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3D density models from normal modes

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Normal modes, or whole Earth oscillations, are the only seismic data that are able to constrain density in the Earth in addition to velocity. Thus, normal modes are key for comparing and combining with constraints on density from neutrino data.

Normal modes are studied by using large earthquakes and Fourier transforming week-long seismograms from the time domain to the frequency domain. The normal mode spectra in a 1D spherical Earth model can be calculated exactly; for a given normal mode with angular order l and overtone number n, the frequencies of the $2l+1$ eigenfunctions, or singlets, are degenerate. Adding ellipticity, rotation and 3D structure removes the degeneracy and results in splitting of the eigenfrequencies (similar to Zeeman splitting for the hydrogen atom). We use perturbation theory to calculate the splitting which also enables us to perform seismic tomography by comparing measured normal mode frequency splitting with calculations for 1D and 3D velocity and density models.

1D density models of the mantle, outer and inner core are made using the measured normal center frequencies. In these models we find, for example, that the outer core has a lightly larger density than PREM and that the inner core has a slightly lower density. Determining the precise density of the outer core and inner core is important because it determines the amount of light elements present in the core in addition to iron.

3D tomographic density models of the mantle are made using the measured singlet splitting of the normal modes, which we visually as maps showing how the normal mode center frequency varies regionally. Such images show regions with slow and fast velocity anomalies, including two large continental size regions just above the core mantle boundary, one located under the Pacific and the other one under Africa (the so called 'LLSVPs'). These two regions have low shear wave velocity, but their role in mantle convection as either a thermal plume or a stable compositional pile is still heavily debated. Using our normal mode splitting measurements, we find that the two LLSVPs in the lower mantle are partially dense at their base while the remaining parts are light. Using a recently developed neural network, we interpret our model which shows that the dense and light parts both have a high temperature; the larger density comes from an increase in iron content which may be stable in mantle convection.

Auteur principal: Prof. DEUSS, Arwen (Utrecht University)

Co-auteurs: VAN TENT, Rûna (Utrecht University); RIJAL, Ashim (Utrecht University); COBDEN, Laura (Utrecht University)

Orateur: Prof. DEUSS, Arwen (Utrecht University)

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