Arctic Sea Ice and Ocean Observations

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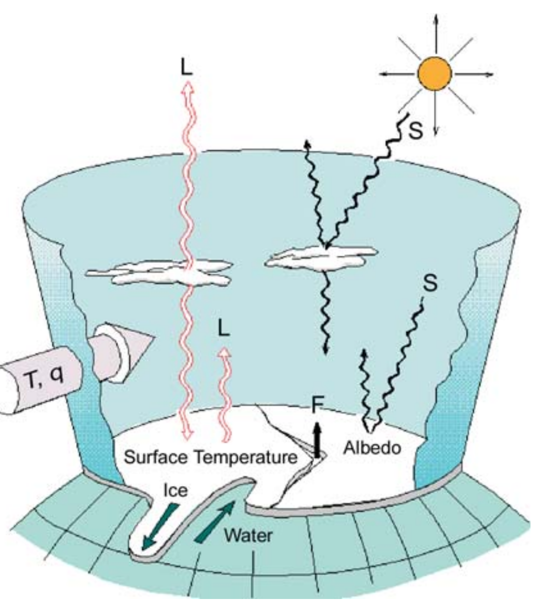
The Arctic and sea ice play several important roles in the global climate system, including effects on the surface heat budget and the global thermohaline circulation. Excess latent and sensible heat from the sun absorbed at lower latitudes is transported poleward by the atmosphere and ocean, where it is radiated back out to space. Sea ice over the Arctic Ocean insulates the atmosphere from the ocean, thus reducing the amount of heat lost to space. Sea ice also has a higher albedo (reflectivity) than the darker ocean, reducing the amount of sunlight absorbed by the sea-ice-covered ocean. A decrease in sea ice would increase the exposed area of the darker ocean, increasing the amount of sunlight absorbed, thus warming the ocean, melting more sea ice, and amplifying the initial perturbations (this is called ice–albedo positive feedback). However, the moisture fluxes into the atmosphere are also higher over open water than over sea ice, which may increase the areal coverage of fog and low clouds, increasing the albedo near the surface and damping the initial perturbations (this is called cloud–radiation negative feedback). These opposing feedbacks underscore the complexity of the Arctic and global climate systems.



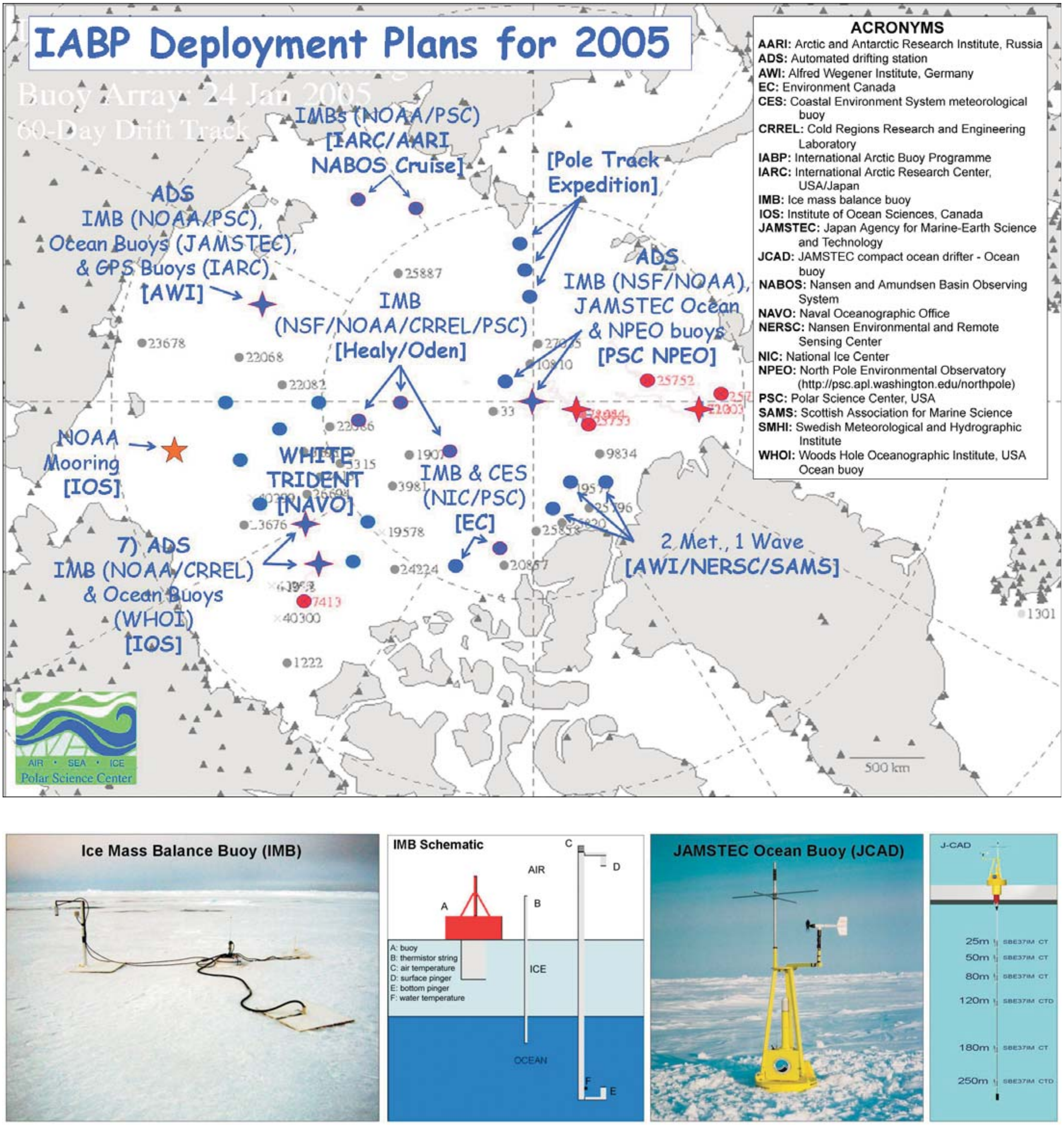
Arctic connections to global climate. Excess heat (temperature, T*, and humidity,* q*) absorbed at lower latitudes is transported poleward by the atmosphere and ocean, where it is radiated back out to space (longwave radiation,* L*). Sea ice over the Arctic Ocean insulates the atmosphere from the ocean, thus reducing the amount of heat lost to space, but it also has a higher albedo than the ocean, which reduces the amount of heat absorbed by the ice-covered ocean (shortwave radiation,* S*). Most of the heat from the ocean escapes into the atmosphere through the cracks in the sea ice (heat flux,* F*).*

Understanding the changes in Arctic climate and sea ice is important, since these changes have significant impacts on wildlife and people. Many species and cultures depend on the sea ice for habitat and subsistence. For example, Inupiat hunt for bowhead whales, and polar bears hunt and raise their young on the sea ice. The lack of sea ice in an area along the coast may expose the coastline to ocean waves, which may threaten low-lying coastal towns and accelerate the rate of erosion. From an economic viewpoint, the extent of Arctic sea ice affects navigation from the Atlantic to the Pacific through the Arctic along the Northern Sea Route and Northwest Passage, which are as much as 60% shorter than the conventional routes from Europe to the west coast of the U.S. or Japan.

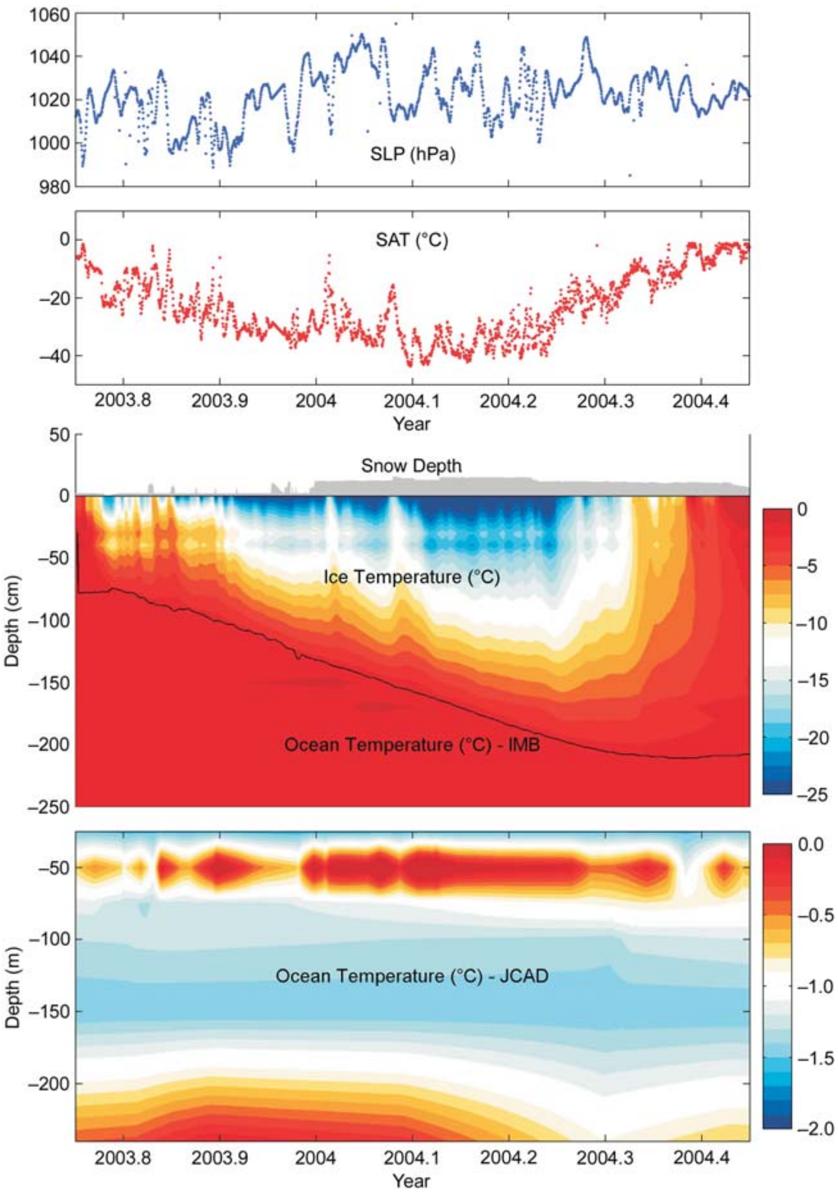
NOAA plays an important role in monitoring the Arctic and supporting research to understand and predict these changes. This article describes some of the many programs that NOAA supports to monitor Arctic sea ice and the ocean, such as the International Arctic Buoy Programme (IABP) and the Study of Environmental Arctic Change (SEARCH).

International Arctic Buoy Programme

In 1974 the U.S. National Academy of Sciences recommended the establishment of a network of automatic data buoys to monitor synoptic-scale fields of sea level pressure, surface air temperature, and ice motion throughout the Arctic Ocean. As a result, the Arctic Ocean Buoy Program was established by the Polar Science Center, Applied Physics Laboratory (APL), University of Washington, in 1978 to support the Global Weather Experiment. Operations began in early 1979, and



Current locations of International Arctic Buoy Programme (IABP) buoys and the IABP deployment plans for 2005. The current locations of fundamental meteorological buoys (gray dots), ice mass balance (IMB) buoys (red dots), and automated drifting stations (ADS) (red stars) are shown. The planned deployments of buoys are shown in blue. More details can be obtained from http://iabpl.apl.washington.edu/Deploy2005/.



Observations from an IABP ice mass balance (IMB) buoy and a Japan Agency for Marine-Earth Science and Technology (JAMSTEC) compact Arctic drifter (JCAD), which were deployed together on the drifting Arctic sea ice. These buoys measure sea level pressure, surface air temperature, ice thickness and temperatures, snow depth, and ocean temperatures and salinity.

the program continued through 1990 under funding from various agencies. In 1991 the IABP succeeded the Arctic Ocean Buoy Program, but the basic objective remains: to maintain a network of drifting buoys on the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes, including support to the World Climate Research Programme and the World Weather Watch Programme.

The IABP currently has 33 buoys deployed on the Arctic Ocean. Most of the buoys measure sea level pressure and surface air temperature, but many buoys are enhanced to measure other geophysical variables, such as sea ice thickness, ocean temperature, and salinity. This observational array is maintained by the twenty participants from ten countries, who support the program through contributions of buoys, deployment logistics, and other services. The U.S. contributions to the IABP are coordinated by the U.S. Interagency Arctic Buoy Program (USIABP), which is managed by the NOAA/Navy National Ice Center. Of the 33 IABP buoys currently reporting, 13 buoys were purchased by the USIABP, and 18 buoys were deployed using logistics coordinated by the USIABP. The USIABP also funds the coordination and data management of the IABP by the Polar Science Center, at the University of Washington. The observations from the IABP are posted on the Global Telecommunications System for operational use, are archived at the World Data Center for Glaciology at the National Snow and Ice Data Center (http://nsidc.org), and can be obtained from the IABP web server for research (http://iabp.apl.washington.edu).

The observations from the IABP have been essential for:

- Monitoring Arctic and global climate change;
- Forecasting weather and sea ice conditions;
- Forcing, assimilating, and validating global weather and climate models; and
- Validating satellite data.

As of 2005, over 500 papers have been written using the observations collected by the IABP. The observations from IABP have been one of the cornerstones for environmental forecasting and studies of climate and climate change. Many of the changes in Arctic climate were first observed or explained using data from the IABP.

USIABP CONTRIBUTORS

U.S. Coast Guard

International Arctic Research Center, University of Alaska Fairbanks

National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration (NOAA), Arctic Research Office

NOAA, National Environmental Satellite, Data and Information Service

NOAA, Office of Global Programs

Naval Oceanographic Office

Naval Research Laboratory

National Science Foundation

Office of Naval Research

The "Vision" for the SEARCH Arctic Ocean Observing System (AOOS), which includes six categories of in situ observations: ocean pathway moorings, cross shelf exchange moorings, basin moorings, gateway moorings, repeated hydrographic sections, automated drifting stations, and drifting buoys
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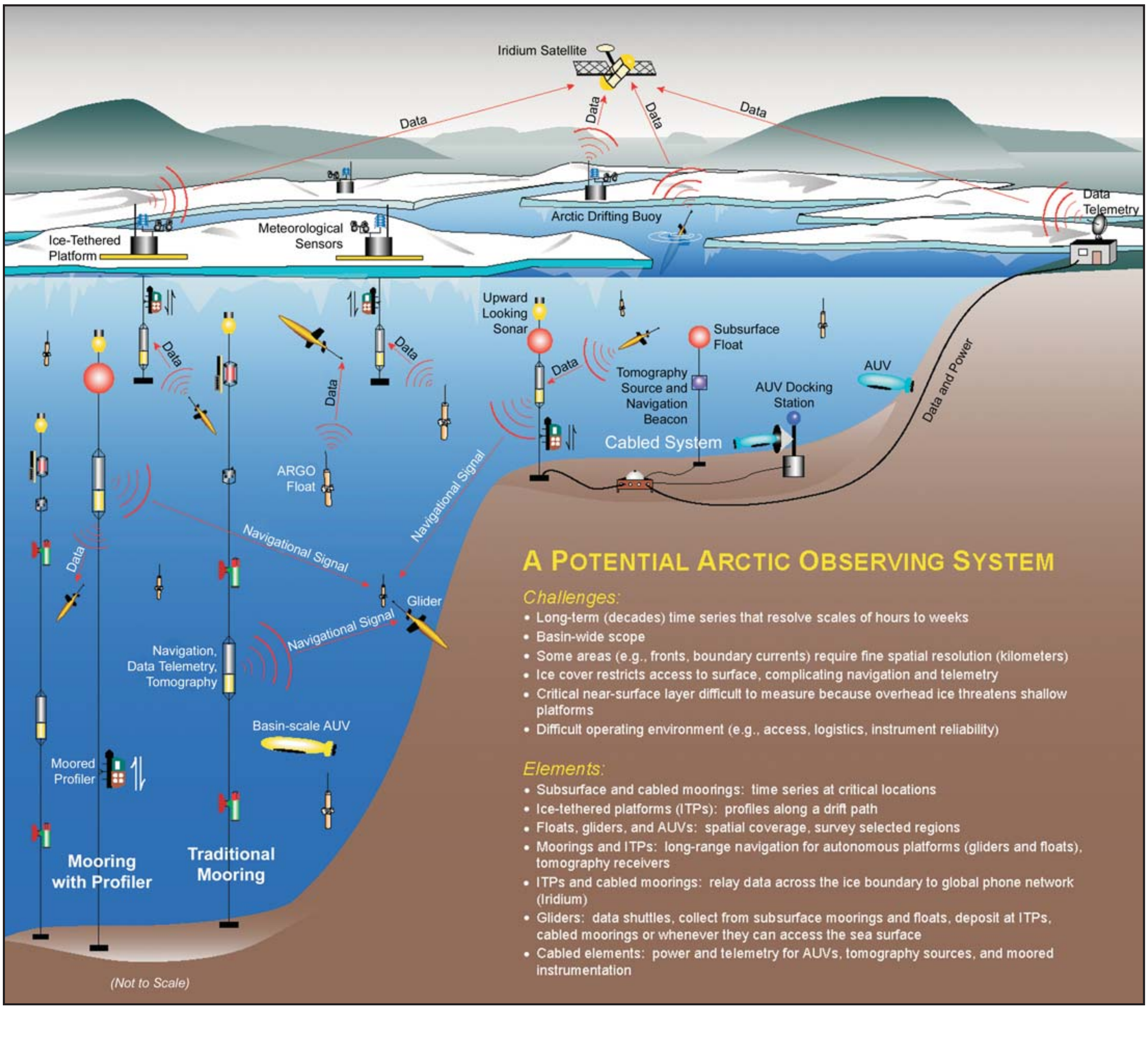
Study of Environmental Arctic Change

SEARCH is a coordinated U.S. interagency program established in recognition of the important role of the Arctic region in global climate. SEARCH's focus is to understanding the full scope of changes taking place in the Arctic and to determine if the changes indicate the start of a major climate shift in this region. NOAA has initiated its contribution to the SEARCH program with seed activities that address high-priority issues relating to the atmosphere and the cryosphere. One element of the NOAA SEARCH program is an Arctic Ocean Observing System (AOOS).

The SEARCH AOOS is envisioned to include six categories of in situ observations: ocean pathway moorings, cross-shelf exchange moorings, basin moorings, gateway moorings, repeated hydrographic sections, automated drifting stations, and drifting buoys. Enhancement of the IABP and deployment of automated drifting stations (ADSs), like the one at the North Pole Environmental Observatory (NPEO: http://psc.apl.washington.edu/northpole/), have been identified as two of the key components of the SEARCH AOOS. These enhancements and the deployment of drifting buoys have been the initial focus of NOAA's efforts. More specifically, the focus has been on establishing a network of instrumentation to monitor and understand changes in the thickness of the ice cover.

Data Collection

Central to the progress that has been made in establishing a network to monitor changes in the thickness of the ice cover has been the development and employment of autonomous ice mass balance (IMB) buoys. An IMB buoy is equipped with thermistor strings that extend through the thickness of the ice cover, acoustic sensors that monitor the position of the top and bottom surfaces of the ice, a barometer, a GPS, and a satellite transmitter. These buoys provide a time series of sea level pressure, surface air temperature, snow accumulation and ablation, ice mass balance, internal ice temperature fields, and temporally averaged estimates of ocean heat flux. Together, these data not only provide a record of changes in the ice thickness, but equally important they provide the information necessary to understand the source of these changes. This is critical to extending the results from these individual sites to other regions of the Arctic. The buoys are installed in the ice cover and, hence, drift with the ice cover. Monitoring the drift of the buoys also provides information on the circular automated drifting stations (ADSs). These sites will be established through collaboration with the Alfred Wegner Institute in Germany, the NPEO, the Japan Agency for Marine-



Components of the Arctic Ocean Observing System (AOOS).

Earth Science and Technology, and Woods Hole Oceanographic Institution's Arctic Group. These stations provide critical atmospheric, ice, and upper ocean hydrographic measurements that cannot be obtained by other means.

Since the drifting buoys move with the ice and surface currents and thus cannot reliably sample the main subsurface currents of the Arctic, these observations must also be complemented by moorings and hydrographic sections across the Arctic Ocean. In August 2003 a new mooring site was established in the northern Chukchi Sea. The mooring is equipped with an ice profiling sonar (IPS) to measure the ice draft and velocity as the ice drifts overhead, providing a measure of the ice thickness distribution. This site was located using the results from a coupled ice–ocean sea ice dynamics model. The model was used to estimate the basin-wide mean annual thickness using a 52-year window: 1948–1999. Using these estimates, a correlation analysis was applied to investigate the effectiveness of establishing a second seafloor-moored IPS to monitor changes in the annual mean thickness of the Arctic sea ice cover. The analysis recognized and was dependent on the existence of the IPS at the NPEO. The results of the analysis indicated that a moored IPS located in the northern Chukchi Sea, coupled with the results from the established NPEO site, could explain 86% of the variance of the basin-wide annual mean ice thickness. The location of a second mooring significantly improves the data collected from a single moored IPS at the North Pole, where the explained variance is estimated to be 65%. Data from the mooring sites are only available after the mooring is recovered. The first recovery of the mooring in the Chukchi Sea is scheduled for September 2004.

A potential AOOS design requires a range of complementary platforms with combined capabilities that address SEARCH requirements. The AOOS includes drifting buoys, moorings, autonomous platforms (floats, gliders, and propeller-driven autonomous underwater vehicles), and hydrographic sections occupied by ships and aircraft landings. Drifting buoys and moorings, already employed for Arctic observing, would provide sites for acoustic navigation and communications beacons and serve as data repositories and links across the ice interface for satellite communications. New autonomous platforms, especially floats and gliders, will provide unprecedented access to Arctic and subarctic regions. These platforms have seen significant successes in mid-latitude oceans and are currently being adapted for use in ice-covered environments as part of the NSF-supported Freshwater Initiative (see http://iop.apl.washington.edu for additional information). The first missions beneath the ice will investigate freshwater exchange through Davis Strait. Broader high-latitude application of autonomous platforms will require the development of long-range acoustic navigation and communications systems. An ideal system would supply long-range acoustic navigation to all platforms (Arctic underwater GPSs), allow mobile platforms to home to targets (drifting ocean buoys and moorings), and provide short-range, high-bandwidth communications for rapid data exchange. In this vision, moored platforms provide time series, data storage, and a relay through the ice to satellites; autonomous platforms provide broad spatial coverage, data shuttling, and satellite links (when in ice-free waters); and ship- and aircraft-based hydrography provide critical tracer measurements that cannot be obtained by autonomous sensors. This combination of platforms offers comprehensive coverage and creates a "store-and-forward" network to improve the timeliness and reliability of data return.

Conclusions

Recent progress has been made in establishing components of an AOOS. The initial focus is on a network of instruments to monitor and understand changes in the thickness of the ice cover and in near-surface ocean characteristics. Central to the success of this network is the coordination of these efforts with other national and international programs. The use of sea ice dynamics models has also been important, helping to optimize the location of instrumentation and the allocation of limited resources.

Data are only just beginning to be received from the recently deployed sites, but regional and interannual variability in the changes in the thickness of the ice cover and upper ocean is already apparent. This observation is consistent with other historical observations.These data will be made generally available to the scientific community for use in validating satellite-derived products; for forcing, calibration, and assimilation into numerical models; and for forecasting weather and ice conditions. Maintaining and further developing this network will provide a more consistent record of change, necessary for improving understanding of this complex and important component of the global climate system.

The establishment of the components of the AOOS discussed in this article would not have been possible without the committed collaboration among many international institutions and programs, such as the participants of the International Arctic Buoy Programme. The authors express their appreciation to the scientific participants and crew members onboard the Canadian icebreakers Louis St. Laurent *and* Sir Wilfred Laurier*, the German icebreaker* Polarstern*, the Russian icebreaker* Kapitan Dranitsin*, the Swedish icebreaker* Oden*, and the U.S. icebreaker* Healy.

References

Arctic Climate Impacts Assessment (2004) *Impacts of a Warming Arctic: Arctic Climate Impacts Assessment*. Cambridge University Press, 139 p.

Lynch, A.H., E.N. Cassano, J.J. Cassano, and L.R. Lestak (2003) Case studies of high wind events in Barrow, Alaska: Climatological context and development processes. *Monthly Weather Review*, Vol. 131, No. 4, p. 719–732.

Melling, H., and D.A. Riedel (1996) Development of seasonal pack ice in the Beaufort Sea during the winter of 1991-1992: A view from below. *Journal of Geophysical Research*, Vol. 101, No. C5, p. 11,975–11,991.

Perovich, D.K., B.C. Elder, and J.A. Richter-Menge (1997) Observations of the annual cycle of sea ice temperature and mass balance. *Geophysical Research Letters*, Vol. 24, No. 5, p. 555–558.

Perovich, D.K., T.C. Grenfell, J.A. Richter-Menge, B. Light, W.B. Tucker, and H. Eicken (2003) Thin and thinner: Sea ice mass balance measurements during SHEBA. *Journal of Geophysical Research (Oceans)*, Vol. 108, No. C3.

SEARCH Science Steering Committee (2001) *SEARCH: Study of Environmental Arctic Change, Science Plan.* Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, 91p.

Zhang, J., D. Thomas, D.A. Rothrock, R.W. Lindsay, Y. Yu, and R. Kwok (2003) Assimilation of ice motion observations and comparisons with submarine ice thickness data. *Journal of Geophysical Research*, Vol. 108, No. C6, p. 3170.