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Global high-frequency 3D wavefields by Instaseis wavefield injection

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Earth structure is multi-scale, yet capturing such a broad range of complex heterogeneities with seismic wave propagation is computationally prohibitive. We present an Instaseis-based (van Driel et al. 2015, www.instaseis.info) framework for injection type hybrid methods on a global scale. Such techniques represent the bulk background medium as a sparse or smooth structure that accounts for source and path effects, and optimally honour complexities in the model to resolve local site effects where necessary. The modified Instaseis interface allows to couple the global wave-propagation solver, AxiSEM (Nissen-Meyer et al. 2014, www.axisem.info) with an arbitrary local three-dimensional solver of choice, and thus embed a heterogeneous 3D domain within a spherically symmetric Earth model. Thanks to reasonable computational costs (10k CPU hours) and storage requirements (a few TB for 1Hz waveforms) of Instaseis databases, the framework provides coupling of 3D wavefields that reach the highest observable frequencies in global seismology. SPECFEM3D_Cartesian (Komatitsch and Tromp 2002, www.geodynamics.org) has already been incorporated into the framework, with other local 3D solvers to follow.

The method can be summarised in three steps that make use of two complete Instaseis databases of Green's functions: (1) A forward Instaseis database is used prior to the local simulation to extract the background wavefield on the boundary of the 3D domain. (2) The wavefield is imposed on the local domain to drive the simulation. (3) A reciprocal Instaseis database is used to extrapolate the locally scattered wavefield back to the receivers at the surface. Since those databases act as a once-and-for-all solution to wave propagation in spherically symmetric models, the framework provides flexibility with respect to parameter alterations, such as modifications in source properties (radiation patterns, source-time function), in the source-receiver geometry, and in local domain dimensions and location (including regions around the source or receivers) without the need of re-running the global simulation.

Possible applications include near-source structures and their influence on earthquake or explosion source estimates, characterisations of large finite ruptures, resolution limits of heterogeneous structures at depth, SV-SH conversions in the deep mantle, and hybrid inverse modelling.