On resolutions of surface wave tomography: Geometrical rays and finite-width rays

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Recent developments of two- and three-dimensional sensitivity kernels for surface waves allow us to incorporate finite frequency effects in tomographic inversions. Unlike conventional methods based upon the geometrical ray theory, the finite-frequency kernels enable us to efficiently perform forward and inverse modeling taking account of the effects of finite-frequency caused by scattering and diffraction from surrounding regions around surface wave paths. Working with such finite frequency kernels, we can expect to achieve improved resolution of surface wave tomography.

We have developed and applied a three-stage inversion technique to obtain three-dimensional shear wave speed models in the Australian region incorporating finite-frequency effects by using the influence zone about surface wave paths (Yoshizawa and Kennett, 2004 JGR). We have shown that the influence zone, in which surface waveforms are coherent in phase, can be represented as approximately one-third of the width of the first Fresnel zone (Yoshizawa and Kennett, 2002 GJI). In this study, by using the influence zone kernels, we perform synthetic experiments to assess the intrinsic differences in the resolutions and reliability of tomography models with or without the incorporation of finite frequency effects.

The results of checker board resolution tests clearly indicate the improved resolving power of finite frequency models; i.e., we can recover both the amplitude and patterns of lateral heterogeneity at scales down to a few hundred kilometers quite well. Large-scale heterogeneity patterns with the scale length over 500 km can be retrieved well by both the ray theory and finite-frequency theory, but some artificial patch-like features contaminate the ray-theoretical models.

The variance reductions achieved by phase speed models in the Australian region derived from finite frequency theory are nearly 10% higher than those achieved by the ray-theoretical models. Predicted phase speed perturbations calculated from the ray theoretical models tend to be overestimated, whilst those derived from the finite frequency models are rather suppressed. Such differences are likely to be caused by the differences in the spatial sensitivity. In the ray theory, a constant sensitivity along the path is assumed. On the contrary, the finite-frequency kernels have conspicuous peaks of the sensitivity near the source and receiver locations, and thus the along-path sensitivity cannot be constant, which results in better resolutions in regions around high sensitivity regions. Such effects are apparent in the actual tomography models in the Australian region, i.e., clearer images of plate subductions can be seen in the New Hebrides and Tonga-Kermadec.