TECHNICAL COMMITTEE REPORT

# Underwater Acoustics

**Megan S. Ballard**

*Postal:*
Applied Research Laboratories
The University of Texas at Austin
PO Box 8029
Austin, Texas 78713-8029
USA

*Email:*
meganb@arlut.utexas.edu

*The Technical Committee on Underwater Acoustics is concerned with sound-wave phenomena underwater and with the interaction of sound with the boundaries of the oceans.*

In contrast to electromagnetic waves, which are highly attenuated in water, acoustic waves can propagate long distances in underwater environments. For this reason, sound waves are used in water in much the same way that electromagnetic waves are used in the atmosphere to sense the environment and communicate. The Technical Committee (TC) on Underwater Acoustics (TCUW) is concerned with sound-wave phenomena underwater and with the interaction of sound with the boundaries of the ocean (the seabed and sea surface), with emphasis on the following topics: wave propagation, scattering and reverberation, ambient noise, sonar processing, and underwater acoustic instrumentation. The field of underwater acoustics has a rich history that has been motivated by and asserted influence on world events. According to Goodman (2004), "The development of underwater acoustics in the Twentieth Century was closely related to, and for the most part, driven by the significant world events of the time, e.g., two world wars and the ensuing Cold War. No other field of acoustics was so affected by these events or had such importance in their outcome." Today, work done by members of the TCUW represents a broad area of research, including topics with applications to fisheries, climate change, environmental remediation, and underwater communication. Here I describe some historical context as well as recent advances in each of the aforementioned research areas.

Propagation modeling has long been an essential area of study in underwater acoustics because it is necessary for understanding ambient noise, predicting detection thresholds, and designing acoustic arrays. The field of ocean acoustic modeling has reached a mature state of development, and a multitude of numerical techniques are available to solve the wave equation in the heterogeneous ocean waveguide (Jensen et al., 2011). Increasingly capable propagation models are continually being developed, and some advancements include models that incorporate elastic and poroelastic media. Another area of development is the inclusion of three-dimensional (3-D) propagation effects. Historically, sound propagation has been calculated using two-dimensional (2-D) models by assuming that the environment is symmetrical around the source. Although this approximation is suitable for many underwater propagation environments, features in the water column (e.g., nonlinear internal waves) and bathymetry (e.g., the shelf break) can cause out-of-plane propagation effects. The development of 3-D propagation models has been spurred by these observations as well as by the availability of increasingly more capable computing resources.

Characterization of target scattering and environmental reverberation is necessary for the effective use of active sonar systems. The target-scattering problem involves the detection, identification, and acoustic signature (target strength as a function of angle and frequency) of an object that is compared with a library of templates (Burnett, 2015), including an accounting of the effect of propagation in the waveguide to and from the target. The reverberation problem is concerned with determining ways to detect targets while screening out environmental reverberations caused by the interface roughness, variations in water temperature, schools of fish, and other sources of geological and biological clutter. One example of a high-frequency application is the detection and identification of underwater unexploded ordnance (UXO). Sea disposal of munitions was an accepted practice until it was recognized as an environmental hazard and banned in the 1970s, after an estimated 200 million pounds of UXO had been dumped into the world's oceans. Advancements in synthetic aperture sonar, automatic target recognition, and high-fidelity models have made rapid wide-area surveys for UXO possible. In another application, low-frequency sound has been used to image fish populations over thousands of square kilometers. This technique provides an advantage over conventional methods that use slow-moving research vessels to monitor highly localized transects, which significantly undersample fish populations in time and space.

Propagation and reverberation of acoustic fields in shallow water depend strongly on the spatial and temporal variability of water column and seabed properties, and lack of knowledge of environmental variability is often a limiting factor in acoustic modeling applications. Although water column properties can be directly measured, seabed properties are more efficiently estimated through remote sensing techniques. Since the 1990s, matched field inversions have been applied to measurements of acoustic signals for geoacoustic parameter estimation and probabilistic inference for uncertainty estimation. In more recent work, the focus has been on Bayesian methods, which are characterized by the use of distributions to summarize data and draw inferences. Advances have been made in optimization algorithms, such as simulated annealing and genetic algorithms, and methods of automated environmental parameterization.

Ambient noise in the ocean is the sound field against which signals must be detected, and scientists have sought to characterize it since the 1940s. Sources of ambient noise include dynamic processes of the sea, biological sources, such as marine mammals and snapping shrimp, and anthropogenic causes such as ships, geophysical prospecting, and construction, with significant spatial variation throughout the world's oceans (Carey and Evans, 2011). The construction and operation of offshore wind farms have become an important source of underwater noise because the increased demand for renewable energy drives their production. Analyses of historical data suggest low-frequency ambient-noise levels have been increasing at a rate of 3 dB per decade since the 1960s (Hildebrand, 2009). Future increases in ambient-noise levels are expected to be exacerbated by ocean acidification, which will lower seawater attenuation. In Arctic regions, the dramatic reduction in sea ice is expected to change the overall character of the ambient noise from being dominated by ice-generated processes, such as ridging and cracking, to being controlled by human activities, including shipping, seismic exploration, oil and gas development, and fishing. Although ambient noise is often viewed as an interfering source that masks a signal of interest, it can be used as a remote sensing tool. Scientists also use ambient noise to image the seabed, estimate precipitation and wind speed, and monitor deep ocean temperatures.

A great number of signal-processing techniques have been developed for different applications in underwater acoustics. As a widely used method for processing acoustic data recorded on a linear array of hydrophones, the adaptive beamformer is prime example of sonar signal processing. Although many variants exist, all adaptive beamformers work by combining signals in a manner that increases the signal strength from a chosen direction and combining signals from undesired directions in a benign or destructive way. Methods for working with sparsely populated linear arrays, including the design of coprime arrays or application of compressive-sensing techniques, have also been developed in recent years. In other work, signal-processing techniques from quantum mechanics, including path integral methods and random matrix theory, have been applied to explain sound propagation through a stochastic ocean. A variety of techniques for estimating ocean acoustic parameters have also been applied to ocean acoustics problems. Some examples are warping methods to estimate modal eigenvalues, particle filters to infer geoacoustic properties, and the waveguide invariant to localize sound sources.

Underwater acoustic instrumentation represents an area of extraordinary engineering achievements. The sound surveillance system (SOSUS), which began in the 1950s, was an early example of cabled acoustic observatories. The initial objective of SOSUS was the long-range detection of diesel submarines, but today, retired SOSUS installations are used for research in earthquake and volcano seismicity, the monitoring of marine mammal behavior, and the use of acoustic methods for ocean acoustic tomography and thermometry

(Orcutt et al., 2000). Significant engineering advancements have also been made in the development of technologies for autonomous underwater vehicles (AUVs), which are programmable, robotic vehicles that can drift, drive, or glide through the ocean without real-time control by human operators. AUVs rely on acoustic signals for navigation and communication when submerged. Use of acoustic signals for the precise localization of Seagliders has been proposed for use in tomography experiments and for extending the use of AUVs to ice-covered environments. Research in acoustic communication systems has resulted in improved performance and robustness spurred on by applications in marine research, oceanography, marine commercial operations, the offshore oil industry, and defense. Finally, the proliferation of small omnidirectional and directional sensing nodes with high-endurance recorders has made making ocean acoustics measurements more assessable.

A full description of the research activities conducted by the members of the TCUW is too extensive to be contained within a single article. The summary provided herein is meant to present the general scope of the of the breadth of research conducted by the TC. Furthermore, the members of the TCUW are also active in research associated with other TCs. There is strong overlap between the TCUW and the TC on Acoustical Oceanography, and many members of the TCUW are also involved in the TCs on Physical Acoustics, Signal Processing, and Animal Bioacoustics. Additionally, the membership of the TCUW is also well represented on the Administrative Committees of the Acoustical Society of America (ASA).

The ocean is one of the most challenging environments in which to work and conduct research due to the harsh physical conditions affecting both people and equipment. The ocean is also one of the most expensive natural laboratories due to the costs of ships, equipment, and personnel to run them. The membership of the TCUW is made up of a collection of individuals who endeavor to take on this challenging environment. They come from a wide variety of backgrounds, including physics, mathematics, geophysics, oceanography, and engineering, and they conduct work in both basic research and applied programs. Perhaps most importantly, the TCUW has a collegial, welcoming, and supportive atmosphere. It is an environment where students and young investigators are encouraged and given opportunities to become involved in the TC as well as in the ASA as a whole.

## References


Burnett, D. (2015). Computer simulation for predicting acoustic scattering from objects at the bottom of the ocean. *Acoustics Today* 11(1), 28-36.

Carey, W. M., and Evans, R. B. (2011). *Ocean Ambient Noise*. Springer-Verlag, New York.

Goodman, R. R. (2004). A brief history of underwater acoustics. In Bass, H. E., and Cavanaugh, W. J. (Eds.), *ASA at 75*. Acoustical Society of America, Melville, NY, pp. 204-227.

Hildebrand, J. A. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 935, 5-20.

Jensen, F. B., Kuperman, W. A., Porter, M. B., and Schmidt, H. (2011). *Computational Ocean Acoustics*. Springer-Verlag, New York.

Orcutt, J., de Groot-Hedlin, C., Hodgkiss, W., Kuperman, W. A., Munk, W., Vernon, F., Worcester, P., Bernard, E., Dziak, R., Fox, C., Chiu, C.-S., Collins, C., Mercer, J., Odom, R., Park, M., Soukup, D., and SpindeI, R. (2000). Long-term observations in acoustics—The Ocean Acoustic Observatory Federation. *Oceanography* 13, 57-63.