Constraints on Ocean Internal Wave Spectra from Long-Range Acoustic Transmission Data

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Abstract: Acoustic measurements collected in recent ATOC experiments are used to provide constraints on the statistics of the oceanic internal wave field, using the Garret-Munk spectrum as a starting point. Attention is focused on the following parameters to which our simulations are sensitive: the strength parameter $E$, the mode number cutoff $j_{max}$, and the horizontal wavenumber cutoff values $k_{min}$ and $k_{max}$. Both full wave and ray-based model simulations are compared to data to examine issues of wavefront stability in the presence of ray chaos.

Data sets collected as part of recent Acoustic Thermometry of Ocean Climate (ATOC) experiments are examined in an attempt to improve our understanding of forward scattering of sound in deep ocean environments. Attention is focused on internal waves as they have been identified as the primary scattering mechanism for ATOC type propagation (1,2). The Garrett-Munk (hereafter GM) internal wave spectrum is the basis of our description of the internal wave field. Direct comparison of simulation results to data allows for an examination of the bounds of several GM parameters to which simulations are sensitive including wavenumber range $(k_{min}, k_{max})$ and mode number cutoff $(j_{max})$. After constraining $j$ and $k$, direct comparisons are made to qualify the magnitude of the GM field strength parameter $(E)$ for different ATOC environments.

Three acoustic modeling techniques are used: full wave $c_0$-insensitive (hereafter $C_{in}$) PE, deterministic ray theory (hereafter DRT), and stochastic ray theory (hereafter SRT). Both $C_{in}$ PE and DRT simulations use deterministic descriptions of individual realizations of internal wave induced sound speed perturbation (4). The $C_{in}$ approximation is implemented because it offers second order accuracy which is critical for megameter propagation. Comparisons of data and simulations are examined both as timefronts in depth and as plane wave beamformed outputs. The limited sampling of the water column by ATOC receiver hydrophore arrays makes beamformed outputs crucial to successful comparison of data to simulation. The AET array, for example, consisted of 40 hydrophones extending from 900 m to 1600 m in depth. Timefronts in arrival angle are examined in order to measure the sensitivity of simulations to input GM parameters by comparing the relative transmission losses at different points along the timefront for different simulations.

Ray theory, used in concert with full wave theory and comparisons to data, gives insight into chaotic behavior induced by internal wave fields in ATOC type environments. If all rays exhibit chaotic behavior, the results of DRT should agree with SRT. To motivate this, Fig. (1) is introduced in which the three modeling techniques are compared in a canonical background environment with a broadband internal wave field $(k = 0.01 \ldots 1.0 \text{ cycles/km}, j_{max} = 50, E = 350 \text{ Joules/m}^2)$. Acoustic simulations using $C_{in}$ PE had a frequency range of $250 \pm 50 \text{ Hz}$. Note the good agreement between the three techniques in predicting features commonly associated with internal wave scatter such as vertical spreading and temporal smearing of individual peak arrivals. All three techniques predict the additional timefront leg at the end of the signal.

Full wave and DRT results show intermittent structure that SRT does not. Even though DRT does not have the phase information of $C_{in}$ PE, localized regions of high and low intensity within the waveform of the $C_{in}$ PE results correspond to regions of high and low ray distribution in DRT. A bifurcation of the timefront near the surface at roughly 670.7 seconds is evident in both models. Fig. (2) shows DRT propagation through several realizations of an internal wave field in the same environment as the previous figure. The appearance of timefront bifurcations seems to depend on the individual realization of the internal wavefield. Even the additional timefront leg at the leading edge of the signal seems to vary with each realization.
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REFERENCES