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Displacements induced by seasonal temperature variations on an elastic Earth with realistic mechanical properties and degree one deformation

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Seasonal GNSS station position time series are affected not only by atmospheric, non-tidal oceanic and hydrological loads but also by thermoelastic effects. The horizontal and vertical displacement fields induced by seasonal temperature variations can be viewed as the sum of two components: (1) a mostly vertical 'shallow component', due directly to the thermal expansion of the few meters below the surface, and of the antenna, and (2) a 'deep component' generated by the stress perturbations induced at depth.

We show that horizontal displacements associated with the 'deep component' are proportional to the Young modulus in the topmost meters of the Earth's surface E_{surf} times the Love number $l^{'''}$ equal to $3/(2n+1)(l''n(n+1)/2 + l' - l)$. For the low spherical harmonics degree, it is therefore proportional to the ratio of E_{surf} over a Young modulus characteristic of the deep mantle.

While large wavelengths horizontal displacements could be of the order of 1 mm for a uniform elastic Earth, they are predicted to reach a maximum amplitude of 0.2 mm for a more realistic spherical and layered elastic Earth based on PREM, with an external layer of unaltered granite outcropping everywhere on the continents. Horizontal displacements induced by seasonal temperature variations would be even smaller for a more realistic soil covered Earth, with a maximum amplitude of 0.01 mm. Thus, thermoelastic deformation is unlikely to contribute to low degree horizontal GNSS observations. Similarly, for low degrees, vertical motion due to deep deformation is proportional to E_{surf} times the Love number $h^{'''}$ and is predicted to be less than 0.1 mm for a realistic Earth.

We conclude that the low degree displacements due to thermoelasticity are generated by the 'shallow component' and are only significant for the vertical component. However, at a more regional scale (e.g. at higher spherical harmonic degrees), millimetric horizontal deformation arise at the rim of outcrops with large elastic moduli (granite, sandstone...) and induces stress variations of the order of 10 kPa at a few km depth.

Additionally, in a 'Center of Mass of the Solid Earth' reference frame, seasonal thermoelasticity generates degree one vertical motions of a millimetric amplitude and thus a measurable degree-1 deformation of the Earth. Therefore, the seasonal degree-1 deformation derived from GNSS time-series cannot be used to infer degree one loads without appropriate thermoelastic corrections. Using 689 globally distributed continuous Global Navigation Satellite System (GNSS), and correcting for the spherical harmonic degree l>2 loads derived from GRACE, we separate the degree-1 deformation deduced from GPS data into two components found to be of similar magnitude: one related to surface loading and one of thermoelastic origin.