TECHNICAL COMMITTEE REPORT

Acoustical Oceanography

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The Technical Committee (TC) on Acoustical Oceanography (TCAO) was founded in 1991 and is made up of scientists and engineers interested the development and use of acoustical techniques to understand the physical, biological, geological, and chemical parameters and processes that occur in the ocean, broadly described here as "oceanography." This requires a fundamental knowledge of the physics of the generation, scattering, and propagation of sound in a spatially and temporally complex and dynamic ocean. Combining this fundamental understanding with knowledge of the underlying oceanography, allows relevant parameters to be remotely inferred at scales often unachievable by more traditional oceanographic sampling techniques.

There is strong overlap in the areas of interest to the TCAO and the TCs on Underwater Acoustics (TCUW) and Animal Bioacoustics (TCAB). This overlap is highlighted in a recent *Acoustics Today* article on the effects of climate change on acoustical oceanography, animal bioacoustics, and underwater sound (Kloepper and Simmons, 2014). There is also significant overlap with the TCs on Signal Processing, Physical Acoustics, Atmospheric Acoustics, and Biomedical Acoustics, as is evidenced by the number of co-sponsored special sessions at ASA meetings. As with many areas of acoustics, the majority of researchers in acoustical oceanography have not received formal training in acoustics, but instead, "ended up" in the field with backgrounds rooted in a broad array of disciplines. The highly interdisciplinary nature of the research is considered one of the primary strengths and distinguishing characteristics of the TCAO.

An area of research in the TCAO that has received sustained attention is the area of geoacoustic inversion, an area of research with particular synergy with the TCUW. The general approach is to estimate geoacoustic parameters by comparing modeled predictions with measurements, such as transmission loss. In general, the ability to predict transmission loss, particularly in shallow waters typical of continental shelves, is severely constrained by the lack of knowledge of the geoacoustic properties of the bottom, such as sediment layer thicknesses, sound-speed profiles, etc. Since the inception of the TCAO, significant progress has been made in the development of active and passive inversion methods for seabed characterization that complement and extend the capabilities of conventional techniques such as seismic reflection imaging and coring. In 2014 alone, at least ten papers involving different aspects of geoacoustic inversion have been published in the *Journal of the Acoustical Society of America* and *Express Letters*, including papers on the continued development of "passive" geoacoustic inversion methods that exploit ambient ocean noise (Yardim et al., 2014).

Though there is heavy overlap with other TCs in some areas, there are certain areas of research that are almost exclusively studied by members of the TCAO, such as seismic oceanography. The prestigious Munk Award, granted for significant original contributions to the understanding of physical processes related to sound in the sea, was awarded in 2013 to Steven Holbrook, who was honored as the father of seismic oceanography. In one of the seminal seismic oceanography papers, Holbrook et al. (2003) determined that a technique routinely used to image the solid earth beneath the ocean, seismic reflection profiling, could also provide details of thermohaline fine structure within the ocean, at horizontal scales of tens to hundreds of kilometers and at full ocean depth. This was exciting to physical oceanographers as acoustic imaging allowed the dynamics and evolution of thermohaline fine structure to be investigated at unprecedented resolution (Ruddick, 2003). Since then, seismic reflection profiling has been applied to investigate many physical oceanographic processes such as internal tides, internal waves, and fronts.

Ambient noise in the ocean is another archetypal research topic that continues to receive significant attention in the TCAO. Ocean ambient noise is comprised of both natural and anthropogenic sources, and its characteristics are influenced by the strongly frequency-dependent nature of absorption in the ocean, as well as the propagation physics of the natural ocean environment (Hildebrand, 2009). Natural sources of noise in the ocean include wind-driven surface waves, sea ice, rainfall, bubbles, biological sources (marine mammals, fish, snapping shrimp, etc.). For example, there is evidence that the disintegration of Antarctic icebergs results in seasonal increases in ocean noise levels in mid-to-equatorial latitudes (Matsumoto et al., 2014). Ambient noise in the ocean has also been used for often clever and diverse remote sensing and imaging purposes, coined "ambient noise oceanography." A recent example includes the use of seismic ambient noise to obtain high resolution tomographic maps of ocean surface waves (Sabra et al., 2005).

Much of the recent attention, however, has focused on anthropogenic sources of sound, including sonars, seismic exploration, shipping traffic, and construction, such as noise generated by wind farms and pile driving. Noise due to shipping traffic alone is thought to have increased almost 12 dB over the past few decades (Hildebrand, 2009). Some regions are particularly susceptible to increases in anthropogenic ambient noise, such as the Arctic. It is expected that the reduction in sea ice cover will lead to increases in oil exploration and shipping traffic, resulting in increases in anthropogenic ambient noise. An important motivation for understanding the steady (Ross 2011) and pervasive increase in anthropogenic ambient noise stems from the generally deleterious consequences to marine animals. Understanding the background "din" these animals experience is an active area of research. Describing the health of marine ecosystems in terms of their soundscape is a current hot topic, with significant overlap with research performed in the TCAB. Papers are emerging on "soundscape ecology" (Staaterman et al., 2014), with particular attention given to reef habitats as model systems, though there is still no convergence on a formal definition of the term with consensus amongst the various TCs.

Herman Medwin, past President of ASA, first chair of the AOTC, and founder of the ASA Medwin Prize in Acoustical Oceanography, has been recognized in large part for his work on bubbles in the ocean. His work includes some of the first backscattering, attenuation, and dispersion measurements of microbubbles in the laboratory and ocean, experimental attribution to the Knudsen sea noise spectrum to bubbles produced by breaking waves, understanding bubble noise produced by rainfall, and the development of methods for measuring the vertical distribution and sizes of bubbles close to the sea surface. One could argue that Medwin didn't leave a lot of stones unturned when it comes to understanding the role of bubbles in the ocean, and yet this continues to be an area of active research within the TCAO. Bubbles near the sea surface impact such critical issues such as air-sea gas exchange, affect ambient noise generated by breaking waves, modify acoustic scattering from the surface of the sea, and can have significant impact on the performance of acoustic communications systems (Deane et al., 2013).

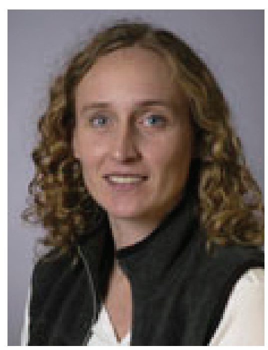
One important recent development in "bubble acoustical oceanography" is the possibility of quantifying the flux of methane from gas seeps on the seafloor to the atmosphere and dissolved into the ocean (Weber et al., 2014), thus potentially affecting ocean acidification and the global carbon cycle. In fact, acoustic techniques may play a potentially critical role in mapping natural methane seeps. For example, Skarke et al. (2014) have recently used multibeam mapping to identify extensive methane gas seeps along the US Atlantic margin, a region not generally considered for widespread seepage. To extend this work from imaging to quantification of gas bubble size distribution it will be necessary to understand the role of hydrate coating and significant deviations from spherical bubbles.

Other areas of research that fall into the TCAO purview include the use of active acoustic scattering and propagation techniques for the remote quantification of marine organisms (Medwin and Clay, 1998; Simmonds and MacLennan, 2005). Fisheries acoustics research is particularly active, with multiple special sessions dedicated to this topic over the last decade or so. One of the goals of fisheries acoustics is to assist in making wise fisheries management decisions for the sustainable exploitation of this natural resource. Traditional fisheries acoustics approaches for quantifying fish biomass and abundance involve the use of single frequency sonars typically at frequencies much higher than the resonance frequency associated to the swim bladder. Recent progress in developing sea-worthy broadband sonar techniques (Stanton et al., 2010) has opened to the door to improved quantification of fish by allowing the swim bladder resonance to be mapped. In fact, Holliday (1972) used broadband explosive acoustic sources in 1972 to very successfully map the spectral returns of various pelagic fish schools and compared the measured spectra to predictions based on rigorous acoustic approaches. However, there are significant modern headaches associated to obtaining permits for use of explosive sources! Fisheries acoustics worldwide has generally been very receptive to advances in acoustics techniques and in adopting such technologies into fisheries management decisions.

Other acoustical approaches to quantifying fish include resonance absorption spectroscopy and the use of ocean waveguide acoustics for synoptic imaging, which takes advantage of the waveguide generated by trapping sound between the air-sea and ocean-seabed boundaries (Makris et al., 2006). In fact, marine ecosystem acoustics, involving the use of acoustic techniques for quantifying and monitoring entire marine ecosystems at the spatio-temporal scales on which they occur (Godo et al., 2014), is currently a growing area of research. It is anticipated that ecosystem acoustics approaches will be one of the principal tools in operational Ecosystem Based Integrated Management. The success of this approach is yet to be determined, but depends on co-operation between fisheries acoustics, physics, engineering, biology, oceanography, and ecology. This is precisely the type of interdisciplinary science that the TCAO thrives on. An entire upcoming ICES symposium (May 2015), co-sponsored by ASA, will focus on marine ecosystem acoustics.

Although the TCAO is one of the smaller technical committees within ASA, its primary strength lies in the highly interdisciplinary nature and impressive scope of the research performed by its members. A glance at recent recipients of the Lindsay Award, A.B. Wood Medal, and the Medwin Prize, reveals that the TCAO is home to a talented, rigorous, and gritty cohort of young scientists sustaining multifaceted careers, despite a particularly challenging funding environment, and simultaneously advancing research in acoustical oceanography by building on a legacy of excellence in research developed by the founding members of the TCAO. As current chair of the TCAO, it has been my pleasure to see the level of involvement of these younger scientists in the affairs of the ASA, and their commitment to performing outstanding research in acoustical oceanography, the best possible approach to maintaining the TCAO healthy and vibrant.

Biosketch



Andone C. Lavery received the B.A. degree in mathematics from Cambridge University, U.K., in 1991 and a Ph.D. degree in physics from Cornell University in 1999. She was a Postdoctoral Scholar/Fellow from 1999 to 2002, and was hired onto the scientific staff in 2002, at the Woods Hole Oceanographic Institution. Her research interests include acoustic scattering and propagation in discrete and continuous random media, with a focus on marine organisms and small scale fluid processes. Dr. Lavery is a member of ASA, current chair of the Acoustical Oceanography Technical Committee, and associate editor for JASA-EL.

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