S-velocity upper mantle structure beneath the NW Pacific from surface-wave tomography

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The main objective of this study is to obtain a detailed three-dimensional S-wave velocity model of the upper mantle beneath the north-western Pacific region from surface wave analysis. The model displays the expression of the tectonic phenomena and related deep processes in S-wave velocity anomalies. The three-dimensional lithospheric structure is investigated by multimode surface wave tomography, incorporating finite frequency effects. A strong heterogeneity of the region resulting in large off-great circle propagation and scattering effects is taken into account. The resolution of surface wave imaging with depth is increased by using the waveform inversion which includes the fundamental and the first higher mode of Rayleigh wave.

The data are collected from the IRIS (Incorporated Research Institutions for Seismology) network in the north-western Pacific region. Three-component broad-band seismograms of FARM (Fast Archive Recovery Method) data recorded from seismic events with magnitudes greater than 5.5 from 1990 to 2005 are used in this study. The initial data set is composed of 25 stations and 353 events. Locations and origin times of the earthquakes are taken from the IRIS catalogue. The centroid moment-tensor solutions are provided by the Harvard CMT catalogue. All the data are corrected for the instrumental response.

The recorded waveforms are processed by the three-stage inversion technique of Yoshizawa & Kennett (2004), which comprises three independent steps: (1) to estimate a path-specific multi-mode phase dispersion from a fully non-linear waveform inversion, (2) to construct phase velocity maps as a function of frequency and mode, incorporating effects of finite frequency as well as off-great-circle propagation, and (3) to combine the phase velocity maps for a model of 3-D shear wave velocity.

The phase velocity dispersion curves are measured for the fundamental mode and the first higher mode by waveform fitting. Then, the dispersion information from all the paths is combined to produce multimode phase velocity maps as a function of frequency. The first approximation is carried out as a linear inversion based on the assumption that each surface wave path follows its great-circle. Subsequently, the 2-D phase velocity maps are updated by including the ray tracing and finite frequency effects. Finally, the local dispersion information is inverted to obtain 1-D S-wave velocity profiles. Three dimensional S-velocity models can be reconstructed from the set of updated multimode phase velocity maps. This method offers the advantage of incorporating various styles of information such as multimode dispersion, off-great circle propagation, and finite frequency effects for surface waves in a common framework.

The 3-D shear wave velocity maps are obtained down to 300 km, using 904 paths. The subducting Pacific plate is clearly imaged as a high velocity anomaly up to 6 percents. A low velocity anomaly beneath Japan Sea and Okhotsk Sea is associated with the mantle wedge. The absolute S wave velocities in the mantle wedge at depth of 125 km are approximately 4 km/s, probably indicating the presence of partial melt in this area. A small-scale high velocity anomaly is located in the northern part of the Okhotsk Sea. The position of this anomaly correlates well with the high velocity anomaly found in the P-wave tomography of Gorbatov et al. (2000), which may be interpreted as a relict of the subducted Okhotsk plate.

We also performed a preliminary mapping of azimuthal anisotropy in this region. In the eastern margin of the Sea of Japan, we found the abrupt change in the fast direction of Rayleigh-wave phase speed in the period range from 40 to 120 seconds near the plate boundary between the North-American and Eurasian plates. This is very likely to reflect the rapid variation of the horizontal flow in the upper mantle beneath the two plates.