14.11 OCEAN OBSERVING SYSTEMS AND OCEAN OBSERVATORIES, OCEANOGRAPHERS, AND ACOUSTICIANS—A PERSONAL PERSPECTIVE

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14.11.1 INTRODUCTION

Twenty years ago the oceanographic community embarked on the grand endeavor of establishing ocean observatories. First, there was an obvious need to transition basic oceanographic research into products and information that would be useful to society. Information on the evolution of the Earth's climate system and warning systems to mitigate natural disasters of atmospheric, oceanographic, or geologic origin are examples. Second, many oceanic processes or systems evolve at decadal to century timescales and require sustained, long-term observations to properly understand them. These two motivations highlight a semantic difference: "Ocean Observing Systems" (OOSs) are operationally focused, while "Ocean Observatories" are research focused, although the difference is often blurred. "Operational" implies the commitment of the significant bureaucracy and management required to deliver promised data, information, and products to society on a sustained basis, e.g., the national weather services, or the CTBTO (www.ctbto.org) hydroacoustic system. Ocean observing systems are global, basin, or regional scales. Examples of OOSs are the Arctic basin system, or the many regional systems along the coasts of the United States. Neptune Canada (www.neptunecanada.ca) is an ocean observatories program that includes research in acoustics. Australia's Integrated Marine Observing System (IMOS, www.imos.org.au/) has been collecting freely available sea noise data at six sites on the continental shelf since 2008. These data have been used by marine biologists for studying marine mammals and fish, e.g., their vocal behaviors, migration patterns, and populations. Natural processes in the ocean have been observed, such as seismic events, volcano activity, and ice disintegration near Antarctica. IMOS observes the general ocean soundscape, from the continental shelf to the Southern Ocean between Australia and Antarctica. In any observing system, data management and archive are formidable issues that must be addressed.

The possible acoustical applications for an ocean observing system are myriad and cross several disciplines, and a review or survey of these applications is beyond the scope of this chapter (see Ref. [121] for bibliographical information). The discussion here therefore addresses mainly tomography and ocean observing systems [122,123], but it applies to acoustics for biological or engineering applications, as well as pure acoustical science.

14.11.2 OCEANOGRAPHERS

Although the value and unique quality of acoustic measurements, tomography in particular, has long been established, general implementation of this measurement type by oceanographers has not been forthcoming. The value of acoustical approaches has been established according to accepted standards of scientific discourse. A rigorous, objective design of an observing system intended to last a century or longer includes essential contributions from both engineering and observational acoustical techniques. Acoustic techniques for ocean observing or engineering offer tremendous opportunities.

For example, in an analysis of a decade of basin-scale acoustic tomography data from the North Pacific, Dushaw et al. [120] made direct comparisons of the tomographic time series to equivalent time series derived from Argo float data and altimetry. The comparison showed significant differences at all timescales, indicating that the existing observing system was badly estimating the large-scale variability of ocean temperature. Similarly, in the 1988 Greenland Sea Project experiment, the rapid sampling of integrated temperature afforded by the acoustic measurements proved to be essential in estimating the net deep water formation during the winter of 1988/1989 [124]. Concurrent, extensive measurements by conductivity, temperature, depth casts proved to be inadequate to the task. The concluding statement of the international OceanObs'09 conference explicitly noted that "the oceans remained seriously undersampled" (www.oceanobs09.net/statement/).

The applications of acoustic tomography (or acoustics in general) for observing systems have not yet had a rigorous, informed, quantitative examination by oceanographers, however. One argument for excluding active acoustic sources from observing systems has been that deploying such technology will attract environmental concerns, law suits, etc. from concern over the impact of sound on marine life. Such an argument is specious, a crass exploitation of this issue to rationalize excluding the acoustical approach. Significant resources have been expended to research this specific issue, with the published conclusion that existing research acoustic sources have no significant biological impact. Acoustic sources have been regularly used to track the positions of instruments. Scientists should be willing to stand up for correct science. Determining secular changes in the ambient sound of the world's oceans, i.e., man-made noise, is a serious motivation for an acoustics component to a global observing system.

One of the shortcomings of acousticians is in making progress on important oceanographic, rather than acoustics, questions. Oceanographers could greatly assist the process of developing roles for acoustics in an ocean observing system. One pressing example is the need for deep ocean measurements, a critical gap in the observing system (www.oceanobs09.net/). Two acoustical applications are evident. First, acoustic rays traverse the deep ocean, hence offer a natural integrating measurement of deep-ocean temperature. Second, implementation of deep Argo floats for the ocean observing system may require a 30-day cycle to conserve their energy. Acoustics offer an obvious means to determine the position of these floats during their month-long drift in the deep ocean. Both of these applications require considerable oceanographic expertise to determine how they can be best employed to address specific oceanographic questions. The need for stronger symbiotic relations between oceanographers and acousticians on these and other questions seems evident. Oceanographers have to do better with respect to acoustics.

14.11.3 ACOUSTICIANS

If oceanographers have been deficient in integrating acoustical techniques into observing systems, acousticians have not done much better. Implementing any technique for observatories requires considerable community organization, planning, and coordination to address such difficult questions as deploying and maintaining long-term observations for community use and the archival and management of those data. Partly as a result of funding limitations, acousticians lack adequate community will and organization to make much headway into ocean observatories. A key aspect of data from an observing system is standardization, which acousticians are only beginning to address.

With respect to tomography, one vice is the perpetual development of new techniques or tools for acoustical observation or data processing, while oftentimes failing to actually use those tools to learn about the ocean. New techniques are fine, but one must publish what one learns about the ocean using those techniques in the mainstream oceanographic journals. This vice is perhaps understandable, since acousticians are not experts in the oceanographic questions that could be tackled using the acoustic techniques. Just as the oceanographers are unfamiliar with the acoustics science, acousticians are unfamiliar with the oceanographic science. Another vice is the oftentimes lengthy time interval between when data are recovered and when the results of analysis get published; this sort of delay is not inherent in the data type and will eventually be remedied. A much closer collaboration between the oceanographers and acousticians is essential.

While ocean observing systems offer great opportunities for putting acoustical techniques to good use, representation of acoustics at conferences associated with setting priorities, planning, and implementing systems has been poor. To some extent this deficiency is a product of funding limitations—effective participation at these workshops is expensive and time consuming. Also, these workshops are often hosted by oceanographic agencies or organizations, hence not on the acoustician’s sonar. Without better representation and advocacy at these conferences, however, acoustics will continue to be left out of the process. Acousticians have to do better with respect to oceanography.

14.11.4 FUTURE DIRECTIONS

There are many lines of research that may be readily pursued to better set the stage for implementing acoustical components to the ocean observing systems. Here are a few examples, a by-no-means comprehensive list.

Acousticians do not today have access to reliable low-frequency, deep-ocean source technology; development of such sources has lagged. Meanwhile, passive acoustics as a remote sensing technique has had some positive developments in recent years, and remains a possibly fruitful avenue for investigation. The ability to use the ocean's natural ambient sound sources to quantitatively measure its properties would be a major breakthrough, but more work is required to establish this strategy.

Considerable work remains to be done in establishing the utility of acoustics using quantitative design studies through simulations. One remarkable development available to acousticians is the availability of high-resolution, realistic global ocean models. These models provide a convenient way to compute the environmental effects on acoustic transmissions, and they are a valuable asset for acousticians.

One advantage of research quality acoustic data is that historical data are often as precise as present-day data. With new understanding of acoustic and ocean properties, realistic ocean models, and new computational techniques, new analyses of historical data offer significant reward for little investment. Global-scale acoustic data acquired during the 1991 Heard Island Feasibility Test have yet to be fully exploited (data available from 909ers.apl.washington.edu/~dushaw/heard/index.shtml).

As has been often noted, the tomographic data type, together with other data, is best employed in conjunction with techniques for data assimilation. Data assimilation and tomography have been discussed for many years, yet aside from a few notable instances [125,126], these techniques are not developed to the point of practical or more widespread use. Data assimilation approaches that can routinely handle the acoustic data type are essential.

One region that has garnered support for acoustical applications is the Arctic Ocean. The Arctic is suggested because acoustical applications there are not viewed as in competition with floats and gliders. Nevertheless, the under-ice applications of acoustics are many, from biological measurements, to the positioning of instruments under sea ice, to low-frequency, to Arctic Basin thermometry. An ongoing program for acoustical measurements within the Fram Strait has been conducted by the Nansen Center in Norway over the past 5 years (www.nersc.no). Acoustical technologies as contributions to the Arctic Ocean Observing systems are likely to be fruitful in the near future.

14.12 APPLICATIONS OF UNDERWATER ACOUSTICS TO MILITARY PURPOSES

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Military applications of developments in underwater acoustics are still increasing. Despite the emergence of many new fields of applications of underwater acoustics, as represented by other sections in this chapter, the military applications are still forming a majority. Even in spite of a decrease in naval budgets and a reduction in the

[1] 30 March 1937–24 October 2015.