NSF Sponsored Workshop:

Arctic Observing Based on Ice-Tethered Platforms

Woods Hole Oceanographic Institution

Woods Hole, MA

28-30 June 2004

Synopsis: *The overall mission of the workshop is to develop the idea of ice-tethered observing systems and consider various designs for a full Arctic array. At a previous NSF sponsored workshop "Instrumentation for Arctic Ocean Exploration" a basin-scale Arctic observing system was envisioned that included ice-anchored buoys, cabled observatory nodes, and AUVs to acquire and telemeter year-round data from the upper ocean, ice and atmosphere. In addition to serving as a real-time platform for observations (via Iridium satellite), the platforms would also act as navigation beacons and data transmission nodes for autonomous vehicles that would operate between nodes. Specifying the next generation of ice-tethered platforms is the task for the participants of the present workshop, who include Arctic scientists, engineers, industry representatives, and program managers.*

On the first day, the environmental parameters that must be acquired will be defined. Key presentations will summarize the science motivation for various types of measurements in different disciplines, including: physical and biogeochemical oceanography, ice physics and dynamics, and meteorological data. The presentations will also justify the urgent need for observing system development and the need to continue and expand existing measurement programs in order to document, understand and predict the large, low frequency changes that occur in the Arctic Ocean-Atmosphere-Ice system. On the second day, working groups will discuss sensors and instruments that could be employed to obtain specific environmental data. Considerations including measurement frequency, accuracy, longevity, biofouling, cost, and expendability will determine which sensors can realistically be implemented and how. In addition, another working group will consider data communications requirements using ice-tethered platforms to communicate with other subsurface devices such as AUVs or bottom-tethered moorings. This information will be used on the day 3 of the workshop for designing specific ice-tethered platforms.

Day 1. June 28, 2004
Location: (Clark 507)

09:30 Registration and coffee
10:00 Welcome (Andrey Proshutinsky)
10:10 Instrumentation for Arctic Ocean Exploration: summary, conclusions and recommendations from NSF sponsored workshop October 16-18, 2002, Monterey Bay Aquarium, California (Rob Reves-Sohn)

10:30 Workshop overview, identification of major goals and objectives (Andrey Proshutinsky)

Session 1: Scientific Questions and Measurements Required for Arctic Studies

10:45 Ocean (Eddy Carmack, Institute of Ocean Sciences, Canada)

11:10 Sea Ice (Don Perovich, Cold Regions Research and Engineering Laboratory, CRREL, USA)

11:35 Atmosphere (Klaus Dethloff, Alfred Wegener Institute, Germany and Dick Moritz, University of Washington, USA)

12:05 Biology (Carin Ashjian, Woods Hole Oceanographic Institution)

12:25 Geochemistry (Chris Guay, Earth Sciences Division Lawrence Berkeley National Laboratory)

12:45 Ocean-Atmosphere-Snow-Ice Study (**OASIS**, Patricia A. Matrai, Bigelow Laboratory for Ocean Sciences)

13:05-14:15 Lunch

14:20 Tasks for day 1 and formation of working groups (Proshutinsky)
Questions and tasks for working groups:

- What are the major scientific goals and objectives for the Arctic Observing System and particularly for development and design of Ice-Tethered Platforms?

- Formulate major requirements for observational systems of the deep ocean, continental slopes, shelves, river mouths, and straits (specific parameters to be measured and needed accuracy, temporal and spatial resolution and frequency of data acquisition).

Working groups: (rooms Clark 507-509)

- Ocean physics (leaders: Carmack, Owens)
- Ice and Atmosphere (leaders: Perovich, Ezraty, Moritz, Dethlof, Plueddemann)
- Biology and Geochemistry (leaders: Ashjian, Guay, McLaughlin, Matrai)

14:45-17:00 Working group sessions with a 20-minute coffee break at 16:00-16:20

17:00-19:00 Poster session and reception/icebreaker
19:00 Minibus to hotels

Recommended working group participants for DAY 1

- Ocean physics (leaders: Carmack, Owens)

Erberhard Fahrbach	Simon Prinsenberg	Igor Esipov
Cecilia Mauritzen	Ursula Schauer	Jason Gobat
Sergei Pryamikov	Tim Boyd	Tom Pyle
Takashi Kikuchi	Paul Bienhoff	Tim Stanton
Craig Lee	Konstantin Naugolnykh	Jamie Morison

- Ice and Atmosphere (leaders: Perovich, Ezraty, Dethlof, Moritz, Plueddemann)

Cathleen Geiger	Denis Zyryanov	Peter Winsor
Margo Edwards	Humfrey Melling	Roger Colony
Magda Hanna	Jerry Brown	Max Coon
Jenny Hutchings	Danielle Langevin	Jan Bottenheim
Greg Sidall	Vladimir Ryabinin	

- Biology and Geochemistry (leaders: Ashjian, Guay, McLaughlin)

Chris Krembs	Kamran Mohseni	Igor Semiletov
Adedayo Alao	Bernie Petolas	Chris von Alt
Dennis Conlon	Paul Twitchell	Patricia Matrai

Day 2. June 29, 2004 (Carriage House)

Synopsis: *After reviewing, and based on the scientific variables and sensors identified the previous day, the objective of the second day of the workshop is to design specific ice-tethered technology platforms. Workshop participants will be provided with the opportunity to give short presentations on their particular technological interests. Afterwards, working groups will establish specifications for various platforms, including expendable, non-expendable and shelf or seasonal ice zone (SIZ) systems. For example, sensors that are relatively inexpensive and low power consumption may be appropriate for either expendable or non-expendable systems, while systems that incorporate expensive sensors or sample collectors will need to be recovered. Furthermore, distinct technological challenges must be considered for platforms intended for the shelf and SIZ regions. In practice, an array of ice-tethered platforms may consist of a mix of these different systems.*

08:00 – Registration and coffee

Session 2: Engineering solutions (methods and sensors)

08:30 Working group reports
09:00 Ice-tethered instruments for Arctic and Antarctic: history and future development (John Toole, Rick Krishfield)
09:30 MEMS/NEMS sensors for Arctic Observing Platforms (Kamran Mohseni)
10:00 SEARCH-NPEO Ice Tethered Platform (Dick Moritz and Jamie Morison)

10:30-12:30 Short 2-3 slides presentations:

- Plans and progress towards a hybrid Arctic float observational system (Enerhard Fahrbach)
- An Observational array for high-resolution, year-round measurements of volume, freshwater and ice flux variability in the Davis Strait (Craig Lee)
- Development and deployment plan of ARGO-type buoy in the Arctic Ocean (Takashi Kikuchi)
- An energy Conserving oceanographic profiler for use under mobile ice cover (Simon Prinsenberg)
- Upper Ocean Observations from Ice Anchored Buoys (Al Plueddemann)

10:40 -11:00 Coffee break

- Mapping the Base of an Ice Canopy using a 12 kHz Phase-differencing Sonar (Margo Edwards)
- Autonomous ice mass balance buoy (Don Perovich)
- An observation system for small scale sea ice dynamics (Jennifer Hutchings)
- Sea-Ice mass monitor (Greg Siddal)
- Carbon dioxide (and methane) sensors (Igor Semiletov)
- Non-invasive, Highly resolved observations of sea ice biomass (C. Krembs)
- An Autonomous Ocean Flux Buoy (Tim Stanton)

- Efforts toward a high-spatial high-temporal synthesis of sea-ice kinematics and dynamics using surface drifters, SAR imagery, and a Lagrangian discrete element model (Cathy Geiger)
- A Multi-Frequency Acoustic method for Monitoring Ocean Current Velocity (Konstantin Naugolnykh)
- Eulerian approach to the ice drift measurements in the Arctic (Reinert Korsnes)
- Observations of ice draft and ice velocity at the North Pole in 2001-2003. (Dick Moritz)

12:30 Lunch

13:45 Tasks for day 2 and formation of working groups (Proshutinsky)

Working Groups (rooms Carriage House, Clark 201 and Clark 271):

- Oceanographic sensors (leaders: John Toole, Cecilia Mauritzen, McLaughlin)
- Atmosphere and ice sensors (leaders: Melling, Perovich, Moritz)
- Integration with mobile platforms (leaders: Reves-Sohn, Lee)

Questions and tasks for working groups:

- Formulate requirements for sensors and technologies needed for comprehensive observations in the Arctic
- Identify sensors and platforms which can provide reliable observations of the parameters and processes identified during Session 1
- Discuss problems of data transfer, communications with other platforms, satellites, etc., navigation, and energy limitations

14:00-17:00 Working group sessions with a 20-minute coffee break at 15:40-16:00

<u>Recommended working group participants for DAY 2</u>

Will be recommended after day 1

- Oceanographic sensors (leaders: John Toole, Cecilia Mauritzen, Jamie Morison)
- Atmosphere and ice sensors (leaders: Melling, Perovich, Moritz)
- Integration with mobile platforms (leaders: Reves-Sohn, Lee)

Day 3. June 30, 2004 (Clark 507)

Synopsis: *After reviewing, and based on the technology platforms specified the previous day, the objective of the third day of the workshop is to discuss implementation of an array of ice-tethered platforms to observe the Arctic. The numbers and types of platforms to thoroughly encompass the ice pack of the Arctic Ocean need to be defined, as does the rate at which systems must be replaced. Logistics concerns need to be considered, and a strawman program produced in order to provide a working estimate of the costs of developing and maintaining an ice-tethered observatory in the Arctic.*

08:00 – Registration and coffee

Session 3: Implementation procedures, and plans

08:30 Working group reports
09:10 NSF's perspectives (Dennis Conlon)
09:30 European observing system plans (Eberhard Fahrbach/Robert Ezraty)
09:50 Russian plans for observing systems in the Arctic Ocean (Sergei Priamikov)
10:10 Canadian observing plans (Humfrey Melling/Fiona McLaughlin/Eddy Carmack)
10:30 Coffee break
11:00 IABP program, experience and future plans (Dick Moritz, Ignatius Rigor and Magda Hanna)
11:20 SEARCH implementation plan (Dick Moritz)
11:40 Tasks for day 3 (Proshutinsky)

11:50 Working lunch and panel discussion.
Panelists: Ashjian, Carmack, Dethlof, Ezraty, Moritz, Fahrbach, Mauritzen, Melling, Owens, Perovich, Plueddemann, Proshutinsky, Pryamikov, Conlon, Toole, Morison

Major questions and tasks:

12:10
What is a role of ice-tethered platforms in the Arctic Observing strategy?
Synthesize information obtained during first two days and design an ice-tethered platform taking into account your group basic expertise.

13:10
Evaluate costs of designed systems and present implementation plan for Arctic observing based on these systems.

14:10 Formulate summary and conclusions for this workshop.

15:00 – Coffee break

15:30 – Final remarks. Summary and conclusions

16:00 Adjourn

REPORTING PLAN and AFTER WORKSHOP ACTIVITY

July 15 – group leaders and reporters send their reports to WHOI
July 25 – draft report to NSF
July 27 – submit a paper for EOS about workshop results, conclusions and recommendations
September 25^{th} – final report to NSF

ABSTRACTS

A.
B.
C.

Scientific Questions and Measurements Required for Arctic Ocean Studies

Eddy Carmack, Institute of Ocean Sciences

The Arctic Ocean's role in global climate - while now widely appreciated - remains poorly understood. Knowledge gaps of key process (e.g. freshwater storage and release, shelf-basin exchange, mid-depth and deep water formation, sill and strait exchanges fast-ice processes) will continue to block our understanding (and reliable model development) until appropriate and practical observational and monitoring programs are put into place. Advances in understanding the physical environment must be linked to biota. And while moving ahead in data acquisition (by application of both existing and new technologies) we must always ask: are we addressing the most important problems; are we forgetting something?

D.

Arctic climate simulations with global and regional models

K. Dethloff, A. Rinke, D. Handorf, W. Dorn, S. Saha, R. Gerdes and the ARCMIP and GLIMPSE groups, Alfred Wegener Institute for Polar and Marine Research, Telegrafenberg A43, 14473 Potsdam, Germany

The earth's climate is largely determined by the spatial structure of large-scale atmospheric circulation patterns and their associated temporal changes. Climate variations on seasonal and decadal time scales are influenced by externally and anthropogenically caused climate variability as well as by the global dynamics of preferred oscillation modes of the coupled atmosphere-ocean-sea-ice system. Regional feedback mechanisms in the Arctic climate system within the coupled atmosphere, ocean and sea-ice and land system have additionally the potential to influence the global climate. The maximum temperature increase in IPCC coupled model projections at the end of this century is in the central Arctic Ocean, whereas the observations show the high latitude temperature increase over the continents. With these uncertainties the Arctic poses severe challenges to generate credible model-based projections of climate change. There is a need to understand the influence of large-scale dynamic variability connected with the natural circulation modes of the global climate system and the regional feedbacks involved in the complex Arctic atmosphere-sea-ice-ocean-land interactions. In the EU project GLIMPSE we address the deficiences in our understanding of the Arctic by developing improved physical descriptions, understanding and parameterizations of regional Arctic climate feedbacks in atmospheric regional climate models and coupled atmosphere-ocean-sea-ice regional climate models with high horizontal and vertical resolution on the basis of data from the Surface Heat Budget of the Arctic Ocean - SHEBA project. For the first time in the Arctic Regional Climate Model Intercomparison Project - ARCMIP seven different Arctic regional climate models have been compared and shown that there is a pronounced intermodel scatter. The improved parameterizations from regional models of the Arctic will be implemented into state-of-the-art coupled Atmosphere-Ocean General Circulation Models, to determine and understand their global influences and consequences for Arctic climate feedbacks and decadal-scale climate variations. The regional atmospheric model HIRHAM has been applied for simulations of the Arctic climate in a pan-Arctic integration domain. Arctic climate changes associated with large-scale atmospheric circulation changes as well as with land surface and aerosol cloud processes have been studied in detail. The importance of increased vertical and horizontal resolution has been investigated. The atmosphere-sea-ice interaction has been investigated in the coupled atmosphere-ocean-sea-ice model HIRHAM-MOM of the Arctic. Observed features of the atmospheric circulation and the sea-ice concentration patterns during spring to early summer over the Arctic Ocean are reproduced.

E.

Mapping the Base of an Ice Canopy using a 12kHz Phase-differencing Sonar

M.H. Edwards, R.B. Davis and R.M. Anderson, Hawaii Mapping Research Group, Hawaii Institute of Geophysics and Planetology, University of Hawaii, 1680 East-West Road, Honolulu, HI, 96822

In 1998 and 1999, NSF sponsored deployment of the Seafloor Characterization and Mapping Pods (SCAMP) aboard a SCICEX submarine to map Arctic Basin topography. A recently discovered byproduct of mounting a 12 kHz interferometric sonar on the hull of the USS Hawkbill is that in addition to mapping seafloor topography, SCAMP also mapped the base of the arctic ice canopy [Edwards et al., 2003]. During standard topographic processing of SCAMP data, coherent signals were observed in "water column data," i.e., those data collected between the outgoing sonar pulse and the first returned bottom echoes. Processing was modified to produce swath maps of the information collected from the beginning of ping transmission until seafloor echoes were detected. The resulting images show different returns on the port and starboard sides of the submarine and individual features that can be traced from one side of the swath to the other. Unexpectedly, SCAMP had collected the first wide-swath (~2-6 km) images of keels and leads along the base of the arctic ice canopy. The raw SCAMP phase data are coherent prior to seafloor detection suggesting that interferometric approaches could be used to generate maps of ice keel depths; however, the signal-to-noise ratio of these data are too low for this purpose. Nevertheless, this discovery provides a unique opportunity to explore the concept of using a low frequency, platform-mounted upward-looking interferometric sonar to create wide swath maps depicting the shape and texture of the base of the arctic ice canopy.

F.

Plans and progress towards an hybrid Arctic float observation system (HAFOS)

Eberhard Fahrbach and Olaf Boebel, Alfred-Wegener-Institut fuer Polar- und Meeresforschung Postfach 12 01 61 D-27515 Bremerhaven Germany

The ARGO system of vertically profiling floats is expected to become the backbone of a global ocean observing system. However, it can not be easily extended into the Arctic Ocean, since the floats have to get to the sea surface to be located and to transmit the measured data. Since location and data transmission under the ice is presently only possible by acoustic means, an observation system of water mass properties and currents in the deep Arctic or Antarctic Ocean requires the combination of different technologies. It comprises ice resistant profiling subsurface floats, surface drifters on the ice and moored stations. The envisioned system consist of RAFOS (ranging and fixing of sound) type subsurface profiling floats which obtain their position by ranging of sound sources on moored stations. The float measures vertical profiles of temperature and conductivity/salinity, but it does not reach the surface if it floats under the ice. Therefore it has to stores the data until it reaches an ice free area. In this first version no real time data can obtained and the data are lost, if the float does not reach open water again. Therefore a second step is planned to install a sound source on the float (SOFAR). During the period when the float profiles under the ice it transmits a reduced data set acoustically, since the energy consumption for sound transmission is the limiting factor of the system. The full data set is stored until the floats can reach the surface in open water. Receivers are mounted on the moorings with the sound sources for ranging which can be under a seasonally varying or even permanent sea ice cover and on a surface stations deployed as buoys drifting on the sea ice. From the sea ice buoys data can be transmitted to satellites to be available in real time. The development of HAFOS is planned to take 10 years. The first steps were successful to deploy floats which will not return to the surface under ice cover and to determine the acoustic range in ice covered areas by use of RAFOS floats.

G.

Efforts toward a high-spatial high-temporal synthesis of sea-ice kinematics and dynamics using surface drifters, SAR imagery, and a Lagrangian discrete element model.

Cathleen A. Geiger (USACRREL), Chandra Kambhamettu (University of Delaware), Mani Thomas (University of Delaware), Mark Hopkins (USACRREL)

At scales of 10-300 km sea ice consists of a collection of plates with differential motion along discontinuities. It is equivalent to the oceanographic mesoscale (10-100 km) which is rich in high energy dissipation processes (e.g., eddies). At this scale, differential sea-ice motion plays an analogous dissipative role through the development of leads, slip lines, cracks, and pressure ridges. Within the sea-ice community there is no formal definition of this scale, with nomenclature such as "linear kinematic features" (LKFs), "piece-wise rigid motion", and "aggregate scale" beginning to emerge. Researchers are only recently able to explore this scale thanks to availability of high-spatial resolution, all-weather, Synthetic Aperture Radar (SAR) images. A fundamental caveat with SAR imagery on polar orbiting satellites is limited temporal resolution (typically 3 days). Under the influence of fast moving storms, significant non-linear changes in discontinuities occur a t temporal scales much less than 3 days with sea ice deforming rapidly, resulting in large changes in orientation, distribution, and size of continuous and discontinuous regions. Complimentary to polar SAR imagery, ice-mounted GPS-equipped buoys have high-temporal resolution (hourly) but are spatially sparse in the field (low-spatial resolution) with episodic deployments. Our approach is the development of a high-temporal, high-spatial synthesis using buoys, SAR imagery, and Lagrangian discrete element ice model. Such a synthesis provides valuable regional information for improving our understanding of sea-ice processes, short-term (up to one week) forecasting, and model validation. Efforts toward this goal are presented with interim results provided from both Arctic and Antarctic regions.

Geochemical tracers of the freshwater component of Arctic Ocean circulation

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Geochemical tracers are widely recognized as an invaluable tool in modern oceanography. Combined with measurements of temperature and salinity, geochemical tracers provide information about ocean circulation and mixing processes that could not be derived from physical measurements alone. In the Arctic, a suite of conservative and quasi-conservative tracers -- including nutrients (N, P, Si, alkalinity), oxygen isotopes (?18O), and trace metals (e.g., Ba) – has been used to characterize water masses, define their boundaries, and quantify contributions from freshwater sources (sea ice melt and runoff from North American and Eurasian rivers) and marine waters of Atlantic and Pacific origin. Historically, geochemical tracer data have primarily been obtained by chemical analyses of water samples in a ship-based or land-based laboratory. A new class of instruments is emerging that can be deployed on autonomous oceanographic platforms or vehicles and measure geochemical species in situ. These types of sensors typically utilize a combination of optical measurements, onboard chemistry, and/or micro-to-nano scale machining to carry out their analyses. The potential for deployment of autonomous, in situ geochemical sensors in the Arctic environment will be discussed.

H.

International Arctic Buoy Program (IABP)

Magda Hanna (National/ Naval Ice Center), Ignatius Rigor, and Dick Moritz (University of Washington Polar Science Center)

The Arctic has undergone dramatic changes in weather, climate and environment. It should be noted that many of these changes were first observed and studied using data from the International Arctic Buoy

Program (IABP). For example, IABP data were fundamental to Walsh et al. (1996) showing that atmospheric pressure has decreased, Rigor et al. (2000) showing that air temperatures have increased, and to Proshutinsky and Johnson (1997); Steele and Boyd, (1998); Kwok, (2000); and Rigor et al. (2002) showing that the clockwise circulation of sea ice and the ocean has weakened. All these results relied heavily on data from the IABP. In addition to supporting these studies of climate change, the IABP observations are also used to forecast weather and ice conditions, validate satellite retrievals of environmental variables, to force, validate and initialize numerical models. Over 350 papers have been written using data from the IABP. The observations and datasets of the IABP data are one of the cornerstones for environmental forecasting and research in the Arctic.

An observation system for small scale sea ice dynamics
Jennifer Hutchings (UAF) William Hibler III (UAF)

Sea ice deformation is characterized by narrow zones of failure between rigid aggregates of ice, and displays semi-diurnal fluctuations through the polar region at all times of the year. Observing and modeling efforts show that generally this oscillation is driven by inertial motion in the ocean. It is unknown how tides effect the deformation, and how tidal and inertial forcing interact with the material properties of the ice to create large scale oscillating linear failure zones. Field studies to date document the existence of these features. A greater variety of in-situ case studies are required to understand the role of tides, inertial motion, wind stress, boundaries and material properties of the ice on high frequency sea ice deformation. Modeling and observation studies show that high frequency motion affects the mass balance of sea ice. We plan a set of meso-scale ice deformation monitoring stations, in conjunction with measurements of the thermodynamic properties of the sea ice. This will lead to a better understanding of the role of high frequency sea ice deformation on the mass balance of sea ice.

I.
J.
K.

Development and deployment plan of ARGO type buoy in the Arctic Ocean
T. Kikuchi, N. Shikama (JAMSTEC), D. Langevin, T. Monk, and O. Lebreton (MetOcean)

Based on JCAD (JAMSTEC Compact Arctic Drifter) successful performance, JAMSTEC and METOCEAN Data Systems are collaborating in the development of a new buoy system tethering an ARGO type subsurface CTD profiler. The buoy system consists mainly of an Ice Platform and a Subsurface CTD vertical profiler. The Ice Platform is similar to JCAD; it contains the system controller, meteorological sensors, GPS and telemetry system. The vertical profiling system is based on an ARGO float and samples salinity, temperature, and depth from below sea ice down to 1000m. The vertical profiling system communicates with the Ice Platform via an inductive system similar to JCAD. Being part of the North Pole Environmental Observatory (NPEO) since 2000 gave us many buoy deployment opportunities. The data from all JCAD deployed in the NPEO project clearly illustrate oceanographic condition of the upper ocean in the early 2000. We will continue taking part in the NPEO observation us ing the new buoy system to monitor oceanographic condition in the Transpolar Drift area. We are already in the planning phase for the deployments on the 2005 POLARSTERN cruise. The POLARSTERN (AWI research vessel) allows access to the upstream region of the Transpolar Drift area which otherwise would be very difficult to realize. The buoy data will be distributed to not only the Arctic scientists but also the Argo community to understand global climate change.

Non-invasive, Highly Resolved Observations of Sea-ice Biomass Dynamics: A Link Between Biogeochemistry and Climate

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Climatic changes in high latitudes sensitively affect the persistence and dynamic of sea ice. Covering around 12 million square km, sea ice constitutes an ecologically important, transient interface between the atmosphere and the polar ocean. The build up of autotrophic biomass inside sea ice commences early in the season in response to the availability of light and nutrients, at a time when productivity in the water is typically low. Its release constitutes a concentrated pulse of energy to winter starved organisms and increases the vertical organic carbon flux. Sea ice primary productivity estimates range between 30% and 50% of the Arctic marine primary production. Biomass estimates are, however, based on invasive, scattered ice-core observations of low vertically resolution in particular across the ice water interface. A thin pronounced layer of algae at the sea ice-water interface spatially occurs where fluctuations of sea-ice mass, energy transfer and phase transitions are greatest. Due to the extremely transient nature of the ice water interface, highly temporally resolved data are needed to assess the significance of event-driven export processes from the ice. The vulnerability of sea-ice biomass to temperature anomalies is amplified by melt-water runoff and exposure to the water column. Pelagic populations of grazers respond sensitively to the timing, availability and distribution of food, such as algae micro-layers at the bottom of the ice. Current field methods lack the resolution to understand the causal relations of short-term sea-ice export events and resulting population fluctuations. Sediment traps allow integrated information over time and water volumes but do not reflect ambient food concentrations at the ice water interface and hence lack the sensitivity to resolve event driven deviations from annual means, which matter in the survival of species. We describe the seasonal in situ evolution of autotrophic biomass along highly spatially resolved vertical profiles in and across the ice water-interface, by means of a new in situ fluorescence system inside fast-ice of the Chukchi Sea during a 7 month deployment. Algae growth commenced very early (January) with distinct colonization patterns leading to a biomass peak at the end of April and export to the water. Our in situ system illustrates the advantages of a non-intrusive approach in describing the response of biomass to climatic disturbances at the ice-water interface. These achievements lay the foundation of an autonomous biological sea-ice buoy information system which integrates with existing Arctic climatic and physical sea-ice recording systems allowing a investigation of feedback mechanisms between Arctic climate, marine food webs, and biogeochemical fluxes directly below sea ice.

Eulerian approach to the ice drift measurements in the Arctic

Reinert Korsnes, Norwegian Defence Research Establishment, Division of electronics, Box 25, NO-2027 Kjeller, Norway; Denis Zyryanov, Water Problem Institute, Russian Academy of Science, Gubkina st. 3, GSP-1 119991, Moscow, Russia

The proposed Eulerian approach to the ice thickness and drift measurements in the Arctic is based on mechanical concept of flexible ropeequipped with pressure sensors along its body. The flexible rope is a snake-like floater, which by buoyancy is pressed up to the moving drift ice. Its head is pulled down to a deep not reached by the deepest ice keels. It can provide Eulerian measurements of ice drift and other upper ocean physical parameters when it is fixed to the bottom below drifting ice. Time series of data from pressure sensors along its body and a built in compass provide estimates of ice thickness and drift (velocity and direction). This works since the pressure sensors have to pass over irregularities of the bottom of sea ice. The time series of pressure data from the array of pressure sensors along the snake will exhibit a temporal pattern shift from which ice drift can be calculated. These measuring ropes were successfully tested in a water tank. Experiments with different rope tissues frozen into the sea ice were also fulfilled. The results of these investigations show that this approach truly assess the ice thickness and drift and might be a first direct instrumentation applied for the Arctic pack ice drift measurements.

L.

An Observational Array for High-Resolution, Year-Round Measurements of Volume, Freshwater and Ice Flux Variability in the Davis Strait

Craig M. Lee, Jason Gobat, Richard Moritz Applied Physics Labporatory, University of Washington Brian Petrie Bedford Institution of Oceanography

An array consisting of moorings, bottom mounted instrumentation and autonomous vehicles will be deployed across Davis Strait to study exchange between the Arctic and the North Atlantic Oceans. The system employs complementary techniques, combining mature technologies with recent developments in autonomous gliders to address all aspects of flow through Davis Strait, including some measurements that have not previously been technologically feasible. The components of the system include: A sparse array of subsurface moorings, each instrumented with an upward looking sonar, an Acoustic Doppler Current Profiler (ADCP), conductivity-temperature (CT) sensor and conventional current meters, will provide time series of upper ocean currents, ice velocity and ice thickness. These measurements will be used to estimate the ice component of freshwater flux, provide an absolute velocity reference for glider-derived geostrophic shears and derive error estimates for low-frequency flux calculations. Bottom mounted instruments, including ADCPs and CT sensors, will be deployed across the Baffin and Greenland shelves to quantify variability associated with strong, narrow coastal flows. An experimental, quasi-expendable CT sensor will attempt to measure near-surface (20-30 m) water properties. Acoustically navigated Seagliders will provide year-round, repeated, high-resolution hydrographic sections across the Strait. Glider profiles will extend from the seafloor to the surface or ice bottom, capturing the critical (but ice-threatened) upper ocean. The resulting sections will be combined with the moored array data to produce sections of absolute geostrophic velocity and to estimate volume and freshwater fluxes. Glider development, including integration of a 780 Hz acoustic navigation system, represents a major, ongoing component of this effort. During the first year, we will also conduct a small, year-long acoustics experiment designed to investigate attenuation at 780 Hz as a function of stratification and ice cover.

M.

MEMS/NEMS sensors for Arctic Observing Platforms

Kamran Mohseni, Department of Aerospace Engineering Sciences and the NSF Center for Advanced Manufacturing and Packaging of Microwave, Optical and Digital Electronics, University of Colorado at Boulder

Recent advances in fabrication technology and techniques have opened the possibility for a new generation of micro/nano sensors with a wide range of applications. The advantages of MEMS/NEMS devices are often faster response time, lower energy consumption, higher sensitivity, lower cost, lower volume, lower weight, among others. Automation of these sensors could also open new directions in monitoring chemical, biological, and physical agents in arctic environment. Current status of MEMS/NEMS sensors suitable for arctic monitoring will be reviewed and the potential for integrating these sensors into, e.g., AUVs will be discussed.

N.

A Multi-Frequency Acoustic Method for Monitoring Ocean Current Velocity

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Transverse flow of an inhomogeneous current produces fluctuations of the acoustic signal passing through it. These fluctuations vary with signal frequency due to variation of the Fresnel zone linear size. When the ocean inhomogeneous are smaller then the transverse dimension of overlapping Fresnel zone, the fluctuations of the signal at two different frequencies are coherent in a low-frequency range of the spectrum and non-coherent in the high-frequency band. The cutoff frequency of the coherence function of two continuous-wave-frequency-separated signals is therefore a quantitative indicator of transverse current velocity. The longitudinal component of current can be measured by differencing the travel times of signals traveling in opposite directions, and as a result the current velocity can be obtained. This technique provides the basis for a method of ocean current monitoring that can be considered as a "frequency-domain" version of the conventional scintillation approach to the current velocity measurements that is based on the measurement of the signal correlation transmitted from the source to the two separated receivers (space-domain scintillation).

This technique is applicable to scales on the order of 3-10s of kilometers. If source-receiver pairs are deployed on solid ice or buoys the potential exists for continuously monitoring the evolution of the fine scale current structure of the entire water column in a horizontal plane. The proposed equipment would be inexpensive, disposable, and suitable for Arctic conditions. The technique may provide significant advantages over CTD soundings similar to the way in which wind profilers have advantages over rawinsonde measurements in the atmosphere.

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Autonomous Ice Mass Balance Buoys

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General circulation models indicate that Arctic sea ice may be a sensitive indicator of climate change. Accordingly, efforts are underway to improve and expand observing systems designed to monitor changes in the Arctic sea ice cover. The mass balance of the ice cover is an important component of such observing systems, since it is an integrator of both the surface heat budget and the ocean heat flux. Satellites provide information on ice extent, as well as the onset of melt and freezeup and submarine surveys furnish large-scale information on changes in ice thickness. However, neither method delineates potential sources of observed changes: e.g. differences in surface heat budget, variations in ocean heat flux, or modifications due to ice deformation. Ice mass balance data provide this critical insight. Autonomous buoys provide a means of routinely monitoring the ice mass balance at many locations. Ice mass balance buoys consist of a combination of a data logger, an Argos transmitter, a barometer, a GPS, acoustic sensors monitoring the positions of the ice surface and bottom, and a vertical string of thermistors. The buoys provide time series information on vertical temperature profiles, ice growth and decay, snow accumulation and ablation, and

ocean heat flux. In the past few years, nearly a dozen of these buoys have been deployed as part of the Study of Environmental Arctic Change (SEARCH) program. The ice buoys have been collocated with other instruments including ice thickness profilers and ocean and meteorological buoys. Data from these integrated sensor systems will be assimilated and synthesized with other direct observations, remote sensing data, and sea ice models, to study the large-scale evolution of ice mass balance.

Rapid Profiling of Ocean Velocity and Acoustic Scattering Strength in the Arctic
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The vorticity field of the Arctic ocean is strangely quantized, with values near zero and near being most common. The highly rotational motions are associated with coherent vortices, whose genesis remains somewhat of a mystery. Any long-term survey of the Arctic must include the vorticity field. A census of theeddies and a series of process experiments which lead to an understanding of vorticity quantization must play a central roll. Given the short inertial day in the Arctic and the tendency of eddies to attract (refract) inertial waves, traditional (mid-latitude) sampling rates of 4-8 per day are too slow for proper eddy monitoring. A mix of in-situ and acoustic Doppler approaches is advised. A critical acoustic "by-product" is the scattering strength signal, which is revealing much about the biological communities of the upper Arctic Ocean.

Upper Ocean Observations from Ice Anchored Buoys
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Ice-Ocean Environmental Buoys (IOEBs) are special-purpose platforms designed for long-term measurement of meteorological and oceanographic variables in the Arctic. IOEBs include instrumentation below the ice and are designed to be recovered. Between 1992 and 1998, three IOEBs were deployed a total of six times on multiyear pack ice in the Arctic. Acoustic Doppler Current Profilers (ADCPs) on the IOEBs provided observations of velocity in the western Arctic pycnocline (25-300 m depth) that were used to investigate the distribution and properties of subsurface eddies. Forty-four months of data were available from three IOEB deployments within the Beaufort Gyre between 1992 and 1998. The majority of eddy center depths were between 50 and 150 m and the mean thickness was 126 m. Thus, eddies were found predominantly within the cold halocline. Maximum rotation speeds were typically 20-30 cm/s. Faster rotation was associated with larger radius and larger vertical extent. Typical radii were 3-6 km. The sense of rotation was predominantly anticyclonic. Eddies in the Canadian Basin tended to be larger, deeper and more rapidly rotating than those over the Chukchi Plateau.

An Energy Conserving Oceanographic Profiler For Use Under Mobile Ice Cover; ICYCLER
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ICYCLER is a moored oceanographic profiler designed to measure surface layer water properties under mobile ice cover. The profiler can provide daily 50 meter salinity-temperature-chlorophyll profiles for a full year. Data are collected during each profiling ascent with an instrumented float that avoids ice impact using an onboard echo sounder. Once measurements are acquired, the sensors are hauled back down to an ice-free depth. An efficient energy-conserving mechanical design minimizes power requirements to allow for autonomous operation using a logistically manageable and hydrodynamically efficient package. An ICYCLER prototype was successfully used in the Canadian Arctic Archipelago for a year-long deployment and a second re-designed ICYCLER is being tested for Arctic deployment in the summer of 2004.

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Seasonal variation of halocline circulation in the East Greenland Current

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We present results from five years of year-round temperature, salinity and current observations in a mooring line in the Fram Strait (79°N). Instruments in the upper layer (about 60 m depth) in the East Greenland Current show a pronounced seasonality both in temperature and salinity. The temperature varies between the freezing point and –1°C and the salinity range is from 32.3 to 34. The parameters are, however, not exactly in phase: The temperature minimum is in winter, while the salinity minimum is mostly in late autumn. The depth of the instruments being below the surface mixed layer and the temperature and salinity range suggest that the variations do not reflect the immediate influence of the atmosphere (melting/freezing/warming) but rather a shift between halocline branches. The results emphasize the need for upstream information of halocline circulation for a full understanding of the involved processes.

The Ocean-Atmosphere-SeaIce-Snowpack (OASIS) Project

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While Polar regions encompass a large part of the globe, little attention has been paid to the interactions between the atmosphere and its extensive snow-covered surfaces. Recent discoveries in the Arctic and Antarctic show that the top ten centimeters of snow is not simply a white blanket but in fact is a surprisingly reactive medium for chemical reactions in the troposphere. It has been concluded that interlinked physical, chemical, and biological mechanisms, fueled by the sun and occurring in the snow, are responsible for depletion of tropospheric ozone and gaseous mercury. At the same time production of highly reactive compounds (e.g. formaldehyde, nitrogen dioxide) has been observed at the snow surface. Air-snow interactions also have an impact on the chemical composition of the snow and hence the nature and amounts of material released in terrestrial/marine ecosystems during the melting of seasonal snow-packs. Many details of these possibly naturally occurring processes are yet to be discovered. For decades humans have added waste products including acidic particles (sulphates) and toxic contaminants such as gaseous mercury and POPs (persistent organic pollutants) to the otherwise pristine snow surface. Virtually nothing is known about transformations of these contaminants in the snowpack, making it impossible to assess the risk to the polar environment, including humans. This is especially disconcerting when considering that climate change will undoubtedly alter the nature of these transformations involving snow, ice, atmosphere, ocean, and, ultimately, biota. To address these topics an interdisciplinary group of scientists from North America, Europe and Japan is developing a set of coordinated research activities under the banner of the IGBP programs IGAC and SOLAS. The program of Ocean- Atmosphere-Sea Ice-Snowpack (OASIS) interactions has been established with a mission statement aimed at determining the impact of OASIS chemical exchange on tropospheric chemistry and climate, as well as on the surface/biosphere and their feedbacks in the Polar regions of the globe. It is proposed that this program will culminate in a concerted field project during the next IPY. In this contribution we will present the details of the emerging OASIS science plan and progress towards its implementation.

Carbon Dioxide (and Methane) sensors: prospective for the greenhouse gases detection in the Arctic Ocean using the ice-tethered platform

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Completing the balance sheet for the global carbon budget is a task at the forefront of natural sciences. Because the CO2 and CH4 inter-hemispheric gradients and seasonal amplitudes show that the northern environment is a major contributor to the Northern Hemisphere CO2 and CH4 maxims and seasonal variations, the role of the Arctic Ocean as sources and sinks of these greenhouse gases must be evaluated. Our present knowledge of the temporal and spatial distribution of the net CO2 flux between ocean and atmosphere is derived from a combination of limited by temporal and spatial coverage data of field measurements and model results. However, until the 1990s, the Arctic Ocean had been generally ignored in understanding the global CO2 budget. Only last decade few research groups investigated the CO2- system in the Arctic Ocean, mainly in the western part of the Eurasian Arctic, including the Barents and Kara Seas. Until now we have very limited information on the carbon chemistry of the Beaufort, Chukchi, East Siberian, and Laptev Seas. Polar marine regions are suggested to have a potential for increased CO2 uptake as a result of seasonally high bio-productivity and high seawater solubility, except shallow Siberian shelf, where a large amount of terrestrial organic material is transported to the ocean (that is induced by coastal erosion and rivers) is decomposed and produce the CO2. It is little known at present about connection between sea ice conditions (and characteristics) and the CO2 flux through sea ice, whereas sea ice cover is permeable medium for CO2. Leads, polynyas, and melt ponds could be the places of effective sink of CO2 in summer and source of CO2 in winter (Kelley and Gosink, 1988; Makshtas et al., 2003; Semiletov et al., 2004, accepted). To evaluate the Arctic Ocean effect on the regional atmospheric CO2 budget, we need to investigate the role of the sea ice and water system in CO2 pumping and dynamics of the carbonate system. Detection of pCO2 beneath the sea ice is an important component of this complex study. Methane. The highest source of natural gases (mostly CH4) is stored in gas-hydrates beneath permafrost in Siberia. There are not any experimental data indicated a present increase in instability of hydrate environment, but the latter would be vulnerable if the permafrost is warming. While the Holocene sea level rise (about 100-120m) should increase the stability of off-shore gas hydrates in term of the pressure increase, the increased temperature could be leading factor in destabilizing of gas hydrates. Note that at present the mean annual temperature at the top of bottom sediment/permafrost is equal to temperature of sea water near bottom and slightly negative (00C - â€“20C), whereas in the past, when during the Late Pleistocene the main part of the Arctic shelf was exposed to atmosphere, the annual mean permafrost surface temperature was 1.50C and lower. Therefore, we can assume that shallow off-shore gas hydrate could be vulnerable because the shallow bottom sediment and underlying permafrost have been warmed about 15C after flooding during the Holocene optimum (about 6-8 kyr ago), whereas hydrostatic pressure was quasi-stable over the last several millenniums. The response of the Siberian permafrost reservoir of ancient carbon to global warming and consequent release of greenhouse gases can be an important feedback in the Arctic climate system. Ebullution of methane from the seabed has been found in the surface waters beneath the sea ice in the Arctic and Subarctic seas (Semiletov, 1999; Obzhirov, 2002) that indicates the possible gas hydrate disturbance. Principally new all-seasonal data could be obtained beneath the sea ice by means of an observing system based on ice-tethered drifting platforms. Authors present results of deployment of the SAMI- CO2 sensor beneath the fast ice near Barrow, and discuss prospective to use the autonomous pCO2 (SAMI) and CH4 (METS) sensors in framework of the new WHOI based project.

Sea-Ice Mass Monitor (SIMMon)

Greg Siddall, Bedford Institute of Oceanography

Development of a new instrument to measure sea-ice thickness and freeboard. A miniature self-spooling winch climbs an ice-tethered cable until it contacts the ice. The small and light-weight design enables helicopter transportability and hand-deployment through an 8 inch ice-hole. Drift position and ice data are relayed by Argos satellite communication.

An Autonomous Ocean Flux Buoy (AOFB)

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Advances in high resolution, low-powered sensor technology, (particularly in current measurement), and the stable platform provided by the perennial ice pack have provided an opportunity to make un-attended measurements of vertical momentum, heat and salt fluxes through the ocean mixed layer using direct eddy correlation techniques. Under NSF funding, an ice-deployed ocean flux buoy has been developed to measure these fluxes and upper ocean current structure as the buoy drifts for periods of up to 2 years. During the development stage, three buoys have been set in near the North Pole since April 2002 as a component of the North Pole Environmental Observatory. Co-located ice flux and bulk atmospheric measurements (including solar radiation) by NPEO collaborators, provide year-long ocean-ice-atmosphere fluxes for the ice floe through an annual cycle before the ice drifts into the Atlantic Ocean. An instrument cluster suspended from the buoy 6m below the ice base measures time series of (u,v,w,T,C) while an ADCP measures current structure into the pycnocline. The main controller/processor within the buoy provides switched power and communication for up to 8instruments, processes the data streams, and stores outbound data frames for transmission twice a day. The buoy uses Iridium satellite phone technology to bring back platform position and velocity, current profiles, spectral covariance quantities, raw time series, and processed fluxes, and has sampling strategies updated with each daily data transmission.

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