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A Technique for Measurements of Physical Librations from Orbiting Spacecraft: Application to Mercury

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Abstract

We present a technique for the direct measurement of planetary physical librations from orbiting spacecraft. In order to perform this measurement our approach combines in situ laser altimeter and image data obtained by onboard instruments. The technique benefits from the advantages of those individual data sets as well as their complementarity.
Knowledge of the physical libration of a planet or a moon is important for accurately constraining the geodetic reference system of the celestial body. These reference systems are used to produce accurate maps and for mission planning. In special cases, e.g., Mercury, it is also possible to determine constraints on the internal structure and, by extension, the thermal evolution of a planet by measuring the amplitude of the librations. In this paper we present the application of our method to physical librations of Mercury. We use image data and laser profiles obtained by the NASA MESSENGER spacecraft now in orbit about Mercury.

1. Introduction

The longitudinal librations of Mercury are related to the orbital motion of the planet and have a main period of approximately 88 days [1]. Previous estimates from Earth-based radar observations suggest an amplitude of 35.8 arcseconds, i.e., more than 400 m at the equator [2]. The MESSENGER spacecraft has been collecting image and laser altimeter data since Mercury orbit insertion in March 2011 (Fig. 1). The instruments on the spacecraft carry out comprehensive measurements of Mercury's topography, gravity and magnetic field, surface chemical composition, and other first-order science observations on this extraordinary planet.

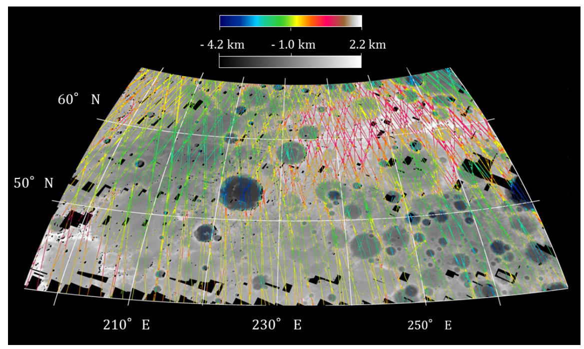

Fig 1: Stereo terrain model of the H03 Shakespeare quadrangle (lateral resolution = 250 m, gray scale) and MLA profiles (color scale).

2. Method

We use a recently developed method for co-registration of laser altimeter profiles and digital terrain models (DTMs) obtained from stereo imaging [3]. Provided that the planetary surface is sufficiently rough, topographic data sets can be co-registered with very high accuracy, much below the size of individual laser spots or terrain model grid elements. The basis of our study is the set of topographic profiles acquired by the Mercury Laser Altimeter (MLA) in the primary and extended orbital phase of the MESSENGER mission between 29 March 2011 and 28 April 2012. In addition, we use stereo photogrammetric DTMs computed from stereo images obtained by the Mercury Dual Imaging System (MDIS) [7]. Co-registration is performed using least-squares fitting, i.e., by minimizing the standard deviation of the two datasets (Fig. 2).
The parameters of the co-registration are a latitudinal tilt α, a rotational offset φ, and lateral offsets δ_{lat} and δ_{lon} [8]. Optimal values for the parameters are iteratively determined by a grid search method. The sources for the different offsets are currently being studied and could be related to orbit geometry, image

acquisition, uncertainties in rotational parameters of Mercury, or a combination thereof.

In order to measure the libration amplitude we first derived the position of the MLA profiles on the surface, under the assumption of no libration effects. After co-registration with the stereo DTM we obtained systematic longitudinal shift patterns of the laser profiles in relation to the fixed stereo DTM, probably representing the libration signature.

In our measurement we assumed that the stereo model correspond nearly to a single time [5,6], as the DTM are typically composed of large blocks (groups) of images taken within a few tens of minutes. During the DTM block adjustments the offsets between the different blocks are removed. The response of data residuals to the longitudinal shift and the number of laser spots were used to derive an error for the measurement. A total of 88 individual co-registrations were carried out.

We used the mathematical model described by Peale [1] and the observations obtained by Margot [2] for the libration function and introduced an additional amplitude scaling factor, *A,* which describes the deviation between the measured amplitude and that predicted by the model function (A = 1).

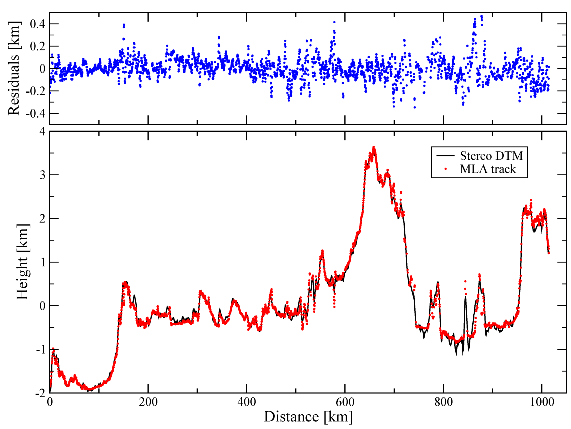

Fig. 1: Bottom: MLA profile (red dots) and the heights derived from a stereo DTM (black line) after co-registration of the data sets. Top: residuals between the two data sets after co-registration (RMS residual = 130 m).

2. Results

Even though errors in co-registrations are on the order of the libration amplitude, we can clearly see a temporal variation showing the characteristic period and phase of the expected librations (Fig. 3). On the basis of the libration function we obtained a scaling factor of A =1.02 ± 0.09 through an error-weighted fit. The strong scatter of the shifts and consequently the large error bars are mainly caused by three factors: the height resolution of the DTM, the number of MLA spots per track and the topography of Mercury in that region. Due to the fact that the DTM is located at relatively high latitudes the libration amplitude is in the same orders as the error bars.

We are working on the improvement of the co-registration method, to be followed by further analysis of the results. With the acquisition of more MLA profiles and DTMs at more favorable locations and higher spatial resolution, we expect to reduce the error and to obtain an accurate and independent in-situ measurement of the libration function.

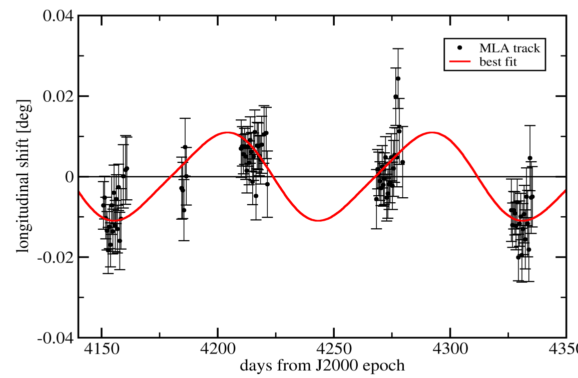

Fig.3: Fit of a libration model function to shifts between MLA tracks and stereo topographic models (black dots). The amplitude of the libration model function (red line) was determined to A = 1.02 ± 0.09. The value A = 1 corresponds to perfect agreement with the previously determined value of 35.8 arcseconds [2].

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