Research Report - Michael S. Thorne

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Topic: Analysis of *SPdKS* waveforms recorded at Hi-Net tiltmeter stations

Thin and enigmatic zones of ultra-reduced wave speeds sitting directly on top of the core-mantle boundary (CMB), and referred to as ultralow-velocity zones (ULVZs), were first discovered in the early 1990's [*Garnero and Helmberger*, 1995; *Garnero et al.*, 1993]. These zones are generally described as being thin (less than 40 km in height) regions sitting on top of the core-mantle boundary (CMB) with ultra-reduced seismic wave speeds. Wave speed reductions as large as large as 45% for *S* waves [*Thorne et al.*, 2013] and as large as 23% for *P* waves [*Brown et al.*, 2015] have been reported.

One past study has indicated the existence of a ULVZ beneath central Mexico by stacking *PcP* waveforms [*Havens and Revenaugh*, 2001]. However, additional studies in this general region have not indicated any ULVZ-like signatures [*Castle and van der Hilst*, 2000; *Hutko et al.*, 2009; *Persh et al.*, 2001] and one study [*Hutko et al.*, 2009] further proposed that the ULVZ originally proposed by *Havens and Revenaugh* [2001] may indeed not exist, but may rather be related to artifacts of the sparse dataset used in this older study.

In this work we analyze recordings of the *SKS*, *SPdKS*, and *SKKS* seismic phases (Figure 1) recorded from deep Central American earthquakes recorded on broadband seismic stations recorded globally and Hi-Net tilt-meter stations. These events are located in a perfect geometry to explore possible ULVZ structure beneath Mexico.

We searched for earthquakes occurring in the Central America region (within latitudes of 5° to 20°N and longitudes 75° to 105°W) with magnitudes ≥ 5.7 and depths ≥ 75 km occurring between 1990 and 2015. We collect recordings from (1) a global search for three-component broadband stations, and (2) horizontal tilt-meter recordings in Japan. Seismic recordings are collected for all broadband stations within the epicentral distance range from 90° to 125°. Broadband seismic recordings are collected from the Incorporated Research Institutions for Seismology (IRIS), the Observatories and Research Facilities for European Seismology (ORFEUS), and the Full Range Seismograph Network of Japan (F-net). Data processing steps included: (1) removing the mean and trends from traces, (2) removing the instrument response, (3) bandpass filtering with corners between .01 and 1 Hz, and (4) rotating the horizontal components to radial and transverse records.

Data for each event discussed above was inspected at the F-Net stations in order to determine which events showed the cleanest *SKS* energy recorded in Japan. Of the 29 events we initially collected data for we collected additional recordings of horizontal tilt-meter sensors for nine high quality events from the High Sensitivity Seismograph Network Japan (Hi-Net) operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), Japan. The NIED operates tilt-meters at over 700 sites across Japan (Figure 2a). These tilt-meter recordings have been used interchangeably as seismic recordings in several previous studies [see for example, *Takeuchi and Obara*, 2010; *Tonegawa et al.*, 2006] and comparison with F-Net broadband recordings shows excellent waveform similarity (Figure 2b). A distance profile of one event is shown in Figure 3.

We compare *SPdKS* waveforms with synthetic seismograms from a large suite of ULVZ models [see *Jensen et al.*, 2013; *Thorne et al.*, 2013]. At this stage we have not yet completed the analysis for all events, however some of the events display clear ULVZ characteristics. For example, data shown for the August 25, 2003 event (Figure 3) shows an *SPdKS* arrival that emerges around an epicentral distance of 112° with larger amplitude than the *SKS* arrival which is consistent with ULVZ presence. However, for this event, *SPdKS* arrivals behave similar to PREM predictions at distances greater than roughly 114°, which provides important clues to the spatial extent of the ULVZ. Initial analyses indicate that the *SPdKS* waveforms for this event can be explained by a ULVZ model with a *P*-wave velocity reduction of 5% (with respect to the PREM model), *S*-wave velocity reduction of 15%, a thickness of 30 km, and a length along the great circle arc direction of 100 km. However, we note that tradeoffs between ULVZ position, thickness, and velocity reductions exist. Furthermore, the waveform fits are not perfect at this stage and additional synthetic modeling is currently being performed which will refine these values.

In addition to *SPdKS* waveform analysis, additional evidence in support of ULVZ presence comes from measurements of *SKKS* – *SKS* differential travel-times. Figure 4 shows *SKKS* - *SKS* differential travel-times from the August 25, 2003 event. Shown are measurements made on peak *SKS* arrivals relative to $3\pi/2$ phase shifted peak *SKKS* arrivals. Gray circles show measurements made on individual seismograms (only F-Net and Hi-Net recordings shown). Because, some interference from depth phases may contaminate these measurements we also measured and show in Figure 4 (red squares) the differential times from vespagrams [*Rost and Thomas*, 2009] where we could be sure we were picking the *SKKS* arrivals based on their slowness which is significantly different from the depth phase arrivals. The measurements from vespagrams necessarily average over a larger epicentral distance range and thus show reduced amplitude of differential times, but corroborate the pattern. The pattern shown in Fig. 4 shows a large decrease in *SKKS* – *SKS* time relative to PREM predictions up to a distance of about 113° after which the differential times appear more PREM-like. These travel-times are also consistent with ULVZ model described above.

Overall, our initial efforts indicate the presence of a ULVZ beneath Mexico as evidenced by our analysis of *SPdKS* and *SKKS* - *SKS* differential travel-times. Our ongoing work continues to improve the ULVZ model and to analyze the full set of data.

Figures

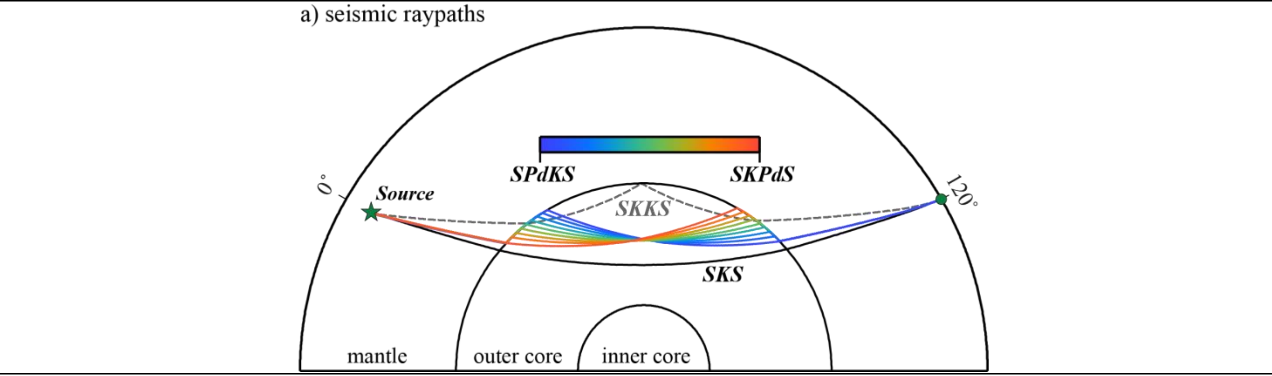

Figure 1. Seismic ray paths. (a) Ray paths are drawn for *SKS* (black), *SKKS* (dashed gray line), and the *SPdKS* + *SKPdS* system. Rays range from pure *SPdKS* (darkest blue) to pure *SKPdS* (dargest orange) ray paths. Ray paths are drawn for a 500 km event depth (green star shows event location) at an epicentral distance of 120° (green circle shows receiver location).

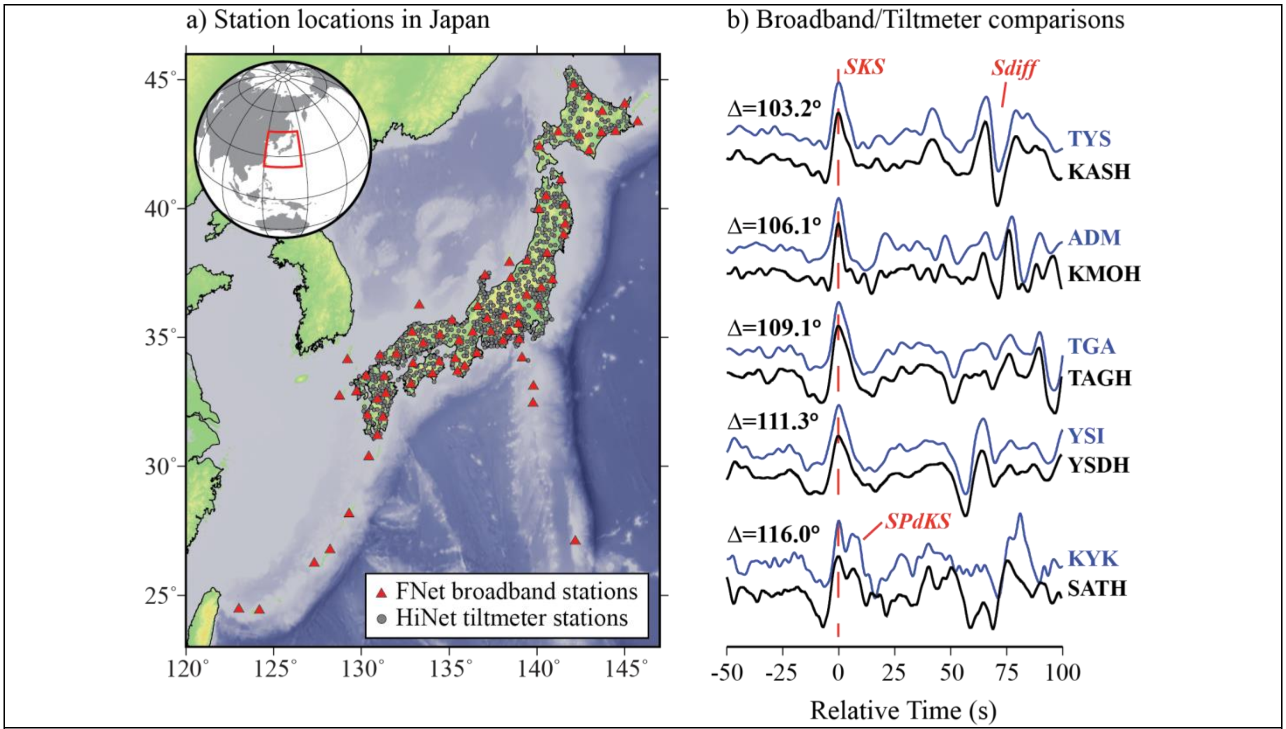

Figure 2. F-Net broadband stations and Hi-Net tiltmeter stations. (a) The locations of F-Net broadband seismic sensors are drawn with red triangles and the locations of Hi-Net tiltmeter stations are drawn with gray circles. (b) Comparison of F-Net broadband seismic recordings (blue traces) with Hi-Net tiltmeter recordings (black traces). Shown are radial component displacement traces aligned and normalized to unity on the *SKS* arrival. All records are bandpass filtered with corners between .02 and 0.2 Hz. F-Net stations shown are: (1) TYS - Tonoyamasaki, (2) ADM - Akadomari, (3) TGA - Taga, (4) YSI - Yoshida, and (5) KYK - Nagata. Records are shown for the February 25, 2011 (depth 122.7 km) event.

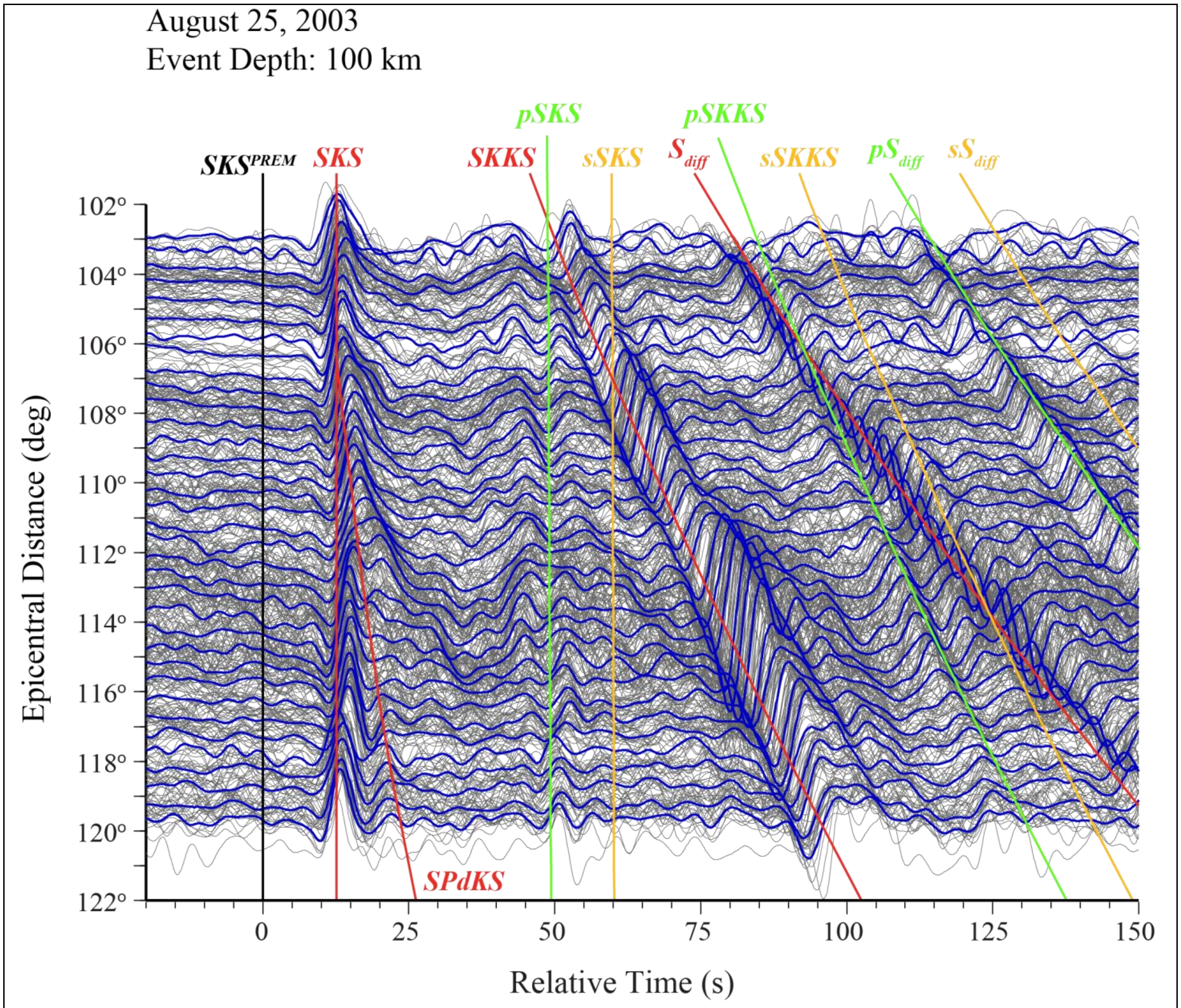

Figure 3. Record section from the August 25, 2003 event recorded at Hi-Net tiltmeter stations and F-Net broadband stations. The traces are aligned on the PREM predicted arrival time for *SKS*. Displacement seismograms are shown and are normalized to unity on the peak amplitude in the vicinity of the *SKS* arrival. Gray traces show the original data and blue traces show linear stacks of the data in 0.5° epicentral distance windows. The arrival times of major seismic phases in this time window are indicated.

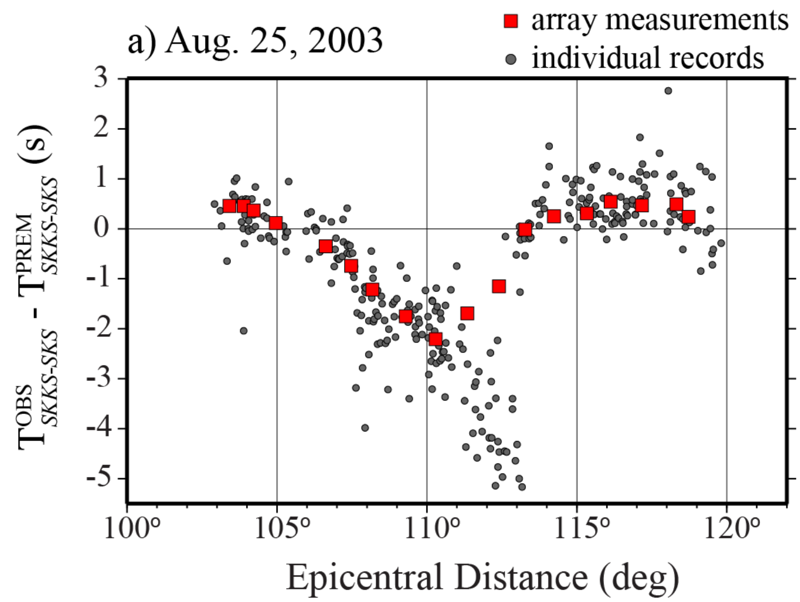

Figure 4. Shown are *SKKS-SKS* differential travel-times relative to the PREM prediction for the August 25, 2003 event. Gray circles are measurements taken from individual seismograms. Red squares are measurements made from vespagrams.

References

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