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Mantle Convection Models Constrained by Seismic Tomography

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Although available three dimensional models of the lateral heterogeneity of the mantle, based upon the latest advances in seismic tomographic imaging (e.g. Ritsema et al. 2004, JGR, vol.109, B02302) have provided profound insights into aspects of the mantle general circulation that drives continental drift, the compatibility of the tomography with explicit models of mantle mixing has remained illusive. For example, it remains a significant issue as to whether hydrodynamic models of the mixing process alone are able to reconcile the observed detailed pattern of surface plate velocities or whether explicit account must be taken of elastic fracture processes to account for the observed equipartition of kinetic energy between the poloidal and toroidal components of the surface velocity pattern (e.g. Forte and Peltier, 1987, JGR, vol.92, p3645). It is also an issue as to the significance of the role of mantle chemical heterogeneity in determining the buoyancy distribution that drives mantle flow, especially given the expected importance of the spin transition of iron that onsets in the mid-lower mantle, at least in the ferropericlase component of the mineralogy.

In this paper we focus upon the application of data assimilation techniques to the development of a model of mantle mixing that is consistent with a modern three dimensional tomography based model of seismic body wave heterogeneity. Beginning with the simplest possible scenario, that chemical heterogeneity is irrelevant to first order, we employ a three dimensional version of the recently published control volume based convection model of Shahnas and Peltier (2010, JGR, vol.115, B11408) as the basis for the assimilation of a three dimensional density field inferred from our preferred tomography model (Ritsema et al. 2004, JGR, vol.109, B02302). The convection model fully incorporates the dynamical influence of the Olivine-Spinel and Spinel-Perovskite+Magnesiowustite solid-solid phase transformations that bracket the mantle transition zone as well as the recently discovered Perovskite-post-Perovskite transition (Murakami et al, 2004, Science, vol.304, p855) that appears to define the D" layer at the base of the mantle. In this initial phase of what will be a longer term project we are assuming that the internal mantle viscosity structure is spherically symmetric and compatible with the recent inferences of Peltier and Drummond (2010, Geophys. Res. Lett., vol.37, L12304) based upon glacial isostatic adjustment and Earth rotation constraints.

The internal density structure inferred from the tomography model is assimilated into the convection model by continuously "nudging" the modification to the input density structure predicted by the convection model back towards the tomographic constraint at the long wavelengths that the tomography specifically resolves, leaving the shorter wavelength structure free to evolve, essentially "slaved" to the large scale structure. We focus upon the ability of the nudged model to explain observed plate velocities, including both their poloidal (divergence related) and toroidal (strike slip fault related) components.