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Resolution constraints by complexity-driven wave propagation through multiscale 3D structures

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Seismic waveforms recorded along the surface encode information from heterogeneous multi-scale structures from anywhere within the Earth's interior. This relation is defined by the physics of wave propagation. Although we have comprehensive 3D numerical techniques at hand, such forward modeling (especially in the context of tomography) is mostly used solely to deliver synthetic waveforms to define misfit criteria and gradients (sensitivity kernels) for tomographic inversions. This is sufficient for the purpose of performing inversions, but possibly depreciates a wealth of complementary information that can be obtained from the complexity of the wavefield. In this paper, we address the imprint of complex 3D heterogeneities on the wavefield and observed waveform, and the resultant question on physical resolution limits not due to tomograhy but the physical wavefield itself. We examine various parameters of relevance and scattering regimes for which deep structures are obscured by the time the waveform reaches the surface. This will help for understanding the relation of tomographic images to the actual Earth, an offers a means for quantitatively and objectively selecting optimal seismic data before performing inversions.

We use AxiSEM3D, our new method that accurately solves global wave propagation for visco-elastic, anisotropic 3D structures wit boundary topography at highest resolution and efficiency by exploiting azimuthal smoothness observed for realistic wavefields. This is done by via a coupled Fourier expansion-spectral-element approach. The method link cost to complexity and is ideal for exploring the relation between waveforms and structures. We will present scenarios for multi-scale heterogeneities which remain or obscur in the waveform. "Wavefield learning" will be used to examine th wavefield complexity and to discriminate between scattering structures that can reliably be seen by surface measurements. We will rely on a large number of realistic 3D simulations performed for 10 tomographic models and alterations to them to deduce these scattering properties. This leads to the question of invisibility and physical resolution limits. We thereby attempt to offer complementary insight as to why tomographic images still show significant differences for smaller-scale heterogeneities despite advances in data acquisition and modeling procedures.