EPSC Abstracts
Vol. 10, EPSC2015-514, 2015
European Planetary Science Congress 2015

Estimation of Ganymede's Topography, Rotation and Tidal Deformation – a Study of Synthetic Ganymede Laser Altimeter Observations

T. Steinke (1,2), A. Stark (1), G. Steinbrügge (1), H. Hussmann (1), J. Oberst (1)
(1) German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, (teresa.steinke@dlr.de),
(2) Karlsruhe Institute of Technology (KIT), Institute of Geophysics, Karlsruhe, Germany

Abstract

We implement an iterative least-squares inversion routine to study the estimation of several dynamic Ganymede rotation parameters by laser altimetry. Based on spherical harmonic expansions of the global topography we use simulated Ganymede Laser Altimeter observations representing the synthetic topography of the satellite. Besides the static topography we determine the dynamical parameters, such as the rotation rate, the amplitudes of physical librations, the spin pole orientation, and the tidal deformation. This parameters may strengthen implications for a liquid ocean beneath Ganymede's icy shell and, in addition, constrain geodetic frame parameters essential for various space-borne experiments.

1. Introduction

A major task for characterizing the habitability of the outer solar system is the exploration of subsurface oceans of icy satellites. Time-variable torques cause the satellite to respond according to their interior. Recent studies suggest that the responses observed at the satellite's surface may reveal structural and rheological characteristics of materials beneath the surface ice. The European Space Agency (ESA) is preparing a mission to the Jovian system with its final destination Ganymede. JUICE (JUpiter ICy moons Explorer) will orbit the satellite by 2033. The on board Ganymede Laser Altimeter (GALA) will provide global and local topographic mapping of Ganymede's surface. Since limited coverage with stereo imaging will be available the simultaneous estimation of the topography, rotation state and response parameters of the surface using laser altimeter data will be of great benefit.

2. Method

First, the JUICE's ground track at longitude λ_i and latitude θ_i of Ganymede's fixed reference system is calculated for each time epoch t_i resulting in a globally distributed laser spot pattern concentrated in the polar regions. The applied rotation model for Ganymede is defined by three time-dependent angles: the right ascension $\alpha(t_i)$ and the declination $\delta(t_i)$ (both describing the position of the bodies north pole towards the celestial reference system) and the prime meridian $\omega(t_i)$. To model the complex time evolution of the Ganymede's resonant rotation state we use a series expansion (derived from the standard IAU [2] formulation) up to second order in t_i centred at the time of arrival of the spacecraft in Ganymede orbit. Additionally, we add k time-variable libration modes

$$\omega_{\text{lib}}(t_i) = \sum_k A_{\text{lib,k}} \sin(f_{\text{lib,k}} t_i + \phi_{\text{lib,k}}), \qquad (1)$$

to the ω angle, where $A_{\text{lib,k}}$, $f_{\text{lib,k}}$ and $\phi_{\text{lib,k}}$ are the libration modes' amplitudes, frequencies and phases. In the second step, GALA observations described by the radial distance $r_{\text{obs,i}}$ from Ganymede's center to its surface at JUICE's ground track are modelled by the equation

$$r_{\text{obs,i}} = \sum_{n=0}^{n_{\max}} \sum_{m=0}^{n} \overline{P_{\text{nm}}}(\theta_i)\{C_{\text{nm}} \cos m\lambda_i + S_{\text{nm}} \sin m\lambda_i\} + h_2 V_{\text{pot}}(\lambda_i, \theta_i, t_i). \qquad (2)$$

Here $\overline{P_{\text{nm}}}$ is the fully normalized associated Legendre function of degree n and order m. Based on the Kaula power law we generate random static topography coefficients C_{nm} and S_{nm} up to degree $n_{\max} = 200$ whereas the dynamic tidal deformation is calculated by the Love number h_2 and a known tidal potential $V_{\text{pot}}(\lambda_i, \theta_i, t_i)$. [1] simulated BepiColombo Laser Altimeter data for Mercury to solve for the spherical harmonic topography coefficients C_{nm} and S_{nm}, the Love number h_2 and the main libration amplitude A_{lib} for given phase and frequency. Here, in addition, we estimate the total rotation, including the orientation of the main spin axis and the rotation rate up to the considered second order. Since the simultaneous determination of rotation state and topography results in a highly non-linear inversion problem an iterative reduction of the misfit between the synthetic and estimated (obtained by updated starting values) observation vectors $r_{\text{obs,i}} - r_{\text{model,i}}$ is required. Due to polar and equatorial gaps of laser spots and a large degree of correlation we test regularisation of the normal matrix by a priori information and weighting techniques. In addition, the degree of the estimated spherical expansion is optimised to reduce the trade-off between cumulative error degree variances (commission error) and non-modelled remaining topography signal (omission error).

3. Results and Conclusion

We apply the inversion routine to several JUICE mission scenarios and observation errors (including orbit, pointing and instrument errors) and show the resulting measurement accuracy of the estimated parameters C_{nm}, S_{nm}, $A_{\text{lib,k}}$, h_2 and α, δ, ω up to the second order. While the determination of the orientation of the rotation pole, the rotation rate and short libration periods are promising, long periodic variations beyond the Ganymede orbit phase and the expected small quadratic terms of the rotation state may not be detectable.

References

[1] Koch, C., Christensen, U., Kallenbach, R.: Simultaneous determination of global topography, tidal Love number and libration amplitude of Mercury by laser altimetry. Planetary and Space Science, Vol. 56(9), pp. 1226-1237, 2008.

[2] Archinal, B.A., A'Hearn, M.F., Bowell, E., Conrad, A., Consolmagno, G.J., Courtin, R., Fukushima, T., Hestroffer, D., Hilton, J.L., Krasinsky G.A., Neumann, G., Oberst J., Seidelmann, P.K., Stooke, P., Tholen, D.J., Thomas, P.C., Williams, I.P.: Report of the IAU Working Group on cartographic coordinates and rotational elements: 2009. Celestial Mechanics and Dynamical Astronomy, Vol. 109(2), pp. 101-135, 2011.