A Survey of Earth's Lowermost Mantle Utilizing Core-Diffracted Waves

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Abstract

We probe lowermost mantle structure with frequency-dependent measurements of core-diffracted wave phase slowness and amplitude decay rate from large earthquakes (mb>5.8). Exploiting these observables aids in establishing strong constraints on the fine-scale radial velocity structure above the core-mantle interface in a manner analagous to surface wave observables constraining uppermost mantle structure. To estimate the frequency dependence of the slowness and decay rate coused by the diffraction process, we measure the relative arrival time and amplitude of both Pdiff and SHdiff arrivals for a series of frequency bands between 0.01 and 0.2 Hz and make corrections for bias introduced by ellipticity, geometrical spreading, and 3D structure above the lowermost mantle. Utilizing MOMA, a linear transect of broadband seismometers arrays, we highlight the limitations and improvements of a two-station approach compared to multi-station measurements. We then compare the observations with a library of measurements on synthetics to infer lowermost mantle compressional and shear velocity structure.

Figure 1 (BELOW): Sdiff travel time kernel from Zhao and Jordan 2006. Diffracted waves are highly sensitive to the D" region as they diffract about the Earth's core. The longer the the diffraction the greater the sensitivity to the velocity structure of the lowermost mantle.

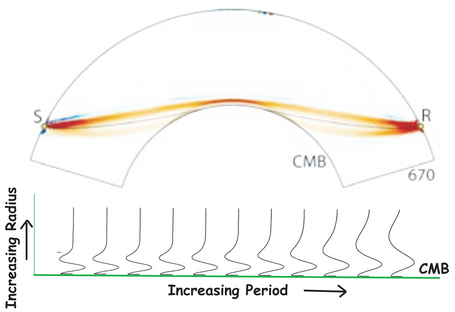
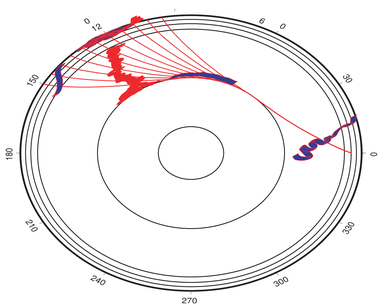


Figure 2 (ABOVE): Flipped 1D surface wave sensitivity kernels demonstrate how core-diffracted waves over a range of frequencies "sense" the D" region differently during diffraction.

Figure 3 (BELOW): By measuring differences in diffracted arrivals for co-azimuthal stations (that is stations along the same azimuth from an earthquake), we exploit the fact that core-diffracted waves share the same source-side path (the core-grazing one) and thus can safely ignore any source-side structure and source parameters. This is known as diffracted wave profiling. Unfortunately these profile measurements are still sensitive to structure on the receiver-side including the ellipticity of the Earth.



MOMA Data

The MOMA array was a linear transect of broadband seismometers deployed in 1995 to 1996 from Missouri (MO) to Massachussetts (MA). The array consisted of 18 stations roughly equally spaced between 2 permanent stations (HRV and CCM). All data used in this study were prepared by conversion to displacement, rotating to the backazimuth, resampling at 5sps, and narrow band filtering at one of 17 butterworth bandpasses between 5 and 100 seconds. Records with a SNR less than 3 were removed from the slowness and decay rate estimation for that frequency band. Multi-channel cross correlation (Van Decar and Crosson, 1990) was used to estimate the relative arrival times of Pdiff and SHdiff between stations. Measurements were then corrected for 3D structure of the mantle (HMSL-06), crust (crust2.0), ellipticity, and geometrical spreading.

We were able to find 6 earthquakes during the deployment of the MOMA array with strong enough diffracted arrivals to estimate the frequency dependence of both the slowness and decay rate of Pdiff. Three of those events were significant enough to allow the same operation to be done on SHdiff.

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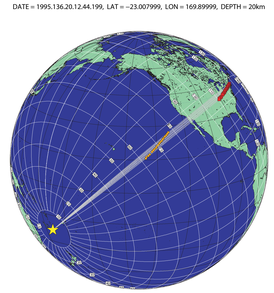

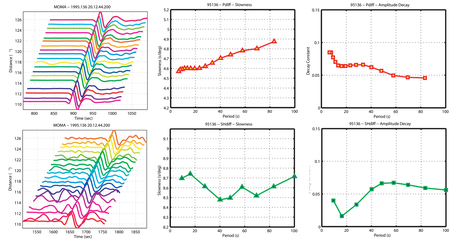

Figure 4 (ABOVE): Earthquake in the Fiji region nearly along strike of the MOMA array. Raised Pdiff slowness may be due to a possible ULVZ or just a slower than PREM region. Note the deflections which are indicative of a discontinuity. This coincides with a strong increase in slowness for SHdiff (with a corresponding drop in decay rate).

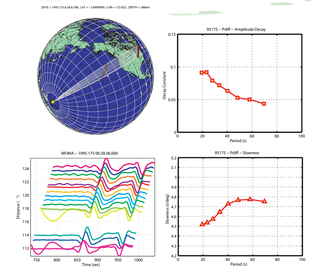

Figure 5 (ABOVE): Papau New Guinea event. Note the strong drop in slowness at 40s - a strong resemblance to the RJK2705 model of Valenzuela and Wysession.

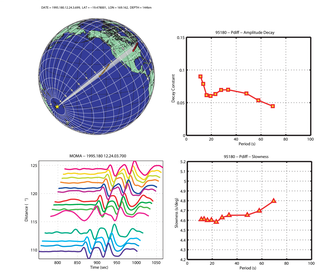

Figure 6 (ABOVE): A complex rupture in Fiji region. Note that Figure 4 is from a similar location. The match in slowness and decay rate between these two events is striking.

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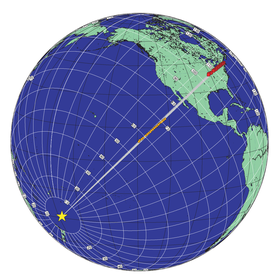
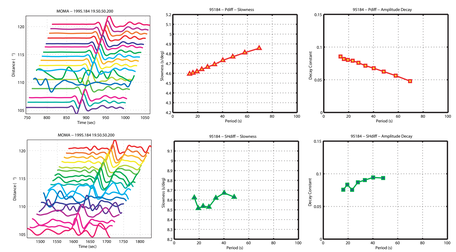


Figure 7 (BELOW): Nearly perfectly along strike event from the Tonga region. Both the slowness and decay rate for Pdiff are almost perfectly linear. SHdiff shows more variation but the frequency range is limited.



DATE = 1995.235.7.6.2.599, LAT = 18.841, LON = 145.19501, DEPTH = 597km

Figure 8 (BELOW): Deep event from the Marianas. Pdiff dispersion at the shortest periods deviates strongly. SHdiff dispersion exhibits an even stronger deviation that is suggestive of a substantial slow layer at the base of the mantle. Note that amplitudes actually increase for some short periods.

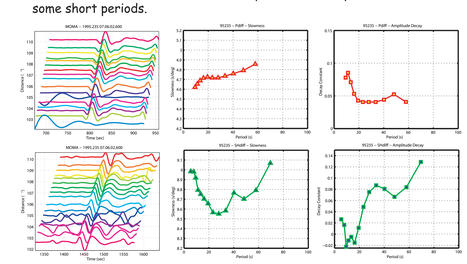
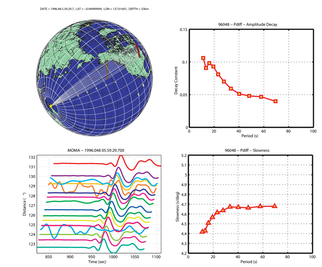


Figure 9 (BELOW): Another event near Papau New Guinea (see Figure 5). The match in slowness and decay rate dispersion between the two is quite good. Also the match to the North is fair (Figure 8).



Synthetic Data

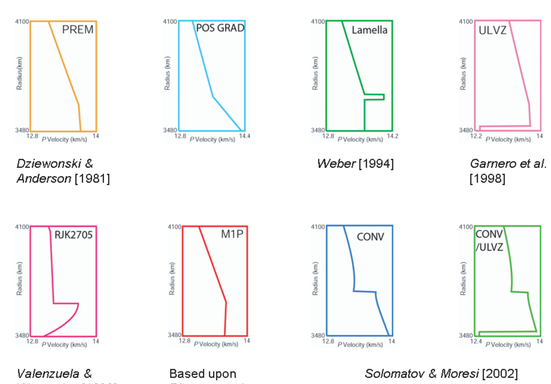
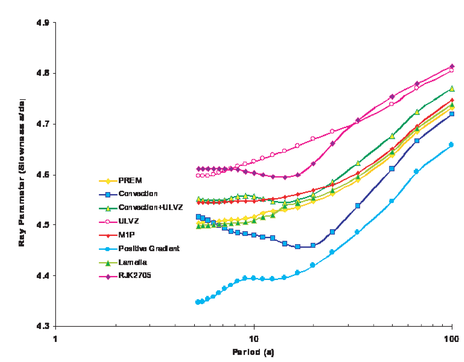


Figure X (BELOW LEFT): Several 1D models previously proposed for the CMB region P velocity structure. Significantly more models need to be added to better constrain the uniqueness of slowness/amplitude decay dispersion.

Figure Y (BELOW): Ray parameter dispersion curves corresponding to the models given in Figure X are shown for the range of 6 to 100 seconds. Several curves show clear deflections that demonstrate this methods sensitivity to a discontinuity in the lowermost mantle.



Remarks

Significant slowness dispersion (7%) for several profiles is unlikely to be as a result of intrinsic attenuation (expected to be 0.1% for a Qmu of 250).

Several profiles exhibit strong deviations in slowness that suggest non-PREM radial velocity structure that is best fit by strong discontinuous changes in seismic velocities in the lowermost mantle .

Repeatability of 2 pairs of events indicates that the measurements are not effected by source effects for either the slowness or the decay rate. It is also indicative that our method is able to extract the slowness and decay rate reliably.

The lowermost mantle below the Northeast quadrant of the Pacific ocean displays lateral and radial velocity structure for both P and SH.

SHdiff and Pdiff dispersion appear uncorrelated.