Figure 5: Left: Difference degree amplitudes (solid) and formal errors (shaded) of degree 200 for GRAIL gravity field model GRL200B (top) and GRGM900C (bottom) compared to GR-grids. The error bars represent a 95% confidence interval. Right: differences in the second truncation (up to d/o 200) of GRL200B and GRGM900C, which use GRGM900C as a priori field up to d/o 200 and 660, respectively.

Conclusions

- The adaption of the CMA from GRACE to GRAIL allows for good-quality lunar gravity fields obtained entirely within the Bernese GNSS-software.
- We present our first independent solution for GRAIL gravity field computed from original Doppler and KBRR data, hence showing our ability to extend our activities to the analysis of planetary mission data.
- Our gravity field solutions are so far computed without explicitly modeling non-gravitational forces and demonstrate the potential of pseudo-stochastic orbit parameterization. However, to fully exploit the precision of the Ka-band observations, we recently started to address an explicit modeling of solar radiation pressure in our modeling.

References

Bertone et al. (2018) Gravity field from GN11B and KBRR data (d/200). We also present our latest solutions up to d/o 200 using the GN11B and KBRR data, which are computed using SGM150J. We will present the modeling setup and compare our results to the most recent results.

Contact address
Stefano Bertone
Astronomical Institute, University of Bern
Stellag 51
3012 Bern (Switzerland)

GRAIL Gravity Field Determination Using the Celestial Mechanics Approach

First results from Doppler and KBRR data

Introduction

To determine the gravity field of the Moon, the two satellites of the NASA mission GRAIL (Gravity Recovery and Interior Laboratory) were launched on September 10, 2011 and reached their lunar orbits in the be-ginning of 2012 (Zuber et al., 2013). The concept of the mission was initiated from the Earth-orbiting mission GRACE (Gravity Recovery and Climate Experiment) in that the key observations consisted of ultra-precise inter-satellite Ka-band range measurements. Together with the one- and two-way Doppler observations from the NASA Deep Space Network (DSN), the GRAIL data allows for a determination of the lunar gravity field with an unprecedented accuracy for both the near- and the far-side of the Moon. The latest official GRAIL gravity field models contain spherical harmonic coefficients up to degree and order 900 (Koschel et al., 2014, Lenaerts et al., 2014).

Based on our experience in GRACE data processing, we have adapted our orbit and gravity field recovery, the Celestial Mechanics Approach (CMA, Beutler et al., 2010), to the GRAIL mission within the Bernese GNSS-software. We use the level 1b Ka-band range-rate (KBRR) data as well as two-way Doppler observations from the DSN (relative weighting 10:1). Earlier results using KBRR data along with JPL-provided GNI1B position data (Arnold et al., 2013) are also presented. The following results are based on the release 4 data of the primary mission phase (PM, 1 March to 29 May 2012).

The Celestial Mechanics Approach (CMA)

The idea of the CMA is to rigorously treat the gravity field recovery as an extended orbit determination problem. It is a dynamic approach allowing for appropriately constrained stochastic pulsces (instantaneous changes in velocity) to compensate for inevitable model deficiencies. For each satellite, the equations of motion can be written as \( \mathbf{r} = \mathbf{a} + \mathbf{a}_r \), where \( \mathbf{a}_r = -V \) denotes the acceleration due to the gravity potential \( V \), which we parameterize in terms of the standard SH expansion, and \( \mathbf{a} \) denotes the sum of all perturbing accelerations. We consider 3rd body perturbations according to JPL ephemerides DE421, forces due to the tidal deformation of the Moon and relativistic corrections. We do not yet model direct or indirect solar radiation pressure explicitly.

All observations contribute to one and the same set of parameters, which are simultaneously estimated. Depending on the setup, these are chosen amongst:

- Orbit initial conditions every 24h, constant and once-per-revolution (OPR) accelerations in R,S,W (radial, along-track, out-of-plane), stochastic impulses in R,S,W estimated periodically. Their spacin is to be chosen as a compromise between making up for model deficiencies and not absorbing too much of the gravity signal.
- Static gravity field: the coefficients of the SH expansion up to the chosen degree and order.

Doppler and KBRR data are combined on the Normal Equation (NEQ) using a weighting appropriate to the relative accuracy (\( \sim 10^{-12} \)). The resulting daily NEQs are then inverted to solve for the improved orbital parameters.

Combined orbit determination

Doppler and KBRR data are combined on the Normal Equation (NEQ) using a weighting appropriate to the relative accuracy (\( \sim 10^{-12} \)). The resulting daily NEQs are then inverted to solve for the improved orbital parameters.

Reference

S. Bertone, D. Arnold, A. Jäggi, G. Beutler, L. Mervart
Astronomical Institute, University of Bern, Bern, Switzerland

Gravity field from GN11B and KBRR data (d/200)

For AIUB-GRL200A, we set up stochastic pulses every 40 minutes. AIUB-GRL200B is based on the impact of the omission of GW1-1300A on our solutions. The consistency between AIUB-GRL200B and GRGM900C markedly drops around degree 150. A thorough analysis revealed that the coefficients of order \( \sim 30 \) (as well as the nodal terms) are degraded, and that this degradation shows a correlation with the spacing of the pulses (see Fig. 5, right). A possible explanation was identified in the geographical location of the pulses, showing a very regular pattern dependent on their spacing. Finally, a less problematic spacing of \( \sim 15' \) was chosen for AIUB-GRL200B.

Conclusions

- The adaptation of the CMA from GRACE to GRAIL allows for good-quality lunar gravity fields obtained entirely within the Bernese GNSS-software.
- We present our first independent solution for GRAIL gravity field computed from original Doppler and KBRR data, hence showing our ability to extend our activities to the analysis of planetary mission data.
- Our gravity field solutions are so far computed without explicitly modeling non-gravitational forces and demonstrate the potential of pseudo-stochastic orbit parameterization. However, to fully exploit the precision of the Ka-band observations, we recently started to address an explicit modeling of solar radiation pressure in our modeling.