North Pole Environmental Observatory Delivers Early Results

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Scientists have argued for a number of years that the Arctic may be a sensitive indicator of global change, but prior to the 1990s, conditions there were believed to be largely static. This has changed in the last 10 years. Decadal-scale changes have occurred in the atmosphere, in the ocean, and on land [Serreze et al., 2000]. Surface atmospheric pressure has shown a declining trend over the Arctic, resulting in a clockwise spin-up of the atmospheric polar vortex. In the 1990s, the Arctic Ocean circulation took on a more cyclonic character, and the temperature of Atlantic water in the Arctic Ocean was found to be the highest in 50 years of observation [Morison et al., 2000]. Sea ice thickness over much of the Arctic decreased 43% between 1958–1976 and 1993–1997 [Rothrock et al., 1999].

Many of the programs that monitored the arctic environment, and particularly the Arctic Ocean, from the 1940s to the 1980s ended just as these changes began to occur. Two examples are the North Pole long-term drifting stations and the Sever airborne hydrographic surveys, both sponsored by the Soviet Union.

The North Pole Environmental Observatory (NPEO) was recently established to provide the types of long-term, multi-faceted research observations that are needed to understand how the Arctic is changing. Early results from the NPEO are helping to track the ongoing changes in the arctic environment until more widespread observational efforts are instituted to replace the long-term observation programs that have been lost in recent years. The operational lessons learned in the first NPEO deployments will aid development of future long-term observation strategies. Further information on NPEO, near-real-time North Pole data, and past data can be found at http://psc.apl.washington.edu/northpole/index.html.

NPEO demonstrates how to provide the long-term measurements needed to track the changing arctic environment. Some of the measurements needed are time series beneath the surface at fixed locations. Others are needed at the surface in a reference frame drifting with the sea ice, and still others—such as ocean temperature and salinity—are needed as repeated sections over hundreds of kilometers. Thus, the North Pole Environmental Observatory is more than a single installation (Figure 1). It includes a deep-sea instrument mooring, an automated drifting station consisting of a cluster of buoys fixed to the drifting sea ice, and airborne hydrographic surveys conducted each year during deployment of the mooring and drifting station. The instrumented mooring is installed close to the Pole and stretches from the ocean floor at a depth of over 4000 m to within 50 m of the surface. The drifting buoys measuring atmosphere, ice, and upper ocean properties are installed near the Pole, and during a year’s time, they drift out of the Arctic Ocean. Ocean hydrographic sections run from the Pole into several key basins of the Arctic Ocean.

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Figure 1. This schematic of the North Pole Environmental Observatory shows that it consists of an automated station that drifts with the ice from an installation point near the North Pole, a mooring that remains anchored to the bottom near the North Pole, and a yearly airborne hydrographic survey that is performed as part of the deployment effort.
The North Pole is an excellent location for such activities. Near the flank of the Lomonosov Ridge, it has proven to be a sensitive site for changes in upper ocean frontal structure and in the Atlantic water flowing along the ridge [Serreze et al., 2000; Morison et al., 2000]. A history of expeditions to the North Pole provides a benchmark of ocean observations there. Drifting station deployment at the North Pole fills a gap in drifting buoy coverage that has plagued the International Arctic Buoy Program's measurements of ice drift, atmospheric temperature, and pressure. Time series observations of ice thickness there provide a unique measure in the transpolar drift of sea ice. Airborne hydrographic surveys radiating from the Pole provide repeated sections of ocean properties in critical areas that are difficult to reach by other means.

Deployments of the NPEO were carried out in the spring of 2000 and 2001. The program will continue through 2004. The location of the hydrographic stations, the deployment position and tracks of the automated drifting stations, and the mooring location in 2001 are shown in Figure 2.

Operating from the Canadian Forces Station Alert in Nunavut, Canada, in 2000, a six-member science team deployed the first NPEO drifting station and conducted the first hydrographic survey. The station consisted of five buoys measuring ocean, ice, and atmospheric variables (Figure 1, inset). The first hydrographic survey included seven hydrographic stations between Alert, the North Pole, and beyond (Figure 2; detailed hydro station positions are available at the NPEO Web site).

In 2001, a slightly larger group deployed a similar automated drifting station, performed a 300-km hydrographic section from the Pole toward Alaska (Figure 2), and installed the first long-term oceanographic mooring at the North Pole. Information is still being collected from the 2001 instruments. Initial results from NPEO 2000 and 2001 are generally consistent with the changes observed in the 1990s.

**Hydrographic Surveys**

During NPEO 2000, hydrographic stations were made with conductivity-temperature-depth (CTD) instruments and two lightweight, battery-operated winches capable of profiling to 500 m and 1000 m. The winch equipped for shallower depth provided for taking single water samples with a small-diameter, 1.5-liter Niskin sampling bottle. It was used at most stations to sample at 5 m and 125 m. Samples were drawn for salinity, barium, 18O, and nutrients. The survey in 2001 utilized a larger winch that was operated directly from the survey aircraft, with provisions for making CTD casts with sampling bottles at four depths and for drawing the water samples in a heated space.

Temperature and salinity measured at the North Pole in 2000 and 2001 have been compared with profiles from the U.S.-Russian winter atlas [EWG, 1997], the 1991 cruise of the Swedish icebreaker *Oden*, and the NSF- and ONR-sponsored SCICEX U.S. Navy submarine cruises of 1993, 1995, 1997, 1998, and 1999. The NPEO 2000 and 2001 results are similar to the SCICEX data of the 1990s, in that salinity in the salt-stratified halocline is elevated about 1 above the climatological values of the 1950s through the 1980s. In 2001, the North Pole surface salinity, above 25 m, was somewhat less than in 2000 and the late 1990s, and it was about equal to the maximum found in the 1950s through the 1980s. The 2000 and 2001 temperature data reflect the increased Atlantic water temperature characteristic of the 1990s. The depth of the temperature maximum was 300 m in 2000 and 2001. This is about 25 m deeper than was found during SCICEX, but not nearly as deep as the 400 m characteristic of the 1950s through the 1980s. The temperature below 600 m is greatest in the 2000 data; due to equipment failure, there were no CTD data below 500 m in 2001.

In general, ocean conditions at the Pole in 2000 and 2001 appear to have relaxed somewhat toward climatology near the surface, remained nearly steady at mid-1990s values in the Atlantic water core (250–300 m), and departed slightly farther from climatology at depth. This variation in trends with depth may be related to the ocean response time at different depths to changes in atmospheric forcing. In 2001, the Arctic Oscillation (AO) index, for which positive trends correspond to decreasing arctic atmospheric pressure, showed a significantly negative winter average for the first time in over 10 years. Many suspect that the decadal change in upper ocean conditions is caused by the decadal increase in the AO. In our experience, it is reasonable to assume that the ice and mixed layer could respond to changes in AO on seasonal-to-annual time scales and produce the decreased 2001
mixed-layer salinity. The deeper Atlantic water near the Pole probably responds on time scales comparable to the transit time from the Fram Strait to the Pole; that is, several years. The water below the Atlantic water probably responds to changes in atmospheric circulation on time scales of a decade or more.

The NPEO 2000 and 2001 CTD survey sections capture the counterclockwise shift of the front between Atlantic-derived and Pacific-derived upper ocean waters that characterized the 1990s: increased salinity Atlantic-derived water appears at the Pole and decreased salinity Pacific-derived water appears off Ellesmere Island. Figure 2 shows the deviation of NPEO 2000 and 2001 measured salinities from the 1950–1990 climatology [EWG, 1997]; contours of deviation from climatology appear in perspective view below the hydrographic station tracks. The salinity deviation in the upper ocean near the Pole (NPEO 2000 station 1, NPEO 2001 station 1) and in the Amundsen Basin (NPEO 2000 station 3) is 1.5 to 2, a condition characteristic of the change in the 1990s. The 2001 section shows that the salinity increase in the upper halocline extends across the Makarov Basin and the southernmost portion shows a +1 salinity anomaly between 50 m and 100 m. These anomalies are similar to those measured near the same locations during SCICEX cruises in 1995, 1998, and 1999. Except for salinity at NPEO 2001 station 3, where the 200-m salinity anomaly was slightly greater in 1995, the NPEO 2001 anomalies at stations 3, 4, and 5 are greater than the SCICEX anomalies near the same locations. In contrast, the southern end of the NPEO 2000 section shows a minus 1.5 salinity deviation. Conditions there are similar to those found by Newton and Sotirin [1997] in 1994 and represent movement of Pacific-derived upper ocean waters eastward along the Canadian margin.

NPEO 2000 ocean temperature anomalies (not shown) indicate a 1°C warming relative to climatology in the Atlantic water layer near the Pole and in the Amundsen Basin. The southern portion of the 2001 section suggests a positive temperature anomaly at 200 m centered at station 4. These are consistent with the pattern in the 1990s. The position of the temperature and salinity anomalies over the north slope of the Alpha Ridge and the timing of the most recent increases in salinity suggest that we are seeing a progression of the 1990s' Atlantic water and upper halocline changes counterclockwise around the Makarov Basin and toward Canada along the Alpha Ridge.

All the surface water tracers measured in 2000 showed a gradation toward more Pacific-like character extending from the Pole south toward Ellesmere Island, with a marked transition between stations 2 and 4. In 2001, surface waters showed increasing Pacific-like character from the Pole toward Alaska, with a pronounced transition between stations 4 and 5. Barium concentrations in surface waters were generally higher approaching Ellesmere Island and Alaska, consistent with more barium-enriched riverine inputs in the Pacific sector. Relatively high barium concentrations were observed in the surface water at the 2001 station 3 over the Makarov Basin. This correlates to a riverine oxygen isotope signal imbedded in a mostly Atlantic seawater contribution. Variable riverine contributions in the transpolar drift are the likely cause of this. Higher phosphate concentrations trended toward the south in both years, presumably due to the enriched phosphate contents of the Bering Sea input. Nitrate-to-phosphate relationships suggest that the surface waters in the southern part of the NPEO 2000 section and at station 5 in the 2001 section are almost completely Pacific-derived. Together, the 2000 and 2001 tracer data suggest that the 50% Atlantic-Pacific boundary has shifted toward Ellesmere Island and toward Alaska relative to its 19931996 position reported by Jones et al. [1998].

Measurements of Si, indicative of Pacific influence, in the upper halocline were limited in 2000, although an upper halocline Si maximum was observed at stations 5 and 6. No pronounced Si maximum was found in the halocline at any 2001 stations. The upper halocline layer of Pacific origin has yet to re-occupy the Makarov Basin as it did before the 1990s.

Figure 3. (a) Horizontal distribution of salinity at 20-m depth is shown. Note that the data along the trajectory are measured by J-CAD1, and the background describes the EWG [1997] winter climatology. Vertical profiles of (b) temperature and (c) salinity are shown in the vicinity of the North Pole at 89.371°N and 45.317°W (red) for J-CAD1 and at 89.364°N, 45.000°W for EWG (1997) climatology (blue).

Automated Drifting Stations

The buoys of the automated drifting stations are tracked with Global Positioning System receivers and ARGOS. Data are gathered continuously and telemetered through the ARGOS and ORBCOM (JCAD) satellite systems (see the
greater than the climatology for upper ocean conditions. The JCAD-1 20-m salinity is 1.0, illustrating the measured 20-m salinity, representative of ocean change through the Amundsen Basin. Figure 3a shows the track of the JCAD-1 buoy at the station provides a picture of ocean change through the Amundsen Basin. Figure 3a illustrates the measured 20-m salinity, representative of upper ocean conditions. The JCAD-1 20-m salinity is 1.0, greater than the climatology [EWG, 1997]; along the same track, the measured temperature at 250 m is 0.5–1.0ºC warmer than climatology. The 1990s' advance of higher salinity, Atlantic-derived surface water toward the Alaskan end of the Arctic Basin is apparent. The profiles of temperature and salinity from JCAD-1 in Figure 3b and 3c illustrate the effect on the cold halocline. They are compared with the climatological salinity and temperature profiles near the middle of the Amundsen Basin. The JCAD-1 profiles reveal that in spite of return of the cold halocline to the Russian end of the Amundsen Basin [Boyd et al., 2002], the salinity in the upper ocean along the drifting station track was still elevated so as to greatly weaken or eliminate the cold halocline.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) ice mass balance buoy provides a thermodynamic history of the NPEO 2000 drifting station ice floe. Ice temperature contours from CRREL buoy 1, as well as air temperature, water temperature, snow temperature, and the calculated ocean heat flux are shown in Figure 4. The ice temperature profiles allow an estimation of heat conducted through the ice. The depth below which the temperature becomes constant at the freezing point is taken as the ice-water interface. Tracking this depth reveals bottom melt and growth rates. The ocean heat flux to the ice shown in Figure 4 is computed as a residual between conduction and the heat lost for growth. Snow thickness is measured by the CRREL buoy using an acoustic sounder. In April, the upper part of the ice was quite cold, but by June 25, it warmed to near the freezing point. The snow disappeared about the same time. Once this occurred, top and bottom ablation was substantial, even though the air temperature (top panel) was not above 0ºC. Without the high albedo of the snow, radiative heating readily melts the ice. The radiation is able to produce bottom melt as well as top surface melt because some radiation penetrates the ice cover and heats the water. This, in turn, causes ocean heat flux to melt back the ice-water interface. In late August, the snow returned and surface melt stopped, though gradual bottom melt continued. Starting in November, near the time the station reached Fram Strait, the ice cooled rapidly and began to grow at the lower surface. This continued until the buoy came near the ice edge in late January and ocean heat flux from below melted the floe rapidly.

The buoys comprising the NPEO 2001 drifting station were similar to those deployed in 2000. Unfortunately, many of them were damaged or destroyed by major ice deformation in the early part of the drift. The meteorological sensors on the JCAD buoy and the radiometer buoy continued to operate. The station was visited on 15 September 2002, by an air crew from the U.S. Coast Guard Cutter Healy. They installed an additional atmospheric temperature and pressure buoy from the Alfred Wegner Institute (AWI). The station drifted in a circuitous pattern in the Amundsen Basin for an extended time and had not reached Fram Strait as of the end of 2001 (Figure 2; see the NPEO Web site for updated positions). The NPEO 2001 PMEL/CRREL Radiometer Buoy has provided the first successful automated measurement of radiation through the spring heat balance transition. The observed shortwave solar radiation and atmospheric longwave radiation are characterized, especially in the early part of the record, by a diurnal cycle in solar radiation on clear days with low infrared; see the NPEO Web site for an illustration of these data. On cloudy days, the longwave radiation is enhanced and sunlight is reduced. The last record from the radiometer buoy was on 14 August 2001.
The NPEO Mooring

The first recovery of the NPEO mooring is planned for April 2002. The mooring (Figure 1) incorporates an upward-looking sonar at 50 m to measure ice draft; temperature/conductivity recorders at 55 m, 110 m, 210 m, 260 m, 1000 m, 1701 m, and 2500 m; an acoustic Doppler current profiler to measure water and ice velocity in the upper 80 m; and recording current meters to measure water velocity, temperature, and conductivity at 84 m, 235 m, 600 m, and 1700 m. The mooring was established at the North Pole to fulfill the following objectives:

- Determine the statistics and low-frequency—including annual to inter-annual—variability of both the ice drift and water velocity in the mixed layer and halocline
- Quantify the vertical and temporal scales of variability in temperature and salinity, especially in the halocline and the Atlantic layer, where many of the dramatic changes of the past decade have occurred
- Assess the impact in this region of large-scale changes in the circulation and properties of the Arctic Ocean
- Provide a long-term comparison base for earlier measurements in the region.
- By measuring time series of sea ice draft, estimate the temporal variations of the sea ice thickness distribution in the transpolar drift and compare these with concurrent variations in the local environment, and with variations in the AO, North Atlantic Oscillation, and other indices of change.
- Provide a platform for community-wide Eulerian measurements in the interior Arctic Ocean.

2002 Deployment

The 2002 NPEO deployment was completed as this article was going to press. The 2001 mooring was recovered successfully and a new mooring deployed at the same location. The drifting station was also deployed and includes a new ocean flux buoy from the U.S. Naval Postgraduate School and a Web camera that provides near real time images of the station. The hydrographic survey consisted of a closely spaced CTD section across the Lomonosov Ridge and two full hydrographic stations in the Makarov Basin. The data from these efforts are beginning to be retrieved and analyzed. For the most recent results, data, and up-to-date images of the 2002 drifting station, visit the NPEO Web site at http://psc.apl.washington.edu/northpole/index.html.

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References


