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Coupling mantle convection and tidal dissipation: applications to Enceladus and Earth-like planets

Marie Behounkova (1), Gabriel Tobie (2), Gael Choblet (2), and Ondrej Cadek (1)

(1) Charles University, Department of Geophysics, Prague, Czech Republic (behounek@karel.troja.mff.cuni.cz), (2) Universite de Nantes, Nantes Atlantique Universites, CNRS, Laboratoire de Planetologie et Geodynamique, UMR 6112

Anelastic dissipation of tidal forces is often proposed to significantly contribute to the thermal budget of several satellites of giant planets and Earth-like planets closely orbiting other stars. In order to address how tidal heating influences the thermal evolution of such bodies, we develop a new numerical tool that solves simultaneously mantle convection and tidal dissipation in a three-dimensional spherical geometry. Since both processes occur at different time scales, we propose a model where tidal dissipation averaged over a forcing period is included as a volumetric heat source for mantle dynamics. In the case of the long-term flow, a purely viscous material is considered. Numerical approach employing a grid-based method Choblet et al. (2007) efficiently solving viscous flow with large lateral viscosity variations is used. For tidal visco-elastic deformations, a Maxwell-like formalism where effective viscosity is introduced in order to reproduce observed dissipation function is employed. This problem is treated in the time domain and uses a combined spectral and grid-based spatial discretization (Tobie et al. 2008). Since both mechanisms are associated to strongly temperature dependent rheological properties, the coupling is achieved via the temperature field.

We apply this model to two examples: Enceladus and an Earth-like planet. In both cases, the tidal dissipation focuses in the polar regions owing to the presence of a liquid layer at the base of the mantle. As a consequence, hot upwellings tend to concentrate at high latitudes whereas cold downwellings are mostly located in the equatorial region. In the case of Enceladus, we demonstrate that tidal stresses calculated with our new 3D method are strongly reduced in hot upwellings when compared with classical methods based on radially layered interior models. As a consequence, the classical methods could overestimate tidal dissipation locally by a factor of 2 which can lead to a final difference of more than 30% in the global power. In our calculations heat flux at the base of Enceladus' ice shell is strongly reduced at the poles, thus favoring the preservation of a liquid reservoir at depth. For Earth-like planets, tidal dissipation patterns are predicted for different orbital configurations. The obtained results suggest that an energy equilibrium can be found for a relatively narrow interval of orbiting periods and thermal runaway is observed for orbital periods smaller than a critical value (e.g. 30 days for an eccentricity of 0.2 and 3:2 resonance). This is likely to promote large scale melting of the mantle and Io-like volcanism.