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Lower mantle structure beneath the Pacific analysed using out-of-plane reflections

Lina Schumacher and Christine Thomas
Institut für Geophysik, Westfälische Wilhelms-Universität Münster, Münster, Germany (lina.schumacher@uni-muenster.de)

The Earth's mid- and lower mantle is thought to be dynamically well mixed and more homogeneous than the upper or lowermost mantle. Recent global seismic tomography models show a good agreement for the large-scale structure in the lower mantle, and the geographical distribution of reduced shear-wave velocities in the deep mantle appears to be consistent across these models. One region of strongly reduced seismic shear-wave velocity, often referred to as Large Low Shear Velocity Province (LLSVP), is centred beneath the Pacific Ocean. Although progress has been made in imaging variations in seismic velocities associated with large-scale mantle convection, these images are long period filtered snap shots of the dynamics of the deep mantle and there is significant inconsistency in small-scale structures between models. Furthermore, direct observations of small-scale mantle heterogeneities are scarce yet necessary to make inferences about their nature. In this study, we investigate the lower mantle structure with seismic array methods. We search for seismic signals that reach a seismic array with a backazimuth deviating from the theoretical backazimuth of the earthquake and, therefore, call them out-of-plane signals. Information on slowness, backazimuth, and travel time of observed out-of-plane arrivals is used to back-trace the wave through a 1-D velocity model to its scattering or reflection location. Assuming only single scattering in the back-tracing algorithm, most detected out-of-plane signals have to travel as P-to-P underside reflections, and only a few can be explained as S-to-P converted phases or topside reflections. The focus of this study lies on out-of-plane signals reflected once beneath the Pacific at a depth greater than 800 km. We obtained these by processing broadband vertical component seismograms from earthquakes located in the western Pacific with a magnitude greater than 5.6 and a focal depth grater than 100km, recorded at North American networks (e.g. USArray, Alaska and Canada). In addition to mapping seismic heterogeneities in the lower mantle, we analyse waveforms and polarities of these signals. Taking into account the radiation pattern of each event in direction of the calculated reflection point, it is possible to compare the observed polarities and waveforms of the out-of-plane signals with synthetic Hilbert-transformed direct P waves having the same slowness. We validate our approach by synthesizing and processing seismograms, which are computed with a 3-D wave propagation code through a model containing a low velocity zone as well as a slab like structure. This study suggests, that the detailed analysis of waveforms as well as polarities of out-of-plain signals, combined with synthetic modelling, can help to characterise the Earth's structure in the lower mantle.