Acoustics in Global Process Ocean Observatories

Working to Advance Climate, Biological, Geological and Biogeochemical Studies

By Timothy F. Duda
Associate Scientist
Applied Ocean Physics and Engineering Department
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Bruce M. Howe
Principal Oceanographer
Applied Physics Laboratory
University of Washington
Seattle, Washington

and

James H. Miller
Professor
Department of Ocean Engineering
University of Rhode Island
Narragansett, Rhode Island

A network of ocean observatories providing power and communications may transform the use of acoustics in oceanography. Global-scale processes can be studied with three acoustic measurement techniques that share much of the same infrastructure: long-range positioning, tomography/thermometry and passive listening. The data from these applications can be used for climate, biological, geological and biogeochemical studies.

Measuring the large range of time and space scales of ocean processes is a challenge. Sensors and sampling strategies must be matched to each of the many scales. Oceanographic studies using ships, moorings and other portable assets have long been the norm, and have resulted in many advances. But, the research community now recognizes the value of persistent observations.

The U.S. National Science Foundation’s Ocean Observatories Initiative (OOI) is a new program to implement global, regional and coastal-scale observatory networks with cyberinfrastructure as research tools to provide long-term and real-time access to the ocean. Acoustical oceanography is interdisciplinary by its nature, with many processes affecting the sound field simultaneously.

Here, three acoustic measurement technologies suitable for long-term observatories are discussed: long-range positioning and navigation, thermometry (including tomography) and passive listening. The first two use generated sound, but aspects of the received signals for these systems are intimately linked with the environment through which the sound propagates, containing important information about the physical environment. Passive listening senses environmental information directly.

Active Systems

Acoustic systems that apply pulse-type transmissions for navigational purposes in the sea have been used for many decades. The signals can be short duration pulses or impulses synthesized from long-duration coded transmissions. While high-frequency systems (tens to hundreds of kilohertz) will be used for local nets in the OOI...
which uses linear frequency modulation (FM) sweep signals (260 hertz with a 1.5-hertz bandwidth). Moored sound projectors transmit on schedules to localize receivers, typically isobaric or isopycnic subsurface drifters. Localization and tracking of earlier SOFAR transmitter floats and (later) RAFOS receiver floats has led to many advances in the study of surface circulation, transport and dynamics.

The precision and accuracy of the RAFOS system is limited by the small signal bandwidth. An implementation using higher bandwidth signals would enable more accurate and precise localization of all types of platforms, improving the ability to study high wave number and high-frequency processes. Signals with a 50-hertz bandwidth in the range of 100 to 200 hertz have been considered.

Ocean acoustic tomography uses similar signals to measure travel times over many crossing acoustic paths. Using these travel times, inverse techniques can solve for 3D maps of ocean temperature, source and receiver positions, and clock drifts. The use of similar data from individual acoustic paths to infer ocean heat content along these paths is known as thermometry. The probable sparseness of the global network means that only thermometry will likely be possible along a small number of paths that are 1,000 to 5,000 kilometers in length. Tomography would only be possible with the addition of equipment moored at locations surrounding a global network site, or as part of the regional cabled observatory planned in the northeast Pacific Ocean.

Localization and thermometry applications are closely linked because they both involve transmission of coded low-frequency signals, and codes that can perform both functions simultaneously are available. Linear FM, as used by RAFOS, is one such signal. Thus, one set of transceivers could serve both purposes. Passive studies would follow directly from such a deployment, utilizing the listening devices.

The value of mobile platform deployments, projecting sensors spatially from fixed sites, can be improved using low-frequency acoustics for navigation. Ubiquitous navigation without expending energy to surface can be valuable for variable-buoyancy devices. Inexpensive deep-submerged drifters can measure ocean currents and temperatures, providing conditions in the larger area surrounding the intense local measurements made at the observatory site. Another step would be to use acoustic hardware to transmit and receive small amounts of data, or control signals, to and from underwater/seafloor platforms incapable of reaching the surface for satellite communication.

Giders, autonomous powered vehicles and profiling floats can measure an ever-increasing number of environmental parameters and processes. While submerged, they can use the observatory acoustic system, improving the quality of measurements and making the devices into passive velocity sensors after accounting for their own propulsion. Deployment of traditional drifting floats can be made on a regular basis in each ensonified observatory region, providing long-term records of Lagrangian trajectories and flow over large areas. For example, it is possible to equip these with new sensors by adding sediment traps and fine-structure sensors. An important application is under the ice in polar regions, where reaching the surface for navigation purposes is impossible. An alternative is to track and navigate platforms with low-frequency sound. Control signals could also be sent to the platforms.

### Passive Listening

Passive acoustic listening has been applied to many branches of marine science, and signal recognition is paramount. Signal processing techniques have been developed to study natural sounds generated by physical processes, such as bubble oscillation from wind and rain, earthquakes and sounds generated by animals. Passive techniques are widely used for marine mammal studies and, to a lesser extent, for fishery studies. They have been very important for studies of undersea seismicity, wind and rain.

**Marine Mammals.** Calls of whales and other marine mammals can be easily sensed. The low-frequency sounds of some species can be heard at great distances, enabling scientists to determine the locations and numbers of calling animals over large areas for long periods of time. Some of the sounds that mammals make are strongly linked to their activity and behavior, providing a means to document these important factors, an active area of research.

**Fisheries.** Although active sonar is more commonly used to estimate abundance of fish, passive sonar can be used to identify fish and invertebrate species. Sound is produced by crustaceans and fish with swim bladders. Snapping shrimp are a familiar producer of sound—their extremely loud snaps can be used to locate colonies, making abundance and migration studies possible. Several fish species produce sound during courtship and spawning, and during aggression. The behavior of these fish species can be studied using sound, such as spawning habitat preference, but assessing abundance and spatial distribution is not completely reliable because the sounds are not made at all times. Fitting fish with transponding acoustic tags allows them to be tracked. The Census of Marine Life program has taken the lead in developing these techniques.

**Seismic Studies.** The sounds generated by earthquakes in the ocean are referred to as “T waves.” These hydroacoustic waves trapped in the ocean sound channel travel at approximately 1,500 meters per second. Often, very small earthquakes that cannot be sensed from land stations, or which cannot be sensed well enough to be localized, can be detected using hydrophones and localized using T wave signals. Data show that earthquakes of magnitude 3.0 can be detected 1,000 kilometers from the epicenter. Closer hydrophones can detect correspondingly smaller earthquakes. This detection threshold is a fraction of that for land-based stations. Of course, seafloor seismometers placed near zones of small earthquakes are of interest, but seismometers are more complex and costly than hydrophones. For observatories placed at positions not specifically guided by geophysical processes, the hydrophones will measure T waves and aid in studies of larger, but more distant, underwater earthquakes.

**Wind.** Breaking waves, and the resulting bubble oscillation near the surface, which are correlated with wind, generate sound, leading to estimations of ocean winds made from acoustic data. Although the correlation between the wind and the sound is less...
than one (and may depend on things such as crossing sea and swell, duration of wind speed and direction, and fetch), the relationship between surface roughness and the sound spectrum is clear. Pursuing this link, the prospect of measuring hurricane-strength winds using underwater sound has recently been examined.

**Rain.** Bubbles from raindrop splashes produce noise that can be distinguished from wind noise, each with distinct spectral shapes. In particular, the ratios of sound intensity at two kilohertz and 15 kilohertz are quite different for wind-generated noise and rain-generated noise. Wind noise decreases monotonically with frequency, rain noise does not. Rainfall is now measured using underwater sound, with total rainfall being measured quite well, instantaneous rain rate less so (measuring rain at sea can be difficult because of the effects of sea spray). Hydrophones at global observatory stations can provide data on wind and rain, which can be used for in-situ validation of satellite data and computational model estimates of these fields.

**Human Activity.** Many human activities in the ocean generate noise, which may alter the behavior of animals, possibly in a detrimental way. Monitoring the noise from ships, resource extraction, geophysical exploration and scientific instrumentation is required to establish benchmark levels and trends. Baseline measurements, such as those from observatories, can be used to determine effects of noise on individuals and the community.

**Conclusions**

Hydrophones at the global network sites will provide data on many processes and organisms that generate noise. The addition of low-frequency sound sources to the infrastructure allows for the study of circulation via float tracking and heat content via thermometry. It also allows a limited communication capability for instruments not able to reach the surface.

**References**


Visit our Web site at www.sea-technology.com and click on this article in the Table of Contents to be linked to the respective company’s Web site.

Timothy F. Duda specializes in physical oceanography and acoustic propagation at the Woods Hole Oceanographic Institution. He is also the current chair of the Institute of Electrical and Electronics Engineers/Oceanic Engineering Society Environmental Acoustics Technical Committee.

Bruce M. Howe works with ocean acoustic tomography and cabled sensor networks (including moorings and profilers) and acoustic Seagliders at the Applied Physics Laboratory at the University of Washington. He has led an Acoustical Society of America committee to integrate acoustics into observatory efforts, such as the Northeast Pacific Time-Integrated Undersea Worked Networks Experiments and Ocean Research Interactive Observatory Networks.

James H. Miller teaches and conducts research in acoustical oceanography, sonar processing, and bioacoustics in the Department of Ocean Engineering at the University of Rhode Island. In the past, he has chaired the Integrated Acoustics Systems for Ocean Observatories committee.