Geophysical Research Abstracts
Vol. 20, EGU2018-9066, 2018
EGU General Assembly 2018

Surface Deformation Induced by Annual Loads and Kinetics of Mantle Phase Transformations

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Hydrological loads at the Earth's surface induce pressure variations down to the mantle transition zone. The structure of this particular zone consists of smooth velocity variations, caused by pyroxene-garnet-perovskite phase transitions, punctuated by discontinuities at 410, 520 and 660km, related to sharp olivine-wadsleyite-ringwoodite-perovskite phase transformations. The response of these mineralogical transformations to pressure variations induced by surface loading is unknown. However, in regions with a two-phase equilibrium, where high and low-pressure phases coexist, we expect the induced pressure variations to disrupt the equilibrium, inducing re-equilibration processes and volume changes.

Using an Earth model including the possible occurrence of mantle phase transitions, we show that the phase transformations involving olivine and its polymorph lead to limited phase re-equilibration under surface loading except if the effective viscosity in the narrow zone of phase equilibrium is very low. On the other hand, we estimate that the broad phase transitions involving pyroxene and its polymorphs, could induce up to 3 times the horizontal and 1.15 times the vertical surface displacements predicted by a purely elastic Earth model undergoing long wavelengths loading.

By comparing our models results to a set of over a thousand of globally distributed GNSS site position time series from the IGS repro2 solutions, we show that the observed displacements at the Earth's surface are close to the ones predicted for an elastic Earth. We detect no significant phase shift between the signal observed and that predicted for an elastic Earth under loads derived from GRACE. However, the best fit to the geodetic observations is achieved when the amplitude of the horizontal displacements is increased by 10%, suggesting the potential but very partial occurrence of re-equilibration occurring with a time-scale smaller than a year.