Measuring Ganymede's tidal deformation by laser altimetry: Application to the GALA experiment

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Background

Measurements of Ganymede's induced magnetic field suggest a salty water layer under the icy crust [1]. However interior structure models consistent with Ganymede's moment of inertia and total mass cannot constrain the ice thickness or ocean depth. In order to reduce the ambiguity of the structural models, it has been proposed to measure the dynamic response of Ganymede's ice shell to tidal forces exerted by Jupiter characterized by the Love numbers h_2 and k_2. The h_2 value depends on the tidal frequency, the internal structure and the rheology, in particular on the presence of fluid layers and the thickness and rigidity of an overlaying ice shell. Combined with measurements of k_2, which can be inferred from radio science experiments, and a simultaneous determination of linear combinations of h_2 (laser altimetry) and k_2 (radio science) the obtained data would significantly reduce the ambiguity in structural models [2].

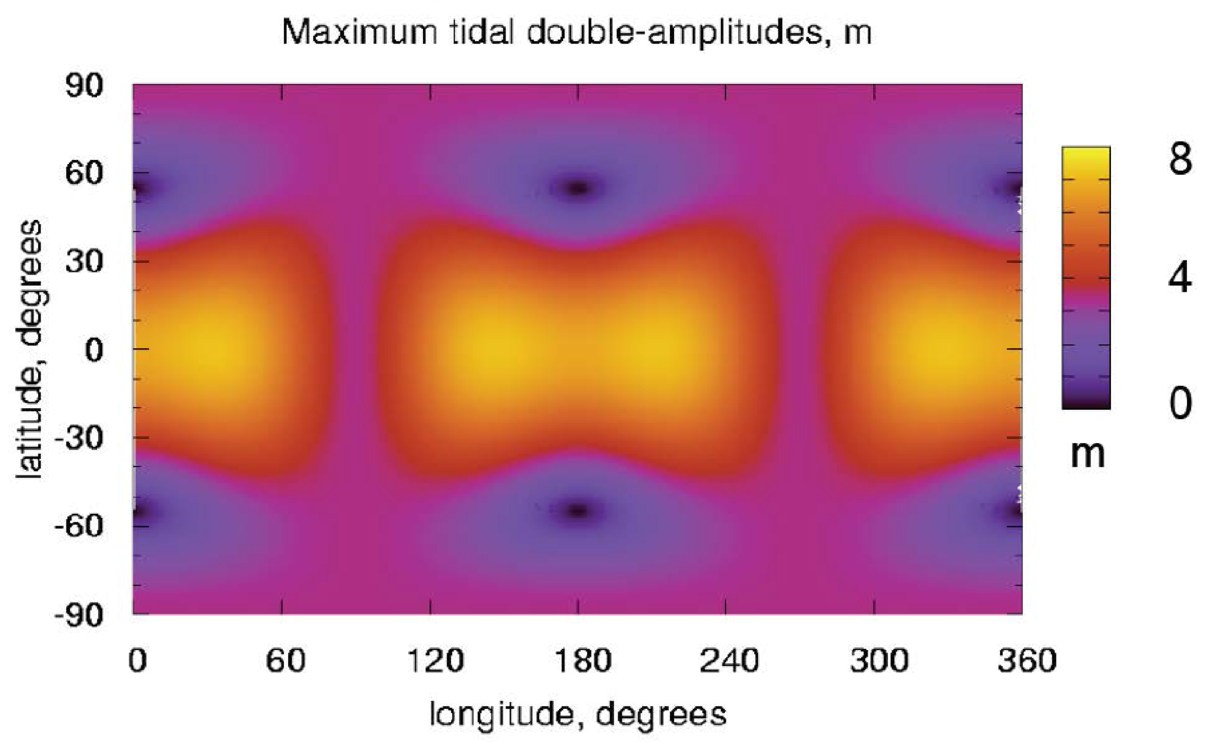
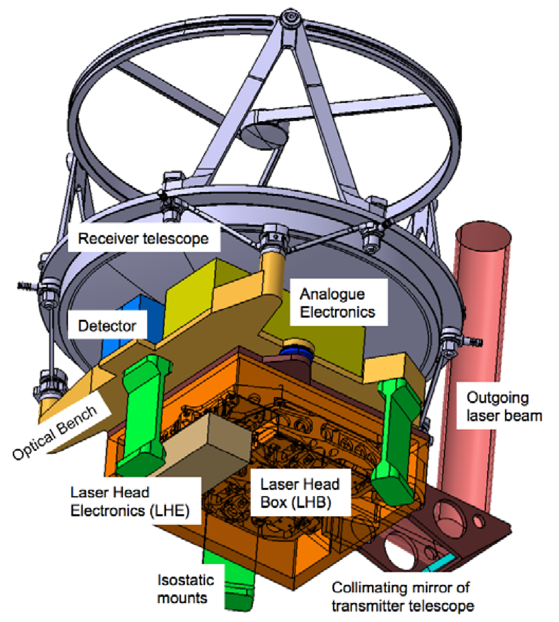


Figure 1: Maximal double amplitudes if an ocean is present.

The Instrument

The Ganymede Laser Altimeter (GALA) will perform globally distributed altitude measurements from a low circular 500 km and 200 km orbit. It contains a 17 and 2.8 mJ laser.



Methods

A way to determine tidal effects in Ganymede's topography and therefore the h_2 value by a spacecraft in orbit is the crossover method: Different orbit tracks will intersect at certain surface locations at different times so that the tidal signal can be extracted from a differential altimetry measurement.

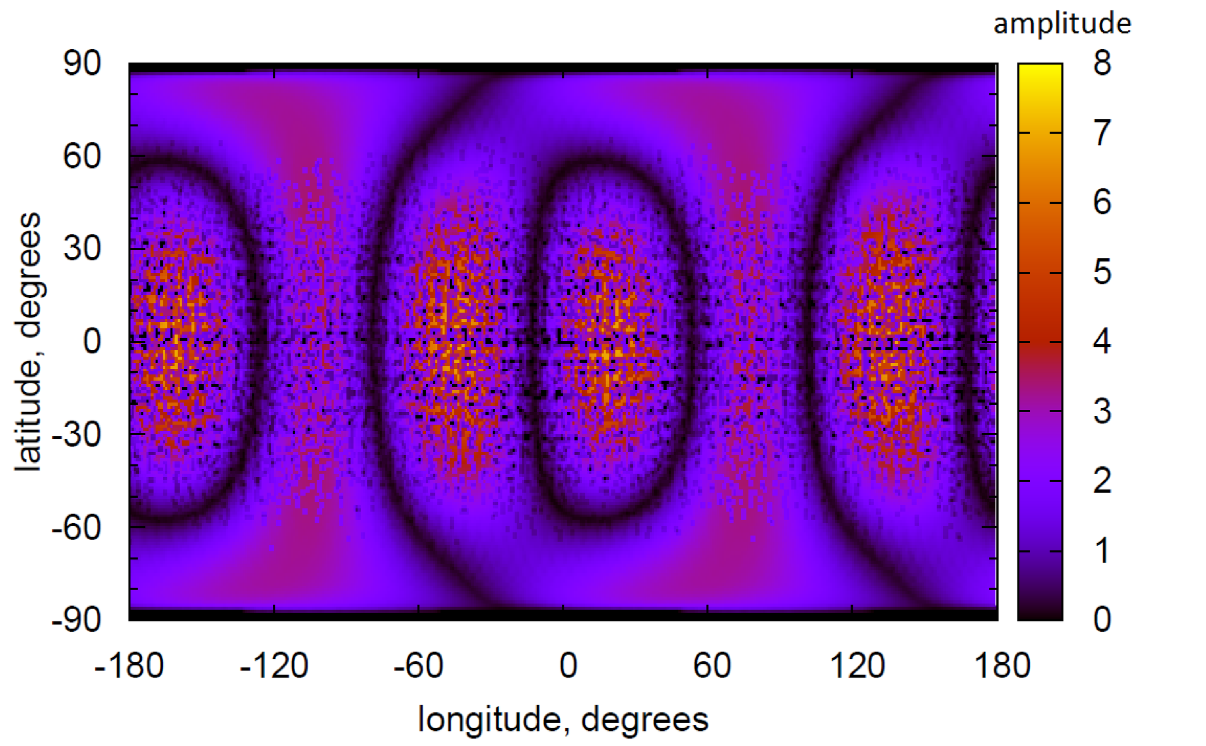
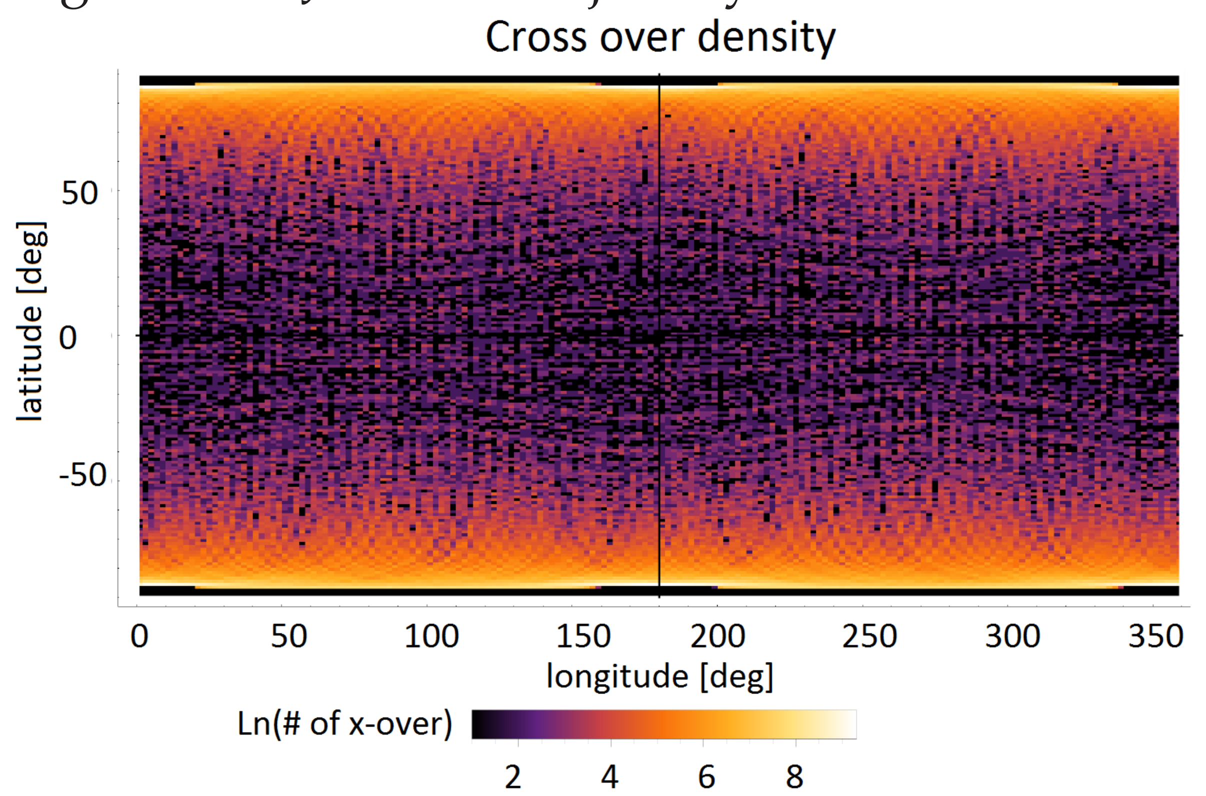


Figure 2: The map shows the maximal measurable tidal amplitudes in a grid with a resolution of 1° derived from the current JUICE orbit scenario.

The accuracy of the tidal measurement is dependent on the amount of cross-overs available for the analysis and therefore dependent on the mission and operational scenario. We consider the following possible operational scenarios:

- S1 GALA continuous operation except 8h per day reserved for downlink
- S2 GALA operating every third orbit - 8h reserved for downlink

Both scenarios have been analysed using the JUICE trajectory SPICE kernel.



Numerical Simulations

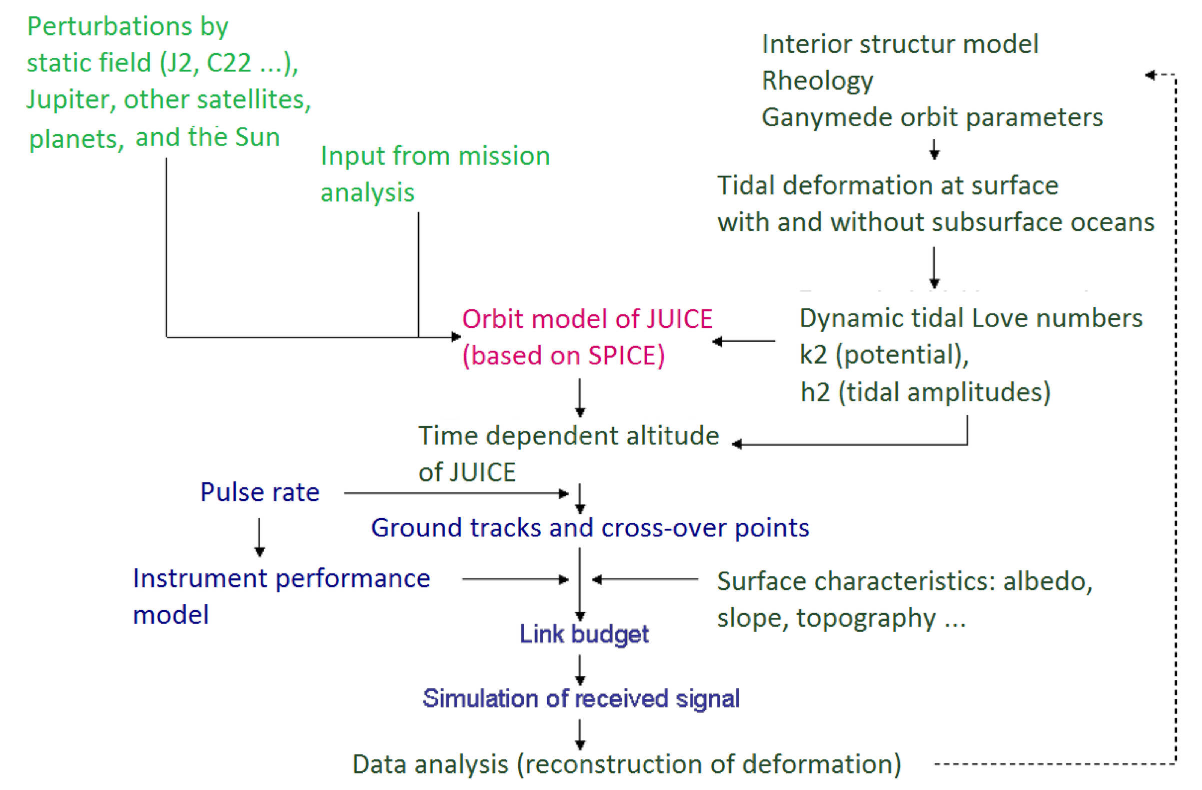


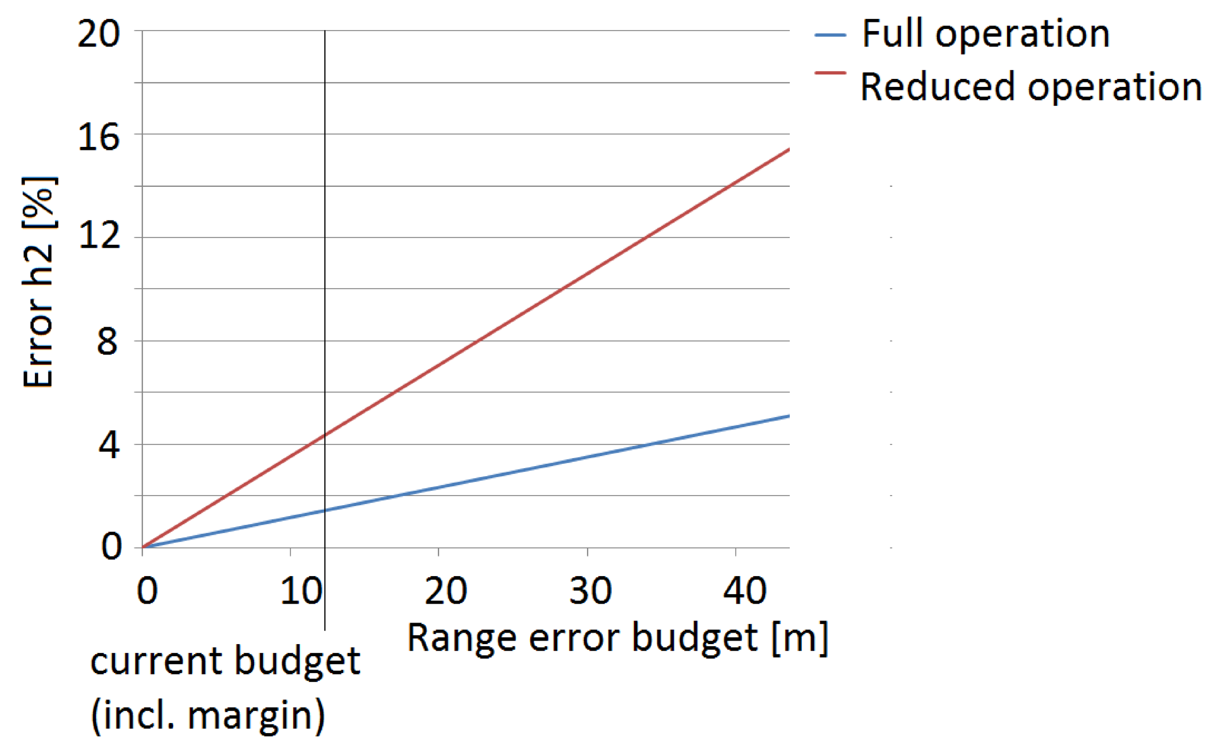
Figure 3: Flowchart of the numerical model

The environmental factors influencing the instrument accuracy are the altitude and the slope. Also orbit and pointing errors as well as interpolation errors between the cross-over points have to be taken into account. Since all measurement errors are of statistical nature, a consolidated statistical analysis is necessary. All single error components are evaluated for each individual shot. After averaging over all cross-over points the average error defines our mean measurement error.

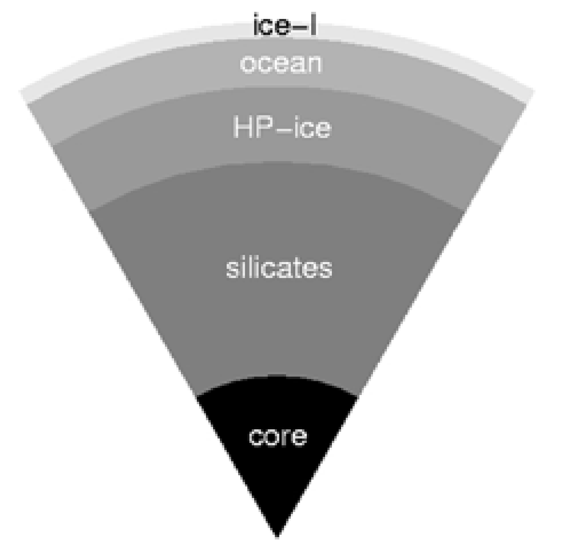
Results

For the full operation scenario S1, the estimated error of the h_2 value would be 1.3% while the reduced case S2 (every 3rd orbit) would give an error of 4.0%. For a typical value (e.g. $h_2 = 1.50$) as derived from models of the tidal response of Ganymede (compare Fig. 1) we get

$h_2 = 1.50 \pm 0.02$ for S1 and
$h_2 = 1.50 \pm 0.06$ for S2



Conclusions



We compared a set of interior models covering a large range of possible layer thicknesses and material properties but consistent with Ganymede's mass and moment of inertia to their h_2 and k_2 value. From the scatter and the predicted h_2 error one can estimate the constraints for the ice-I thickness as resulting from the tidal measurement.

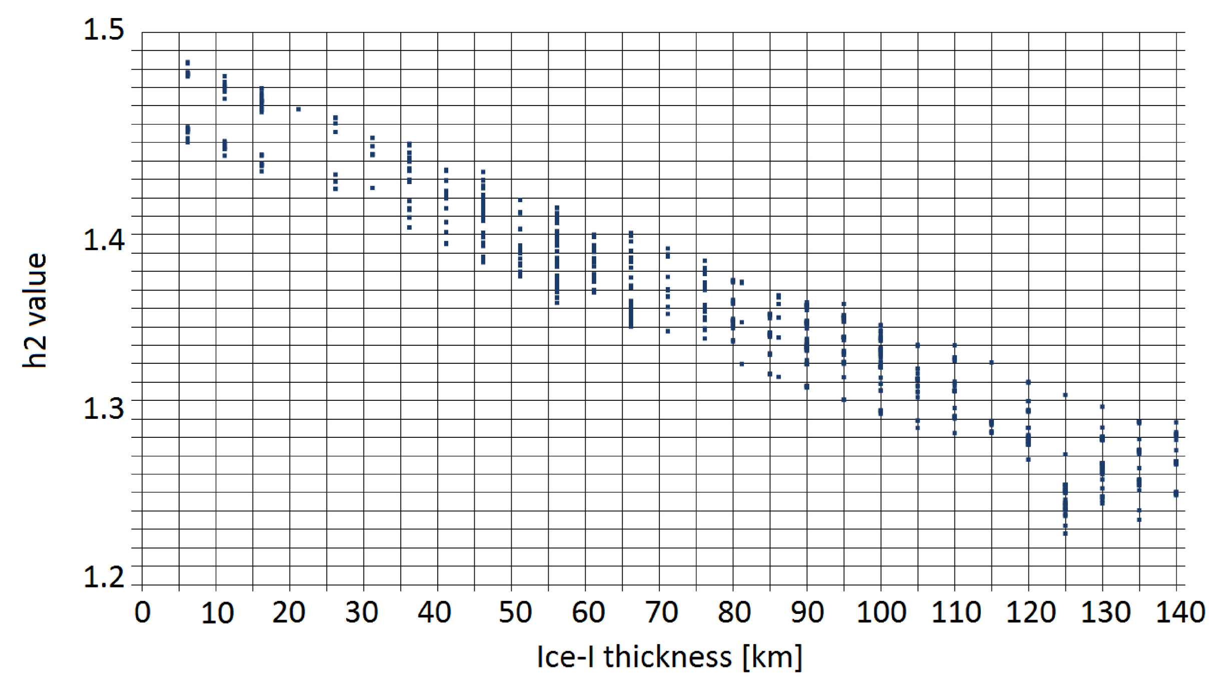


Figure 4: h_2 values of interior models in dependence of different ice thicknesses.

The measurement uncertainties of 1-4% are sufficiently small to unambiguously confirm the existence (or to prove the non-existence) of an ocean under Ganymede's ice shell. Further the thickness of the ice-I layer can be constrained by the h_2 value to an order of 10-20 km. Note that this constrain can be even further improved when using a linear combination of h_2 and k_2.

References and Contact

[1] M. Kivelson et al., The permanent and inductive magnetic moments of Ganymede, Icarus, 157, 507-522, 2002.
[2] J. Wahr et al.,Tides on Europa and the thickness of Europa's icy shell, Journal of geoph. research, vol 11, 2006.

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