Sounds in the Sea

From Ocean Acoustics to Acoustical Oceanography

The oceans are a vast, complex, mostly dark, optically opaque but acoustically transparent world that has been only thinly sampled by today's limited technology and science. Underwater acousticians and acoustical oceanographers use sound as the premier tool to determine the detailed characteristics of physical and biological bodies and processes at sea. Myriad components of the ocean world are being discovered, identified, characterized, and imaged by their interactions with sound.

Sounds in the Sea is a comprehensive and accessible textbook on ocean acoustics and acoustical oceanography. "Ocean acoustics" describes the traditional way in which our knowledge of ocean temperature and salinity allows us to use sound to find fish, submarines, icebergs, and the depth of the ocean. "Acoustical oceanography" interprets the distinctive details of time-varying, sound amplitudes, and phase, over acoustical paths to deduce the physical and biological parameters of the specific ocean through which the sound has traveled.

This is an invaluable textbook for any course in ocean acoustics in the physical and biological ocean sciences, engineering, and physics. It will also serve as a reference for researchers and professionals in ocean acoustics, and an excellent introduction to the topic for scientists from related fields.

Chapters 1 to 9 provide the basic tools of ocean acoustics. The following 15 chapters are written by many of the world's most successful ocean researchers, who use sound in innovative ways to learn about the sea and its contents. These chapters describe modern developments, and are divided into four parts: Studies of the near-surface ocean; Bioacoustical studies; Studies of ocean dynamics; Studies of the ocean bottom.

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From Ocean Acoustics to Acoustical Oceanography

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This book is dedicated to my dear wife, Eileen

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Preface
The world of ocean sounds

This book is the reader's gateway to a science that spans physics, oceanography and marine biology. Wherever possible we perform the trick of Janus, the mythological Roman God, who simultaneously faces in opposite directions. One view, called "ocean acoustics," is the traditional direction in which the knowledge of (or assumptions about) the ocean temperature and salinity allows one to use sound to find fish, submarines, icebergs, and the depth of the ocean. The opposite view, "acoustical oceanography," interprets the distinctive details of time-varying, sound amplitudes and phases over acoustical paths to deduce the physical and biological parameters of the specific ocean through which the sound has traveled . . . It is best to look in both directions.

We will be considering the diverse potentialities of passive listening, as well as benign probing by unobtrusive sound: in rough seas and smooth seas; deep seas and shallow seas; clean seas and seas made locally dirty by dumping of man's garbage; seas of uniform temperature and those that are thermally layered; dead seas and seas noisily filled with abundant life ranging from the grand whales to microscopic zooplankton and phytoplankton. It is a vast, complex, mostly dark, optically opaque, but acoustically transparent world that has been only thinly sampled by today's limited technology and science.

Tragic beginnings

In retrospect, the impetus for the effective use of sound in the sea occurred in 1912 when the steamship TITANIC struck an iceberg. The subsequent loss of hundreds of lives triggered man's use of sound to sense scatterers in the oceans of the world. Within a month of the disaster, a patent application was filed by L. R. Richardson in the United Kingdom (10 May 1912) for "detecting the presence of large objects under water by means of the echo of compressional waves – directed in a beam – by a projector." The basic idea was that a precise knowledge of the speed of sound in water, and the travel time of the sound from source to scatterer and back to the source/receiver, permits the calculation of the distance to the scattering body. This was to be the beginning of the use of underwater

sound projectors and receivers. They were to be called "SONARs" i.e. devices for **SO**und **NA**vigation and **R**anging.

In fact, the speed of sound in fresh water had already been measured very accurately almost a century before. Corrections for depth dependence and salinity dependence of the speed were soon determined. A grand variety of new commercial and military activities were immediately practical, including acoustical fish finding (patented in 1935), acoustical measurements of ocean depth, and acoustical detection of submarines.

Present status, future promise

Since those early days, underwater acousticians and acoustical oceanographers have used sound as the premier tool to determine the detailed characteristics of physical and biological bodies and processes at sea. Myriad components of the ocean world are being discovered, identified, characterized, and imaged by their interactions with sound. Chapters 1 through 9 of this textbook, "Fundamentals," provide the basic tools of ocean acoustics. The following 15 chapters, written by some of the world's most successful ocean researchers, who are using sound in innovative ways to learn about the sea and its contents, describe several modern developments. Their contributions are divided into the four sections, titled: "Studies of the near-surface ocean"; "Bioacoustical studies"; "Studies of ocean dynamics"; "Studies of the ocean bottom."

Acknowledgements

Inspiration for this book has come from my professors at the University of California at Los Angeles, my students and associates at the Naval Postgraduate School and colleagues in the Acoustical Society of America. I had the great fortune of being a student at UCLA during those vital, early post-WWII years when the Physics Department at UCLA was the world's finest academic environment for teaching and research in physical acoustics. The names of my professors read like a "who's who" of acoustics in the latter half of the twentieth century: Leo Delsasso, Carl Eckart, Vern O. Knudsen, Robert W. Leonard, and my outstanding thesis advisor, Isadore Rudnick.

Let me pay tribute to my Naval Officer students at the Naval Postgraduate School, who were some of the brightest, most energetic people I have ever had the pleasure of working with. They wrote theses, part of the requirement for their M.S. degrees in Acoustical Engineering, that would have satisfied the academic quality and significance of Ph.D. research at many of the world's colleges and universities. Most of these energetic students went on to become Admirals and Captains in the navies of the USA and Turkey and West Germany; their fine student research is appropriately identified and referenced throughout this book.

My years of book co-authorship with C. S. Clay (1977, 1998) remain a high point of my work in the field of acoustics. The first nine chapters of this book have been extracted from the graduate level textbook, Medwin and Clay, *Fundamentals of Acoustical Oceanography*, Academic Press (1998), (abbreviated *M&C*). Much of that material has been updated and rewritten here for undergraduates or beginning graduate students in physical and biological sciences. Many of the unidentified figures were drawn by C. S. Clay, for *M&C*, and I am grateful that he allowed them to be re-used here.

Some topics, based on the research of others, are identified simply by the author names and the date of publication. More complete references will be found in the References or Bibliography sections, or on the Internet. Descriptions of a special few publications are in "Further reading" at the ends of each of the first nine chapters.

Valuable extensive discussions have been held with Aubrey Anderson, Steven Baker, Mohsen Badiey, Jonathan Berkson, William Carey, Jacques Chamuel, N. Ross Chapman, Dezang Chu, Lawrence Crum, William Cummings, Peter Dahl, Grant Deane, Chris Feuillade, Fred Fisher, Charles Greenlaw, Mark Hamilton, Richard Keiffer, Saimu Li, Michael Longuet-Higgins, James Lynch, Kendall Melville, James H. Miller, Jorge Novarini, Wesley Nyborg, John Potter, Andrea Prosperetti, Jeffrey Simmens, Kevin Smith, Eric Thorsos, Alex Tolstoy, Ivan Tolstoy, and O. Bryan Wilson.

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I am most grateful to my oceanographer colleague at the Naval Postgraduate School, Professor Ching-Sang Chiu, who has been generously critical of my attempt to open our subject to undergraduates in the ocean sciences. Also special thanks to Dr. Steve Haddock, marine biologist of the Monterey Bay Aquarium Research Institute, who has gently led me into twenty-first-century word processing techniques.

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Herman Medwin