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High-degree gravity models from GRAIL primary mission data

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[1] We have analyzed Ka-band range rate (KBRR) and Deep Space Network (DSN) data from the Gravity Recovery and Interior Laboratory (GRAIL) primary mission (1 March to 29 May 2012) to derive gravity models of the Moon to degree 420, 540, and 660 in spherical harmonics. For these models, GRGM420A, GRGM540A, and GRGM660PRIM, a Kaula constraint was applied only beyond degree 330. Variance-component estimation (VCE) was used to adjust the a priori weights and obtain a calibrated error covariance. The global root-mean-square error in the gravity anomalies computed from the error covariance to 320 × 320 is 0.77 mGal, compared to 29.0 mGal with the pre-GRAIL model derived with the SELENE mission data, SGM150J, only to 140 × 140. The global correlations with the Lunar Orbiter Laser Altimeter-derived topography are larger than 0.985 between $\ell = 120$ and 330. The free-air gravity anomalies, especially over the lunar farside, display a dramatic increase in detail compared to the pre-GRAIL models (SGM150J and LP150Q) and, through degree 320, are free of the orbit-track-related artifacts present in the earlier models. For GRAIL, we obtain an a posteriori fit to the S-band DSN data of 0.13 mm/s. The a posteriori fits to the KBRR data range from 0.08 to 1.5 μm/s for GRGM420A and from 0.03 to 0.06 μm/s for GRGM660PRIM. Using the GRAIL data, we obtain solutions for the degree 2 Love numbers, k_{20}=0.024615±0.0000914, k_{21}=0.023915±0.0000132, and k_{22}=0.024852±0.0000167, and a preliminary solution for the k_{30} Love number of k_{30}=0.00734±0.0015, where the Love number error sigmas are those obtained with VCE.

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1. Introduction

[2] The pair of spacecraft comprising the NASA Discovery Gravity Recovery and Interior Laboratory (GRAIL) mission successfully mapped the gravity field of the Moon from a mean altitude of 55 km between 1 March and 29 May 2012 [*Zuber et al.*, 2013a]. The GRAIL mission used a modified version of the precision intersatellite ranging system used on the Gravity Recovery and Climate Experiment (GRACE) mission [*Tapley et al.*, 2004a]. The GRAIL Lunar Gravity Ranging System (LGRS) measures precisely the range between the two co-orbiting spacecraft [*Klipstein et al.*, 2013]. The GRAIL mission is the latest and the most comprehensive effort to map the lunar gravity field. *Asmar et al.* [2013, Table 1] give a detailed summary of the differences and similarities between GRACE and GRAIL.

[3] The earliest efforts to determine the lunar gravity field date to the 1960s and 1970s and used the S-band Doppler tracking of the Lunar Orbiters 1–5, the Apollo Command Modules, and the *Apollo* 15 and 16 subsatellites. *Muller and Sjogren* [1968] demonstrated the existence of mascons over the large lunar maria from an analysis of Lunar Orbiter data. The data from the Apollo Command Module and *Apollo* 16 subsatellite were acquired from very low altitude orbits (12–30 km altitude); however, the tracking coverage provided only localized sampling of the lunar gravity field using S-band Doppler [*Gottlieb et al.*, 1970; *Sjogren et al.*, 1972, 1974; *Phillips et al.*, 1978]. The S-band Doppler of this era had a precision of a few mm/s, while the GRACE and GRAIL Ka-band range rate (KBRR) data have a precision of 0.1 μm/s or better. The Lunar Orbiter and Apollo subsatellite data provided low-altitude coverage over the equatorial regions to ±30° latitude. In the early 1990s, the S-band data to the Apollo-era lunar orbiters were reanalyzed with the

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