# First-order Control Factors for Ocean-bottom Ambient Seismology Interferometric Observations

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## ABSTRACT

Forward modeling the lower-frequency band of seismic energy sources, particularly below 2.0 Hz, is essential for enhancing the stability and effectiveness of elastic full waveform inversion (E-FWI). Conventional air-gun sources have a limited ability to generate low-frequency energy, while ambient seismic wavefields, driven by natural energy sources like ocean waves, offer a promising alternative. To effectively use ambient wavefield energy recorded on ocean-bottom sensor arrays for seismic imaging or inversion, it is crucial to understand the first-order factors that influence seismic observations. These include the mechanisms, lateral and vertical distribution of ambient energy sources, variations in ocean-bottom bathymetry, and Earth model heterogeneity. Understanding these factors is required for determining wave-mode excitation and partitioning, particularly as observed in the context of ocean-bottom ambient seismic interferometry.

To illustrate these factors, we develop a forward modeling framework that simulates cross-correlation wavefields generated by ambient seismic sources in a coupled acoustic-elastic system for dense ocean-bottom sensor arrays. This framework avoids relying on seldom-realized Green's function retrieval assumptions (e.g., isotropic ambient source distribution) (Wapenaar 2004). Modeling three particle-velocity components leads to nine cross-component correlation wavefields (also known as virtual shot gathers or VSGs) as well as the pressure auto-component VSG (not shown here). The resulting VSGs explore the effects of ocean-bottom velocity structure, ambient source distributions, and bathymetric variations on seismic wave excitation and propagation in the (ultra-)low-frequency range (i.e., 0.01-2.0 Hz). Results show that both the distribution of ambient energy source locations, whether at the seabed or sea surface, and the ocean-water depths significantly affect excited wave-mode characteristics. Notably, guided P-wave modes increase with greater water depths, affecting the energy distribution and frequency content of Scholte waves. Ambient energy sources near the ocean surface, typically associated with secondary microseism, generate significant guided P-wave modes when ocean water depths exceed the wavelength corresponding to the source frequency. In contrast, near-seabed sources - characteristic of primary microseism sources - excite minimal guided P-wave modes and the majority of source energy is concentrated in surface waves. Love waves are particularly evident in the presence of substantial lateral and vertical bathymetric variations and heterogeneous Earth structure. Additionally, not all VSG components provide unique insights into wave-mode excitation and partitioning.

Recent findings from VSGs and PVFs derived from ambient seismic data in the Mississippi Canyon area and the Amendment OBN array in the Gulf of Mexico (Girard et al., 2023, 2024) show a strong resemblance to the modeled pressure and velocity VSGs and PVFs using representative GOM velocity models. This work enhances the understanding of low-frequency ambient wavefields in ocean environments, with potential applications in long-wavelength structural imaging and elastic velocity model estimation through full-waveform inversion (FWI) analysis.

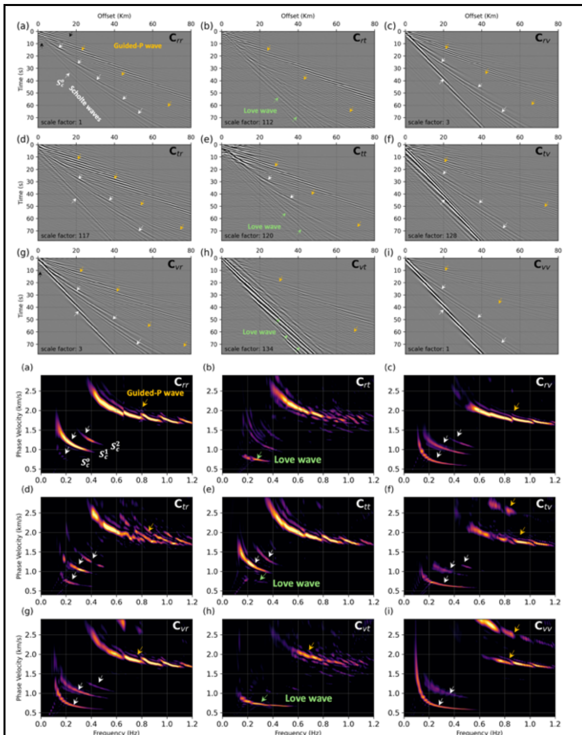


Figure 1: VSG tensor components (upper) and correspinsding PVFs (lower). (a) radial-radial , (b) radial-transverse (c) radial-vertical (d) transverse-radial (e) transverse-transverse (f) transverse-vertical (g) vertical-radial (h) vertical-transverse and (i) vertical-vertical component OBN recording for a 3-D velocity structure with variable ocean-bottom bathymetry. Scholte and guided P-wave modes are highlighted by white and yellow arrows, respectively, while Love waves are denoted by green arrows.