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Expected insights on Mercury's interior from the BepiColombo Laser Altimeter

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Abstract

We simulate data of the BepiColombo Laser Altimeter (BELA) and investigate the retrieval accuracy for two parameters which pose constraints on Mercury's internal structure: the tidal Love number h_2 and the amplitude ϕ_0 of Mercury's 88-day libration. Periodic radial displacements of the surface due to solar tides have an amplitude of ~ 1 m at the equator. Mercury's eccentric orbit and asymmetric mass distribution cause its solid shell to librate at orbital frequency with an amplitude $\phi_0 \approx 39$ arcsec, equivalent to ~ 460 m at the equator. Both of these signals are contained in the laser altimetry data. In this study, we extract h_2 and ϕ_0 along with the global topography, parametrized as an expansion in 2D cubic B-spline basis functions. We show that a tighter constraint on the size of Mercury's liquid core and a detection of the inner solid core will be feasible.

1 Introduction

The h_2 tidal Love number describes the radial displacement of the surface due to the solar tides. Computing h_2 for interior structure models that match available observational constraints reveals that it is most strongly dependent on the size of a potential solid inner core [1]. However, the insufficient hemispherical coverage by the Mercury Laser Altimeter (MLA) aboard the Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) mission has so far prevented a successful measurement of h_2. Because of BepiColombo's near-polar orbit, the analysis of cross-overs of laser altimetry ground tracks is not promising for the retrieval of h_2 [2].
Mercury's 88-day libration amplitude ϕ_0 is directly related to the moment of inertia of its solid shell, and thereby the size of its fluid core. Previously, Stark et al. [3] used MESSENGER laser altimetry and stereo photogrammetry to determine $\phi_0 = 38.9 \pm 1.3$ arcsec. Additional constraints on both inner and outer core size from tidal Love number and 88-day libration amplitude would improve our understanding of Mercury's dynamo and its thermal history.

2 Method

We simulate the orbit of the Mercury Planetary Orbiter (MPO) by propagating an initial state considering Mercury's gravity field up to degree and order 50, tides, and solar radiation pressure. Measurements are taken whenever the range is 1050 km or less. They contain four sources of error:

1. A synthetically generated topography of Mercury follows a power law up to spherical harmonic degree and order 7999, equivalent to a spatial resolution of 478 m at the equator
2. Topography at even smaller scales and an instrument range error with 2 m standard deviation are modelled as Gaussian noise
3. Uncertainty in the attitude knowledge is modelled as a jitter with standard deviation of 2 arcsec and a 20 arcsec amplitude systematic effect correlated with spacecraft temperature
4. Perturbed orbits are propagated based on the spacecraft state covariance expected from multi-arc orbit determination

The tidal and librational signals are finally added using a-priori values for h_2 and ϕ_0.

An iterative least-squares fit solves the simulated measurements for h_2, ϕ_0, and the coefficients of 2D cubic B-spline basis functions which represent the topography on a global equirectangular grid. This is an improvement over a previous study which only used cubic B-splines in latitude direction [4].

3 Results and Discussion

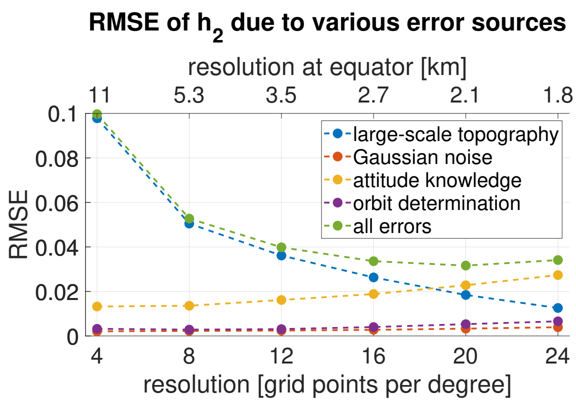

Figure 1: RMSE of h_2 as a function of the resolution of the topographic grid and contribution of each error source.

We generate 100 independent random realizations of the measurements for a nominal one-year mission. At first, we only simulate one error source at a time and do not include librations. For each random realization, a corresponding h_2 solution is computed using various grid resolutions of the topography. The resolutions range from 4 to 24 grid points per degree, equivalent to 10.6 km to 1.8 km at the equator, respectively. Computing the root-mean-square error (RMSE) of the h_2 solutions for each resolution and error source shows that for a higher resolution of the topographic grid, less topography remains unmodelled and contributes to the error (Fig. 1). The other error sources contribute more strongly for increasing resolution. The tradeoff between these two behaviors results in an optimum resolution at about 20 grid point per degree. The uncertainty in attitude knowledge is the dominant error source at higher resolutions.
In a second step, we also simulate librations and solve for h_2 and ϕ_0 at the optimal resolution. Through the addition of this additional parameter, the RMSE of h_2 increases from 0.032 to 0.083. The RMSE of ϕ_0 is 0.30 arcsec. We note that these retrieval accuracies are likely to be further improved by a one-year mission extension and successful range measurements from above 1050 km. Therefore, we expect that BELA measurements will pose valuable constraints on Mercury's interior structure and specifically the size of its outer and inner core.

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