Waveform Modeling of the Slab underneath Japan

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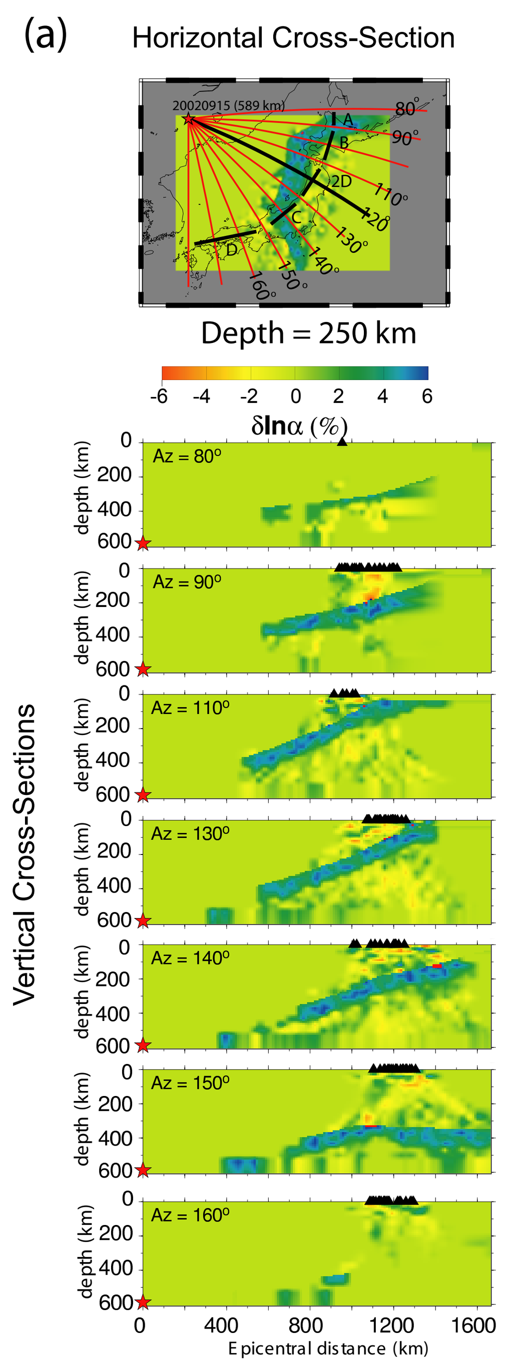
Abstract

We study 3-component seismograms from more than 600 Japan Hi-net stations produced by two earthquakes in the Japan subduction zone, which occurred in the down-going Pacific Plate at depths greater than 400 km. We simulate body-wave propagation in the 3-D P-wave model (Zhao, et al., 1994) using 2-D finite-difference (FDM) and 3-D spectral-element (SEM) methods. As measured by cross-correlation between synthetics and data, Zhao et al.'s P-wave model (1994) typically explains about half of the traveltime anomaly and some of the waveform complexity, but fails to predict the extended SH wavetrain. In this study we take advantage of the densely distributed Hi-net stations and use 2-D FDM modeling to simulate the P-SV and SH waveforms. Our 2-D model suggests a thin, elongated low-velocity layer (LVL) exists atop the slab, extending down to a depth of 300 km with an S-wave velocity reduction of 14% if a thickness of 20 km is assumed. Further 3-D SEM simulations confirm that this model explains a strong secondary arrival which can not easily be imaged with standard tomographic techniques. The low-velocity layer could explain the relatively weak coupling associated with most subduction zones at shallow depths (<50 km), generally involving abundant volcanic activity and silent earthquakes, and it may also help to further our understanding of the water-realted phase transition of ultra-mafic rocks, and the nature of seismicity at intermediate depths (~70 - 300 km).

3-D P-wave models

Figure 1. **Cross-sections** trough the regional and global tomographic P-wave models derived by Zhao et al. (1994) and Zhao (2001). Colors indicate P-wave velocity anomalies relative to 1-D Earth model IASPEI91. (a) The regional model. (b) Comparison between the global and regional P-wave models.



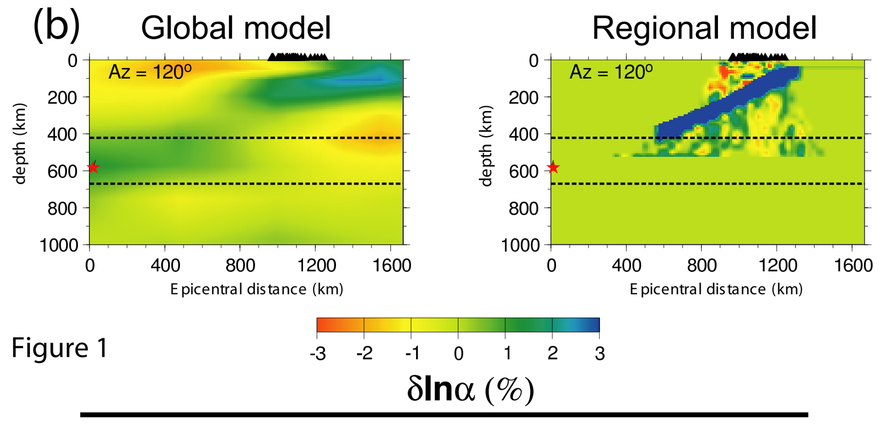
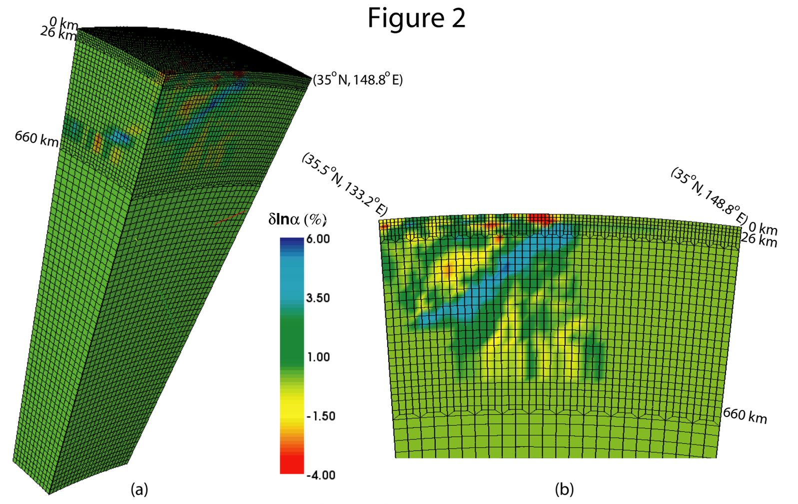


Figure 1



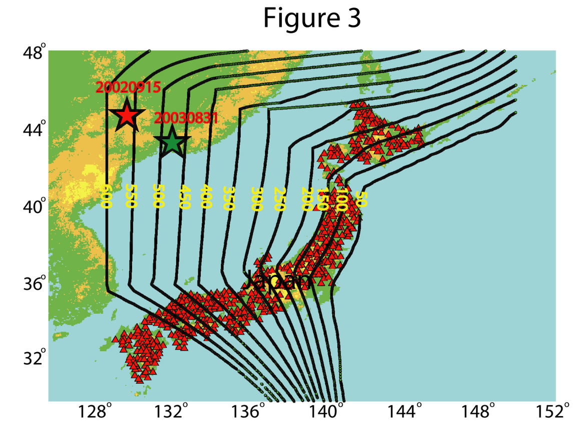
3-D Spectral-Element mesh

Figure 2. P-wave velocity anomalies are superimposed on the mesh. For parallel computing purposes, the one-chunk SEM simulations are subdivided in terms of 25 slices. The center of the chunk is at (38.5° N, 137.5° E), and the lateral dimensions are 30° X 30° . (a) Full view of two neighboring slices. (b) Close-up view of the upper mantle mesh.

Events and Stations

Figure 3. Map view of the study area : Hi-net stations are indicated by red triangles and contours of the upper plate boundary of the Pacific are indicated by black lines. The location of event 20020915 is marked by the red star and event 20030831 is indicated by the green star.

Figure 3



Data selection and model testing

Figure 4. P waveforms. (a) Az = 120° - 130° . (b) Az = 130° - 140°.

Figure 5. P-wave data-synthetics cross-correlation.

Figure 6. S-wave data-synthetics comparison. (a) Radial S waves. (b) Vertical S waves.

f = δln β/ δln α . β : S-wave velocity. α : P-wave velocity. Preferred scaling factor : f = 1.5 - 2.0.

Figure 4

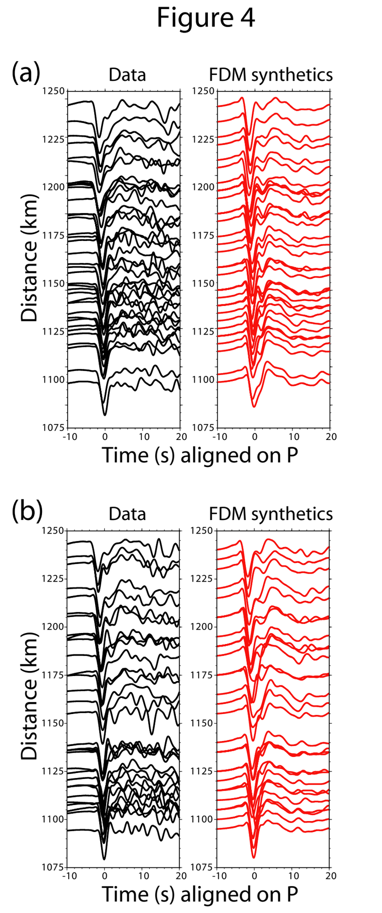


Figure 5

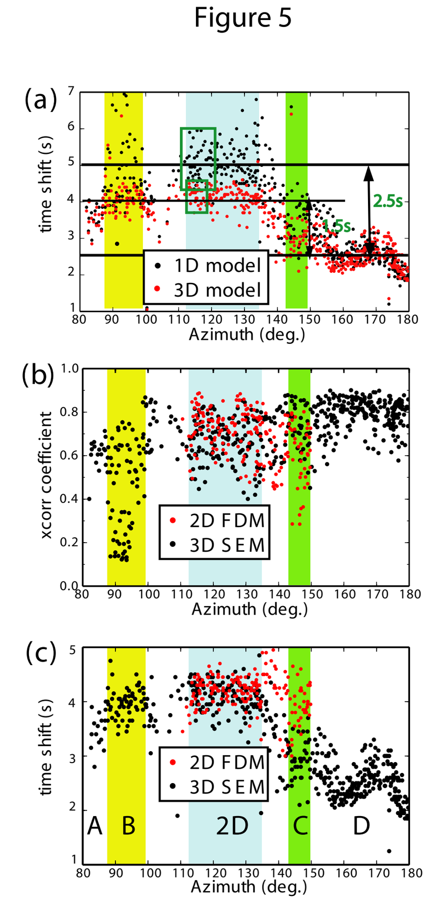


Figure 6

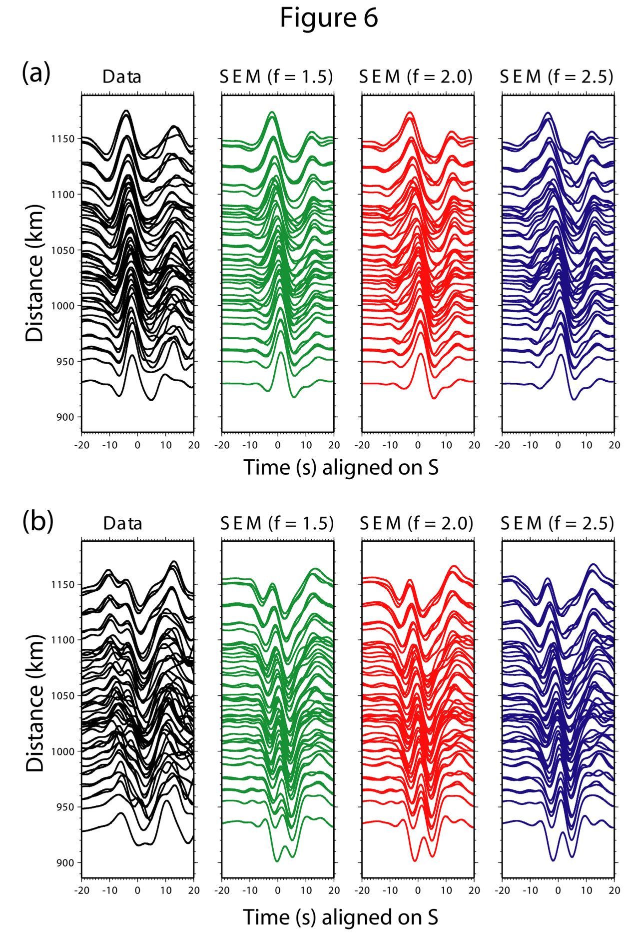


Figure 9. S-wave data-synthetics cross-correlation.

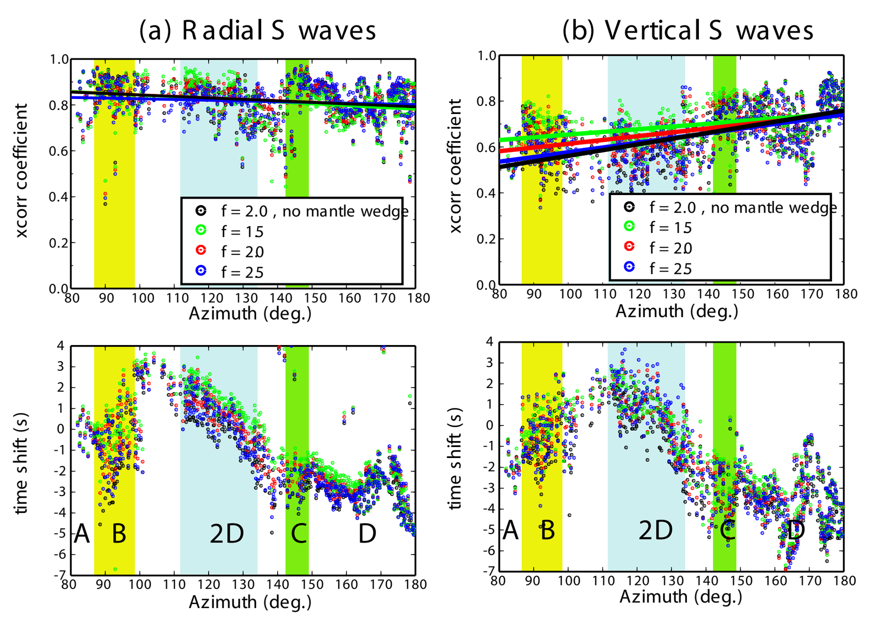


Figure 8. Map of Japan subduction zone area

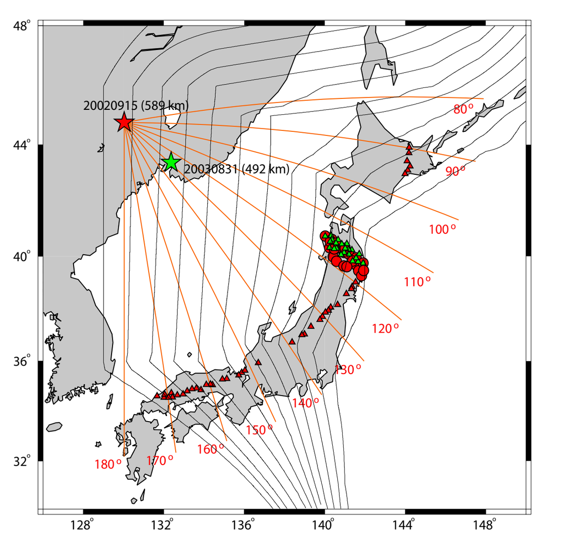


Figure 9. Azimuthal profile

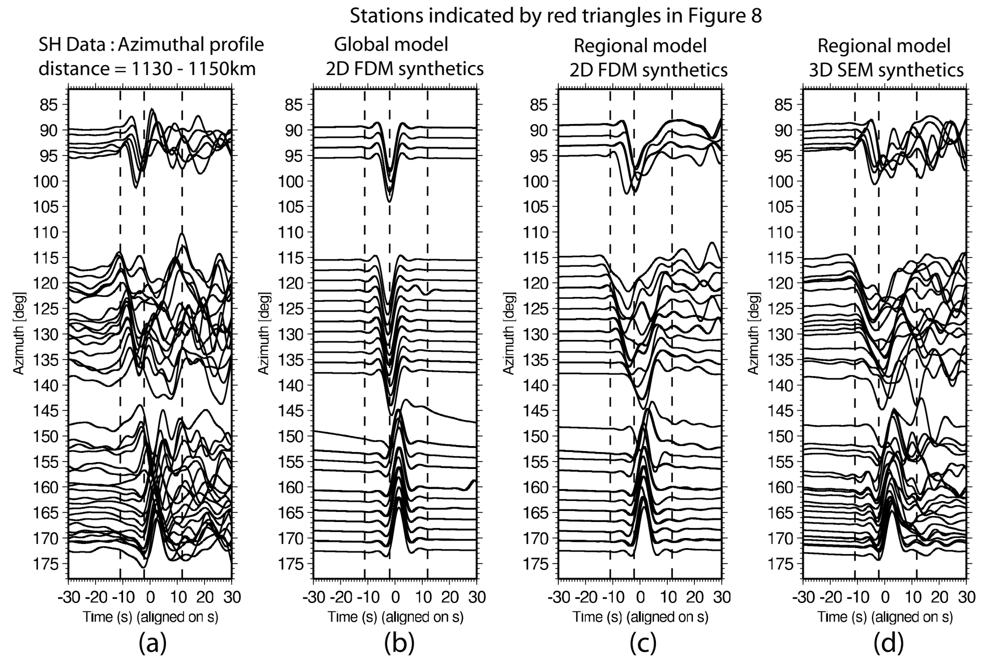
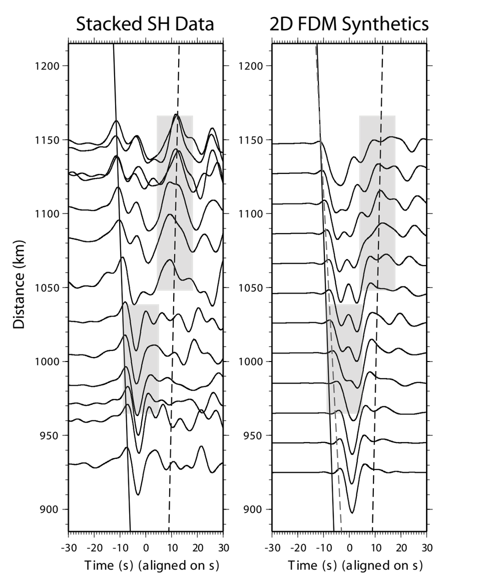


Figure 10. Distance profile



FDM simulations

Figure 11. Base models with a slab inside the transition zone

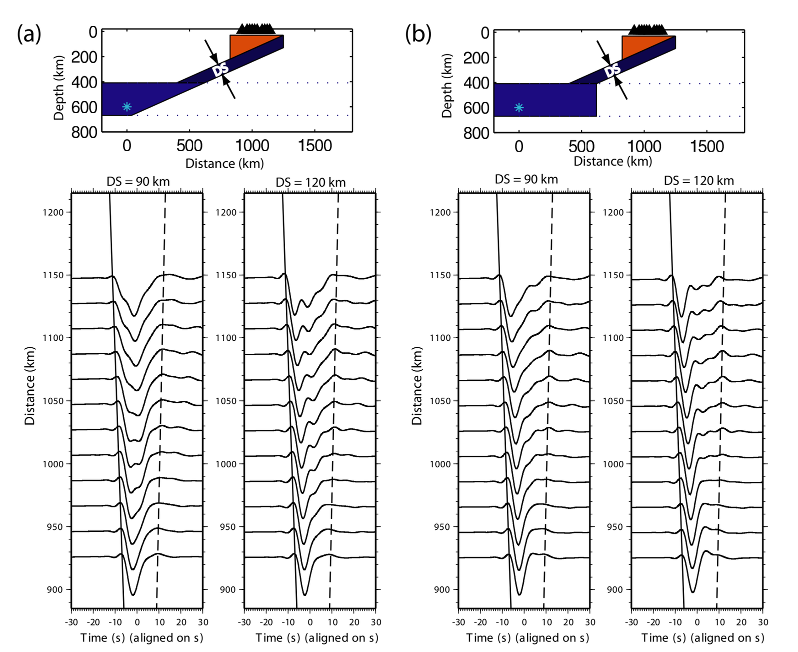
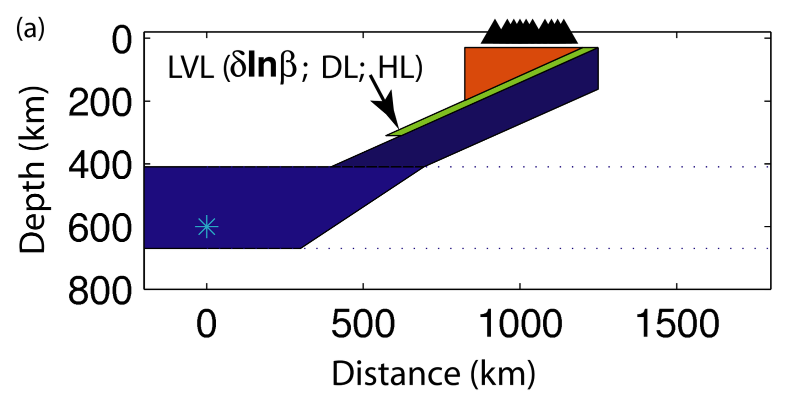
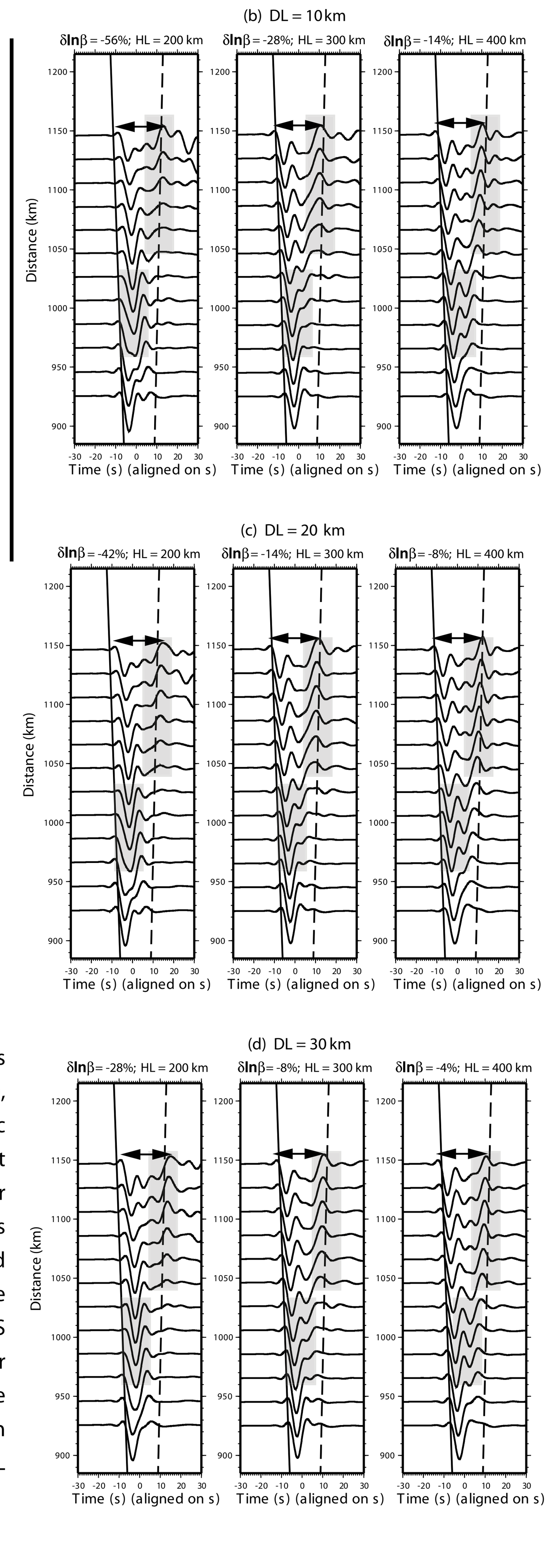


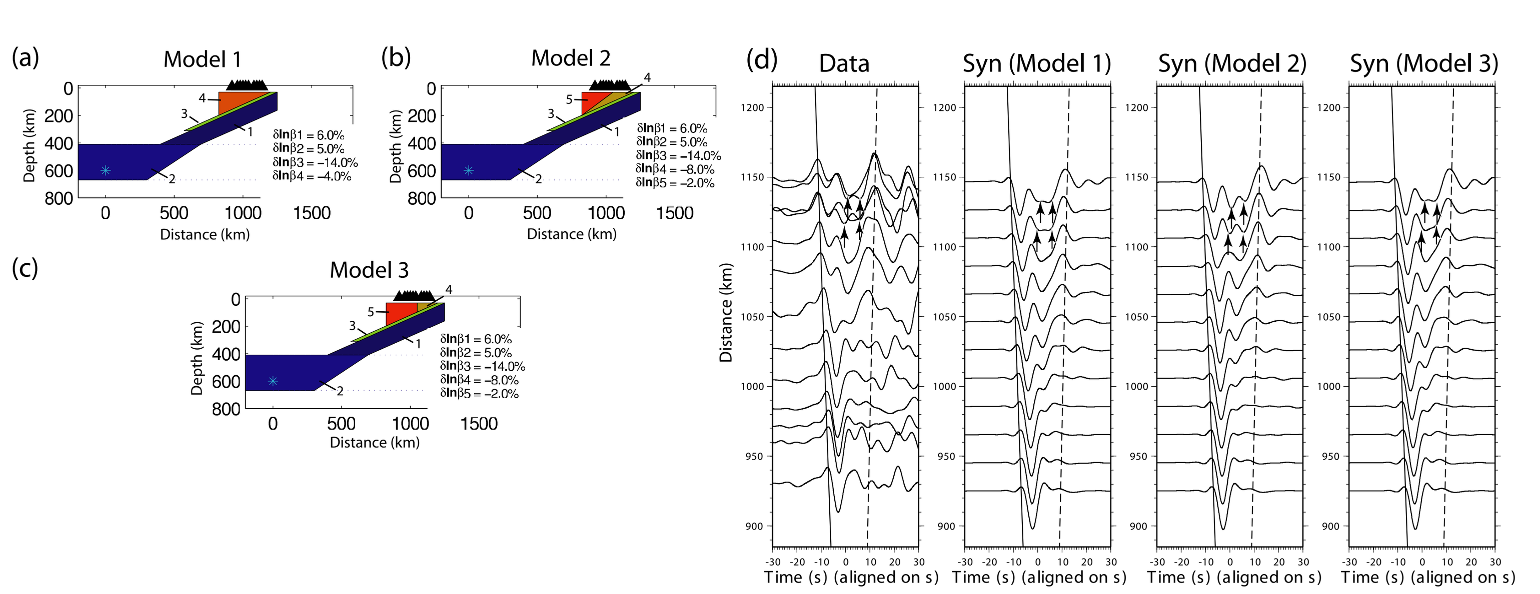
Figure 12. Slab models with a low velocity layer





The LVL is indicated by the green polygon in (a). It is characterized by its thickness (DL), its maximum depth (HL), and its relative velocity perturbation (δlnβ). (b, c, d) Synthetic waveforms calculated for nine models with different thickness DL (10, 20, or 30 km), and depths HL (200, 300, or 400 km). The length of the bar with two-way arrow-heads indicates the largest separation between the first arrival and the later arriving up-swing phase, which is 23 s at a distance of 1150 km. The solid lines indicate the approximate first S arrival and the dashed lines align with the peak of the later arriving up-swing phases in the data. The waveforms sensitive to the LVL are highlighted by the gray boxes. The comparison between data and synthetics indicates models with a LVL extending over a depth of 300 km are preferable.

Figure 13. Three models with different types of mantle wedges



3-D SEM Verification

Figure 14 Three-component S-waveform and vertical P-waveform comparison bewteen data (black lines) and 3-D SEM synthetics (red lines). SEM synthetics are calculated for Model 2 in Figure 13 . Both data and synthetics for S waves are filtered between 6 - 29 s, and for P waves between 3 - 29 s. (a) Event 20020915 (depth 589 km). (b) Event 20030831 (depth 492 km). Model 2 is our preferred model and fits the data for both events on all three components adequately.

Figure 14

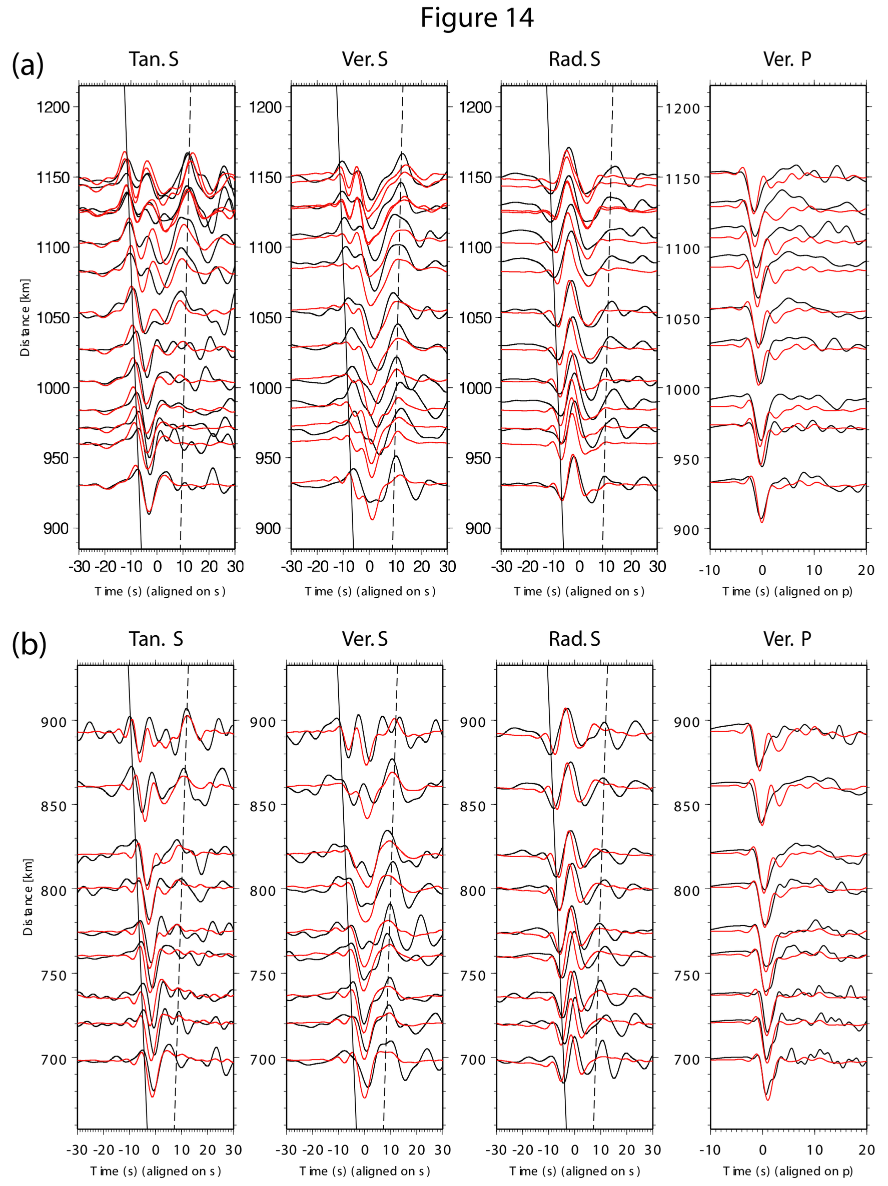


Figure 15

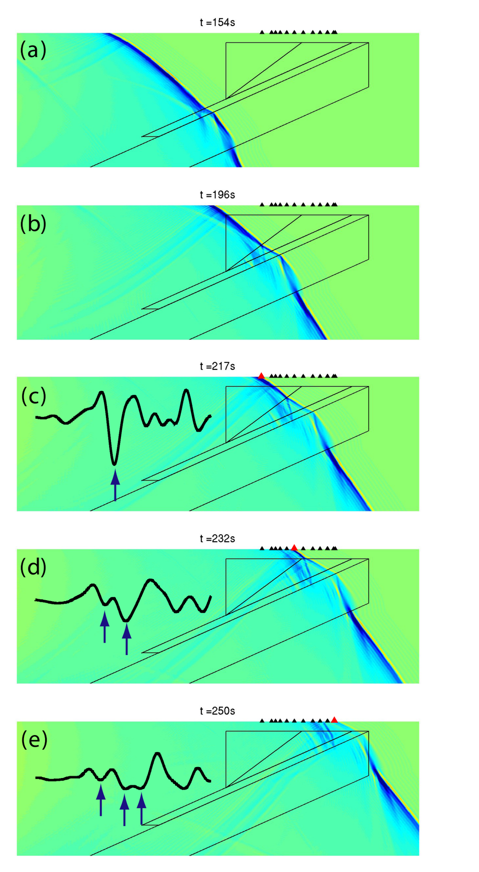


Figure 15. 2-D FD snapshots of SH-wave propagation.

Figure 16

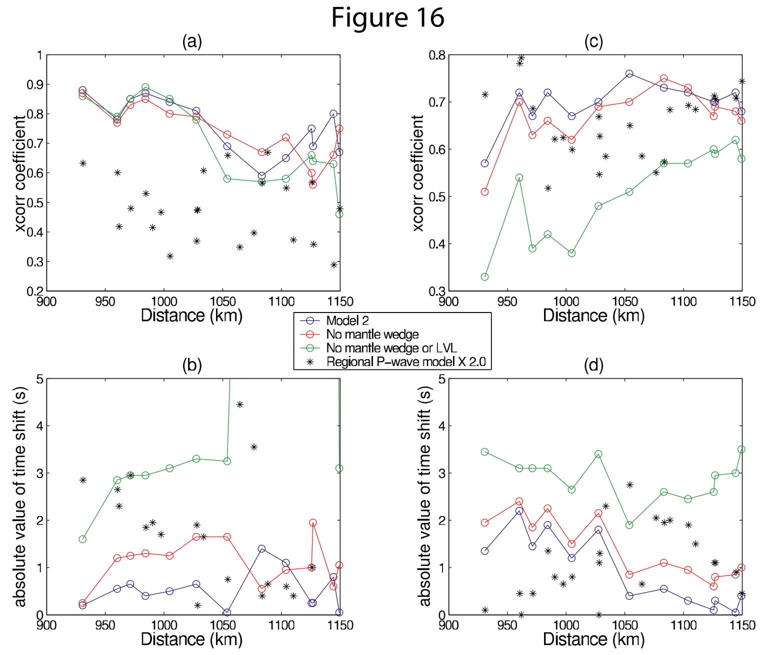


Figure 16. Comparison of cross-correlation coefficients (upper panel) and traveltime anomalies (bottom panel) between data and SEM synthetics for four different models.

Black stars : Regional model.

Blue circles : Model 2.

Red circles : Model 2 without a slow mantle wedge but with a LVL.

Green circles : Model 2 without a slow mantle wedge and a LVL.

Conclusion

The 2-D slab model indicates there is an elongated low velocity layer above the slab extending down to a depth about 300 km, with an S-wave velocity reduction of 14% compared to the normal mantle if the thickness of the LVL is 20 km. However, the thickness of the LVL trades off to some extent with the low S-wave velocity in the LVL. We interpret the LVL beneath NE Japan to be composed of hydrated mafic and/or ultramafic rocks : above a depth of 150 km the LVL could be composed of hydrous mafic crust and serpentinized peridotite above and/or below the descending crust; below a depth of 150 km this hydrous layer is more likely composed of serpentinized peridotite (or at the greatest depth, phase A) above or below the fully eclogitized oceanic crust. Water released from the dehydration reactions in this hydrous zone could cause the abundant arc volcanism, the intermediate intra-slab seismicity (70 - 300 km), and possible silent slip events, which have been observed in other subduction zones.