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Modeling the polar motion of Titan

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Abstract

We study the influence of the presence of a global subsurface ocean and of tidal deformations on the polar motion of Titan forced by its atmosphere and lakes.

1. Introduction

Due to the presence of a global subsurface ocean under an ice shell, the rotation of the interior of Titan can differ from the rotation of its surface, leading to torques between the different layers (see for example [6] for the case of the length-of-day variations of Titan). Tidal deformations of the different layers of a satellite also affects its rotation and for example reduce the libration amplitude to values close to that of an entirely solid satellite [2, 3, 7]. We here study the changes in the orientation of the rotation axis with respect to the solid surface, or polar motion of Titan, and include the effects of a subsurface ocean and deformation.

2. Polar motion

2.1 Model

We assume that the internal layers of Titan are flattened due to rotation and tides. For each layer j, we can write the angular momentum equation in the Body Frame of that layer as

$$\frac{d\mathbf{L}_j}{dt} + \boldsymbol{\omega}_j \times \mathbf{L}_j = \boldsymbol{\Gamma}_j \qquad (1)$$

where $\mathbf{L_j}$ is the angular momentum of the jth layer (interior i or ice shell s), $\boldsymbol{\omega}_j$ is the rotational vector axis and $\boldsymbol{\Gamma}_j$ the total torque exerted on the j-th layer.

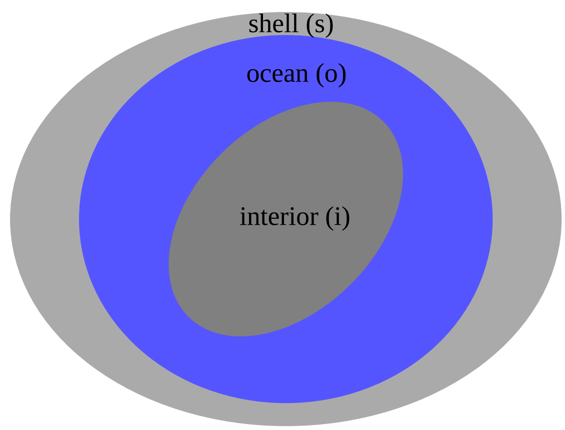

Figure 1: Schematic representation of the different orientations of the interior and the ice shell in the presence of a global subsurface ocean (not to scale).

In the Body Frame of the layer j of the satellite with equatorial axes x and y and polar axis z, the rotation vector $\boldsymbol{\omega}_j$ is written as $(\omega_{j,x}, \omega_{j,y}, \omega_{j,z})$ where $(\omega_{j,x}, \omega_{j,y})$ expresses the polar motion of Titan. Polar motion can then be extracted from the first two components of Eq.1 while the z-component gives the length-of-day variations of Titan.

The total torque $\boldsymbol{\Gamma}_j$ is the sum of the external gravitational torque exerted by Saturn, the gravitational torques acting between the different layers of Titan and the pressure torque exerted by the ocean on its bottom and top surfaces. The atmosphere and lakes of Titan also exert torques on the shell of Titan. These two torques are obtained from Atmospheric Angular Momentum data obtained from a Global Circulation Model of the atmosphere of Titan (from [5]) and the Oceanic Angular Momentum data (from [4]), respectively.

Averaging Eq. 1 over the forcing periods, the first two equations constitute an eigenvalue problem characterized by a free frequency, the Chandler wobble frequency. The Chandler wobble period is about 112 years. With a subsurface ocean, we obtain two free periods: while the first period is close to the free period for an entirely solid Titan, the second period largely decreases with decreasing ice shell thickness and can be as small as 4 years for thin ice shells. As the atmosphere dynamics of Titan presents periods smaller than one Saturnian year (29.42 years), we can expect resonant amplifications of the solution.

2.2 Results

For a solid Titan, the polar motion forced by its atmosphere follows an anticlockwise trajectory with a main period of 29.42 years and an amplitude of about 40 m in the x direction and 60 m in the y direction. Tidal deformations of Titan change the trajectory of the polar motion by no more than 5 m. The polar motion forced by the lakes of Titan is smaller than 1 mm and can therefore be neglected.

With a subsurface ocean and for large ice shell thickness (larger than 70 km), the polar motion forced by its atmosphere follows an anticlockwise trajectory with a main period of 29.42 years and an amplitude that can be several orders of magnitude larger than for a solid Titan (about 400 m in the x direction and 1000 m in the y direction for an ice shell thickness of 100 km). For ice shell thicknesses smaller than 70 km, the main period of the polar motion can differ from the annual period and its amplitude can reach several kilometers due to the resonance with the free period.

3 Conclusion

We have studied the polar motion of Titan forced by its atmosphere and lakes. For a solid Titan, the rotation axis of Titan follows an annual trajectory with an amplitude of 60 m on the surface of Titan. With a subsurface ocean, the polar motion amplitude can be increased by several orders of magnitude depending on the ice shell thickness. Tidal deformations of Titan induce a small modification of the trajectory of the polar motion.

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