NSF Autonomous and Lagrangian Platforms and Sensors (ALPS) Workshop Report

Application of ALPS Technologies to High-Latitude Science Issues

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The high-latitude oceans serve as freshwater sources and heat sinks for the global thermohaline circulation, exerting significant influence on ocean general circulation and climate variability. Warm surface flows carry heat toward the poles where intense heat loss to the atmosphere drives densification and produces an equatorward return flow of intermediate and bottom waters. This exchange establishes the meridional overturning circulation (MOC) which, when combined with the inter-basin exchange permitted by the zonally unbounded Southern Ocean geometry, supports the global thermohaline circulation. High-latitude convection thus ventilates the many mid- and low-latitude density layers which outcrop in the polar/subpolar oceans, setting subsurface density structure and removing carbon to the ocean interior. In contrast, net precipitation in the polar regions produces an equatorward freshwater flux that is largely confined to the upper ocean. Fresh waters exiting the Arctic can form a low-density surface barrier that inhibits convective overturning at the deep water formation sites in the Labrador and Greenland Seas, modulating the strength of the MOC and thus the exchange of heat from equator to pole. The high-latitude freshwater balance plays additional roles in the climate system. For example, the combination of Arctic riverine discharge and brine rejection during sea ice formation generates a strong halocline which insulates the ice from the warmer waters below. Processes that impact high latitude heat and salt balances (and thus circulation) exert strong influences on global climate through this series of connections and feedbacks.

Geographic remoteness, severe operating conditions and issues associated with ice cover have hindered high-latitude measurement efforts and thus limited our understanding of polar and subpolar regions. Icebreakers, aircraft and occasionally submarines provide access for hydrographic and mooring programs, but are costly and unable to operate in many areas of interest. The presence of permanent or seasonal ice cover makes year-round time series extremely difficult to obtain. There are relatively few ice-capable ships, and these cannot readily access difficult regions such as the Canadian Basin. Weather and available daylight restrict aircraft operations to narrow time windows. Likewise, though many critical processes occur in the upper ocean, the threat posed by overhead ice prevents moored instruments from sampling the region directly below the ice bottom. The resulting paucity of data has left many broad, fundamental questions unanswered and places some aspects of polar oceanography on an exploratory footing reminiscent of earlier periods of lower latitude science. Important outstanding issues include:

- Mapping the hydrography, pathways and inter-basin connections that characterize Arctic regional circulation.

- Exploring the dynamics and variability of the Arctic Ocean boundary current, which carries Pacific water through to the Atlantic and transports heat from the Atlantic into the basin interior.
- Understanding freshwater exchange with the Arctic and its response to decadal scale climate fluctuations.
- Quantifying ice draft variability and the role of ice in the freshwater balance.
- Investigating the processes governing circulation and watermass transformation beneath Antarctic ice shelves and along Arctic and Antarctic ice margins.
- Understanding the dynamics that govern circulation over broad, shallow Arctic shelves and the processes that drive exchange with the adjoining basins.

Efforts to address these issues might range from the intensive, short-duration process studies (timescales of hours/days and spatial resolutions < 1 km) required to quantify the fine-scale dynamics governing watermass transformation to long-term (years to decades) basin-scale programs aimed at understanding the response of freshwater exchange to climate variations.

Application of developing ALPS technologies could ease many of the cost and accessibility issues that currently hinder high-latitude measurement programs. Autonomous floats have been successfully employed in studies of deep water formation in the Labrador Sea (Lavender and Davis, 2002; Steffen and D'Asaro, 2002) and exchange across the Antarctic Circumpolar Current (Gille, 2003), providing an extensive set of measurements that would have been impossible to obtain using combinations of ship-based surveys and moorings. These deployments illustrate the use of ALPS technologies to collect measurements over extended time periods (2 years or longer) in remote, operationally difficult (though not inaccessible) locations.

ALPS technologies offer critical paths for extending observational capabilities to regions subject to seasonal or permanent ice cover. Quasi-synoptic survey capability, similar to that used in investigations of mesoscale and finescale dynamics in ice-free regions, would facilitate many important process studies. A growing class of powered AUVs (e.g. Autosub, Bluefin Odyssey and the Atlantic Layer Tracking Experiment (ALTEX) vehicle) promises the ability to conduct limited duration surveys (hours to days) beneath the ice. The Lead Experiment (Morison and McPhee, 1998) and the Surface Heat Budget of the Arctic Ocean program (Hayes and Morison, 2002) provide pioneering illustrations of how AUVs might be used to conduct process studies beneath the ice. These vehicles execute preprogrammed patterns, profiling in the vertical, following the underside of the ice or tracking a specific property surface. Inertial navigation can be employed for short-range missions, eliminating the need to deploy a separate array of navigation beacons. Though range-limited (typically < 100 km), these platforms offer unprecedented access to the ice shelf boundaries and could be employed in studies of shelf dynamics, watermass transformation processes and shelf-open basin exchange. The vehicles could also be carried into basin interiors to access regions far beyond the ice edge. Because these operations require ships, an effective strategy might be to combine ship-based surveys with AUV deployments, using the AUVs to provide three-dimensional context and extend observational ‘reach’ to the underside of the ice.

The Autonomous Polar Geophysical Explorer (APOGEE) project illustrates another AUV-based strategy for providing access to ice-covered regions. This vehicle will land an ocean bottom seismometer on the Nansen-Gakkel Ridge where it will over-winter, returning to meet a recovery vessel the following year.

Adaptations of extended endurance platforms such as autonomous gliders (Eriksen *et al.*, 2001; Sherman *et al.*, 2001), profiling floats (Davis *et al.*, 2001) and heavily instrumented Lagrangian floats (D'Asaro, 2003) offer promising avenues for leveraging ALPS technologies to access ice covered regions. Relatively low cost and long mission durations (months to years) make these platforms ideal for circulation studies and long-term monitoring efforts. Gliders can also hold station (acting as profiling moorings) or transit between prescribed waypoints, executing tightly spaced (kilometers) profiles along the route. Significantly, this class of platforms can periodically profile upward to the ice bottom while spending the balance of their time deep enough to be protected from collisions. Typically, these platforms navigate using GPS and employ satellite telemetry (e.g. ARGOS, Irridium and ORBCOM) to exchange data and instructions with shore-side command centers, making them highly dependant on surface access. Efforts are currently underway to integrate RAFOS navigation into gliders and floats, which will enable them to determine their position by triangulating from an array of moored sound sources. High-latitude salinity stratification creates a surface sound channel that forces rays to reflect off the ice bottom, producing large transmission losses that depend on ice bottom roughness and water depth. When operating beneath the ice, RAFOS frequency (260 Hz) sources achieve ranges of only 150-300 km (Jin *et al.*, 1994; Manley *et al.*, 1989), an order of magnitude poorer than typical mid-latitude performance. These relatively short ranges place practical limitations on the size of the ensonified region. A modest number of sources can provide navigation for regions spanning several hundred kilometers, facilitating studies of straits, ice shelves and select regions of major basins. Large-scale circulation studies and trans-Arctic sections would require either an extensive network of sources or an alternative technology. Although RAFOS navigation eliminates the need to surface, it does not address telemetry issues. Under-ice deployments thus require a high degree of vehicle autonomy and depend on post-mission interrogation via satellite (upon encountering open water) or physical recovery to access the data stored aboard.

Ice-capable floats and gliders can also be used in tandem with conventional moorings and ship-based operations to provide complementary measurements. Consider, for example, the monitoring of an ice-covered strait. A moored array could provide Upward Looking Sonar (ULS) and Acoustic Doppler Current Profiler (ADCP) measurements for estimating ice draft, ice velocity and upper ocean currents. Gliders could contribute high-resolution spatial coverage, collecting profiles of physical, optical and (eventually) biogeochemical variables that extend upward to within a few meters of the ice bottom. The combined system would provide year-round characterization of liquid and ice fluxes that would be impossible to obtain using a single platform.

The many unresolved high-latitude science issues suggest future development paths for ALPS technologies. Operation of powered AUVs and gliders in ice-covered regions requires robust autonomy, especially for extended missions which are subject to a wide range of environmental conditions. Designing and implementing appropriate behavior is a difficult, ongoing task. Development of a basin-scale navigation system for under-ice operations would dramatically improve the utility of AUVs, gliders and floats. Such a system would facilitate extensive float/glider efforts which could efficiently characterize basin scale circulation. The availability of data telemetry during under-ice operations would dramatically reduce experimental risk, as platform loss would no longer be synonymous with catastrophic data loss. The ALTEX AUV employs data capsules designed to melt through overhead ice to gain access to the surface, though alternative approaches might include periodic transfer to moored data depots or to other vehicles. Current platforms impose strong restrictions on payload size and power consumption, severely limiting the selection of acceptable sensors. Simultaneous development of new sensor technologies, especially for biogeochemical properties, and of vehicles with enhanced endurance and payload capability would facilitate interdisciplinary observational efforts. Ideally, biological and chemical measurements would be conducted with the same spatial and temporal resolution as the simpler physical (e.g. temperature and conductivity) measurements. Careful attention must be paid to issues of size and power consumption when developing sensors for autonomous platforms. Shallow high-latitude shelves remain resistant to measurement efforts. Ice scouring poses a serious threat to bottom mounted instrumentation while the region between the ice and the seabed is often too narrow to permit AUV, float or glider operations. The instrumenting of shallow, ice-covered shelves presents a difficult challenge that will likely require a combination of conventional (trawl-resistant bottom landers) and APLS technologies. System designs may need to be capable of tolerating significant losses while still providing useful data return.

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Information on the Web

MARVOR floats (PALACE floats with RAFOS receivers):
http://www.ifremer.fr/dtmsi/produits/marvor/marvor.htm

APOGEE
http://www.whoi.edu/science/PO/arcticgroup/projects/apogee.html

AUTOSUB
http://www.soc.soton.ac.uk/SOES/MSC/OC/CEO/aui/aui.html