Long wavelength characteristics of Earth structure

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Considerable efforts have been paid to analyse digital seismic network data and ISC (International Seismological Center) data during the last decade. Although there are still uncertainties in seismic maps, some consistent results for long wavelength characteristics of Earth's heterogeneity have emerged. We briefly summarize those features in this paper.

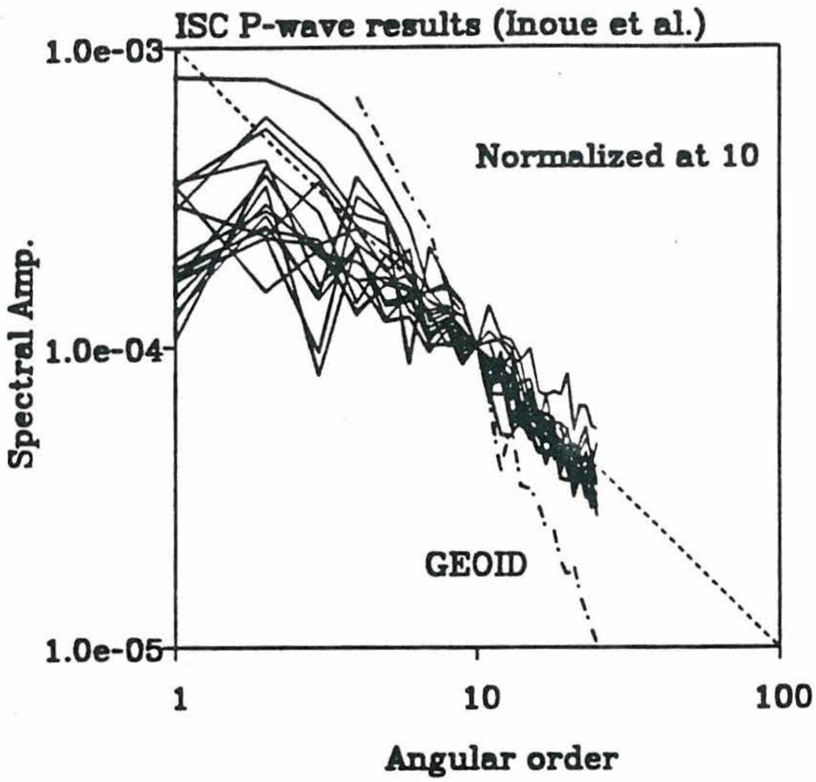
Figure 1 shows spectral amplitudes of mantle P-wave heterogeneity as a function of harmonic degree (horizontal wavenumber). The results are from Inoue et al. (1990) based upon ISC data and each line corresponds to a particular depth. As a reference, a line for l^{-1} is given by dash line. Geoid is shown by a chain line. The figure demonstrates that seismic heterogeneity spectra (amplitude) varies as l^{-1}, while geoid varies as l^{-2} (Kaula's rule). The geoid data, however, may not be relevant to deep structure at least for higher l ($>$10). This is because variation of topography can explain this feature. Topography produces a surface density anomaly of ρh, where ρ and h are density and topography. The geoid can then be written $N=(4\pi Ga)/g(2l+1)*\rho h$ and since topography h varies as l^{-1}, l^{-2} dependence is expected for N. Furthermore, geoid and topography have fairly good correlation as shown in Figure 2 (from l=2 to 36), which supports the surface origin of geoid signal for higher l. Note that SEASAT maps generally support this. The l^{-1} dependence seems to be an important feature of mantle heterogeneity that must be explained by any modeling efforts.

Figures 3a and 3b shows the variation of total heterogeneity amplitudes as a funciton of depth. Variations from five studies are shown, all of which show peaks at top, decrease with depth and a secondary peak at the bottom. Most of lower mantle shows relatively small heterogeneity. There are a factor of few differences among various studies but overall trend seems consistent. Locations of boundary layers are indicated at top and bottom of the mantle in these figures, and the figure also indicates that average level of heterogeneity is about twice as much higher in the upper mantle than in the lower mantle. These results must be further confirmed with more recent results, but place an important constraint on the differences between upper and lower mantle.

Since overall spectra of heterogeneity follow l^{-1}, lower harmonic components are of considerable importance. We have noted that l=2 components are generally the largest throughout the mantle; but the pattern of anomaly produced by l=2 components are quite different between upper and lower mantle. Correlation among 11 layers in the mantle, for which 1 is the shallowest and 11 is the bottom layer (D"), are given in Figure 4. The results from two models, MDLSH in Tanimoto (1990) and M84A (Woodhouse'and Dziewonski, 1984) plus L02.56 (Dziewonski, 1984) are shown here. White circles denote positive correlation and black negative correlation. Circles along the diagonal components are 1. Note the lack of correlation or negative correlation between layers 1-4 and 5-11. It is important to note that the largest component of the model (l=2) does not show correlations.

Depth slices at the equatorial plane are shown in Figures 5a and 5b. Figure 5a contains components l=1 to 3, while Figure 5b contains l=1 to 6. Dark areas are fast velocity and white areas are slow. The figures basically support that locations of fast velocity anomlies in upper and lower mantle are shifted with respect to each other. It seems to suggest that there are important qualitative differences between upper and lower mantle.

Figure 1: Spectral amplitudes of heterogeneity are plotted as a function of harmonic degree (l). As a reference, the diagonal dash line for l^{-1} is shown. Geoid follows l^{-2} trend, the well-known Kaula's rule. Higher harmonic parts ($l>10$) can be explained simply by topography. Note the good correlation of geoid and topography in Figure 2.



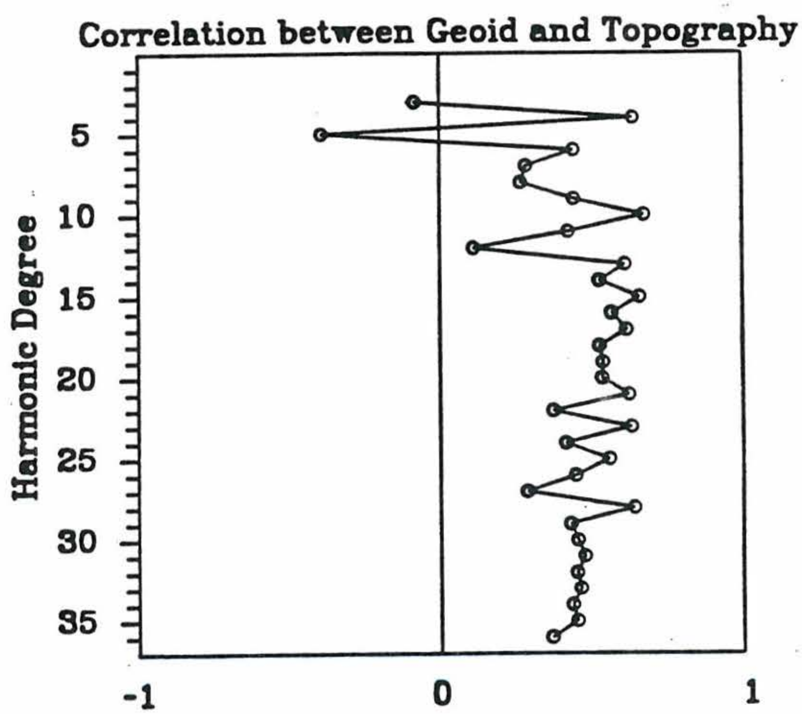
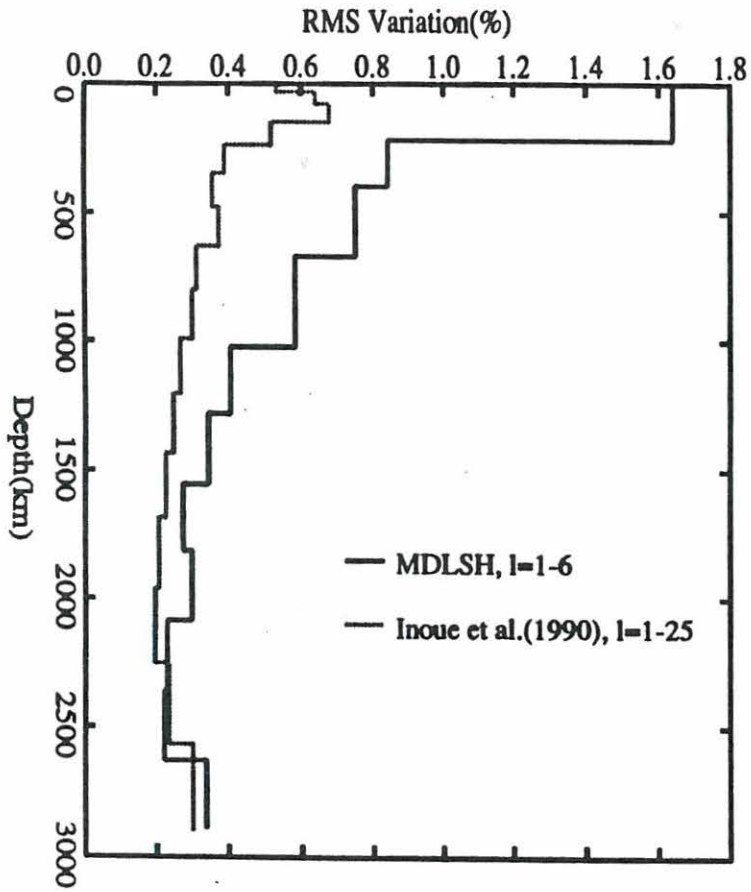


Figure 2: Correlation coefficients as a funciton of l between geoid and topography.

Figure 3a: RMS variation (total heteorgeneity) as a function of depth. Two models are from Tanimoto(1990,MDLSH) and Inoue et al.(1990). Note the peaks both at the top and the bottom of the mantle, which suggests the locations of boundary layers there.



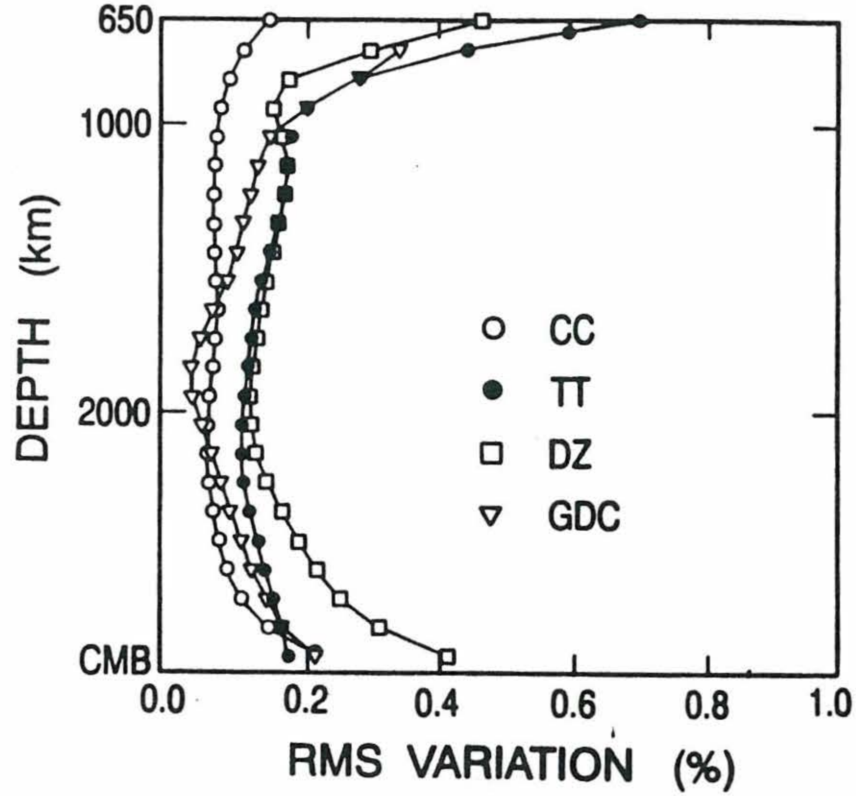
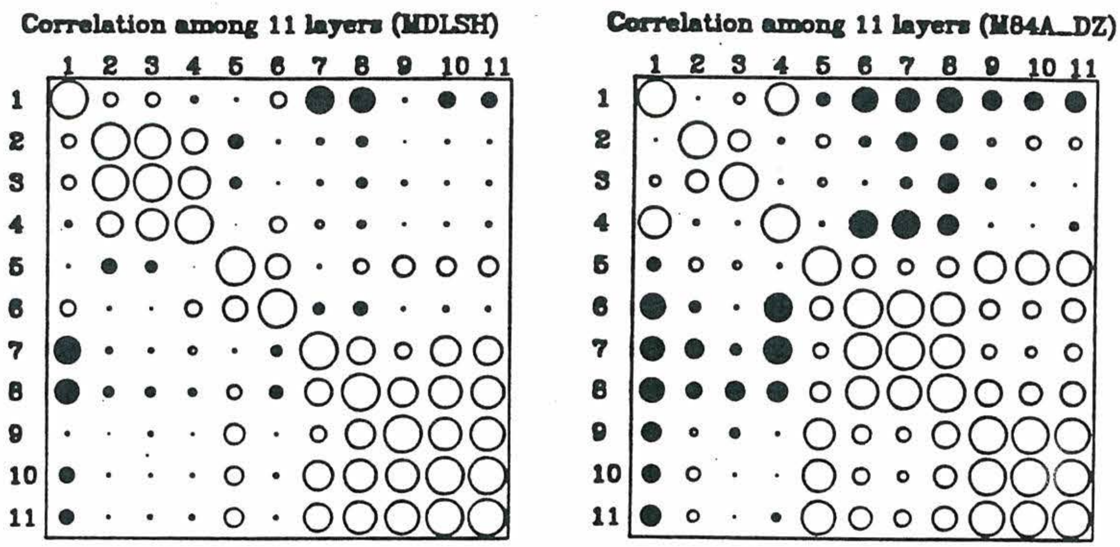


Figure 3b: RMS variation of four models in the lower mantle. CC is Clayton and Comer (1983), TT is the same with MDLSH, DZ is L02.56 (Dziewonski, 1984) and GDC is by Gudmundsson et al.(1990). Note that all models show small heterogeneity in the mid- lower mantle.

Figure 4: Cross correlations of l=2 component among 11 layers in the mantle. The eleven layers are from the top (1) to the bottom (11) of the mantle and have thicknesses of about 250-300 km. Both MDLSH and composite M84A plus L02.56 model demonstrate the *lack* of correlation between upper and lower mantle.



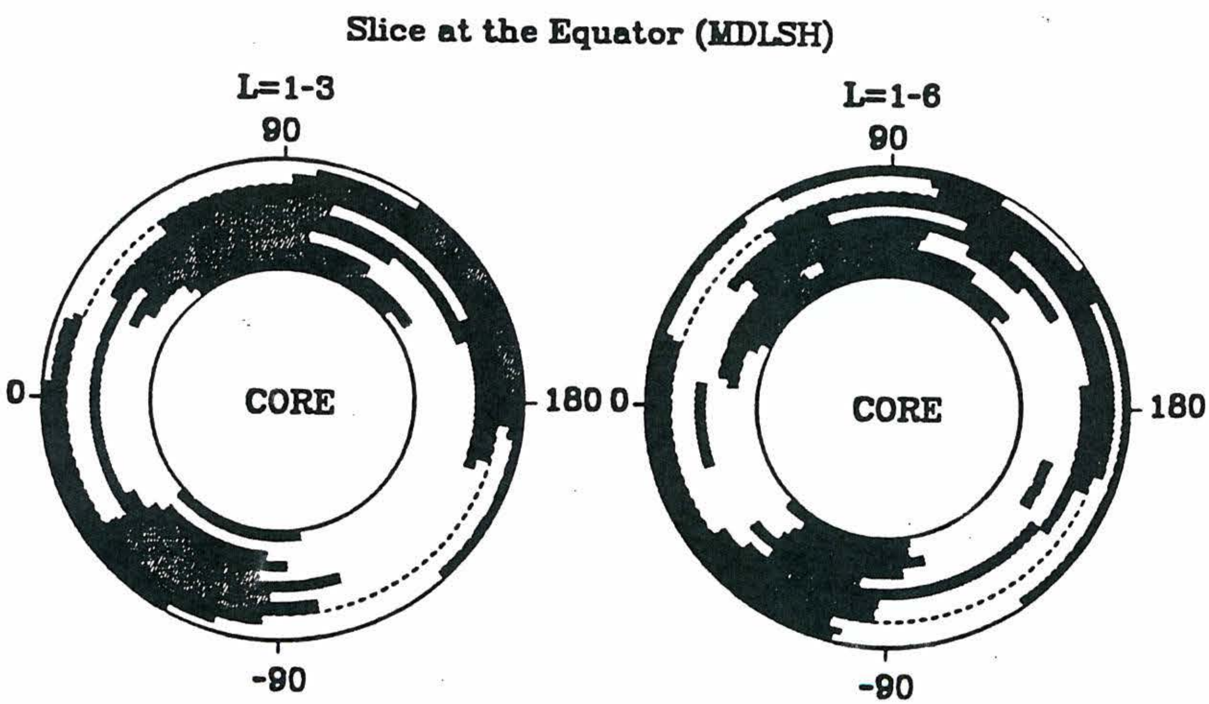


Figure 5a and 5b: Depth cross sections of MDLSH at the equator. The left figure contains spherical harmonic components from l=1 to 3, while the right figure contains from l=1 to 6. Because of the l^{-1} dependence of spectra, those low harmonic components are dominant. Dark areas are fast velocity and white areas are slow. It is clear that fast velocity anomalies in the lower mantle are shifted with respect to those in the upper mantle.

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