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# A seminal paper linking ocean acoustics and physical oceanography

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JASA REFLECTIONS

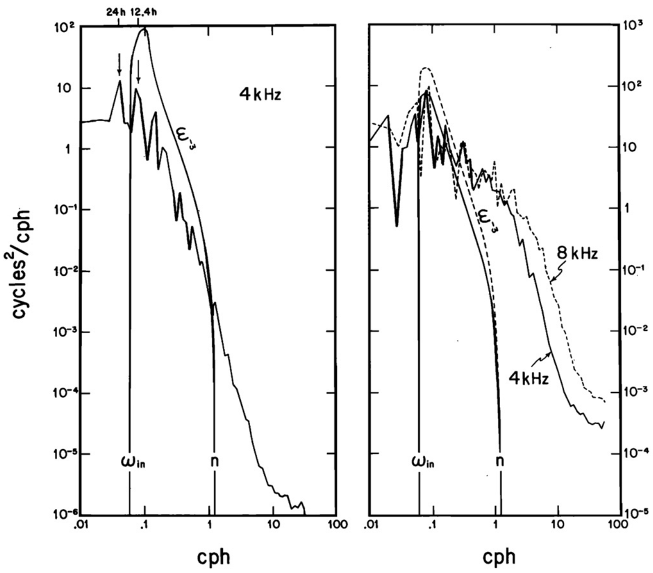
The *Reflections* series takes a look back on historical articles from *The Journal of the Acoustical Society of America* that have had a significant impact on the science and practice of acoustics.

# A seminal paper linking ocean acoustics and physical oceanography

**Article:** Sound propagation through a fluctuating stratified ocean: Theory and observation
**Author:** Walter H. Munk and Fred Zachariasen
**Publication Date:** April 1976 (JASA **59**, 818); https://doi.org/10.1121/1.380933

## ARTICLE OVERVIEW

In the early 20th century, the field of ocean acoustics was born out of civil and naval needs. The development of the acoustic echo sounder, for example, had a profound impact on safe navigation in harbors and coastal regions, and the use of sound for anti-submarine and mine warfare was critical in countering the Nazi and, later, Soviet Naval threats. In the post-World War Two era, as ocean acousticians made measurements with higher and higher precision, it quickly became apparent that the inherent variability of the ocean was a major limiting factor. Efforts to predict the ocean's acoustical impacts unfortunately utilized methods divorced from ocean dynamics and had limited success. At the same time, physical oceanographers with new and better tools to sample the ocean more frequently and more accurately were coming to the realization that the ocean has energetic and dynamic fields of internal waves and eddies on quite short time and space scales. The need for ocean acoustics and physical oceanography to come together was clear, and the Munk and Zachariasen (MZ) paper,[1] as well as a companion paper by Dyson *et al.*[2] in 1976, provided the necessary spark and much, much more. Not only were they able to show how stochastic and deterministic physical oceanographic processes, like internal waves and tides and impact acoustic propagation, but they were also able to show that ocean acoustic measurements could be expressible in terms of physical oceanographic processes and parameters; that is, acoustic measurements could tell one something about the ocean. In concluding their paper, MZ[1] write:




Computed (smooth curves) and observed spectra of phase (left) and intensity (right) at Cobb Seamount. Only the 4-kHz results are shown for phase; at 8 kHz computed and observed values both are higher by 6 dB. Reprinted with permission from W. Munk and F. Zachariasen, J. Acoust. Soc. Am. 59, 818–838 (1976). Copyright 1976 Acoustical Society of America (Ref. 1). Figure to be Reproduced: Fig. 7.

> *"We end up, …., with quite simple and transparent formulae for the acoustical fluctuations. The formulae make explicit the dependence of the various oceanographic and acoustic parameters. The need is to apply these results to a variety of experimental situations."*

## IMPACT OF THE ARTICLE

In treating the problem of ocean sound propagation through the stochastic internal-wave field, MZ[1] were revolutionary on many levels. First, they brought physical oceanographic principles to the problem of sound propagation, describing the ocean sound channel and its fluctuations in terms of oceanographic variables such as temperature and salinity structure, adiabatic gradients, and density stratification. Second, previous work had attempted to describe ocean sound-channel variability in terms of ad-hoc correlation functions or to treat the ocean sound-speed fine structure using ideas of homogeneous isotropic turbulence borrowed from atmospheric optics. However, MZ correctly identified internal waves as a critical source of the fine structure and, using the newly developed Garrett-Munk (GM) internal-wave spectrum[3] and a perturbation method termed the Rytov approximation, they solved a fundamental problem in stochastic wave propagation in which the medium was anisotropic, inhomogeneous, had a dispersion relation, and most importantly, involved a background waveguide. Their analytic work was a tour de force with over 182 equations and the introduction of several dozens of new parameters. Not content to just present theory, they compared theoretical predictions to numerical simulations and observations from two field efforts using controlled electronic sources and precise timing and navigation. Their calculations of mean-square phase, phase rate, and log-intensity, as well as frequency and wavenumber spectra, were shown to be in agreement with the available observations mostly within a factor of two, greatly improving upon previous treatments. The successes and tantalizing questions raised by MZ spurred a flurry of observational and theoretical work on the subject over the last four decades looking at the problem from shallow water and continental shelves to basin and global scale propagation. Interestingly, later work using the Feynman path integral approach, which has much wider applicability than the Rytov approximation used in MZ, showed that, while some details changed, the basic physical picture provided by MZ remained.[4,5] Last, with the success of their data/theory comparisons, they planted the seed that ocean acoustic measurements could reveal important information about ocean physics. Not long after MZ, Munk and Wunsch[6] proposed ocean acoustic tomography, in which acoustic travel times are used to infer large- and mesoscale temperature and current structure. With new developments in the field,[5] we are looking towards the day when acoustic fluctuation measurements will be used to describe the ocean internal-wave field, thus bringing the MZ work full circle.

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