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Measurement of Lunar Rotation with Lunar Orbiter Laser Altimeter data

Alexander Stark (1), Serena Annibali (1,2), Jürgen Oberst (1,2), Hauke Hussmann (1)
(1) German Aerospace Center (DLR), Berlin, Germany (alexander.stark@dlr.de) (2) Institute of Geodesy and Geoinformation Science, Technische Universität Berlin, Germany.

Abstract

We use Lunar Orbiter Laser Altimeter (LOLA) data to measure the rotational state of Earth's moon. After more than seven years in orbit about the Moon the LOLA instrument onboard the Lunar Reconnaissance Orbiter (LRO) provided excellent coverage of the lunar topography [1]. In particular, at polar regions the density of highly accurate laser altimeter measurements permits creation of digital terrain models (DTMs) with spatial resolution of up to 10 meters. With the large amount of spatially concentrated and time-distributed measurements we can precisely track the rotation of the Moon.

1. Introduction

The Moon exhibits a complex rotational state, including precessions, nutations and librations. While some early measurements were made from Earth-based telescopic observations, the current knowledge on Moon's rotation arises from decades of Lunar Laser Ranging (LLR) from Earth to retroreflectors on the lunar surface [2,3]. Indeed, the accuracy level of the orientation solution reaches up to the meter level and allows valuable insights in the deep interior of the Moon [4].

There are two commonly used reference frames for the Moon: the mean Earth/rotation axes (MER) frame and the principal axis (PA) reference frame [5]. The former gives the orientation of Moon's surface and the latter is connected to the Moon's principal moments of inertia. A static transformation, realized by three rotations, relates the two reference frames to each other. This transformation depends on the gravity field coefficients of the Moon and is through that connected to a certain lunar ephemeris. Indeed, the lunar orientation solutions are initially obtained with respect to the PA frame as it allows more convenient modelling and integration of equations of motion [5].

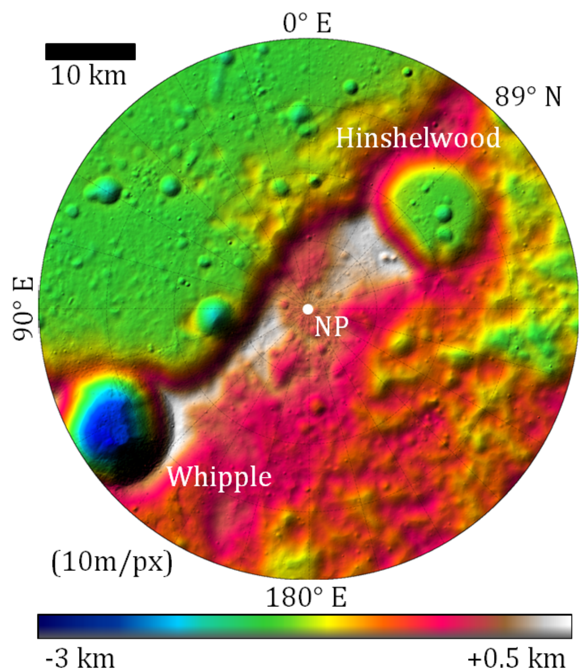

Figure 1: Color-shaded relief of a LOLA DTM at the lunar north pole (heights are given with respect to a 1734.4 km reference sphere).

2. Method

In order to perform our measurements of the lunar rotation we construct reference DTMs based on LOLA footprints at the lunar poles with a grid size of 10 meters (Figure 1). These reference DTMs are obtained by iterative self-registration of individual profiles to the DTMs constructed from other profiles in the same area. In this iterative process, with up to 50 iterations, we remove the offsets within the profiles caused by residual mis-modelling in LOLA pointing, LRO orbit reconstruction, and rotation state of the Moon. Finally, we compute the inertial coordinates of the nominal LOLA footprints and solve for the rotation parameters required to bring them in agreement with the reference DTMs. In particular, we solve for instantaneous values (at the time of the LOLA measurements) for the Euler angles of the mean Earth/Rotation axis (MER) frame. Thereby, the Euler angles φ, θ, and ψ denote rotation angles to be applied in a *z*-*x*-*z* rotation sequence.

3. Results

Based on almost 50 million LOLA footprints from the lunar north (6441 profiles) and south (7062 profiles) pole we demonstrate the recovery of small oscillations in the orientation of the lunar rotation axis (in the order of ten arc seconds) in agreement with models obtained from LLR data (dashed lines in Figure 2). In particular, we have recovered the corrections to the rotation model to be applied to the IAU MER rotation model [6] (dots in Figure 2). Although our estimates cannot improve on the LLR based solution yet, the presented method may be applied to laser altimeter data from other planetary objects where high-accuracy data is not available (e.g. Mercury).

Acknowledgements

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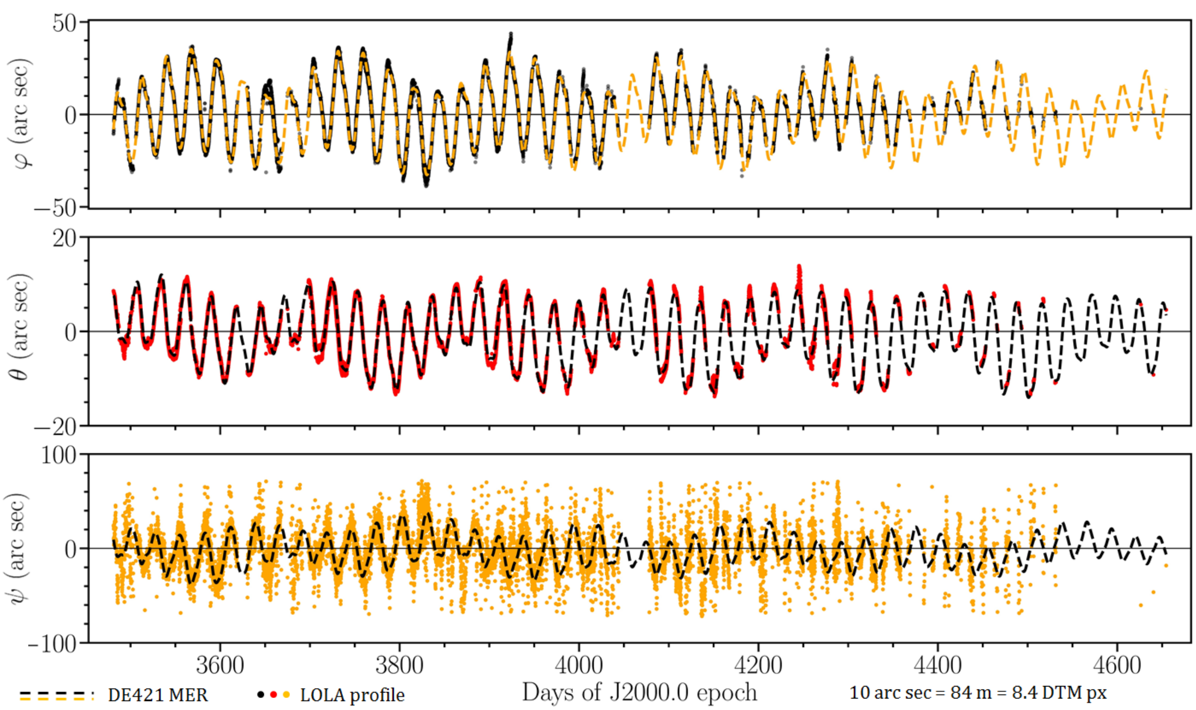

Figure 2: Corrections to Euler angles of the IAU MER rotation model [6] obtained from the self-registration of LOLA profiles.