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Measurement Methods for Ganymede's Librations from Laser Altimetry Observations

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Abstract

We investigate the potential for the Ganymede Laser Altimeter (GALA) on board the JUICE (JUpiter ICy moons Explorer) mission to measure the tidal deformations and the rotational state of Ganymede, in particular physical librations. A subsurface ocean would cause the upper ice shell to librate decoupled from its interior. Two distinct iterative least-squares inversion routines have been implemented to estimate simultaneously for the topography, the orientation of the rotation pole, the mean rotation and the libration amplitudes and tidal deformations using synthetic laser altimetry data. We follow the approach of a global expansion of spherical harmonics and as a second method the parametrization in 2D B-splines. Results indicate that a global ocean could only be found for a very thin ice shell thickness, if the ice shell is elastic and fully decoupled of the interior. However, to prove the non-existence of an ocean is difficult due to small libration amplitudes and their possibly ambiguous interpretation. In this case independent observations, such as the Love numbers, provide more unique constraints on the interior structure.

1. Introduction

The Ganymede Laser Altimeter [1] is one of the scientific instruments selected for the JUICE mission by the European Space Agency (ESA) [2]. JUICE is scheduled for launch in 2022 and expected to enter Ganymede's orbit in 2033. The laser is a 17 mJ laser and is nominally operated at 30 Hz. During the 132 days of in-orbit operation GALA aims at measuring the global topography of the moon, the radial tidal deformations, the rotational state including physical librations, the roughness at footprint scale and the albedo at the laser wavelength of 1064 nm [3]. Previous work investigated the performance of the laser altimeter [4] and the perspectives to measure tidal deformations by using cross-over points [5]. In this work, we focus on the rotational state of Ganymede from laser altimetry data only. Of particular interest are the physical librations of Ganymede, since their amplitude depends on the interior structure of the satellite. If the shell is decoupled by a global ocean and if it is assumed to be rigid, then the libration amplitude can reveal the ice shell thickness and density [6]. This comes with the caveat that models by Van Hoolst et al. (2013) [7] including elastic effects and additional pressure and gravitational coupling of the surface and interior, show that the libration amplitude can be significantly decreased in the presence of tides.

2. Methods

We investigate two different methods. Method I is a classical least squares inversion based on a spherical harmonics expansion of the global topography and solves simultaneously for the topography itself as well as for the rotational state and the tidal Love number h_2. However, this method is computationally expensive as it requires that the expansion is performed to high degree and order to reduce the omission error [8]. We therefore also examine a second model where the topography is modeled by 2D B-splines on a rectangular grid [9, 10].

The values for the rotational state used in this work have been derived from the resonant rotation states assuming that the satellite occupies a Cassini state 1 with zero obliquity [11]. Furthermore, we assume that the free precession period is much smaller than any periods in the orbit orientation variations. With these assumptions, the satellite's rotation axis is precisely following the instantaneous orientation of the orbital plane. This assumption is supported by the fact that amplitudes of very short variations of the orbital orientation are typically very small and can be neglected in practice.

Since Ganymede's global topography has not been mapped, a synthetic topography model has to be modelled in terms of spherical harmonics. To model realistic large terrain slopes real topography models and derived power laws of other celestial bodies are used.

3. Results

For the inversion based on a spherical harmonics expansion we find that the differences of the true and recovered libration amplitudes on the 7-day, 50-day, and 483-day period are highly dependent on the degree of the expansion. The root-mean-squared errors of the libration amplitudes show a strong hyperbolic decay with increasing inversion degree indicating that the accuracy of the spherical harmonics expansion is limited by the omission error. The method using B-splines on a rectangular grid has significant computational advantages over the spherical harmonic expansion but also shows some dependence on the grid resolutions. The amplitudes of the 7 days and 50 days libration periods are easier detectable than the 450 days period and a coupled analysis of the two lower periods increases the detectability of an ocean compared to the 7 days amplitude alone.

4. Conclusion

The precise knowledge of Ganymede's rotational state is a prerequisite for mapping and the definition of the reference frame of the satellite. We show that laser altimetry is a suitable method for this purpose. Measurement of Ganymede's libration can also enhance the constraints on the interior if the amplitudes are large. Ocean existence can be proved by the measurement of tidal deformations. This synergy of independent observation has a big potential to improve our understanding of icy satellites from the JUICE mission.

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