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Retrieval of Mercury's h_2 from BepiColombo Laser Altimeter data

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Abstract

We simulate the measurements which will be carried out by the BepiColombo Laser Altimeter (BELA) and investigate whether spatial resolution and temporal coverage will be sufficient to retrieve the Love number h_2. The Sun's tidal potential causes periodic radial displacements of the surface with an amplitude of $\sim$ 2 m at the equator. This displacement is measured by laser altimetry. In this study, we extract it by solving simultaneously for the static global shape of Mercury and its variability in time in a least-squares adjustment. We parametrize the shape using 2D cubic splines as basis functions. Under nominal measuring conditions, we achieve a relative accuracy of 8.7% and 2.7% after 12 and 26 months, respectively.

1 Introduction

The tidal Love number h_2 describes the vertical tidal response of the solid body and can give constraints on the interior structure of Mercury, such as inner and outer core radius and core composition [4]. Therefore, it is an important input quantity for models of the magnetic dynamo and the thermal history. So far, h_2 could not be retrieved from Mercury Laser Altimeter (MLA) data which only cover the Northern hemisphere of Mercury. The shape data to be acquired by BELA from the year 2026 on will cover much more densely both the Northern and Southern hemisphere.
The h_2 Love number of the Moon has been retrieved by comparing intersecting ground tracks [3]. As the Mercury Planetary Orbiter (MPO) will carry BELA on a near-polar orbit, intersections will be mostly very close to the poles or at sharp angles, resulting in unfavorable geometries and low amplitudes of the displacement signal. In this study, we use a different method which does not use ground track crossovers, but takes all measurements into account to solve for the static and time-variable parts of the global shape simultaneously. We use 2D cubic splines as basis functions which is an advance over previous studies which only used cubic splines in longitude direction [2] .

2 Methods

We simulate the global shape of Mercury based on low-degree spherical harmonic coefficients derived from a photogrammetric digital elevation model [1]. These simulations are necessary to assess the uncertainty induced by a specific shape realization. We also simulate the orbit of MPO using the official premission trajectory models provided by ESA. Simulated measurements assume nominal instrument operation conditions and a priori values for the libration amplitude of Mercury and h_2.
The k-th shape measurement is then given by

$$T_k = T(\theta_k, \lambda_k + \Phi_{\text{lib}} f_{\text{lib}}(t_k)) + u_r(\theta_k, \lambda_k, t_k) + e_k \tag{1}$$

where θ_k, λ_k, t_k, and e_k are the co-latitude, longitude, time, and noise of the measurement, respectively. Φ_{lib} is the 88-day libration amplitude of Mercury and f_{lib} is a series expansion describing the librations. The radial tidal displacement is

$$u_r = h_2 \frac{V_2}{g} \tag{2}$$

where g is the gravitational attraction at the surface and V_2 is the second degree term of the dynamic tidal potential exerted by the Sun. In Eq. 1, T is the static global shape which is parametrized by a linear combination of 2D cubic spline functions. Each linear coefficient corresponds to a shape value on a global grid with N points. The coefficients are zero outside of the 16-neighborhood of the measurement in the grid, and higher the closer they are to the measurement location. The observation equation (Eq. 1) is solved for the N

coefficients of the basis functions, Φ_{lib}, and h_2 using non-linear least-squares and a direct sparse solver (Intel MKL PARDISO).

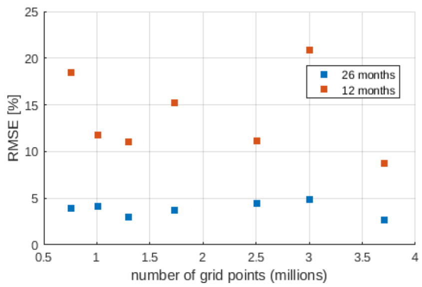

Figure 1: Dependence of the RMSE of h_2 on number of shape grid points N and the duration of the mission.

3 Results and Discussion

We compute solutions for different mission durations and different amounts of basis functions N. A large N corresponds to a high-resolution shape grid. For each combination of these two parameters, solutions are computed for different random realisations of the global shape and the noise to ensure a representative solution. The low-degree shape coefficients up to degree 50 are taken from the stereo-photogrammetric digital elevation model [1], the coefficients up to degree 1399 are simulated, and the power contained in the higher degrees is added to the nominal measurement error of 1 m. Each random realisation results in one best-fit value of h_2. We use 6 shape realisations and 9 noise realisations for each of them and take the RMSE of the resulting 54 best-fit values (Fig. 1). The highest relative accuracy is 2.7% or 8.7% for a mission duration of 26 months, corresponding to $3.3 \cdot 10^8$ measurements, or 12 months, corresponding to $1.5 \cdot 10^8$ measurements, respectively. Therefore, a large amount of measurements will be essential to retrieve h_2. The RMSE values also indicate that h_2 can generally be retrieved more accurately when the static shape is represented by a denser grid. The most accurate estimations have been performed for a $N = 3704400$ grid which has a resolution of approximately 5 km at the equator, the highest under investigation in this study. Even higher resolutions are in principle possible, but limited by the computational effort.

4. Summary and Conclusions

We have presented a method for the retrieval of the tidal Love number h_2 from laser altimetry data which is an improvement over a previous method [2]. Simulations of BELA measurements have shown that h_2 can be retrieved with a relative accuracy of 2.7% after 26 months of measurements or 8.7% after 12 months. Therefore, a large number of measurements is essential to obtain an accuracy which allows useful constraints on models of the interior structure of Mercury. The improved method can also be applied to the measurements of the Lunar Orbiter Laser Altimeter (LOLA) for validation purposes or to MLA data.

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