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 begin-ning of 2012 (Zuber et al., 2013). The concept of the mission was inher-
ted from the Earth-orbiting mission GRACE (Gravity Recovery and Cli-
mate 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 allow 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 (Kanoplopoulos et al., 2014; Lemoine et al., 2014).

Based on our experience in GRACE data processing, we have adapted our classical orbit and gravity field determination, the Celestial Mechanics Approach (CMA, Beeler 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 10^9). Earlier results using KBRR data along with JPL-provided GN1B 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 processes (instantaneous changes in velocity) to compensate for inevitable model deficiencies. For each satellite, the equations of motion in orbit space as well as the equations for the gravity field are derived from a priori initial elements and parameters and an accurate model of light propagation are used to compute the Doppler residuals. The latter are used to weight the observations, along with the corresponding variational equations, to improve the a priori estimates of the orbit and gravity field improvement process.

We use the positions provided by the GRAIL navigation team as initial condition for a two-way orbit and then perform an orbit integration with the force model presented in the previous section. The initial orbital elements and, possibly, dynamical and stochastic parameters are then adjusted to the Doppler data (with an integration time of 10 s) using a classical least-square procedure. Observations are screened for outliers by setting a threshold on the residuals and by applying an elevation cutoff at 25°.

Doppler orbit determination

Several tests were performed to show the impact of different background fields and parameterizations (dynamic or pseudo-stochastic) on the im-
proved orbits. Fig. 2 (left) shows two-way Doppler residuals for GRAIL-A over days 70-72 of the PM phase w.r.t. an accuracy of Doppler residuals of the order of 0.1 mm/s (in green). The residuals are relatively large and clearly show the occurrence of pseudo-stochastic processes. The green and blue bars indicate the time spans during which each satellite is in sunlight. The obvious correlation between these time spans and the large discontinuities suggests that radiation pres-
sure modeling is crucial since the chosen parameterization is not able to fully compensate the deficiency.

Gravity field from Doppler and KBRR data (d/o 120)

The orbit determination in the first step serve as a priori information for a common orbit and gravity field estimation based on daily arcs. A clas-

ci least-square approach is performed after an orbit integration with the force model presented in the previous section.

Figure 4: D/0 RMS values of the KERR residuals in the combined (Doppler and KBRR) orbit solution. Lower plots are zooms of upper ones. The fits are relatively bad when using the SELENE (GMI1B) gravity field and become better (more consistent) when introducing NASA’s official GRAIL field GRGM900C (Lemoine et al., 2014). The plots are divided into three parts: Right: KERR residuals and time spans for which GRAIL-A (green) and GRAIL-B (blue) are in sunlight. Vertical black lines indicate locations of pseudo-stochastic pulses.

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 missions.

• 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 ad-
iress an explicit modeling of solar radiation pressure in our model-
g

References


Lemoine et al. (2014) GRAIL, Gravity Recovery and Interior Laboratory: An overview of the GRAIL Gravity Model, Precise and Extended Mission Results. JPL Publication.

Zuber et al. (2013) Gravity field of the Moon from the gravity recovery and interior laboratory (GRAIL) mission. Science, 339(6120): 668-671

Conclusions

• The adaptation of the CMA from GRACE to GRAIL allows for good-

ness 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 missions.

• 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 ad-

dress an explicit modeling of solar radiation pressure in our model-

Gravity field from GNM1B and KBRR data (d/o 200)

We also present our latest solutions up to d/o 200 using the GNM1B and KBRR data and compare these results with those computed in (Arnold et al., 2015). Fig. 5 (left) shows the differ-

ence degree amplitude of solutions AIUB-GRL200A and AIUB-GRL200B, which use GRGM900C as a priori field up to d/o 200 and 660, respectively.

For AIUB-GRL200A, we set up stochastic pulses every 40 minutes. AIUB-

GRL200B restricts the impact of the stochastic terms on our solutions. The consistency between AIUB-GRL200B and GRGM900C markedly drops around degree 150. A thorough analysis revealed that the coefficients of order ~5 (as well as the zonal terms) are degraded, and that this degra-
dation 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 regular pattern dependent on their spacing. Fi-

dedi

Copyright: NASA