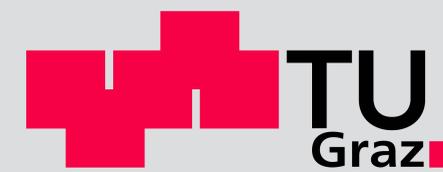


The latest GrazLGM lunar gravity field model: developments in the framework of project GRAZIL

Beate Klinger¹, Harald Wirnsberger², Sandro Krauss² and Torsten Mayer-Gürr¹

¹Institute of Geodesy, NAWI Graz, Graz University of Technology, ²Space Research Institute, Austrian Academy of Sciences



Introduction

The project GRAZIL aims at recovering a highly-accurate lunar gravity field based on the measurements provided by the Gravity Recovery and Interior Laboratory (GRAIL) mission. We present our latest lunar gravity field models GrazLGM350c and GrazLGM300cx derived from inter-satellite Ka-band ranging (KBR) observations collected by GRAIL during primary mission (PM) and extended mission (EM) phase. For gravity field recovery, we exploit the KBR data by an integral equation approach using short orbital arcs.

In this contribution we demonstrate the progress of Graz lunar gravity field models (GrazLGM), achieved by a refinement of the processing strategy (incorporation of non-gravitational accelerations, covariance estimation) in conjunction with an increase of the spectral resolution. We validate our results against state-of-the-art lunar gravity field models computed at NASA-GFC (NASA Goddard Space Flight Center), NASA-JPL (NASA Jet Propulsion Laboratory) and AIUB (Astronomical Institute, University of Bern).

Orbit determination (OD)

To allow for a fully independent lunar gravity field recovery, a dynamic precise orbit determination is implemented. The concept of variational equations is adopted to determine the orbits of the two GRAIL spacecraft based on radio science data.

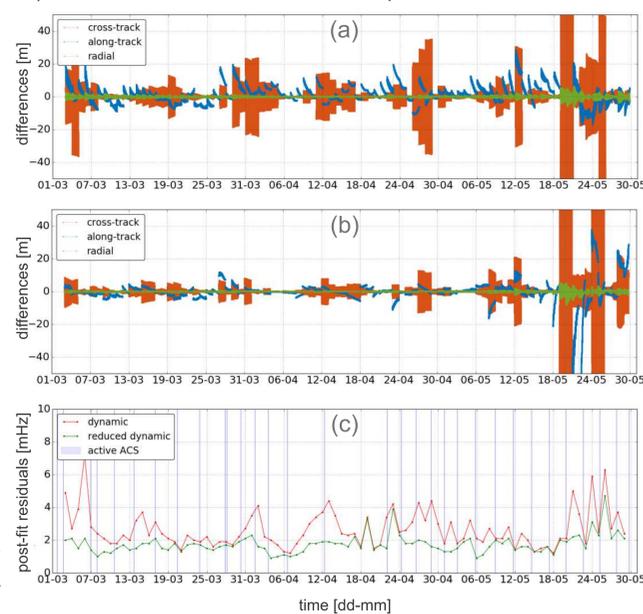
- OD based on variational equations
- Batch least-squares estimator
- S-band two-way Doppler data collected by the Deep Space Network (DSN)

Observation modeling

- Development of in-house OD software package following formulation of Moyer [7]
- **Background model:** GL0660B truncated at d/o 350
- **Dynamic:** No empirical accelerations estimated
- **Reduced dynamic:** Empirical accelerations in along-track, cross-track and radial (const., 1 / rev, 2 / rev), scale factors for solar radiation pressure and Albedo

During PM the Attitude Control System (ACS) performed several propulsive maneuvers (cf. Fig. 3), which affect the solutions of the initial value problem, as they are not consistent with our force modeling. Therefore, we estimate empirical accelerations in all 3 directions in the reduced dynamic case. Hereby, the a posteriori residuals of two-way Doppler range rates are reduced to ~2 mHz (cf. Fig 1 (c)). The nominal accuracy of GRAIL S-Band observations is ~1 mHz, which corresponds to ~0.15 mm/s. In order to avoid effects on the gravity field solution, these maneuvers should be excluded from OD.

Fig. 1: Comparison of the dynamic (a) and reduced dynamic orbit (b) to the GNI1B RL04 product; (c) Two-way Doppler residuals for both cases during PM.



Gravity field recovery (GFR)

- GFR based on short-arc approach [6]
- Heritage of the gravity field mission GRACE (Gravity Recovery and Climate Experiment)
- Ka-band ranging data (PM and EM)
- Consistent force modeling

Force model and parameterization

- 1) Arc length:**
 - OD: 2.5 days
 - GFR: 60 minutes
- 2) Satellite design:**
 - 28-plate Macro Model [2]
- 3) Empirical parameter:**
 - 4 / rev (along-track, cross-track)
- 4) Time bias**
- 5) Force modeling:**
 - 3rd body accelerations
 - Solid Moon tides
 - Relativistic accelerations
 - Solar radiation pressure
 - Albedo
 - Emissivity

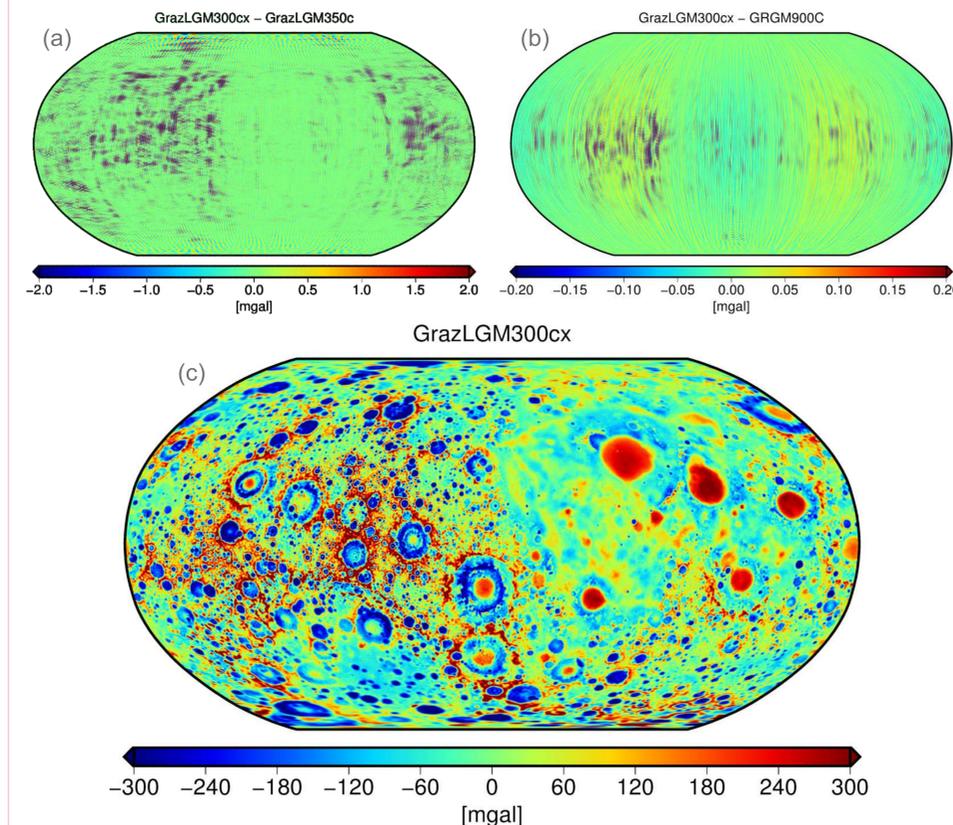


Fig. 2: Absolute (c) and relative (a, b) gravity anomalies of the GrazLGM300cx model on a 0.2° x 0.2° grid (Robinson projection centered around 270°, with the nearside on the right). Differences to the GrazLGM350c (a) and GRGM900C (b) model. Different scales apply.

Results and model evaluation

GRAIL reference solutions:

- NASA-GSFC: GRGM900C [5]
- NASA-JPL: GL0660B
- NASA-JPL: GL0900D [4]
- NAOJ: SGM150
- AIUB: AIUBGRL200B [1]

SCENARIO 1 (a-priori field: SGM150)

- **Iteration 1:** d/o 200
- **Iteration 2:** d/o 300
- **Iteration 3:** d/o 300
- **Iteration 5:** d/o 350

The iteration-steps illustrate, how an increased spectral resolution positively affects the gravity field solutions. Due to the huge computational effort, the solutions are currently limited to d/o 350.

SCENARIO 2 (a-priori field: GRGM900C)

To avoid spectral aliasing, short-wavelength signals are reduced from the KBR data using the GRGM900C model. The GrazLGM350c and GrazLGM300cx models represent the latest lunar gravity field solutions developed in the framework of the project GRAZIL. The GrazLGM300cx model is derived from data collected during both PM and EM phase. It is based on a combination of the GrazLGM350c and individual monthly solutions for the EM phase.

- **GrazLGM350c**
- **Primary:** d/o 350
- **Primary & Extended:** d/o 300
- **GrazLGM300cx**

Compared to the GrazLGM350c model, the resolution is improved due to a lower average altitude (23 km). As a result, improvements are mainly visible in the short-wavelength part of the spectrum; the differences are in the order of ± 2 mgal (cf. Fig. 2 (a) and 3 (b)).

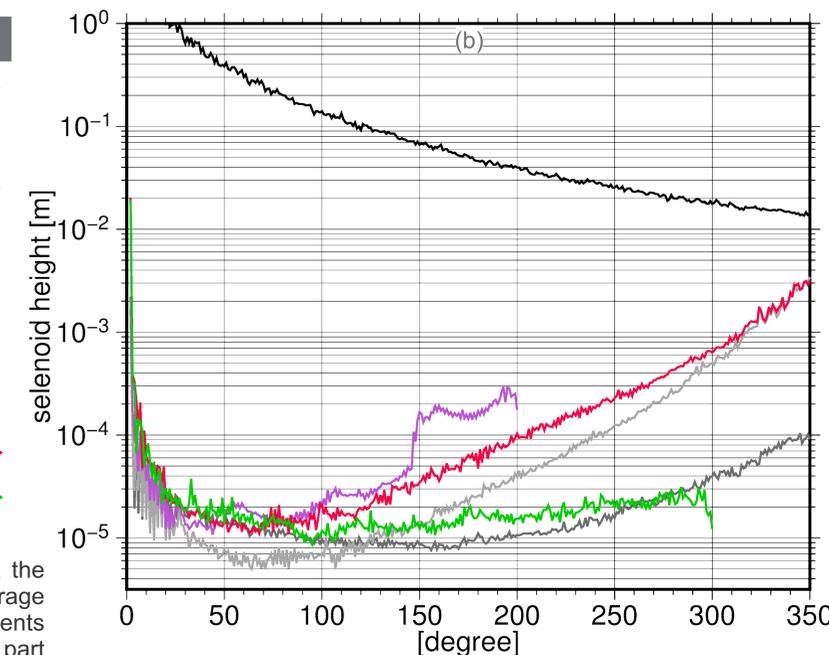
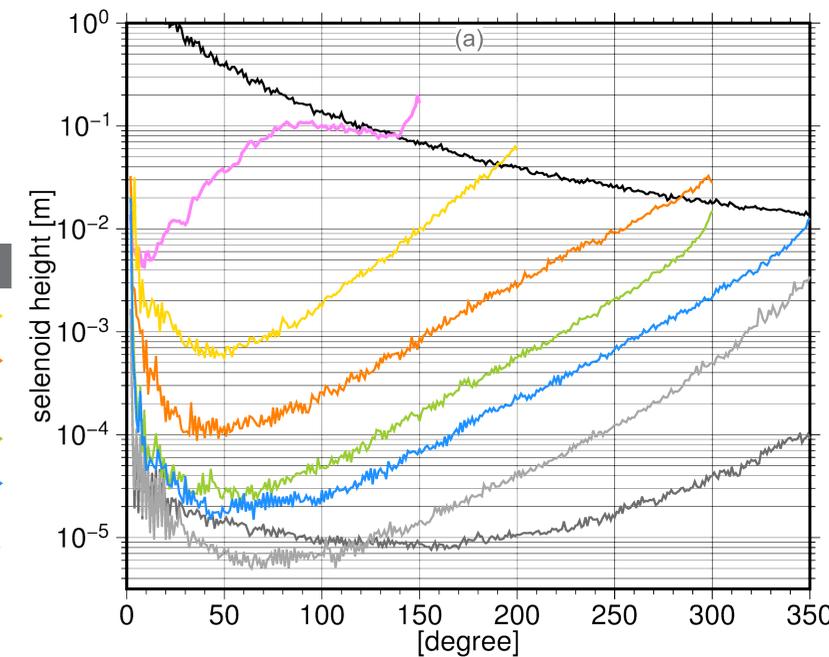


Fig. 3: Degree amplitudes of different lunar gravity field solutions from Scenario 1 (a) and Scenario 2 (b).

Acknowledgements

This poster is presented in the frame of the project **GRAZIL** (Gravity field of the Moon from radio science tracking and inter-satellite measurements of the GRAIL spacecraft) funded by the Austrian Research Promotion Agency (FFG).



References

- [1] Arnold, D., et al. (2015): Icarus, 261, 182-192.
- [2] Fahrenstock, E.G., et al. (2012): AIAA/AAS, Astrodyn. Specialist Conference.
- [3] Klinger, B., et al. (2014): Planet. Space Sci., 91, 83-90.
- [4] Konopliv, A.S., et al. (2014): Geophys. Res. Lett., 41, 1452-1458.
- [5] Lemoine, F.G., et al. (2014): Geophys. Res. Lett., 41, 3382-3389.
- [6] Mayer-Gürr, T. (2006): PhD Thesis, University of Bonn
- [7] Moyer, T. (2003): Deep-space communications and navigation series.

Contact

Beate Klinger
email: beate.klinger@tugraz.at
phone: +43 316 873 6344

