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Latest Bernese advances in Lunar geodesy

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Abstract

The NASA mission GRAIL (Gravity Recovery And Interior Laboratory [1]) inherits its concept from the GRACE (Gravity Recovery And Climate Experiment) mission to determine the gravity field of the Moon. The Ka-Band Range Rate (KBRR) inter-satellite data allows for a highly accurate estimation of the lunar gravity field on both sides of the Moon [2], which is crucial to improve the understanding of its internal structure and thermal evolution. In this presentation we discuss our latest GRAIL-based lunar gravity fields generated with the Celestial Mechanics Approach [3, 4] using the Bernese Software (BSW, [5]). We provide independent solutions based on an optimal combination of one- and two-way Doppler and KBRR data iterated from the pre-GRAIL SGM150J gravity field. Finally, we compare our solutions for several geodetic parameters to other groups and to Lunar Laser Ranging (LLR) and we provide some preliminary results of our analysis.

1. Orbit: data, modeling and parametrization

Based on one-way X band and two-way S-band Doppler data, we perform orbit determination by solving six initial orbital elements, dynamical parameters, and stochastic parameters in daily arcs using a least-squares adjustment. We recently implemented an accurate modeling of non-gravitational forces, including accelerations due to solar and planetary [7] (albedo and IR) radiation pressure, based on the 28-plate macromodel developed by [8] to represent the GRAIL satellites. Empirical and pseudo-stochastic parameters are estimated on top of our dynamical modeling to absorb its deficiencies. We analyze the impact of different parametrizations using either pulses (*i.e.*, instantaneous velocity changes) and piecewise constant accelerations (PCA) on our orbits.

Based on these improved orbits, one- and two-way Doppler and KBRR data are then used together with an appropriate weighting for a combined orbit and gravity field determination process.

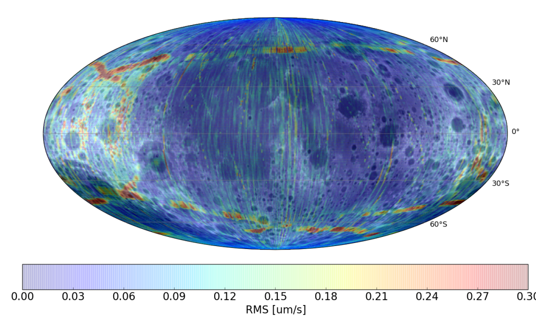

Figure 1: Root Mean Square (RMS) of KBRR residuals using a weighted combination of two-way Doppler and KBRR data, GRGM900C background field and a modeling of non-gravitational forces (solar and lunar radiation pressure) acting on GRAIL satellites. Residuals on most areas are close to the nominal KBRR accuracy of 0.03 μm/s, while correlations with topography are still visible. The sistematic signal at mid-latitudes shall be removed by a more accurate evaluation of light/shadow transitions.

2. Gravity field and tidal coefficients solutions

We present our latest independent solutions of the lunar gravity field, where KBRR data and Doppler one-way and two-way observations from the primary mission phase (PM, March-May 2012) are used. We present our analysis of an optimal combination of all data types on Normal Equations (NEQ) level. Both solutions based on the recent GRAIL GRGM900C gravity field [6] (as validation of our modeling and parametrization) and on iterations from the SELENE SGM150J gravity field (to check the independence of our solution) are presented. We detail our procedure to gradually enlarge the parameter space while adding new data to our gravity field solution. A solution up to d/o 420, comparable to the first GL420 solution [1] by NASA JPL, is achievable with the computational power available on the UBELIX cluster at the University of Bern and with our parallel processing pipeline (based on Intel BLAS/MKL) within the BSW. In addition, we present our latest solution for the Moon tidal Love number k_2. We compare all of our results from the PM with the most recent solutions of the lunar gravity field and of other geodetic parameters released by other groups or obtained using other data and techniques ($e.g.$, LLR).

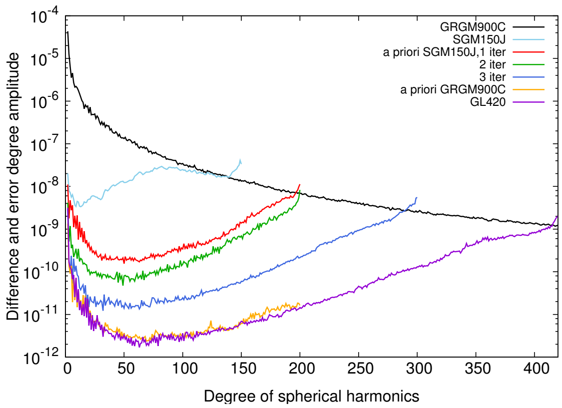

Figure 2: Difference degree amplitudes w.r.t. GRGM900C of 1. iterated solutions from SGM150J with progressively enlarged parameter space; 2. a solution based on GRGM900C up to d/o 600; 3. several reference solutions.

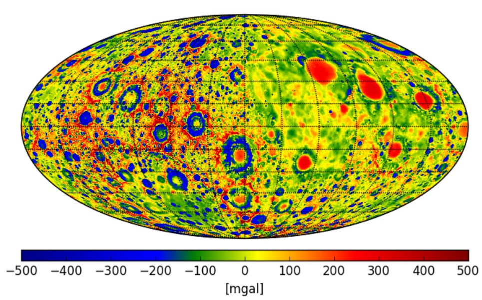

Figure 3: Free-air gravity anomalies on a $0.5^o \times 0.5^o$ grid of our d/o 300 iteration from SGM150J (Mollweide projection centered around 270^o, with the nearside on the right).

3. Summary and Conclusions

We present our most recent solutions for the lunar gravity field and tidal coefficient k_2, where further improvements have been obtained from the introduction of an accurate modeling of non-gravitational forces, an improved data screening and the optimisation of the parametrisation. We review the impact of different empirical orbit parametrizations and combination of data types on the recovery of lunar geodetic parameters. We show that the lunar gravity field can be recovered with a high quality by adapting the Celestial Mechanics Approach, even when using pre-GRAIL gravity field solutions as a priori. Our latest developments and the experience gained with GRAIL open the way to further research projects in planetary geodesy at AIUB and within ongoing collaborations with other groups.

Acknowledgements

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