Predictions and observations of Earth's surface deformation for a 3D viscoelastic Earth's model

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The deformational properties of a terrestrial planet in response to forcing depend on the time-scales of the forcing ranging from a few hours for tides to month or years for post-seismic deformation and present-day ice melting, to tens of thousands of years for glacial isostatic adjustment (GIA), millions of years for long-term tectonic and mantle convection. At short time-scales, the mantle responds as a pure elastic body, at intermediate time-scales, it displays a viscoelastic behavior while at long time-scales the deformation becomes purely viscous.

The equations of motion are usually solved with the assumption of spherical symmetry in elasticity and viscosity structure with 1D radial dependence. Deformational response of the Earth's to forcing is then expressed as a function of the so-called Love numbers (radial impulse response of the Earth) that can be computed by a numerical integration approach using propagator matrices for instance. However the Earth's interior possesses large heterogeneities, the largest being its ellipsoidal flattening. When we consider an Earth's mantle with fully 3D elastic and viscosity structures, the equations of motion must be solved with specific techniques. When lateral perturbations in elastic properties are weak, perturbation methods can be used as for seismic wave propagation (e.g. Dahlen & Tromp 1998) and tidal deformation (e.g., Métivier et al. 2005, Lau et al. 2017). However, because of large lateral heterogeneities in the mantle due to the presence of plumes and slabs for instance, mantle viscosity may vary by several orders of magnitude due to its strong dependence on temperature. Numerical methods are then preferred. A finite element-modeling package, the CitcomSVE package, was recently developed to solve load-induced viscoelastic deformation problems in a 3D spherical shell, a spherical wedge or Cartesian domain. CitcomSVE works for 3D viscoelastic mantle structure with either linear or non-linear viscosity (Zhong et al. 2022). The CitcomSVE package is publicly available. It has proven to be highly accurate and efficient for modeling GIA and tidal loading problems (Zhong et al. 2022) and achieves second order accuracy in spatial resolution, which may be determinant in area of large spatial heterogeneities.

The present PhD subject aims at implementing the CitcomSVE package for application to tidal loading and surface loading processes due to fluid layers (atmosphere, oceans, hydrology, and ice sheets). Predictions of loading with CitcomSVE will be compared with predictions from the traditional 1D viscoelastic Love number approach (Michel & Boy 2022). Geodetic and gravimetric observations will then be analyzed and compared with the 3D viscoelastic predictions for some widely used rheologies (like Maxwell, Burgers and Andrade) (Andrade 1910).

A special attention will be paid to the polar regions where present-day ice melting is superimposed to GIA due to the delayed response to past ice melting after the last glacial maximum and the little ice age.

Finally, we will infer some constraints on the mantle density using worldwide body tide observations. One application might be the revisit of the empirical tidal models in the IERS Conventions (Petit and Luzum, 2010), an international standard widely used in the geodetic community.

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