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Probing asthenospheric density, temperature and elastic moduli below western United States

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Ocean tides are a well-known phenomena resulting from periodic variations in the gravitational attraction of the Sun and the Moon. The Earth's response to ocean tidal loads (OTL) is controlled by internal variations of density and elastic parameters. In principle, observations of the Earth's OTL response can be used to constrain our models of Earth's internal structure. Tidally-related displacements on the surface of the Earth consist of two primary components, solid Earth body tides (SEBT) and the OTL response. SEBT are characterized by sub-meter amplitude and very long wavelength (tens of thousands kilometers and longer). SEBT are relatively insensitive to spatial variations in elastic structure, with less than one millimeter of variation. Hence, we consider SEBT as sufficiently known, and remove an a priori model of SEBT from our observations. In contrast, the OTL response has a richer spatial structure including power at regional length scales (a few hundred kilometers) with typical amplitudes on the centimeter scale. Although, the characteristic amplitude of the OTL response is smaller than SEBT, we show here that the sensitivity of the OTL response to reasonable variations in structure has amplitudes on the centimeter scale, an order of magnitude larger than for SEBT and within the range detectable using the global positioning system (GPS).

Large and dense GPS arrays have been deployed around the globe to improve the spatial-resolution of Earth's surface strain field. Measurement of the OTL response with GPS has dramatically improved in recent years, with an attainable measurement accuracy of better than 1 mm. OTL responses are reasonably well-predicted by global ocean tidal models, derived from assimilation of satellite altimetry and tide-gauge observations, and convolved with the elastic response of the Earth. In traditional GPS processing, these effects are modeled and removed from sub-daily GPS time series. Here, instead of modeling these offsets out, we estimate the OTL response directly from the data.

Using the OTL response as derived from GPS observations made throughout the western United States, we infer depth-dependent material property variations in the mantle down to about 350-km-depth. Seismologists are already adept at producing shear wave velocity (Vs) and compressional wave velocity (Vp) models. For the crust and uppermost mantle, these models are relatively insensitive to density. Typically, estimates of density and elastic moduli for Earth's interior are obtained by combining and/or scaling Vs and Vp models. This conversion step is fraught with uncertainty as to how to scale the inferred seismic velocities to account for both thermal and chemical effects. In contrast, by considering the spatial variation of the horizontal and vertical response (amplitude and phase) to OTL, we can independently constrain the depth-dependence of density and elastic moduli. Such an ability to constrain density variations in the Earth's interior is essential to our understanding of mantle convection and evolution of the overlying tectonic plates.

We present the first depth-dependent model for the crust and upper-most mantle that constrains independently density and elastic moduli below the western United States and nearby off shore regions. This model is unique since it is the first to be derived solely from geodetic observations of surface displacements induced by ocean tidal loads. Our observations require strong gradients in both density and elastic shear moduli at the top and bottom of the asthenosphere but no discrete structural discontinuity at 220 km depth. We find that at least regionally, there is a low-density anomaly in the asthenosphere of about 50 kg/m^3, corresponding to a temperature anomaly of about 300 C. Such a temperature anomaly can also explain differences in inferred elastic structure relative to globally averaged radial seismic models.

Keywords: ocean tidal loads, density, temperature, elastic moduli, asthenosphere, GPS