An Array of Ice-Based Observatories for Arctic Studies

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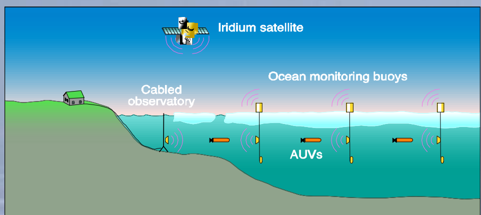
Introduction

The Arctic Ocean's role in global climate - while now widely appreciated - remains poorly understood. Lack of information about key processes within the oceanic, cryospheric, biologic, atmospheric and geologic disciplines will continue to impede physical understanding, model validation, and climate prediction until a practical observing system is designed and implemented.

Several designs for Arctic Observing Systems are emerging as part of the U.S. National Science Foundation's "Study of Environmental Arctic Change" (SEARCH) program and comparable Arctic study programs conceived as contributions to the proposed International Polar Year (IPY) 2007/2008. An outcome of these ongoing discussions is an increasingly focused vision for future Arctic research including: (1) manned expeditions with enhanced capabilities; (2) basin-wide networks of autonomous ice-based instrument systems and autonomous vehicles; and (3) cabled oceanographic observatories.



Schematic depiction of an Arctic Observing System showing different elements including Cable and Ice-Based Observatories and Autonomous Underwater Vehicles.

Following up on the second of these themes, an international workshop entitled "Arctic Observing Based on Ice-Tethered Platforms" was held at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts, USA, June 28-30, 2004. The assembly of 55 workshop participants that included Arctic scientists, engineers, industry representatives and program managers from 8 countries were tasked with detailing the next generation of ice-based technologies that could contribute to a future observing system and begin coordinating plans and instrument development.

Ice-based instrument systems

Autonomous instruments have become an increasingly important source of Arctic data. Since 1978, observations from the International Arctic Buoy Program (IABP) have contributed significantly to polar science by returning meteorological and sea ice drift data for real-time operational requirements and research purposes. Buoys with subsurface instrumentation have also been used with great success, including Polar Ocean Profiler (or SALARGOS) data buoys Ice-Ocean Environmental Buoys (IOEB) and JAMSTEC Compact Arctic Drifter (J-CAD) buoys.

At least four prototypes versions of oceanic observing systems are already operating in the Arctic, providing real time information, including:

- IABP buoy array accompanied by Ice Mass Balance (IMB) buoys
- JAMSTEC J-CAD buoy in combination with IMB buoys
- WHOI's Ice-Tethered Profiler (ITP) in combination with IMB buoy
- North Pole Environmental Observatory (NPEO; which includes Arctic Ocean Flux Buoys (AOFB), J-CADs and IMB buoys).

Requirements and challenges for ice-based observatories

Experience gained in previous studies was brought to bear by workshop participants to develop the concept of an array of ice-based instrument systems, or Ice-Based Observatories (IBO's), necessary to satisfy the needs of international Arctic science programs.

Workshop participants identified IBO's as automated, drifting, ice-based sensor systems providing comprehensive data from the Arctic environment and incorporating the multidisciplinary needs of biological, chemical and physical oceanography, as well as different aspects of atmospheric and sea ice studies. Moreover, in addition to hosting suites of sensors, these observatories could also support a network of acoustic receivers, data transmission nodes, and navigation beacons for autonomous vehicles operating between stations.

Parameters to be obtained by IBOs. (Core parameters are those for which sensors are presently available; expanded parameters include those for which sensors are in development and could be available in the relatively near future.)

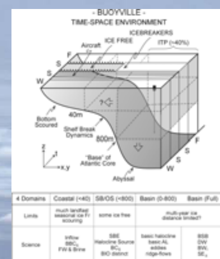
Core Atmospheric Parameters	Sensor
Air pressure	Barometric pressure sensor
Air temperature	Shielded thermistor, at least 2 levels for stratification
Wind speed and direction	Anemometer, 10m if practical
Direction reference	Fluxgate compass or differential GPS
Rime sensor	
Short wave radiation flux (up and down)	Radiometers
Long wave radiation	Radiometers at 1-2 levels
Cloud cover	All-sky Webcam technology
Ozone concentration	Spectrometer
Changing surface and sky conditions	Webcam technology
Expanded Atmospheric Parameters	
Biologically important production of chemically relevant gases: CO_2, O_2, DMS, halogens, methane at different heights above the ice surface	
Deposition of atmospheric material onto the snow/ice (e.g., soot)	

Core Sea-ice Parameters	Sensor
Position (and sea-ice deformation)	GPS (GPS buoy array)
Snow thickness	Acoustic echo sounder
Ice thickness	Acoustic echo sounder
Temperature in snow and ice	Thermistors at 0.1 m vertical resolution
Short wave radiation in ice	Radiometers at 1-2 levels
Snow wetness	Dielectric sensor
Ice surface salinity	Dielectric sensor
Changing surface ice conditions	Webcam technology
Expanded Sea-ice Parameters	
Fluorescence profiles, optical properties (spectroradiometers), permeability, chemical profiles, sea-ice surface and under-ice biology (surface rover, AUV, webcam)	
Sub-ice surface characteristics using cameras, spectral instruments	

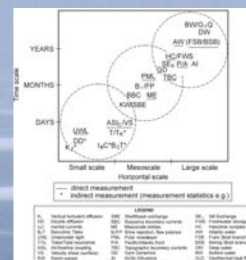
Core Ocean Parameters	Sensor
Pressure	Strain gauge
Temperature	Thermistors
Salinity	Conductivity
Current velocity and backscatter	Acoustic (single point and profiling)
Dissolved Oxygen	Oxygen (e.g. SBE-43)
Fluorescence	Fluorometers
Light Transmission or Turbidity	Transmissometer or scatterometers
Photosynthetically Available Radiation (PAR)	PAR sensors
Optical	(e.g. AC-9)
Nitrate (NO_3)	(e.g. Satlantic ISUS)
Active and Passive Acoustics	Tomography
Turbulent fluxes in the ocean mixed layer	Flux sensors
Carbon Dioxide Partial Pressure (p CO_2)	SAMI- CO_2 sensor
Expanded Ocean Parameters	
pH, organic and inorganic carbon, other nutrients (SiO_4, PO_4) methane, isotope concentrations (e.g. oxygen-18), CFCs, metals	
Primary production (fast repetition rate fluorometer), spectral quality, plankton/particle identification (photography), genetic analysis of plankton	
Sediment traps, discrete water sample collection	

The basic requirements identified at the workshop for a future generation of ice-based unmanned platforms are:

- Observation and real-time reporting, with high-vertical-resolution and high-accuracy, of an interdisciplinary suite of parameters from the near-surface atmosphere, sea ice, and upper ocean for multiple years (assuming deployment on robust ice floes) at temporal resolution appropriate for each parameter.
- Ease of deployment from landed aircraft and helicopters in addition to deployment by icebreaker.
- Modest cost, allowing them to be deployed in large numbers (analogous to the present IABP) and, in some cases, to be considered expendable.
- Accommodation, through standard interface and communication protocols, of future surface and/or subsurface instrumentation, including acoustic communication (for data transfer, and navigation) with autonomous vehicles.



Four-dimensional diagram showing Arctic temporal and spatial limits for long-live IBOs. W, S, S, and F denote Winter, Spring, Summer, and Fall, respectively.



Time/space diagram for key physical oceanic processes and water mass distributions in the Arctic Ocean that could be studied using the IBO concept .

Although much of the necessary IBO technology already exists and routine observations are presently underway using the IBO concept, a variety of challenges must be addressed en route to a comprehensive observing system:

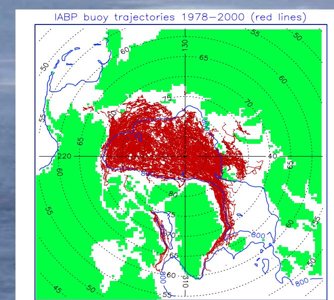
- Platform instrumentation should be improved by continued development of profiling systems for atmosphere, ice and ocean with the goal of sampling biological and chemical variables on the same spatial and temporal scales as physical variables in order to separate biological and /or chemically transformations from changes due to physical mechanisms. Profiling systems for many physical variables are presently available or easily adapted for routine use in the Arctic, whereas bio-chemical profiling systems will require additional development effort.
- IBOs will be best suited to deployment in perennial pack ice. However, the seasonal sea ice zone accounts for a majority of the northern marine cryosphere, and most of this is in shallow water (<500 m). Specialized IBO designs will likely be needed for the seasonal ice zone, platform lifetimes will be short, and frequent re-deployments will be required. Alternate technology (e.g. profiling floats) may also be required.
- The integration of autonomous vehicles with IBO's needs to be addressed in design studies. There are specific technological issues (e.g. navigation, communication and energy transfer) relating to interactions among IBO's, floats, gliders and AUVs that should be addressed concurrently with an IBO array implementation.

Workshop Conclusions and Recommendations

Ice-based instrument systems are a proven means of acquiring unattended high quality air, ice, and ocean data from the central Arctic during all seasons. Arctic Change is ongoing and measurements need to begin now. An array of IBO units, deployed and maintained throughout the central Arctic, is envisioned to observe the spatial structure and annual to decadal variations of the polar atmosphere-ice-ocean environment as one component of a coordinated Arctic Observing System. Practical, cost-effective and proven IBO designs presently exist, can be readily extended to provide interdisciplinary observations, and should be implemented expeditiously as part of a coordinated effort to observe the coupled Arctic atmosphere-ice-ocean system.

Specific recommendations were:

- A relatively simple and robust IBO array, based on presently available technology, should be implemented immediately as part of a stepwise ramp-up to a multi-component, interdisciplinary Arctic observing system. An international body will be required to coordinate the various national programs (eliminate overlap, insure no data holes) and insure compatibility of data and their widespread distribution.
- The 25 years of IABP drift trajectories, existing data climatologies and available numerical simulations should be exploited to derive insight to optimal array design, deployment strategies, sampling intervals, and expected performance of an IBO array.
- Since ice-based observations at a given site may consist of a distributed set of subsystems developed by multiple PIs, the logistics infrastructure for getting to the deployment sites is one of the most important shared assets of the observing system. A long-term, internationally coordinated logistics plan should be developed as an essential component in establishing an IBO array.
- IBO designs should provide accommodation for novel sensors, acoustic receivers, and communication and navigation capabilities for autonomous vehicles. Emerging technologies for Arctic observation should be developed within the framework of an integrated Arctic observing system.



Area of observational coverage based on IABP buoys for 1979-2000. Solid blue line depicts 800 m isobath and red lines show buoy trajectories.

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