonal distributions of temperature, salinity, velocity, and sea surface height (SSH). The final version of the atlas will include the SSH, temperature, salinity, and velocity fields.

Reanalysis of the circulation in the Arctic Ocean (funded by NSF)

A pilot project: Reconstruction of the circulation in the Chukchi Sea during 1990–1991

Existing conventional methods of oceanic modeling with data assimilation do not have algorithms for the coupled ice-ocean systems. In order to reach project goals, we have developed an approach based on employing two models: SIOM and PIOMAS (Zhang et al. 2002). SIOM uses a conventional Four Dimensional Variational (4D-VAR) technique. It does not have sea ice but uses all the needed information from PIOMAS which is a regional coupled ice-ocean model with simplified nudging assimilation of the ice data. A schematic of this procedure is shown at Figure 7.

Figure 7. A schematic of the data assimilation procedure based on 4Dvar assimilation of the ocean data into SIOM and nudging assimilation of the ice data into PIOMAS.

We reconstructed circulation in the Chukchi Sea for a one-year period (1990–1991). Analysis of the reconstructed circulation allows us to identify and quantify the pathways of the Pacific water into the Arctic Ocean.
d) Developing an optimal sampling strategy for the Bering Strait.

We performed an adjoint sensitivity study in order to estimate the efficiency of different sampling strategies in the northern part of the Bering Strait. Our results indicate several regions where the mooring observations provide the maximum correlation with the Bering Strait transport. We showed that accurate estimates of the circulation can be obtained with only four moorings deployed in “hot spots” identified with the adjoin sensitivity analysis. The technique can be extended for other regions.

<table>
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<th>Sections</th>
<th>BS</th>
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<th>BSW</th>
<th>LS</th>
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<td>-0.06</td>
<td>0.23</td>
<td>0.33</td>
<td>0.19</td>
<td>0.14</td>
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</tbody>
</table>

**Figure 8.** a) Climatological mean summer circulation in the northern Bering Sea obtained by variational inversion of the hydrographic, drifter and mooring observations. Contour interval is 0.1 Sv. b) Normalized sensitivity map of the Bering Strait transport to transport observations in the model domain. Locations of the moorings simulated in the twin-data experiments, are shown by capital letters.

**Reconstruction of the circulation in the East Siberian Sea during 1995**

This is a collaborative research with Dr. Kukuchi (JAMSTEC). The basic goal is to reconstruct the circulation and SSH. The reconstructed SSH will provide a non-stationary SSH reference. The snapshot of the reconstructed circulation is shown at Figure 9.
Figure 9. Reconstructed circulation and SSH in the Chukchi and East Siberian seas during September 1995.

Vladimir Ivanov

Our recent (2004–2008) mooring-based observations along the Eurasian continental margin in the Arctic Ocean demonstrate that the temperature in the intermediate Atlantic Water (AW) layer oscillates on a seasonal basis. This newly obtained knowledge has a fundamental significance for the Arctic Ocean climatology. Instead of the traditional concept, which implies gradual downstream cooling in a boundary flow, we have to consider a quasi-periodic ‘wave-like’ pattern with a wavelength defined by the advection length scale. The range of AW heat content variation associated with the seasonal cycle is of the same order of magnitude as the range of local mean AW heat content, suggesting an important role of seasonal changes in the intensity of the upward heat flux eventually affecting the ice cover. In the view of recent reports about substantial warming in the AW layer (e.g. Polyakov et al. 2005, Dmitrenko et al. 2008), reliable information about seasonal changes in AW becomes particularly important if we are to avoid mistaking the seasonal signal for the large-scale thermohaline anomalies. Using a combination of data analysis and modeling, we simulated propagation of the seasonal signal from Fram Strait to the East Siberian Sea. Results of this analysis gave us grounds to predict warming/cooling trends in the AW layer in the Laptev Sea and the East Siberian Seas for the next 5 years.
Figure 10. Observations provide evidence that strong (~ 0.5°C in amplitude) seasonal cycle in the AW layer reaches the East Siberian Sea, about 1500 nautical miles from Fram Strait. Thick lines show 3-months running average.

Igor Polyakov

NABOS cruise

The 2008 research cruise in the Arctic Ocean aboard the icebreaker Kapitan Dranitsyn was the 7th annual expedition under the aegis of NABOS (Nansen Amundsen Basin Observations System) conducted by the International Arctic Research Center (IARC) University of Alaska Fairbanks in partnership with the Arctic and Antarctic Research Institute (AARI) St. Petersburg, Russia. The main goal of the NABOS project is to provide quantitative assessment of circulation and water mass transformation along the principal pathways transporting water from the Nordic Seas to the Arctic Basin. This goal and the opportunities of extended scientific research in the Arctic provided during NABOS expeditions encouraged scientific institutions from the U.S., Canada, and Europe to raise funds, contribute to the cruise program, and send their personnel on the expedition, thus giving it a true multidisciplinary status. The 2008 NABOS cruise was carried out in the beginning of the arctic winter, when the daylight was limited to 4–6 hours, the temperature was continually below zero, and the ice was growing rapidly. Information collected under these extreme conditions is valid for understanding the arctic climate. However, the complexity of all field activities increases tremendously. This report covers the cruise route and schedule and meteorological and ice conditions. It briefly describes observations carried out during the 2008 NABOS cruise.

The icebreaker Kapitan Dranitsyn left Kirkenes, Norway, at 6 p.m. local time on October 2, 2008. The research area included Eurasian continental margin from Spitsbergen to the East Siberian Sea (Figure 11).
Our operation area partly overlapped with the Russian Exclusive Economic Zone (EEZ). Permission to conduct fieldwork within the Russian EEZ was not granted at the time our cruise began, thus restricting maneuvering options. Hence, the work started at the mooring site M1 outside the Russian EEZ on October 7, 2008. An attempt to recover the mooring failed due to a malfunctioning release. An attempt with the other release was not made because of coming dusk and heavy ice conditions (see Section 3). On October 7 and 8, the northern part of transect A (5 stations) was accomplished. Operations at the transect B started late at night on October 10 and continued during the next 3 days. On October 11, permission for operations within the Russian EEZ was received. Ten stations were occupied including the 12-hour shelf station at the southernmost end of this transect. Two moorings at this transect (M8 and M3) did not respond to acoustic signals and were abandoned. The easternmost transect C, containing 8 stations, was occupied within October 13–16. Two moorings (M10 and M9) were recovered and one mooring (M9) was deployed. During October 18–19 the southern part of transect A was accomplished and M1 mooring was deployed. Another attempt to recover M1 mooring was not made because of 100% ice concentration (no leads) and coming dusk. Three days, October 21–23, were spent to recover two moorings (M5 and M6) and to carry out 9 stations at the D transect northeast of the Severnaya Zemlya archipelago. An attempt to pick out the shelf mooring deployed back in 2005 at 180 m depth on the Severnaya Zemlya shelf was unsuccessful, although this mooring did respond after 3 years in the water. On the way to the westernmost transect E, a high resolution (20 XCTD/XBT casts) transect was taken.
Triangulation of moorings M7 and M4 showed large discrepancy (several hundreds of meters) in positions of bottom releases and top transponders. This discrepancy might be caused by strong currents, which incline the wire in the upper part, as was documented at M4 during the 2004–2006 deployment. Both moorings were covered by kilometers-scale ice fields. Besides, instead of full daylight, there was only 3 hours of twilight between dawn and dusk. Under these conditions, it was decided to cancel recovery/deployment of these moorings. However, while taking the stations around M4, the ice situation improved dramatically and the M4 mooring was successfully recovered by 4 p.m. on October 28. Immediately after this recovery, Kapitan Dranitsyn started sailing to Kirkenes to stay within the cruise schedule.

**Contributing to IPY:** NABOS has been an unqualified success. In this time of rapid environmental and political change, it presents to the global community a critically important scientific and political inroad to understanding the Arctic. Our program has become a vital element of the IPY. It enhances international cooperation, resulting in shared research infrastructure and updated databases, and fostering synergy and interdisciplinary dialog (Figure 12). Our observational network has become an important element of the Arctic Observing System by providing key observations about changes in high-latitude regions.

![Figure 12](image)

**Figure 12.** NABOS contribution to the IPY mooring program. Blue dots show locations of moorings deployed by NABOS with partners. Red dots show locations of all other moorings.
**Documenting Arctic Ocean warming:** Our observations in previous years showed that the exceptional warming which entered the Eurasian Basin in 1999 progressed from Fram Strait along the Barents and Laptev slopes (for details see Polyakov et al. 2005, 2007). This year, the CTD cross-section carried out in the East Siberian Sea shows that this warming passed its tipping point. The Near-Svalbard mooring showed a two-year steady cooling trend (Figure 13). NABOS observations documented bursts of warm water passing through halocline (Figure 14), which illustrates the importance of warm intermediate Atlantic Water to ocean and ice heat and mass balance.

**Figure 13.** Observations provide evidence that unprecedented warming of the Arctic Ocean observed in the 2000s passed its tipping point.
Figure 14. Temperature (upper panel) and salinity (lower panel) time series at M5 mooring.
External Presentations


November, 2008, ISAP-1 meeting, Tokyo, Japan.


July, 2009, International Polar Year Conference, St. Petersburg, Russia. Observational program traces Arctic Ocean warming. V. Ivanov

May, 2008, Modeling of oceanographic processes in the Arctic Ocean. Scottish Association of Marine Science (SAMS). Invited speaker, V. Ivanov


Hosted Visitors
Max Yaremchuk, International Pacific Research Center, USA
Vladimir Luchin, Far Eastern Branch of the Russian Academy of Science, Russia

Web Site Addresses
http://www.frontier.iarc.uaf.edu/NABOS
http://www.frontier.iarc.uaf.edu/CABOS
http://www.frontier.iarc.uaf.edu/NABOS/cruise/cruise_04.php
Publications in 2008–2009

Published


Accepted


**In Preparation**

Hutchings J.K. and co-authors. Ship based validation of satellite passive microwave estimates of sea ice concentration.


Monitoring of Soil Respiration in Black Spruce Forest Soil, Interior Alaska

This research was carried out to estimate the continuous monitoring of soil respiration using an automatic chamber system that was equipped with a control system, a compressor, and seven chambers (50 cm diameter, 30 cm high). It was set in sphagnum moss, feather moss, lichen, and tussock in black spruce forest soils, interior Alaska, during the growing season of 2008. The average daily soil respirations were 0.050±0.012 (standard deviation, CV 23%), 0.022±0.020 (91%), 0.082±0.035 (43%), and 0.027±0.010 mgCO2/m2/s (37%) in lichens, sphagnum moss, tussock, and feather moss on black spruce forest soils with a light chamber made with transparent material. The temporal variation of soil respiration in different vegetation types on black spruce forest soils during the growing season of 2008 is shown in Figure 1. The accumulative daily soil
respiration was 5.2, 9.5, 2.3, and 2.8 mgCO$_2$/m$^2$/s in lichen, tussock, sphagnum moss, and feather moss of black spruce forest ground during the growing periods of 103 days, 2008 (Figure 2). Therefore, the averaged regional soil respiration rate is 0.19±0.18 and 0.12±0.08 kgC/m$^2$/(growing season) for 2007 and 2008 in black spruce forest soils, interior Alaska. The winter soil respiration was 0.049±0.013 gC/m$^2$/(winter season), corresponding from 21±7% to 29±13% of the annual CO$_2$ emitted from black spruce forest soils, interior Alaska. This fraction is similar to 23% measured by Kim et al. (2007).

Figure 1. Temporal variations of diurnal soil respiration rate (mgCO$_2$/m$^2$/s) on lichens, tussocks, sphagnum moss, and feather moss on the ground of black spruce forest soils, interior Alaska, during the growing season of 2008. The tussock tundra is a significant source of different vegetations of black spruce forest soils.
Measurement of Stem Respiration of Black Spruce, Interior Alaska

This stem respiration was conducted in parallel with the flux-measurement of soil respiration in different-aged black spruce forest, interior Alaska, during the growing season of 2008. The average stem respiration was 0.011±0.005 mgCO₂/m³/s (range 0.005±0.002 to 0.015±0.008 mgCO₂/m³/s, CV 45%) in black spruce forests, where the DBH (Diameter at Breast Height) of black spruce ranges from 4.3 to 13.5 cm. The temporal variation of stem respiration in different-aged black spruce forest soils during the growing season of 2008 is shown in Figure 3. This suggests that the young black spruce has more than a 3-fold higher metabolism than the old. The Q10 values on temperature of ambient and stem are 3.10 and 2.87, respectively (Figure 4). The seasonal Q10 values on ambient temperature are 2.73 for May/June, 2.55 for July, and 1.59 for August. The Q10 on stem temperatures are 2.53 for May/June, 2.34 for July, and 1.62 for August, respectively. The stem respiration on the ambient temperature is somewhat sensitive rather than stem temperature.
Figure 3. Temporal variations of diurnal stem respiration rate (mgCO₂/m³/s) in different-aged black spruce, interior Alaska, during the growing season of 2008. The younger black spruce have more active metabolism than the old.
Figure 4: Relationship between stem respiration rate (mgCO₂/m³/s) and temperatures of ambient/stem has exponential, which the Q10 values are 3.10 and 2.87 on the temperatures of ambient and stem, respectively.

Jessica Cherry

Estimation of Snowfall and Snow Distributions in Alaska and the Pan-Arctic

The outcome of this project will be a long-term daily product of snowfall (station-based and distributed) for the pan-Arctic for use in change detection.

We collected a large database of daily snow depth records from landmasses north of 44°N. A reconstructed snowfall product was developed using a simple nudging technique in the NASA Global Modeling and Assimilation Office catchment-based Land Surface Model (LSM). This station-based reconstructed snowfall product is now being spatially distributed using multiple models for comparison. These include a statistical optimal interpolation, the Micromet model, and the Georgia Tech snow model.

Anticipated results include a station-based and gridded pan-Arctic daily snowfall product from 1936 onward. This will support detection and attribution of changes in the hydrologic cycle in the Northern Hemisphere. This product may also be used to determine long-term changes in soil temperatures, as the model ground thermodynamics scheme solves for a ground temperature profile. Both snow cover and the surface energy balance contribute to the evolution of ground temperatures. In regions with frozen ground, changes in soil temperatures may also lead to changes in subsurface water storage.

Long-term variability of the atmosphere and the land-surface are inherently tied to the hydrologic cycle, particularly in cold regions. Estimation of snowfall and snow distributions in Alaska and the pan-Arctic help to integrate the study of both the
atmosphere and the land-surface. The project contributes to Themes 2, 3, and 4 of the IARC-JAMSTEC Collaboration Plan.

Estimating Snow Distributions and Snow-Atmosphere Interactions in Alaska

The goal of this project is to estimate spatially distributed solid precipitation, snow depth, and snow redistribution by wind in Alaska.

Our approach is to couple the WRF model to a spatially distributed snow model developed by Liston. Long-term observations of snow properties collected from the North Slope and Seward Peninsula, Alaska, will be used for model verification.

Anticipated results include a nowcast of snow conditions at particular field sites as well as large swaths of northern Alaska.

The estimation of snowfall and snow distributions in Alaska and the pan-Arctic help to integrate the study of both the atmosphere and land-surface. Real time estimates of snow conditions are also important for applications such as tundra travel, aviation, and ice road construction. This research also bridges model development with field-based observations and efforts at the Arctic Region Supercomputing Center. Results from this project may be deployable in the IARC Arctic System Model. The project contributes to Themes 2, 3, and 4 of the IARC-JAMSTEC Collaboration Plan.

External Presentations


Sept 15-17, 2008, 2008 Arctic AAAS Meeting, Fairbanks, USA, Regulating factors on winter soil respiration in black spruce forest soils, interior Alaska. Yongwon Kim, Mamoru Ishii, and Yuji Kodama.


Nov 4-6, 2008, 1st International Symposium on the Arctic Research, Tokyo, Japan, Regulating factors on continuous winter CO2 flux in black spruce forest soils, interior Alaska. Yongwon Kim, Yuji Kodama, and Mamoru Ishikawa.

Nov 4-6, 2008, 1st International Symposium on the Arctic Research, Tokyo, Japan, Ground-based forest survey for biomass estimation by ALOS/PALSAR over boreal forest in Alaska. Rikie Suzuki, Yongwon Kim, and Reiichiro Ishii.


Visitors
Wada, Tomoyuki, Hokkaido University, Japan, April 24 to July 10 and August 4 and September 31, 2008.

Publications


Ueyama, M., Y. Harazono, Y. Kim, and N. Tanaka. Response of the carbon cycle in sub-arctic black spruce forests to climate change; reduction of a carbon sink related to the sensitivity of heterotrophic respiration, Agricultural and Forest Meteorology (in press).
Arctic Atmosphere: Weather and Climate Variability

Participants
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Zhang, Xiangdong

1. Other Collaborators
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Jing Zhang, University of Alaska Fairbanks
Rüdiger Gerdes, Alfred-Wegener Institute
Josefino C. Comiso, NASA Goddard Space Flight Center

2. Summary of Research Activities and Accomplishments

Xiangdong Zhang
Arctic Rapid Change Pattern (ARP) and the Recently-Observed Rapid Changes in Arctic Climate System

Following the substantial changes observed during the recent decades, the Arctic climate system change has conspicuously switched onto a fast track since the beginning of the 21st century. The change is strikingly evidenced by a maximum warm surface air temperature (SAT) anomaly shift from the Eurasian continent to the interior Arctic Ocean; by consecutively broken historical records of low sea-ice coverage; and by the continuously intensifying North Atlantic warm water intrusion. Atmospheric circulation is the route by which global-warming-forcing exerts dynamic effects by driving sea ice motions and exports, ocean currents, heat transport, and so on, in addition to greenhouse-gas-induced static radiative forcing. In particular, atmospheric circulations fundamentally determine formation and distribution of cloudiness, critically modulating surface radiative heat budgets.

However, the Arctic/North Atlantic Oscillation (AO/NAO) has clearly shifted away from the fast track of the change mentioned above, which is surprisingly unexpected from previous studies and global-warming-forced climate simulations. The driving role of the AO/NAO trend in underlying cryospheric, hydrospheric, and terrestrial subsystem changes has been substantially weakened. Therefore, the climate change signature in atmospheric circulations is a missing piece of information explaining the recent rapid changes in the arctic climate system; this lack has seriously puzzled the climate and broader communities. Therefore, in this study, we aimed to untangle the mystery of how atmospheric circulation has changed and how it has connected with the recently observed rapid changes in the arctic climate system and the extreme event of sea ice cover loss in 2007.

We discovered rapid changes in the atmospheric circulation pattern, which is characterized by the Arctic Rapid change Pattern (ARP). The major results in our analysis indicate:

(1) The atmospheric general circulation has experienced a radical spatial shift, represented by the poleward movement of the centers of action and the transition from tri-polar structure to a dipolar structure of the leading pattern (Figure 1). The conventional AO/NAO, which has fixed spatial structure, cannot capture this shift.
(2) The finally formed ARP is a decisive driver in the recent rapid sea ice retreat and ocean and atmosphere warming. Its negative polarization from the mid-1990s to 2006 provided a shortcut for warm air invading the central Arctic Ocean from the North Atlantic and forced the North Atlantic warm water intrusion to increase.

(3) The preceding multiyear polarization toward the negative phase and the swift phase transition to the positive phase during 2006–07 of the ARP played a fundamental role in extreme sea ice cover loss in summer 2007. The phase swinging of ARP orchestrates contributing factors to cause record low of sea ice coverage (Figure 2).

(4) The spatial shift in atmospheric circulations can extremely speedup gradual global-warming-forced climate change to result in a rapid change event, perhaps shedding light on recent arguments about a tipping point of global-warming-forced climate change in the Arctic and indicating that the arctic climate is entering a new state.

(5) Identification of ARP will also improve understanding of past and future rapid climate changes detected in paleo records and climate model simulations. It may provide skillful information for future prediction of extreme events of sea ice cover loss and ocean warming.
Figure 1. (a) Positions of the centers of action from the Rn-EOF/PC analysis for the time period from 1982/83 to 2005/06; and (b) the first EOF/PC spatial patterns in the recent representative time windows. The spatial presence of the atmospheric circulation signature in the recent rapid Arctic climate system change – the ARP – is shown in the time window of 2001/02–2005/06. The circles and triangles represent position of the centers of action for each time window centered in the year shown in the color bar over the polar region and the North Atlantic/North Pacific, respectively.
Figure 2. (a) Projected amplitude time series or index of ARP for all months (note: not only for winters as above) during 2001–07. Following the amplified negative phase during 2001–06 winters, the ARP quickly transitions to a positive phase in summer 2006 that persisted until summer 2007. Composite SIC anomalies and superimposed MSLP anomalies for the extreme (b) negative phase during 2001–2006 and (c) positive phase during 2006–2007 illustrate impacts of ARP and its phase transition. The negative SIC anomalies associated with the negative ARP during 2001–06 persisted in the ARP positive phase during 2006–07 over the Barents, Kara and Greenland seas. The difference of composite MSLP anomalies plotted in (d) is the same as ARP. The selected months for the composite analysis are listed in Table S3 in Supplementary Information.

David Atkinson

High Resolution Temperature and Precipitation Modeling over the Terrestrial Arctic

Work in this last period has launched two endeavors focusing on components of the “Topoclimate Model,” or high-resolution temperature downscaling system for the terrestrial arctic regions. First is to partner with another group here at UAF, “Scenarios Network Planning for the Arctic” (SNAP), who have agreed to fund a programmer to develop a precipitation and hydrological counterpart to the TCM temperature downscaling model. The programmer will be housed at IARC and the work will be overseen by Atkinson at IARC. The second effort consists of a detailed look at the
temporal evolution of the vertical temperature in the lowest levels. The strong surface radiation inversions in the arctic regions are one the most persistently difficult features of arctic climate to capture in models. A field effort to begin spring 2009 will utilize more frequent radiosonde launches to better detail exactly how inversions form and dissipate.

Publications