5. Inversion of Normal Mode Spectra for Mantle Structure

Chaincy Kuo and Barbara Romanowicz

5.1 Introduction

Observations of the Earth's free oscillations have been a valuable complement to seismic body and surface wave data in constraining materi al properties and their lateral variations in the deep Earth. Most normal mode inversions are cast in terms of a two-step formalism, in which "splitting functions" (*Woodhouse et al., 1986*) are first computed for each mode in the data set. In the second step, splitting functions are simultaneously inverted for the distribution of elastic parameters with depth.

While mantle mode data, in principle, provide information on the Vs, Vp and ρ in the mantle, the sensitivity to Vs is dominant, and most studies to-date have assumed an a-priori scaling between the 3 elastic parameters, and inverted for Vs alone (*Giardini et al., 1987; Li et al., 1991; Resovsky and Ritzwoller, 1998*). In particular, the density structure is thought to be rather poorly resolved.

Following *Li et al (1991)*, and *Durek and Romanowicz (1999)*, we have opted for a direct, one step method, which inverts normal mode spectra directly for 3D earth structure. While more time consuming, this approach is more internally consistent. Using this approach, we have performed inversions in which we simultaneously solve for Vs, Vp, ρ structure up to degree 4 in the mantle, for both even and odd degrees. Our models are radially parameterized up to order 7 in Legendre polynomials.

5.2 Velocity and Density Mantle models

We analyze the vertical component spectra of spheroidal mantle modes whose eigenfunctions primarily exhibit particle motion in the mantle (${}_0S$, ${}_1S$, ${}_2S$, ${}_4S$, ${}_5S$ branches). Modes with significant displacement in the core are not included in this study, although some mantle modes in our data set have some sensitivity to outer core structure. The effect of outer core sensitivity on our models of mantle structure is minimal, and this is consistent with conclusions of *Giardini et al. 1987*. Below 5 mHz, the mantle modes in our study are well-isolated in frequency, which minimizes contamination by neighboring modes. On the other hand, our analysis code is capable of taking into account the more complex effects of 3-D structure on the spectra of coupled mode pairs. In total, we have chosen 30 isolated mantle modes and 7 coupled mantle mode pairs, amounting to a total of 44 spheroidal mantle modes, and a total of 2630 individual spectra.

A variance reduction of 71.4% is obtained after 3 iterations of the non-linear inversion from spectra for our model of mantle structure, *PSR.CP.cmb*. Although we only retrieve very large scale features of lateral heterogeneity in degree 4, there is, in general, good correspondence with expected features of the dynamic Earth, as documented in other studies. Low velocity features in the upper mantle correspond to regions of back-arc basins, and spreading ridges. Fast anomalies are associated with regions of subduction, particularly in the Western Pacific and become prominent under South America at 650 km depth. At the bottom of the mantle, both shear and compressional wave velocity maps exhibit high velocity rings around a low velocity Pacific Ocean (Figure 11.9).

Although our confidence in the retrieval of density structure is marginal, as discussed in a previous section, the density structure retrieved from *PSR.CP.cmb* is not unreasonable: patterns of high density anomalies in the mantle correspond to regions of down-going slabs in the mantle. High density features are present southwest of South America and Western Pacific starting at about 250 km depth, in particular near the Tonga Trench. These features surrounding the Pacific extend all the way down to the base of the mantle (Figure 11.10).

5.3 Geoid Predictions

Many authors have computed geoid predictions from forward-modelled mantle density heterogeneity by simulating the history of slab subduction in the mantle (*Hager, 1984; Ricard et al., 1993; Lithgow-Bertelloni and Richards, 1998*) based on plate motion reconstruction extending to ~180 Ma. The predictions of the geoid from these slab models agree with the observations extremely well. We note that the visual correlation of our mantle density structure with that of *Lithgow-Bertelloni and Richards (1998)* truncated to degree 4 is quite satisfying.

We also can make an independent prediction of the Earth's gravitational potential at the surface from our density model and compare it with the observed geoid to assess further our ability to model density. To fit the degrees 2-6 geoid anomaly, we have used a density model inverted up to degree 6. The observed and synthetic geoid are displayed in Figure 11.11 and include degrees

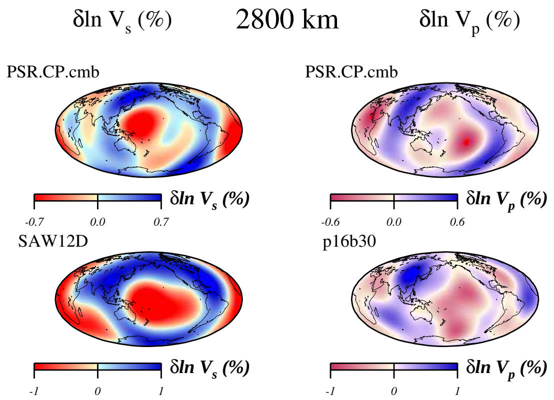

Figure 11.9: At 2800 km, both shear and compressional velocity perturbations exhibit high velocity regions around a slow Pacific. The normal mode spectra derived models are shown at the top (left: $\delta ln V_s$, right: $\delta ln V_p$, and models from time-domain data are shown at the bottom for comparison (left: SAW12D [*Li and Romanowicz, 1996*], right: p16b30 [*Masters et al., 1996*]).

2-6. It is apparent that the correspondence between the observed and predicted geoid is quite good from visual inspection. In general, the pattern of positive and negative geoid anomalies agree, and there is also a strong agreement in the amplitudes.

5.4 References

Durek, J. and B. Romanowicz, Inner core anisotropy inferred by direct inversion of normal mode spectra, In press, *Geophys. J. Int.*, 1999.

Giardini, D., X.-D. Li, and J.H. Woodhouse, Three-dimensional structure of the Earth from splitting in free-oscillation spectra, *Nature*, **325**, 405-11, 1987.

Hager, B.H., Subducted slabs and the geoid: constraints on mantle rheology and flow. *J. Geophys. Res.*, **89**, 6003-15, 1984.

Li, X.-D., D. Giardini, and J.H. Woodhouse, Large-scale three-dimensional even-degree structure of the Earth from splitting of long-period normal modes, *J. Geophys. Res.*, **96**, 551-77, 1991.

Li, X.-D. and B. Romanowicz, Global mantle shear velocity model developed using nonlinear asymptotic coupling theory. *J. Geophys. Res.*, **101**, 22245-72, 1996.

Lithgow-Bertelloni, C. and M.A. Richards, The dynamics of Cenozoic and Mesozoic plate motions, *Reviews of Geophysics*, **36**, 27-78, 1998.

Masters, G., S. Johnson, G. Laske, and H. Bolton, A shear-velocity model of the mantle. *Philos. Trans. R. Soc. London A*, **354**, 1385-411, 1996.

Resovsky, J.S. and M.H. Ritzwoller, New and refined constraints on three-dimensional Earth structure from normal modes below 3 mHz, *J. Geophys. Res.*, **103**, 783-810, 1998.

Woodhouse, J.H., D. Giardini, and X.-D. Li, Evidence for inner core anisotropy from free oscillations, *Geophys. Res. Lett.*, **13**, 1549-52, 1986.

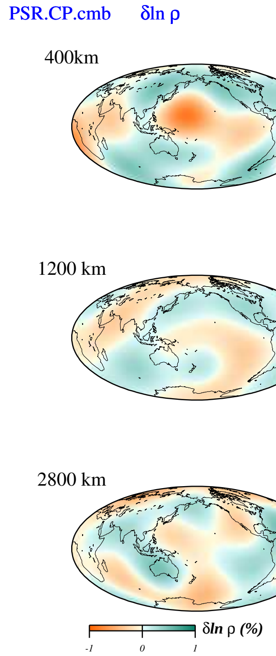

Figure 11.10: Density perturbations at three depths in the mantle