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The Effects of Chemically Distinct LLSVPs on the Geoid: the Results from Both 3-D Thermochemical Convection and Seismically Constrained Instantaneous Flow Models

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The long-wavelength geoid anomalies provide important constraints on mantle dynamics and mantle viscosity structure. Hager and Ricard and their colleagues successfully reproduced the observed geoid using seismically imaged mantle structure as buoyancy force in an isochemical, whole mantle convection model. However, it has been generally agreed that the seismically observed large low shear velocity provinces (LLSVPs) underneath the Pacific and the Africa in the lower mantle are chemically distinct and likely more dense than the ambient mantle. In this study, we investigate how chemically distinct LLSVPs or chemical piles affect the geoid using both time-dependent thermochemical convection model and instantaneous flow model driven by buoyancy derived from seismic models. First, by conducting a series of 3D spherical thermochemical convection calculations, we found that the chemically dense piles above the CMB have a compensation effect on the geoid, and as a result, the total geoid is only controlled by the upper $\sim$1600 km of the mantle. Second, we use buoyancy structure derived from seismic models (e.g., Smean and other models) to study whether the observed geoid can be reproduced by considering the compensation effects of the LLSVPs. The geoid modeling requires a viscosity profile and a seismic velocity to density scaling f. We define a four-layer viscosity model with viscosities for lithosphere, the upper mantle, the transition zone, and the lower mantle . With a fixed non-dimensional lithospheric viscosity at 20, we compute the geoid and search for other three viscosity parameters and scaling parameter f that lead to the maximum variance reduction for the geoid. For the whole mantle, isochemical model, the best model with variance reduction of $\sim$71% for degrees 2-9 has viscosities of 0.5, 0.5, and 35, for the upper mantle, transition zone, and lower mantle, respectively, and the scaling f is 0.24. For the thermochemical model with the bottom 1000 km of structure removed, the best model has a viscosity profile of 20, 0.5, 0.5, 30 for the four layers from the top to the bottom, respectively, and the scaling f is 0.36. This shows that, compared with the isochemical model, a model with chemically distinct LLSVPs requires a larger seismic velocity to density scaling but similar viscosity structures, in order to reproduce the observed geoid.