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Topographic coupling at core-mantle boundary in rotation and orientation changes of planets

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Abstract

We have computed coupling mechanisms at the core-mantle boundaries of terrestrial bodies of the Solar system, and in particular, the pressure torque acting on the topography at the core-mantle boundary. The CMB topography is usually considered to have as a smooth spherical or elliptical shape, while in reality it is bumpy (bumps and valleys at the km-level). The additional torque induced by the topography can be computed from the consideration of an incremental core flow at the CMB with respect to the global rotation considered when Length-of-day changes are computed or with respect to the Poincare fluid motion considered when the nutations are considered. The additional inertial pressure and the incremental torque can be expressed as a function of the coefficients of the development of the core-mantle-boundary topography in spherical harmonics. We follow the philosophy of the computation of Wu and Wahr [1], which allows to solve for the velocity field coefficients in terms of the topography coefficients using a decomposition of the equations into two parts and global boundary conditions.

We have found that there are particular topography coefficients that are enhanced due to resonance effects with inertial waves that appear in the incremental flux. This is important as the total torque is thus shown to be dependent on the geometry of the boundary, enhancing some of the topography coefficients of the topography. This was previously shown with an example in Wu and Wahr, but using numerical values it was not possible to detect whether the enhancements were due to the topography amplitudes themselves or to some other resonance effects. Here we show that this is not an artifact from the choice of the topography but rather a general fact for some of the frequencies close to inertial wave resonance frequencies. However, for frequencies far from the inertial wave frequencies, it might be related to the amplitudes of the topographies as well.

1. Introduction

Nutations of a terrestrial body, i.e. periodic variations of the orientation of the rotation axis in space, length-of-day (LOD) variations, and librations, i.e. oscillating motions in space, are not only related to the external forcing or even to particular geometrical relative positions of celestial bodies but as well to the interior of the terrestrial planet or moon of the Solar system. The observation of nutations, librations, and LOD variations provide information on their interior structure. It is thus of highest importance to model these observations based on an internal structure and compare the calculation output.

The physical state of the core is one of the most important ingredient of interpretation of possible observation. The coupling mechanisms at the core-mantle boundary (CMB) are the only way to transfer angular momentum from the core to the mantle and thus to change the orientation and rotation of the terrestrial body that we are studying.

There are several coupling mechanisms [2][3] that can be considered:

1. The topographic torque due to the rotation and pressure on the CMB topography (which may deform the boundary as well);
2. The viscous torque due to the viscosity of the liquid core;
3. The gravitational torque due to the gravitational interactions between the core and the mantle (and possibly between the outer core and the inner core, and the inner core and the mantle);
4. The electromagnetic torque due to resistance of the stretching of the magnetic field at the boundaries.

The relative importance of these coupling mechanisms is related to the terrestrial body itself. For the Earth we know for instance that the existence of an elliptical liquid core (gravitational torque and pressure torque acting on the elliptical boundary) in a deformable mantle is of high importance for the annual nutations. The electromagnetic torque may be important in planetary object possessing a magnetic field.

We shall revise the relative importance of the coupling mechanisms in the terrestrial bodies, with a particular emphasis on the topographic coupling.

2. Topographic coupling

We have computed the fluid pressure torque on the topography at the core-mantle boundary. This torque can be decomposed into three parts: (1) the constant part of the torque at equilibrium (without additional mantle and core rotations; this part is not computed in our context as this is part of the well-documented general theory), (2) the torque due to the inertial rotation pressure on the flattened core-mantle boundary related to the Poincare part of the fluid or to its global rotation, and (3) the torque due to the inertial rotation pressure on the topography related to the Poincare part of the fluid or to its global rotation. The incremental torque (4) and fluid pressure related to the incremental flux with respect to the global rotation/nutation can be considered too. The two last parts of the total torque involve the coefficients of the development of the topography in harmonics with respect to a hydrostatic equilibrium shape. Only these two last parts are of importance when computing the effects of a perturbing potential and the related additional rotations for the core and the mantle.

The philosophy of the computation follows Wu and Wahr [1] and consists in separating the core flow into two components, (1) the classical core flow for rotation or nutation of an elliptical Earth and (2) an incremental flow induced by the existence of a topography at core-mantle boundary, in introducing a scalar function in the Navier-Stokes equation for the description of the incremental fluid motion in the core, and in separating the Navier-Stokes equations into two equations of which the solutions can be expressed analytically. With the choice for one of the velocity field to be the Poincare flow in the nutation case and a global rotation in the length-of-day case [3], one consider as well the approximation that both parts of the velocity field are incompressible. The boundary conditions at the CMB are imposed on the total velocity and yield thus an additional important relation involving the analytical expressions of the velocity fields and the topography coefficients. This allows to solve for the velocity field coefficients in terms of the topography coefficients [2][3].

We have found [2][3] that there are particular topography coefficients that are enhanced due to the cross-coupling between different spherical harmonics. The resonance effects depend on the frequency of the forcing. This is important as the total torque is thus shown to be dependent on the geometry and on particular amplitudes of the topography, if the forcing frequencies are close to a resonance frequency. This was previously shown with an example in Wu and Wahr [1], but here we show that this is not an artifact from the choice of the topography but rather a general fact.

In addition to computation with application to nutations, we apply the computations on the length-of-day variations. This becomes very important in view of its application to the librations (periodic changes in the rotation) of other planets and moons of our solar system.

References

[1] Wu, X., and Wahr, J.M.: Effects of non-hydrostatic core-mantle boundary topography and core dynamics on earth rotation, Geophys. J. Int., 128, 1, pp. 18-42, 1997.

[2] Dehant V., Folgueira, M., Puica M., Koot, L., Van Hoolst, T., and Trinh, A.: Next step in Earth interior modeling for nutation, in: Proc. Journées Systèmes de Référence Spatio-Temporels 2014, on ‘Scientific developments from highly accurate space-time reference systems’, invited talk, Observatoire de Paris, Paris, France, 16-18 September 2013, in press, 2014.

[3] Dehant, V., Folgueira, M., and Puica, M: Analytical computation of the effects of the core-mantle boundary topography on tidal length-of-day variations, in: Proc. Journées Systèmes de Référence spatio-temporels 2011, Vianna, Austria, 113-116., 2012.