Conversation with a Colleague: Andone Lavery

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Meet Andone Lavery

Andone Lavery is a senior scientist in the Department of Applied Ocean Physics and Engineering at the Woods Hole Oceanographic Institution (WHOI; Woods Hole, Massachusetts). She received her degree in mathematics as well as an MMath from the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge (Cambridge, United Kingdom) and her PhD in physics from Cornell University (Ithaca, New York). She completed her postdoctoral training at WHOI. Andone is a Fellow of the Acoustical Society of America (ASA) and has served as an associate editor for *The Journal of the Acoustical Society of America* (*JASA*) and chair of the Acoustical Oceanography Technical Committee. We asked Andone to give us her elevator pitch and then to elaborate on her inspirations, contributions, and hopes for the future.

Give your "elevator speech" about the thrust(s) of your scholarly work over your career.

Fundamentally, the engine that drives research in acoustical oceanography today is the vast variability that characterizes our oceans. This oceanographic variability spans scales of seconds, (e.g., surface waves) days, (e.g., storms) all the way to decades, (e.g., large ocean currents, part of the ocean conveyor belt) and longer. Similarly, the spatial scales associated to these processes span millimeters in phenomena such as capillary waves, bubbles, and turbulence to hundreds of kilometers accompanying the basin scale process, for example, the formation and dynamics of the Gulf Stream. This physical oceanographic variability forces biological variability. For example, plankton patchiness can play an important role in ecosystem function by impacting biomass distribution across trophic levels, thus impacting energy transfer and marine food web dynamics. Recently, spatial scales and timescales associated with anthropogenic impacts have also become important, but their impacts are relatively unknown at this time. For example, marine heat waves and an apparent increase in the number of warm core rings, a type of mesoscale eddy shed from a large ocean current such as the Gulf Stream, have a relatively unknown impact on ecosystem function. All this variability poses a daunting sampling problem, exacerbated by the challenges in accessing remote sites for field work because the ocean is not always a friendly and cooperative colleague. The use of sound to explore the oceans, to understand this variability, and to make the ocean more "transparent" has driven my research throughout my career.

What inspired you to work in this area of scholarship?

I grew up like driftwood by the ocean, in a family of surfers, moving beach break to beach break, across countries and continents, to find the perfect wave, with one of the only things going for me was that I was surprisingly inspired by and luckily relatively good at mathematics, which bought me a ticket to the University of Cambridge. But the ocean did not call to me at that point, and I was not inspired to study and explore the ocean until much later in life.

https://doi.org/10.1121/AT.2022.18.3.67

After graduating from the University of Cambridge, I decided to become an astrophysicist and ended up heading to the Cornell University Physics Department as a graduate student. I was fortunate that most physics graduate students at Cornell University had to teach undergraduate physics, including teaching physics labs to undergraduates. Not only was this the forum where I actually learned physics, but it introduced me to physics lab work, which I was immediately fascinated by and the main reason I ended up sidestepping a career as an astrophysicist. My graduate research focused on understanding nonadiabatic electron transfer processes during reactive ion-surface collisions, specifically looking at charge transfer and memory loss of low-energy ions scattering from single-crystal surfaces.

As is true for many in ocean acoustics, I landed in the ocean acoustics area almost by accident. While a graduate student at Cornell University, studying condensed matter physics, I met a biological oceanographer at a graduate seminar, Chuck Greene, who encouraged me to reach out to colleagues in the Acoustics Laboratory at WHOI. I was fortunate enough to be scientifically adopted by Tim Stanton, who has become my long-standing colleague and still my mentor, and joined a number of his expeditions focused on acoustic mapping of copepods in the Gulf of Maine. Soon after completing my PhD, I joined the Department of Applied Ocean Physics and Engineering, with no formal training or pedigree in oceanography, engineering, or acoustics.

During my time as a postdoc, I focused on my strengths as a trained physicist, delving deeply into the development of physics-based acoustic scattering models for different marine organisms and small-scale physical processes such as oceanic microstructure and double diffusion. While many of my colleagues at WHOI focused on long-range, low-frequency acoustic propagation, I was more driven to understand the interaction of sound with smaller spatial scales in the ocean, propelled by questions in ecosystem acoustics and coastal oceanography. I was funded by the Office of Naval Research Code 32 to develop physics-based acoustic-scattering models for microstructure and double diffusion and to perform laboratory experiments to verify these models. Acoustic techniques have the advantage of being one of the few effective remote-sensing techniques in the ocean, a distinct advantage for large-scale mapping of small-scale processes needed for understanding how the ocean is effectively stirred and mixed by winds, waves, and tides.

Of all your contributions during your career, which are you most proud of and why?

One of the key driving forces in the area of acoustic scattering for classification and quantification of oceanic "targets," basically any discrete object (e.g., bubble, sediment particle, plankton) or extended process (e.g., stratification, turbulence, fronts) that has an acoustic impedance in the ocean that can scatter sound, is the need to understand the scattering signatures of the targets, that is, a target's individual "fingerprint." I was fortunate enough to enter the field of acoustical oceanography while it was transitioning from active, single-frequency, or narrowband approaches to multifrequency or broadband approaches for classification and quantification. I happened to be in the right place at the right time to lead efforts in the nascent area of broadband field-based acoustical oceanography.

The Shallow Water 2006 Experiment (see doi.org/10.1121/1.2972156), led by Jim Lynch at WHOI, was my first involvement in a large ocean acoustics field effort. According to Jim, enough instruments were deployed to cause the sea level to rise! My own contribution, as an assistant scientist at WHOI at the time, was to deploy a high-frequency broadband acoustic backscattering system to characterize internal waves and zooplankton. I was able to measure the acoustic-scattering signature of microstructure, small-scale fluctuations in temperature and salinity caused by stratified turbulence and spectrally distinguish these signals from those of scattering from zooplankton. I had spent some time working on physics-based acoustic-scattering models of microstructure and was gratified to find that my predictions were in good agreement with the data, especially as there were no free parameters in my model.

I had a growing family at this time in my career, and I actively decided to focus my career on scientific questions that I could address in my own "backyard" without the need to travel extensively to remote field locations. Looking back, if I have one career regret, it was not participating in the GLOBEC Southern Ocean experiments with my colleague Peter Wiebe at that time and the opportunity to study Antarctic ecosystems.

My decision to remain local launched years of research and exploration into estuarine acoustics. I had come to realize that acoustic scattering from microstructure in most open-ocean environments was typically dominated by small-scale fluctuations in temperature. However, it was the exceptions to this "rule" that intrigued me. Salt-finger double diffusion, convective double diffusion, and many estuaries are characterized by strong gradients in salinity, in turn resulting in strong small-scale salinity fluctuations. These salinity fluctuations typically persist down to smaller scales than temperature microstructure, and traditional in situ approaches to measurements of salinity are challenging because they require resolving much smaller scales and additionally require coincident measurements of conductivity and temperature. Resolving both temperature and salinity microstructure using traditional oceanographic technologies at submillimeter scales remains challenging to this day. And yet these are needed to fully resolve the dissipation of rate of salinity variance, an important variable in characterizing turbulent mixing in many environmental flows. High-frequency acoustic techniques allow the salinity variance to be measured remotely at these small scales, and it is sufficiently spectrally distinct from temperature microstructure that it can be distinguished with sufficient broadband signals.

I spent many years mapping salinity variance in the Connecticut River with my colleague Rocky Geyer, and eventually, our research germinated into a large program, the Under Sea Remote Sensing (USRS) Program, to acoustically map different estuaries and their impact on sonar performance. Estuaries can be classified as salt wedge, highly stratified, partially stratified, or well mixed according to the vertical salinity gradients. These different types of estuaries have varying impacts on acoustic scattering, propagation, coherence, and sonar performance.

A persistent feature in many of these estuaries are tidal intrusion fronts, which are surface convergences that typically occur at the mouth of an estuary where fresh, less dense river outflow meets the saltier, denser water. Bubbles are generated and entrained at this front, forming a strong acoustic signal.

Although there have been decades of research on acoustic scattering from bubbles generated by breaking waves, the bubble size distributions in estuarine fronts are strongly modified by the dynamics of the fronts. In addition to mapping estuarine acoustic scattering using broadband echo sounders, I was able to measure the three-dimensional structure and time evolution of shear instabilities, which is typically a challenge because shear instabilities are rapidly evolving. This USRS Program has led to many innovations in how broadband sonars are deployed and has outlined the important role that platforms play in the successful implementation of acoustic technologies.

While my research on estuarine acoustic was going full bore, my colleague Tim Stanton was developing midfrequency broadband acoustic techniques for resonance classification of fish swim bladders for fisheries acoustics applications. Eventually, Tim and I teamed up to continue this development into the deep realms of the ocean.

The ocean twilight zone (OTZ; see twilightzone.whoi.edu) is the vast, globe-spanning layer of water between 200 and 1,000 m depth, home to diverse communities of mesopelagic fishes, cephalopods, crustaceans, and gelatinous organisms. Yet, little is known about the biology, abundance, biomass, distribution, or behavior of these organisms. The OTZ is acoustically characterized by the presence of deep sound-scattering layers (DSL) in shipboard sonar, and, like much of the ocean, it is underexplored and difficult to sample due to a combination of lack of technologies focused on this region, organism patchiness and avoidance, and difficulties capturing fragile species.

Recent evidence suggests that the global OTZ fish biomass may be sufficient to commercially harvest and that much of this biomass performs daily vertical migration (DVM) and may play a critical role in regulating the Earth's climate through the export of carbon to the deep ocean. However, the relative importance of mesopelagic fishes versus zooplankton biomass is still highly uncertain.

Tim and I began the development of an advanced sensor platform, Deep-See (see twilightzone.whoi.edu/deep-see), to fill the technological void for characterizing the OTZ. This towed vehicle integrates wideband, split-beam acoustics (1-500 kHz) with optical, environmental, and eDNA sensors that can address many of the challenges associated with sampling in the OTZ. We have found that a surprisingly high abundance of organisms can be found outside the dense sound-scattering layers, typically below the noise floor at large ranges for shipboard sonar, and that the target strength of many organisms that perform DVM changes with the depth, which is critical to estimate the biomass.

The WHOI OTZ project is still ongoing and represents one of a number of growing international projects focused on understanding the OTZ, with acoustics playing a central role in exploring and mapping the OTZ. Some of the biggest unanswered questions that can be addressed using acoustic techniques revert back to assessing the importance of the spatial and temporal variability of biomass in the DSL, assessing how much of this biomass participates in daily vertical migration and how much DVM varies in space and time, and to understanding the mesoscale physical drivers of this variability. From a human impact perspective, we need to address questions such as: does the OTZ represent sustainable fisheries, how much does the daily vertical migration of mesopelagic organisms contribute to the global carbon pump, and would mesopelagic fisheries activities adversely impact the ocean's ability to sequester carbon, thus impacting climate.

What are some of the other areas in which you feel you made substantive contributions over your career?

I have been fortunate enough to dedicate the lion's share of my career to research and exploration. However, I consider myself extremely privileged to have also been able to mentor many outstanding graduate students and postdocs. They have enriched my research and expanded my understanding of acoustics and oceanography. Time and again they have taught me that there is still so much left to learn. In thinking about my contributions to acoustical oceanography, I hope time will prove that a substantive contribution lies in the teaching and mentoring of the next generation of acousticians.

What do you think are the most pressing open questions that you would like to focus upon over the next 5-10 years?

We still have a long way to go to fully understand the many scales of variability in the ocean, and acoustic techniques will be center stage in the discovery phase of that journey. Anthropogenic forcing will continue to impact our oceans, with corresponding changes in the propagation, scattering, attenuation, and coherence of acoustic signals, particularly in acoustic hot spots such as in regions of abrupt topography. I am optimistic that combining traditional shipboard platforms, ocean observatories, autonomous underwater and surface vehicles, more compact and less costly acoustic systems, continued theoretical development of physics-based acoustic-scattering models, advanced signal-processing approaches, and harnessing the power of artificial intelligence (e.g., through approaches such as developing machine-learning frameworks for the applications of acoustic classification) will allow us to use acoustics to understand the many scales of temporal and spatial variability in the ocean and to continue to contribute toward ocean conservation and sustainability challenges.

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