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Stability of wavefronts at sound propagation in highly structured three-dimensional environments

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Extensive numerical modeling of long-range propagation of sound and seismic waves as well as observations of underwater acoustic fields with line arrays reveal that wavefronts are often much more stable and predictable than the rays comprising these wavefronts. This paper considers multiple scattering of sound by environmental inhomogeneities with spatial scales small compared to the propagation range but large compared to the wavelength. These inhomogeneities include 3-D variations in sound speed and current velocity that are small compared to the average sound speed, can be either random or deterministic, and are superimposed on an arbitrary slowly-varying background. A theoretical explanation of wavefront stability in highly-structured environments is achieved by demonstrating that end points of rays launched from a point source and having a given eikonal (phase) are scattered primarily along the wavefront corresponding to the same eikonal in the unperturbed environment. The ratio of displacements of the ray end points along and across the unperturbed wavefront is proportional to the number of uncorrelated scattering events. The results apply to conventional rays and to horizontal rays describing propagation of adiabatic normal modes in almost-layered media. The origin of relative stability of wavefronts compared to rays is traced back to Fermat's principle.