EPSC Abstracts
Vol. 7 EPSC2012-65 2012
European Planetary Science Congress 2012

Coupling mechanisms at core-mantle boundary in rotation and orientation changes

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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 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 flux 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 follows 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 the 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 very 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.

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 our interpretation of the 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 that can be considered:

1. The topographic torque due to the rotation and pressure on the CMB topography (which may deform 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.

We shall revise the relative importance of the coupling mechanisms in the terrestrial bodies, with a particular emphasize 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 interesting in our context), (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 introducing a scalar function in the Navier-Stokes equation for the description of the fluid motion in the core and in separating it into two equations of which the solutions can be computed analytically. With the choice for one of the velocity field to be the Poincare fluid in the nutation case and a global rotation in the length-of-day case, 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.

We have found that there are particular topography coefficients that are enhanced due to the cross-coupling between different spherical harmonics. This is very important as the total torque is thus shown to be dependent on the geometry and on particular amplitudes of the topography. This was previously shown with an example in Wu and Wahr, 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.