Lunar gravity field recovery: GRAIL simulations and real data analysis

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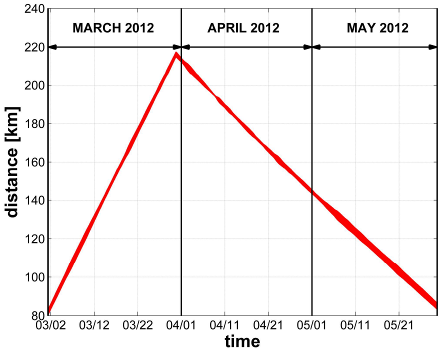
Summary

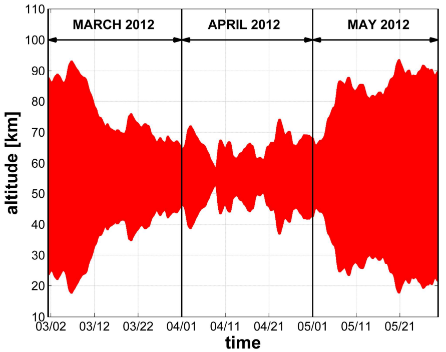
The NASA mission GRAIL (Gravity Recovery and Interior Laboratory) makes use of low-low Satellite-to-Satellite Tracking (ll-SST) between the two spacecraft GRAIL-A (Ebb) and GRAIL-B (Flow) to determine a high-resolution gravity field solution of the Moon. The mission concept is inherited from the GRACE (Gravity Recovery and Climate Experiment) project, a space-gravimetry mission mapping the terrestrial gravity field.

Since the Moon is in synchronous rotation with the Earth, direct tracking of satellites on the farside is impossible, but GRAIL provides global coverage of inter-satellite tracking data. Furthermore, ll-SST observations are much more sensitive to gravitational features than ground-based orbit tracking. Therefore, compared to previous missions, GRAIL enables a more accurate estimation of the lunar gravity field, with a much higher spectral and spatial resolution.

We conducted a series of sensitivity studies based on simulated orbit information (positions) and ll-SST measurements (ranges, range rates, range accelerations). From the simulated observations the spherical harmonic coefficients, which represent the lunar gravity field, are estimated using an integral equation approach. Furthermore, we analyzed one month of real data in order to derive a preliminary lunar gravity field model from GRAIL observables. Observation simulation and parameter estimation is accomplished using the GROOPS (Gravity Recovery Object Oriented Programming System) software package.

GRAIL (Gravity Recovery and Interior Laboratory)





Mission phases	
Launch	10-Sep-2011
Lunar Orbit Insertion	31-Dec-2011 (Ebb)
	01-Jan-2012 (Flow)
Science Mission	Mar-May 2012
Extended Mission Start	30-Aug-2012
Decommissioning	17-Dec-2012

Orbit characteristics	
Revolution period	113 min
Inclination	~89.9° w.r.t. lunar equator
Altitude	~55 km (±35 km)
Separation distance	82-218 km

Fig. 1: Spacecraft separation distance during GRAIL's Primary Mission.

Fig. 2: Orbit altitude during GRAIL's Primary Mission. Altitude is relative to the lunar mean radius of 1737.4 km.

Synthesis

Step 1: Orbit generation

A priori reference field	JGL165P1 (up to d/o 165)
Ephemeris	JPL DE421
Simulation period	March-May 2012

Step 2: Tracking data simulation

Sampling	5 seconds
Noise level (Orbit)	10 m in each direction
Noise level (Ka-band)	1 μm/s

Analysis

Step 1: Least -squares adjustment

Method	Integral equation approach using short arcs
A priori reference field	JGL165P1 clone

Step 2: Reconstruction of gravity field coefficients – simulation

Step 3: Reconstruction of gravity field coefficients – real data

- Synchronization of orbit and tracking data
- Outlier detection

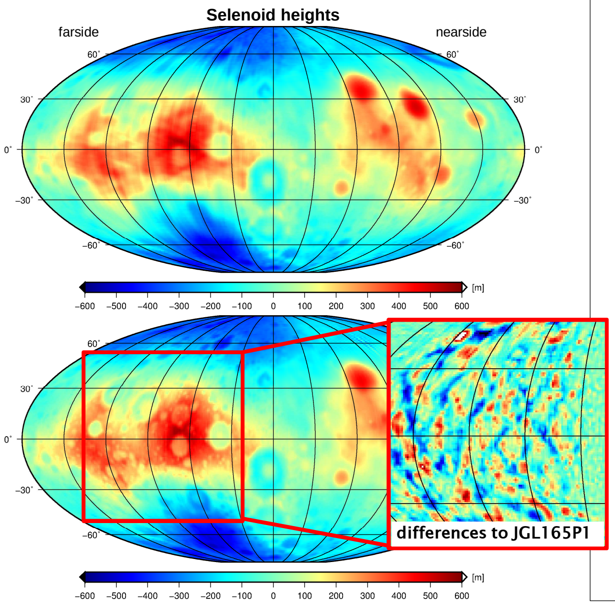


Fig. 3: Selenoid heights in meters from JGL165P1 and from the reconstructed gravity field coefficients using real data with an arc length of 60 minutes. [Mollweide projection, centered around 270° eastern longitude]

How well can the 'true' gravity field JGL165P1 be recovered with evenly distributed noise-free/noisy orbit and tracking data using

- different arc lengths (10/30/60 minutes)
- varying simulation periods (1/3 months ⇒ separation distance + altitude)
- different a priori reference fields (up to d/o 100/165) and resolutions (up to d/o 100/165)

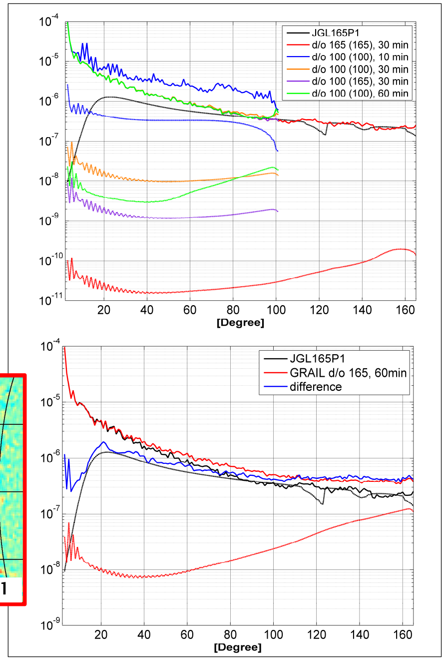


Fig. 4: Degree-error RMS values from simulated data (top) and GRAIL real data (bottom). Top: 1 month simulation showing the influence of arc lengths on d/o 100. Bottom: 1 month GRAIL data using an arc length of 60 minutes.

Discussion

The availability of global inter-satellite tracking data improves the spatial resolution of the lunar nearside and farside compared to previous gravity field models of the Moon. Importantly, the GRAIL mission enables the estimation of a high-resolution gravity field model without any regularization. Open issues include the setup of a validation scheme and the modeling of non-gravitational accelerations such as solar radiation pressure and lunar albedo.

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