Geophysical Research Abstracts
Vol. 19, EGU2017-16357, 2017
EGU General Assembly 2017

Tidal deformation of Enceladus' ice shell with variable thickness and Maxwell rheology

Ondrej Soucek (1), Marie Behounkova (2), Ondrej Cadek (2), Gabriel Tobie (3), and Gael Choblet (3)

(1) Charles University, Mathematical Institute, Prague, Czech Republic (soucek@karel.troja.mff.cuni.cz), (2) Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic, (3) Laboratoire de Planétologie et Géodynamique, UMR-CNRS 6112, Université de Nantes, France.

Tidal deformation of icy moons has been traditionally studied using the spectral approach which is very efficient for perfectly spherical bodies with radially dependent rheological structure. Measurements of Enceladus' topography (Nimmo et al., 2011) and low-degree gravity (Iess et al., 2014) indicate that the ice shell is significantly thinned in the southern hemisphere (Iess et al., 2014; McKinnon, 2015) and according to recent gravity, shape and libration inversion, it may be only a few kilometers thick at the south pole (Cadek et al., 2016). These variations may potentially have a significant effect on the amplitude and pattern of tidal deformation, stress and associated heating inside the shell, but cannot be straightforwardly incorporated into the existing spectral codes. In order to circumvent this difficulty and to quantify the effects of ice-shell thickness variations, we have developed a three-dimensional finite element code in the framework of FEniCS package (Alnaes et al., 2015). Using this numerical tool, we address the changes in tidally-induced deformation amplitude, stresses and tidal heating for structural models of Enceladus' ice shell of various complexity. Considering Maxwell viscoelastic rheology of the shell, we compare models with uniform thickness consistent with the libration data and with constant viscosity, synthetic models with analytically parameterized thinning in the south polar region and depth-dependent viscosity varying over several orders of magnitude, and finally, models with the shell topography and thickness based on the recent model of Cadek et al. (2016). We find that the thinning of the ice shell around the south pole may lead to amplification of the stress and displacement in this region region by a factor of up to 2 and 4, respectively, depending on the average ice shell thickness, the amplitude of thinning and the viscosity structure. Our results also suggest that lateral variations of ice thickness can induce significant anomalies of the surface heat flux and, together with other effects (e.g. Souček et al., 2016), may thus contribute to the hemispheric dichotomy observed on Enceladus.

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