MEETINGS

Acoustic Navigation and Communication for High-Latitude Ocean Research Workshop

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Recent community reports on autonomous platforms and Arctic observing [*U.S. National Science Foundation,* 2002; *Proshutinsky et al.,* 2004; *Rudnick and Perry,* 2003] identify the development of under-ice navigation and telemetry technologies as one of the critical factors limiting the scope of high-latitude measurement efforts. Advances in autonomous platforms (profiling floats, drifters, long-range gliders, and propeller-driven vehicles) promise to revolutionize ocean observations, providing unprecedented spatial and temporal resolution for both short-duration process studies and multiyear efforts designed to quantify long-timescale environmental changes. This new generation of platforms facilitates access to logistically difficult regions where weather and remoteness challenge conventional techniques, making them attractive for polar regions. These platforms could provide persistent, high-resolution, basin-wide sampling in ice-covered regions and operate near the critical ice-water interface.

Currently, however, navigation and telemetry for these platforms relies on global position system and communications satellites (Iridium, ARGOS, ORBCOMM) that are poorly suited for high-latitude applications where partial or complete ice cover restricts access to the sea surface. A similar backbone infrastructure offering basin-wide geolocation and telemetry in ice-covered regions would allow the community to use autonomous platforms to address previously intractable problems in Arctic oceanography.

Motivated by the dramatic advances in temporal and spatial reach promised by autonomous sampling and by the need to coordinate nascent efforts to develop navigation and communications system components for near-term observational efforts, an international group of acousticians, autonomous platform developers, high-latitude oceanographers, and marine mammal researchers gathered recently in Seattle, Wash., for a U.S. National Science Foundation (NSF) Office of Polar Programs-sponsored Acoustic Navigation and Communication for High-Latitude Ocean Research (ANCHOR) workshop.

Workshop Goals and Platform Requirements

Ongoing efforts to use autonomous systems for sampling beneath ice and the ambitious European Union's DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies; http://www.damocles-eu.org), which includes acoustic navigation and communication development, require an overarching system specification to guide the engineering of interoperable systems. A carefully coordinated, multinational, consensus approach to the design and implementation of acoustic infrastructure will be required to overcome logistical and financial challenges and address significant questions in Arctic Ocean science.

Toward this end, workshop goals included (1) defining science and platform drivers; (2) summarizing the current state of knowledge concerning Arctic acoustics, navigation, and communications; (3) beginning development of an overarching system specification to guide community-wide engineering efforts; (4) identifying elements that require additional research; (5) recommending near-term research and development activities; and (6) establishing an active community and steering group to guide long-term engineering efforts and ensure interoperability between elements developed by disparate teams.

Workshop participants considered platform requirements and the needs of key science missions to define system performance specifications. The ANCHOR platform suite includes floats, gliders, propeller-driven autonomous undersea vehicles (AUVs), ice-tethered platforms, and moorings. Potential science missions include broad-scale circulation studies, bathymetric mapping, hydrate and cold-seep characterization, ice thickness studies, investigations of the warm Atlantic layer, and quantification of freshwater ex-change with lower-latitude basins across critical choke points. From these drivers, workshop participants identified several key technical requirements for both navigation and communication.

ANCHOR participants examined a range of science missions that, when taken together, define system requirements. For example, large-scale circulation studies and trans-Arctic sections demand basin-wide navigation at kilometer or better accuracy, meeting participants noted. Gliders rely on access to one or more geolocation fixes per day to accurately navigate, while propeller-driven AUVs currently carry inertial navigation systems that require only occasional reference positions. Although floats do not actively steer, frequent positioning allows them to resolve high-frequency motions such as inertial oscillations and tides. Other missions, such as bathymetric mapping and small-scale process studies, require navigation accuracies of meters, with frequent positioning, over regions spanning 100 kilometers.

Discussions identified mobile (ice suspended) acoustic sources as a potentially important system component, though these elements must be capable of transmitting their position as part of the navigation signal. Participants agreed that all long-range sources, both bottom-moored and ice-drifting, should be designed to send additional telemetry to provide command information to autonomous platforms. The ability to transmit even short (several bytes) command sequences could provide significant mission flexibility. Although technological constraints (e.g., transducer size) prevent outgoing long-range communication from autonomous platforms, short-range (one kilometer) telemetry at rates of one kilobyte per second would allow efficient data transfer between autonomous systems, moorings, and ice-tethered platforms. With standardized acoustic systems, any platform in the system could serve as a node in a store-and-forward network, increasing reliability and data recovery rates.

A High-latitude Navigation and Communication System

ANCHOR workgroups outlined a three-tiered system to provide basin-, regional-, and local-scale navigation, low-bandwidth one-way (source-to-platform) basin- and regional-scale communication, and high-bandwidth, short-range two-way telemetry.

Previous investigations of acoustic propagation loss beneath Arctic ice indicate that 50-hertz sources would provide the necessary transbasin range, with the possibility that source frequencies up to 100 hertz might also suffice. Logistical constraints favor the smallest, most energy efficient (e.g., higher-frequency) sources capable of fulfilling system requirements, while propagation losses associated with surface ducting, reflection off the ice bottom, and high ambient noise levels favor low-frequency sources.

The transbasin range offered by these sources allows a small (<10) number of carefully chosen sites to provide navigation for platforms operating anywhere in the Arctic basin, eliminating the need for multiple project-specific systems and opening the basin to exploration using autonomous platforms. Basin-scale sources might also provide tomographic signals for Arctic Ocean thermometry, monitoring integrated heat content at weekly to decadal timescales.

Nested within this, sources based on a proposed enhancement of one-kilohertz RAFOS technology would provide one-meter accuracy, regional-scale (hundreds of kilometers) navigation, and low-bandwidth, one-way source-to-platform communication. Tasked to support focused studies and mapping efforts, these sources would be relatively inexpensive and sized small enough to facilitate a wide range of deployment options (e.g., moorings, ice-tethered platforms, transport aboard small, ice-capable aircraft).

Existing acoustic modem technologies offer the functionality required for high-bandwidth data transfer and short-range homing navigation. A common protocol, implemented in tandem with vendor-specific functionality, will provide interoperability between all systems while allowing enhanced capabilities for elements using proprietary technologies. The network design must consider that autonomous platforms typically operate on extremely tight energy budgets that exclude large, power-hungry solutions. In particular, large-volume data transfers may come at significant cost to overall mission endurance.

Next Steps and Broader Efforts

The Seattle workshop represents the start of long-term efforts directed at establishing Arctic Ocean navigation and communications infrastructure and, ultimately, at exploiting autonomous technologies to achieve large advances in Arctic oceanography. Knowledge gaps and development steps identified during the workshop, along with the near-term needs of the European Union DAMOCLES program, point to several near-term efforts. Participants discussed marine mammal issues, emphasizing the need for early analysis in order to inform system design, minimize negative impacts, and seek ways to exploit the resulting system for animal monitoring.

The workshop identified several critical-path areas that could benefit from focused, near-term efforts. Additional investigation is required to determine the highest source frequency capable of providing a transbasin navigation signal. Although previous results indicate that 50-hertz signals will span the basin, higher-frequency sources would be less costly, more reliable, and logistically simpler, motivating an effort to optimize source frequency choice. A timely effort might exploit International Polar Year activities to conduct an efficient low-frequency propagation experiment. Likewise, an appropriate regional-scale frequency must be chosen that together with new signal processing techniques, provides improved navigation ranges compared with existing RAFOS systems. Efficient methods for encoding position in the navigation signals must also be researched.

Of necessity, system components will be developed and used by diverse groups, beginning with NSF-supported efforts toward a pilot regional system and the large DAMOCLES observing system. As these and other projects progress, efforts must focus on promoting technical exchange, coordinating development and deployment efforts, and maintaining community consensus as the technical specification evolves.

An international ANCHOR steering group will guide these activities, using mailing lists (anchor@apl.washington.edu), a Web site (http://anchor.apl.washington.edu), special sessions at upcoming meetings, and publications to coordinate activities and promote interaction. ANCHOR products, such as this meeting report, technical documents, and the evolving system specification, will be offered to the community through the Web site.

The ANCHOR Workshop was held 27 February–1 March in Seattle, Wash.

Acknowledgments

NSF grant ARC-0511163 supported the ANCHOR workshop. The ANCHOR steering committee also includes Agnieszka Beszczynska-Möller and Olaf Boebel, Alfred Wegner Institute, Bremerhaven, Germany; Lee Frietag, Woods Hole Oceanographic Institution, Woods Hole, Mass.; Jean-Claude Gascard, Université Pierre et Marie Curie, Paris, France; Bruce Howe, Applied Physics Laboratory, University of Washington, Seattle; and Peter Mikhalevsky, Science Applications International Corporation, Washington, D.C.

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Connections Between Science and Spirituality

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I would like to continue the discussion of points raised in William Carter's response to Robert Frodeman's *Eos* Forum article [*Carter,* 2006; *Frodeman,* 2005]. I have appreciated Frodeman's work and feel that perspectives on science deriving from humanities, philosophy, and religion can add depth, insight, and meaning to our endeavors. I would like to broaden the discussion beyond just space policy to include the relationship between science in general and these, what I would call, spiritual issues.

I can fully understand Carter's aversion to including religious people or perspectives in the formation of science policy. In addition to the examples he cites in which religious motivations have led to some scientifically questionable actions and policies by the U.S. government (having to do with medicine and stem cell research), I would also add the continued attempts by religiously motivated people (some with scientific credentials themselves) to discredit Darwinian evolution and instead advocate alternative models, such as 'intelligent design,' which make room for supernatural creation instead of, or alongside, evolutionary processes.

The recent court case in Dover, Pa., in which the local school board's decision to require presentation of intelligent design as an alternative to evolution was challenged, is a case in point of religion having a negative influence on science; fortunately, this case had a scientifically favorable outcome, with the judge ruling that intelligent design is not science and should not be presented as such in the classroom.

I think, however, what Carter fears is the influence of fundamentalist religion in science, which I would define here as religion in which Scripture is used to trump science in matters of physical phenomena and processes. This is a legitimate fear. I do not think, though, that this is the kind of religious influence that Frodeman has in mind. I believe that Frodeman is suggesting that scientists should explicitly consider the deep questions and issues of life that arise out of their work, questions and issues that are primarily in the realm of the humanities, philosophy, religion, and spirituality. By so doing, this will help us better understand the broad significance of science and technology, and it might help guide the course of work and its communication.

I would like to suggest the possibility that science, in its attempts to be objective and rational, has perhaps appeared to many in the general public (at least in the United States) to be cold, soulless, and disconnected from deep needs and motivations of the human heart. Many undoubtedly find these deep needs met in religion. While I do not myself believe that science is cold and soulless, I am beginning to think that we scientists have not done enough to connect with this spiritual aspect of humans.

There are legitimate differences of opinion about the connection between science and spirituality, but I think neglecting this connection is detrimental both to scientists and to society. I sense a significant anti-science, anti-intellectual mood these days in the United States, which perhaps is a backlash against what many people feel is an overt attempt by science to remove the spiritual (i.e., God) from our lives. In response, we have significant numbers of people who do not believe in evolution and are willing to accept scientifically specious 'theories' that make room for God (according to their