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Development of 3-D waveform sensitivity kernels for finite-frequency surface waves

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Geometrical ray theory has played a major role in seismic tomography despite its crucial limitation; i.e., it cannot take account of finite-frequency effects of seismic waves. In order to overcome the deficiency of the ray theory, we need a more sophisticated approach to seismic tomography, which will enable us to consider complicated effects of seismic wave propagation.

With the assumption of scalar wave propagation in laterally heterogeneous structure, two-dimensional sensitivity kernels for surface-wave phase speeds for a single frequency can be efficiently constructed using the Born approximation linked to asymptotic ray theory [Yoshizawa and Kennett, 2002]. The combination of the two-dimensional sensitivity kernels for phase-speed structures and one-dimensional sensitivity kernels for the reference Earth model yields a representation of the three-dimensional sensitivity of travelling surface waves to shear wave speed structures. Using these time-dependent 3-D sensitivity kernels, suitably filtered seismograms can be inverted directly for 3-D shear wave speed structure without intermediary measurements of the phase and amplitude of surface waves as a function of frequency.

The three-dimensional kernels generally exhibit sensitivity to wide areas around a geometrical ray path, which corresponds to a few orders of the Fresnel zones, with the maximum sensitivity near source and receiver locations. Source radiation patterns have significant influence on the sensitivity kernels, which suggests that the sensitivity kernels can be contaminated by errors in source parameters.

Introducing differential waveforms between two nearby stations, we can construct 3-D sensitivity kernels for the differential waveforms by working with appropriate transfer functions with corrections for slight differences in both propagation distances and azimuths between two stations. Such differential 3-D kernels have nearly zero sensitivity to the source region, leaving high sensitivity to relatively small areas around the receivers. The use of the differential waveforms of two nearby stations as a secondary observable will enable us to investigate shear wave speed structures in and around regional seismic arrays taking the effects of finite frequency into account, and will be of great help in improving the reliability of regional surface wave tomography.