Post-Lunar Prospector Lunar Gravity Field Models: Their Information Content, Quality Assessment and the View of the Estimation Process

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The Lunar Prospector mission has provided a wealthy sample of good quality satellite tracking data over the lunar nearside, during the primary mission phase at a mean altitude of 100 km as well as the extended mission phase where the peripasis altitude was as low as 15 km. While the lunar farside still remains inaccessible for satellite observations, the 2-way Doppler data set collected by the Deep Space Network, due to the low flight altitude, contains good orbit perturbation measurements out to a significant orbital frequency, possibly in the order of 120 cycles per orbital revolution. The major challenge for the developer of lunar gravity field analysts is therefore to combine the excellently sampled nearside data with some kind of regularisation scheme in the form of prior information on the estimate in order to derive a global gravity model using global basis functions, like spherical harmonics.

By virtue of the empirical character of the regularisation schemes applied in present-day lunar gravity field modelling, combined with the scarcity of information available for their verification and calibration, the constraints applied are frequently selected on the basis of orbit determination performance, where improvements in the rms-of-fit is usually seen as an indication of the rightfulness of the prior information. In other cases, like the pre-Lunar Prospector GLGM-2 model, the aim of the constraint relations was also to dampen the high-degree power, and, hence, focus on global-scale selenophysical interpretation. Consequently, the estimation strategy may severely impact the end result and therefore also the physical interpretations that follow.

This paper therefore focuses on the numerical properties of the equation systems that led to the new lunar gravity field solutions LP75G, LP100J and LP100K. It is shown that the counteraction of the catastrophic conditioning of the original non-constrained equation leads to models that behave well in terms of orbit and selenoid height errors when applied as a whole, but at the same time exhibit striking error patterns when studied per order, degree or orbital frequency. Furthermore, it is shown that LP75G is optimistically calibrated and that the actual error is significantly higher than the one published. Frequency spectra of the orbit errors also show large orbit errors at intermediate degrees which are counteracted by higher order components. In other words, the LP75G models suffers from higher negative correlation levels than e.g. GLGM-2.

Furthermore, the critical role of empirical constraint in lunar gravity field modelling has triggered questions about the view of the estimation process. In most causation problems in planetodey, regularised least squares estimation is seen as a kind of collocation. Collocation schemes and error propagation, however, only yield optimal solutions if the prior information is correct, which certainly is questionable in selenopotential modelling. Alternatively, the least squares problem may be seen as a case of biased estimation, for which the error measures next to the propagated error also contains a bias term. It is shown that such an alternative view of the estimation process may change the error levels of up to 50%, with due consequences for the reliability of weak selenopotential features.