The role of position information for the analysis of K-Band data – experiences from GRACE and GRAIL data analysis

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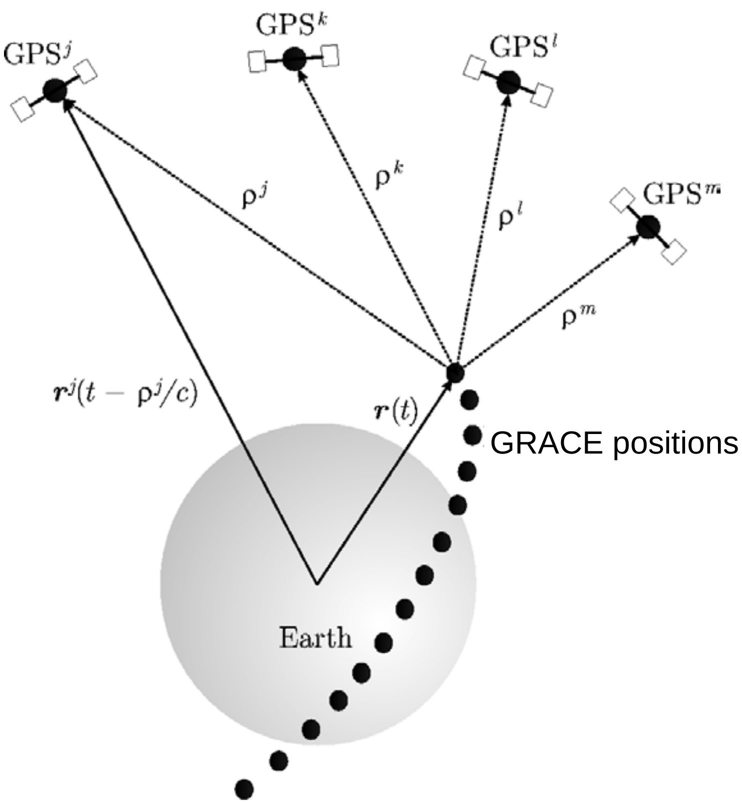
Differences between GRAIL and GRACE

	GRAIL	GRACE
Celestial Body	Moon	Earth
Nom. mission duration	3 months	5 years
Launch date	10th Sep 2011	17th March 2002
Mean altitude	55 km	470 km
N_{max} of SH expansion	420	120
Clock synchronisation	RSB	GPS
Accelerometer	No	Yes
Satellite link	Ka-/S-Band	Ka-/K-Band
Satellite distance	80-225 km	170-270 km
Attitude control	Reaction wheels	Magnetic torquer
Star cameras	1	2
Timing accuracy (abs)	DSN: Millisecond	GPS: Nanosecond
Timing accuracy (rel)	TTS: Picosecond	GPS: Picosecond

Table according to Asmar et al. (2013)

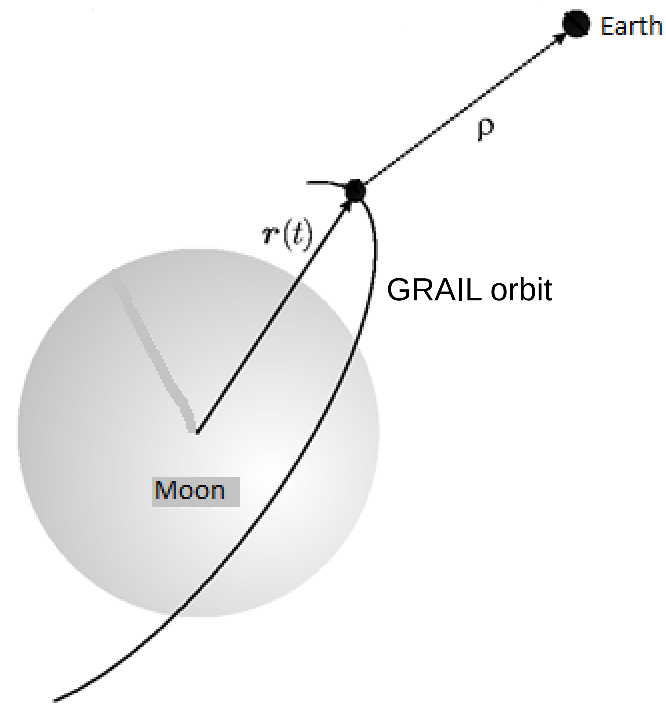
Differences between GRAIL and GRACE

GRACE



The GRACE satellites may be geo-located with cm-accuracy at any time, e.g., by a kinematic precise point positioning (PPP).

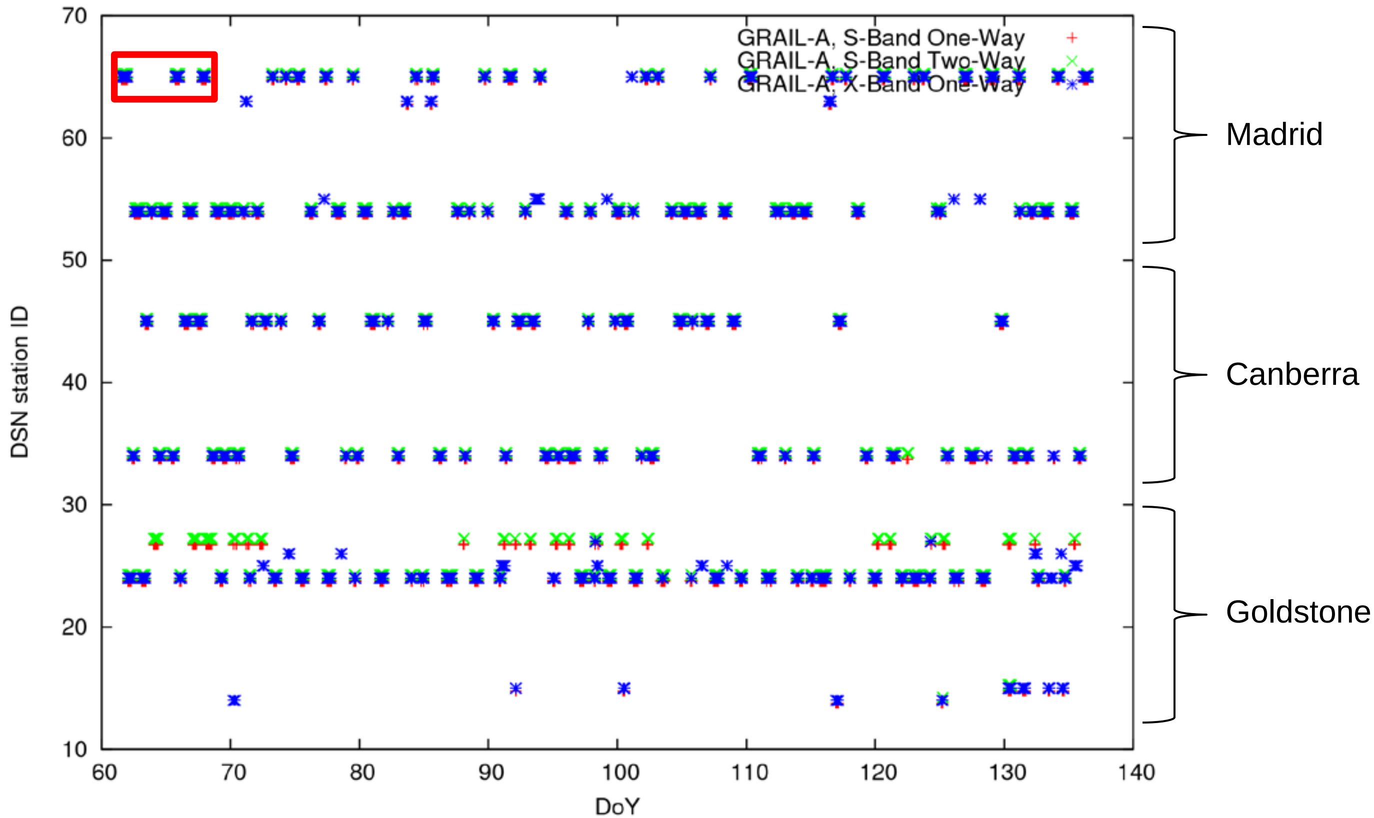
GRAIL



The orbits of the GRAIL satellites may be constrained by Doppler measurements from the Earth only on the near-side of the Moon.

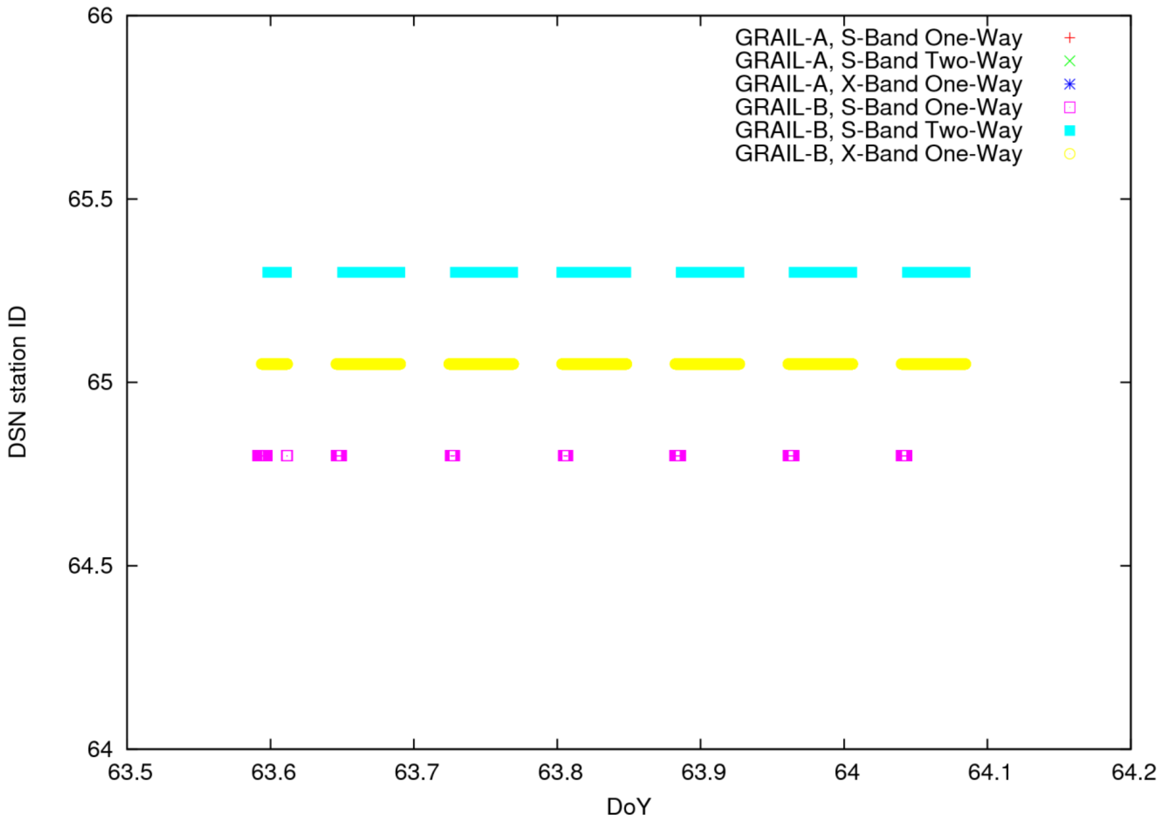
GRAIL Radio–Tracking by DSN

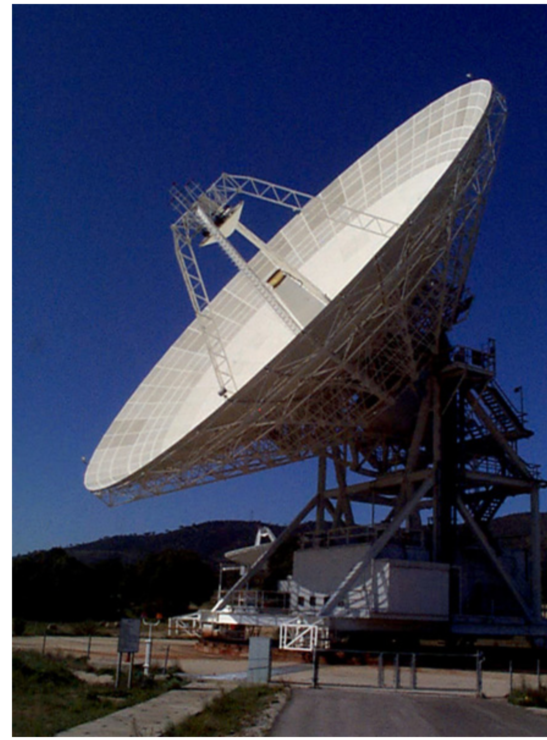
Adrian Jäggi: The role of position information for the analysis of K–Band data – experiences from GRACE and GRAIL data analysis, VIII Hotine Marussi Symposium, Rom, 20. June 2013



Radio-tracking of GRAIL-A by NASA's Deep Space Network (DSN) during the primary mission phase. Several of the 34-m antennas of the each complex of the DSN network have been used for tracking. The X-Band One-Way data are primarily used for orbit determination.

GRAIL Radio–Tracking by DSN





Zoom on the DSN-Tracking of the 34-m antenna DSS-65 in Madrid at begin of the primary mission phase. Gaps are due to the visibility of the Moon and the spacecraft.

Outline of the Talk

Processing of DSN tracking data is not yet implemented into the Celestial Mechanics Approach. Positions from GNI1b products are thus used as pseudo-observations:

- **Experiments with GOCE data**
  - Use of dynamic or reduced-dynamic orbit positions as pseudo-observations for gravity field determination
- **Experiments with GRACE data**
  - Use of positions with artificially reduced coverage for gravity field determination with continuously available K-Band data
  - Use of positions with degraded accuracy for gravity field determination with ultra-precise K-Band data
- **First results with GRAIL data**

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Using Reduced-Dynamic Positions

Using reduced-dynamic positions seems to be attractive to derive the long-wavelength part of the gravity field with high quality. Four GPS-only solutions based on GOCE data from Nov/Dec 2009 have been computed to demonstrate the consequences:

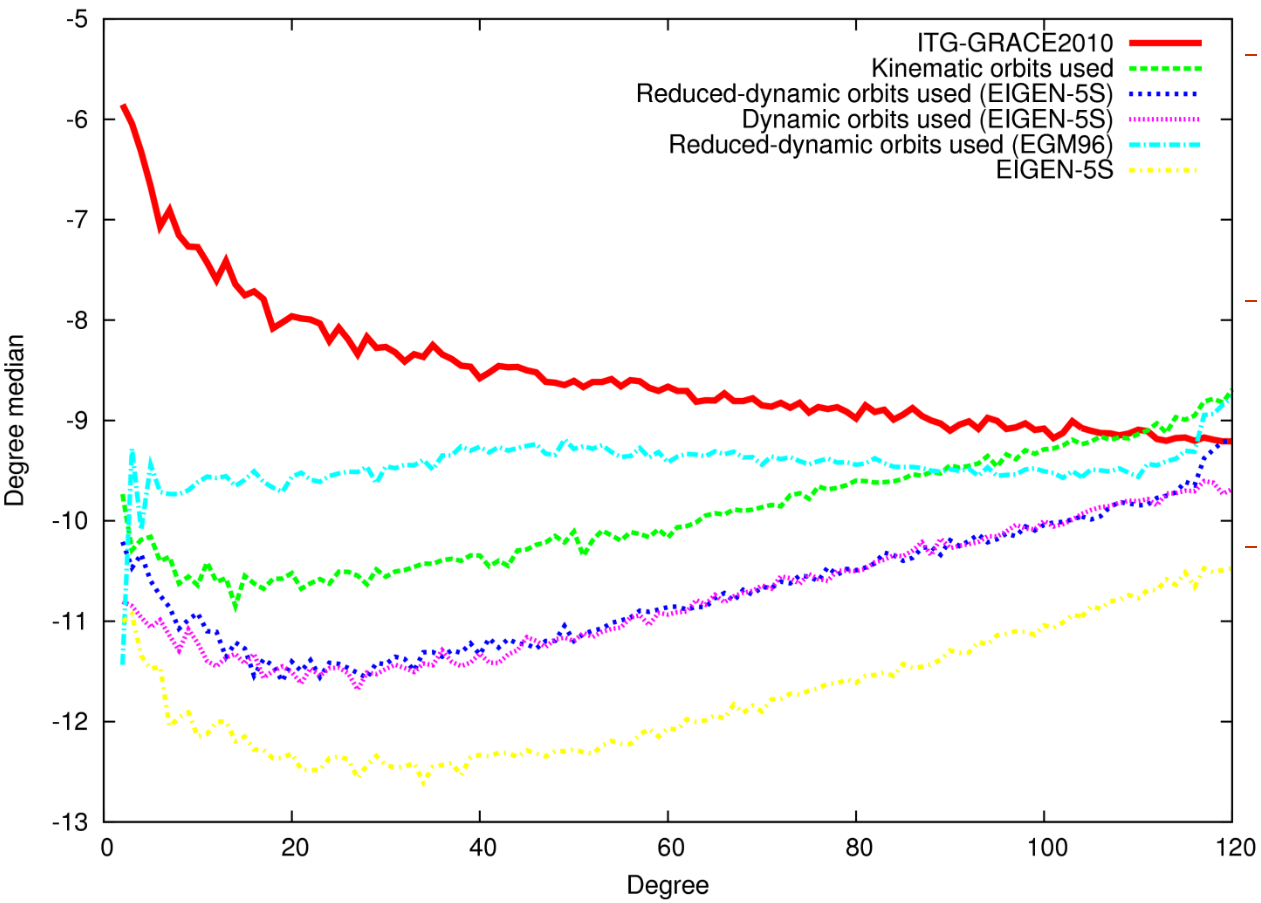
Experiment 1: Use of kinematic orbits from GOCE HPF
Kinematic positions are not affected by an a priori gravity field model

Experiment 2: Use of reduced-dynamic orbits from GOCE HPF
The GRACE gravity field model EIGEN-5S is used for generating the reduced-dynamic orbits. The trajectories are, in essence, error-free particular solutions of the equation of motion defined by EIGEN-5S

Experiment 3: Use of purely dynamic orbits using EIGEN-5S
Trajectories parametrized by just six initial conditions have been generated as particular solutions of the equation of motion defined by EIGEN-5S. They contain almost no independent information

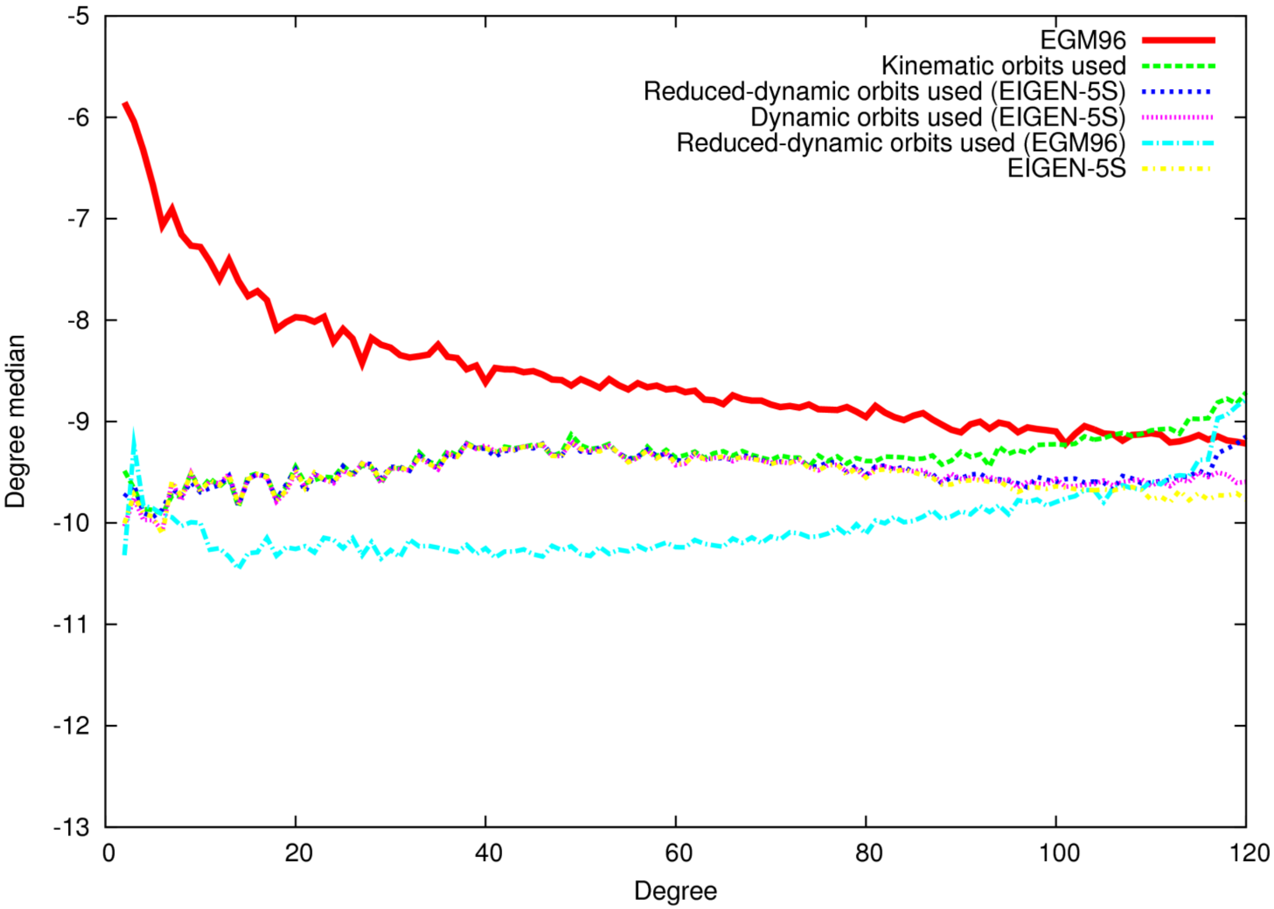
Experiment 4: Use of reduced-dynamic orbits using EGM96

Using Reduced-Dynamic Positions



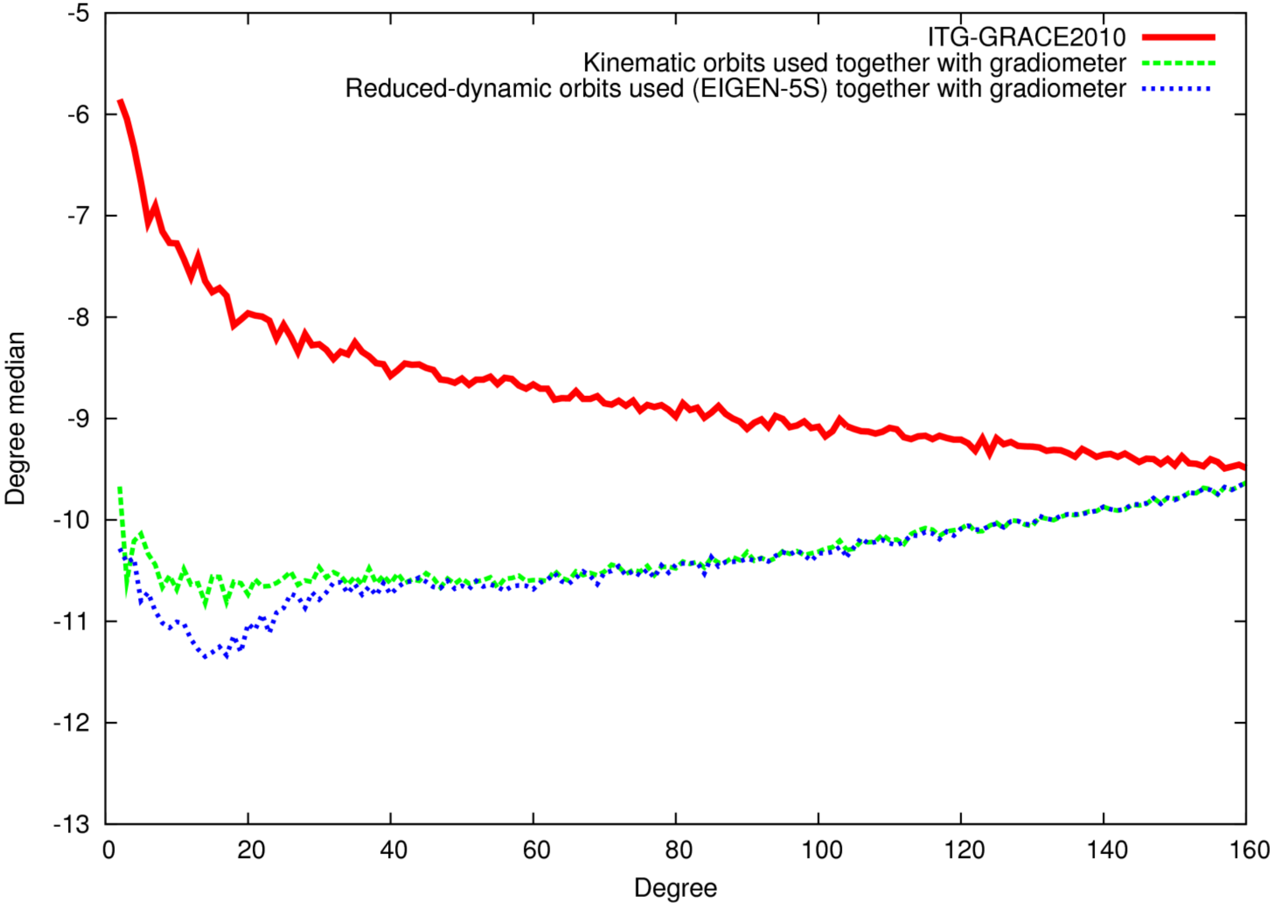
- **Important to note:**
  - **Exp 1 yields a solution representing what actually can be expected from an independent solution based on GPS data only**
  - **Exp 2 and Exp 3 yield almost identical results, which agree very well with ITG-GRACE2010 as EIGEN-5S was used for GOCE POD**
  - **Exp 4 yields a solution which does not agree well with GRACE as EGM96 was used for POD**

Using Reduced-Dynamic Positions



- **Important to note:**
  - Exp 4 provides a solution which agrees best with EGM96

Using Reduced-Dynamic Positions



- **Important to note:**
  - By varying the scaling ratio between GPS and gradiometer NEQs the GRACE impact could be tuned to any level desired

Continuation of the Talk

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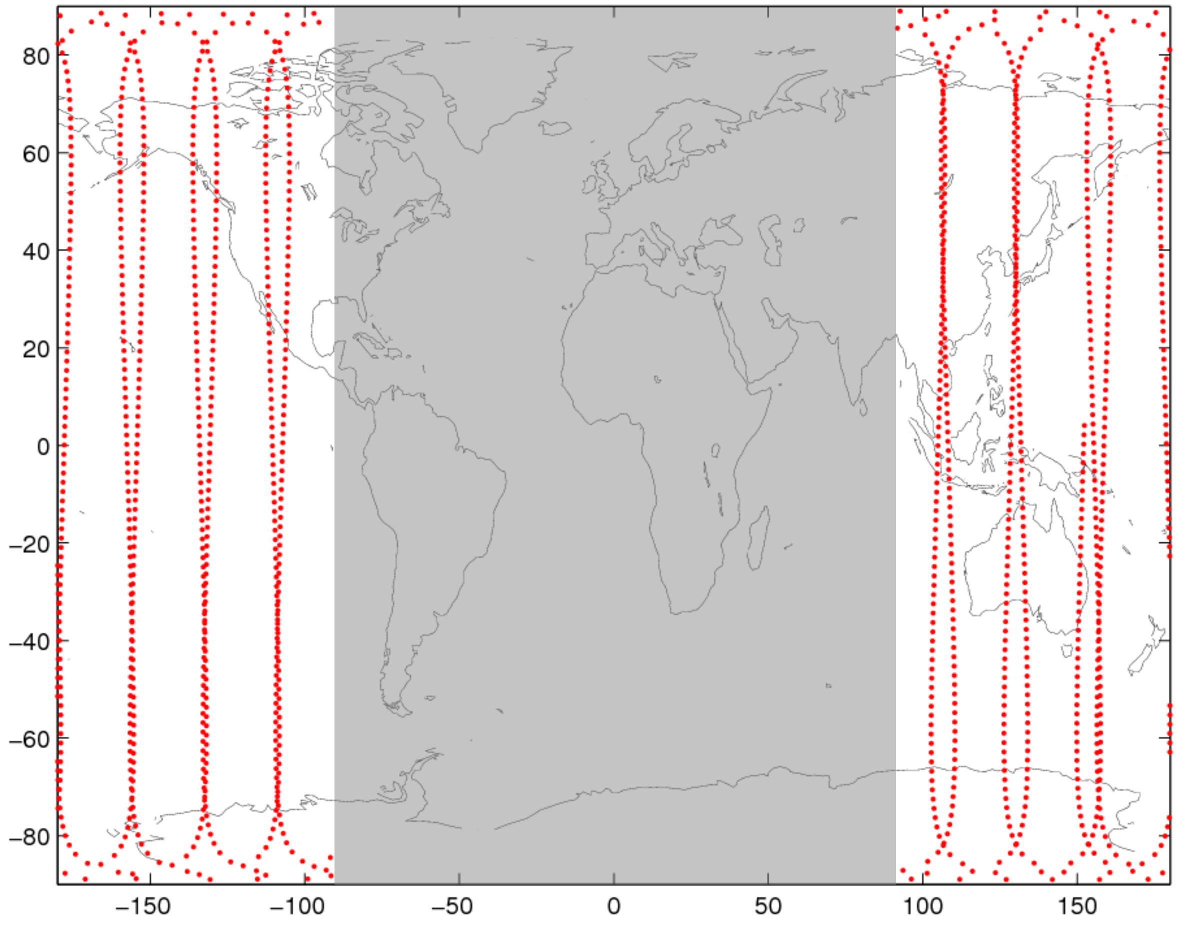
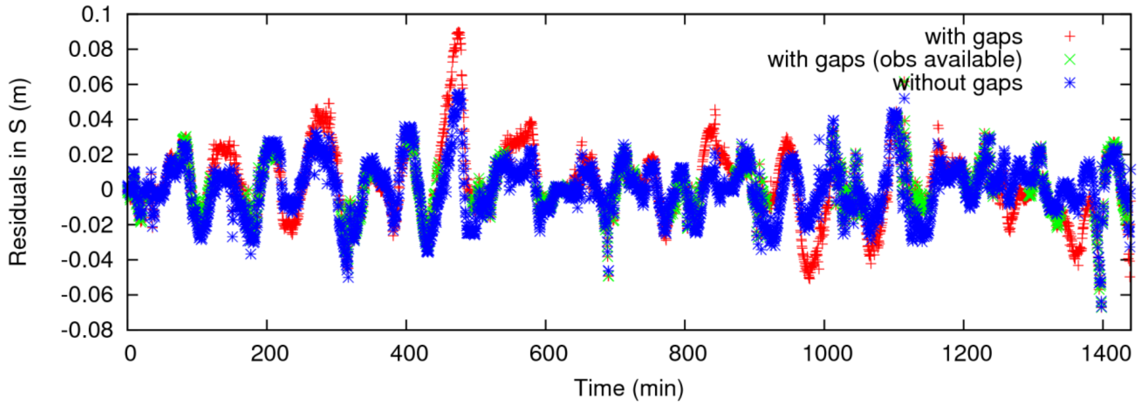
Coverage-Experiments with GRACE

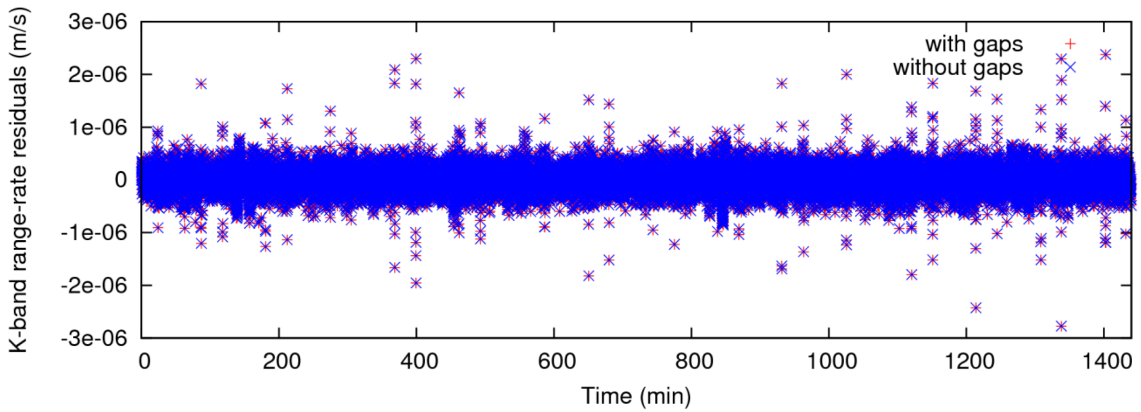
not covered by kinematic positions



An artificial degradation of the coverage with kinematic positions is used in the following to illustrate the impact of a “far-side effect” for $-90° < \lambda < 90°$ on the combined orbit and gravity field determination, whereas the K-Band observations are continuously available.

Coverage-Experiment 1

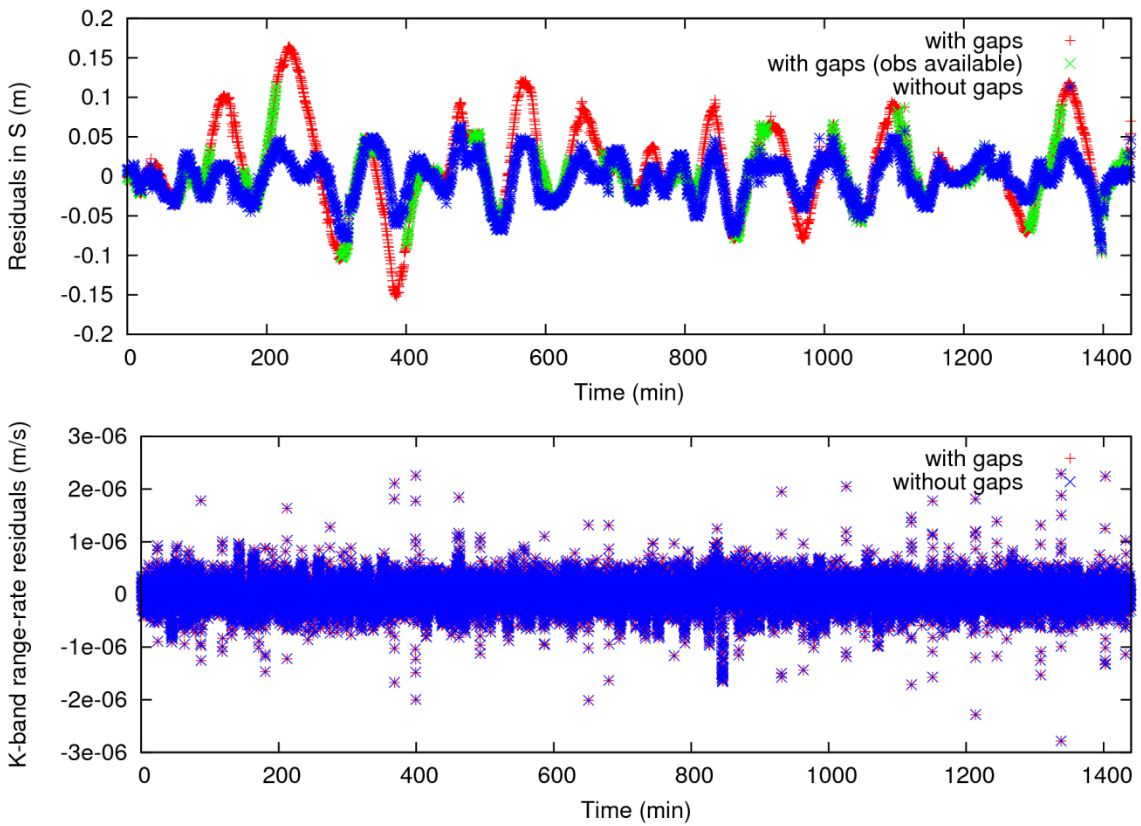




A priori orbits are exactly generated in this way for monthly GRACE gravity field recovery at AIUB

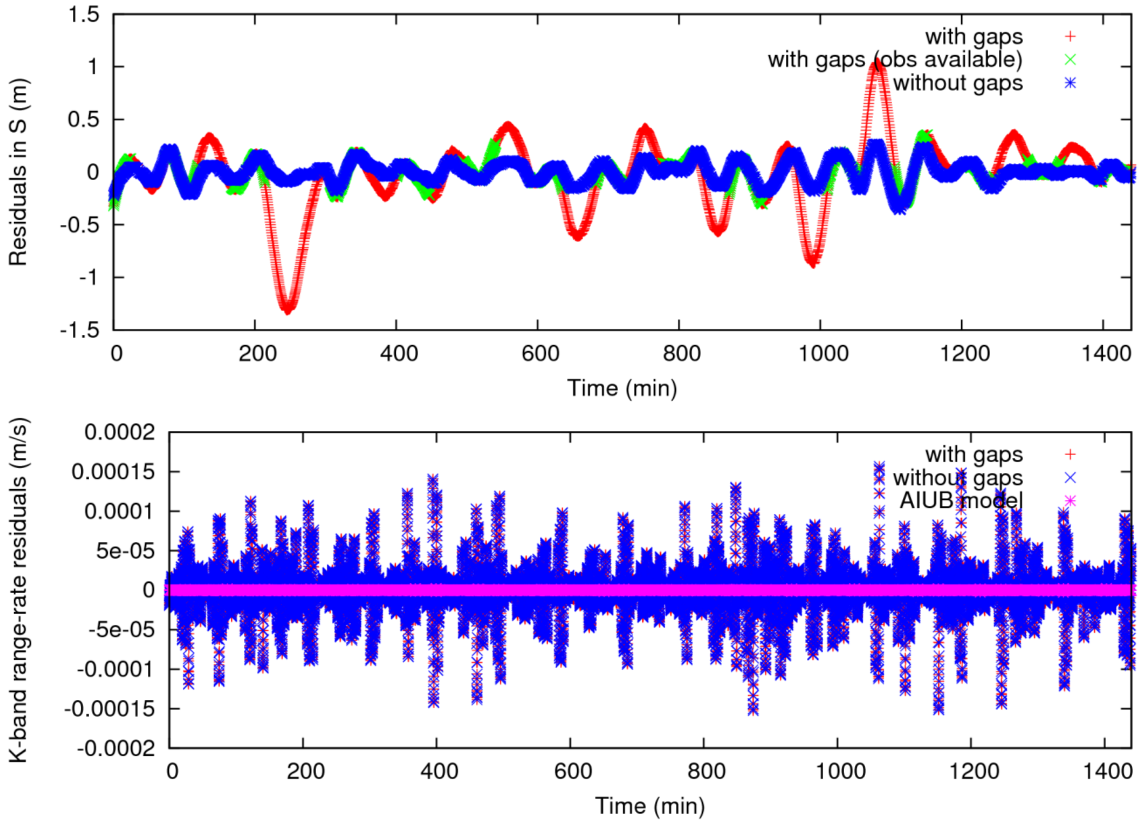
Along-track position residuals for GRACE-A from a combined orbit determination using K-Band and position pseudo-observations with gaps and without gaps. The AIUB-GRACE03S static gravity field model up to n_{max} = 160 was used together with accelerometer data. Almost no differences are seen in the K-Band residuals.

Coverage–Experiment 2



Along-track position residuals for GRACE-A from a combined orbit determination using K-Band and position pseudo-observations with gaps and without gaps. The AIUB-GRACE03S static gravity field model up to n_{max} = 160 was used, but **no** accelerometer data was used. Larger differences are now seen in the positions, but not in the K-Band residuals.

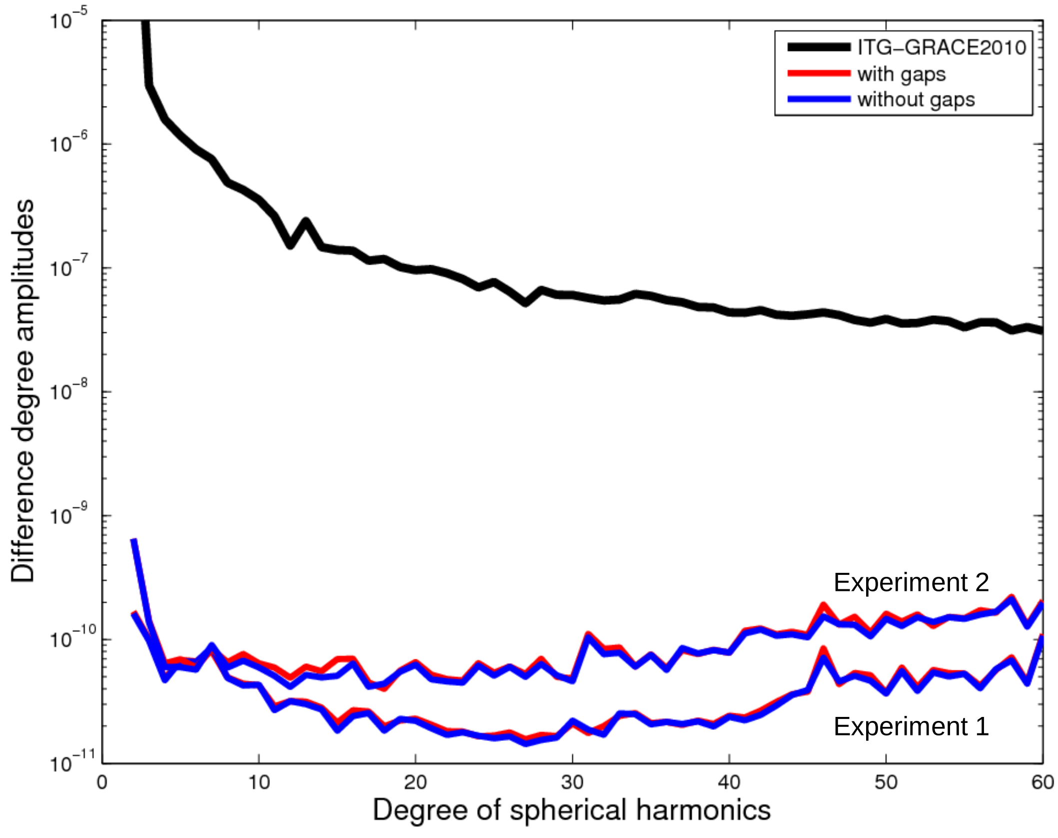
Coverage–Experiment 3



A priori orbits are generated in a similar way for GRAIL gravity field solutions at AIUB

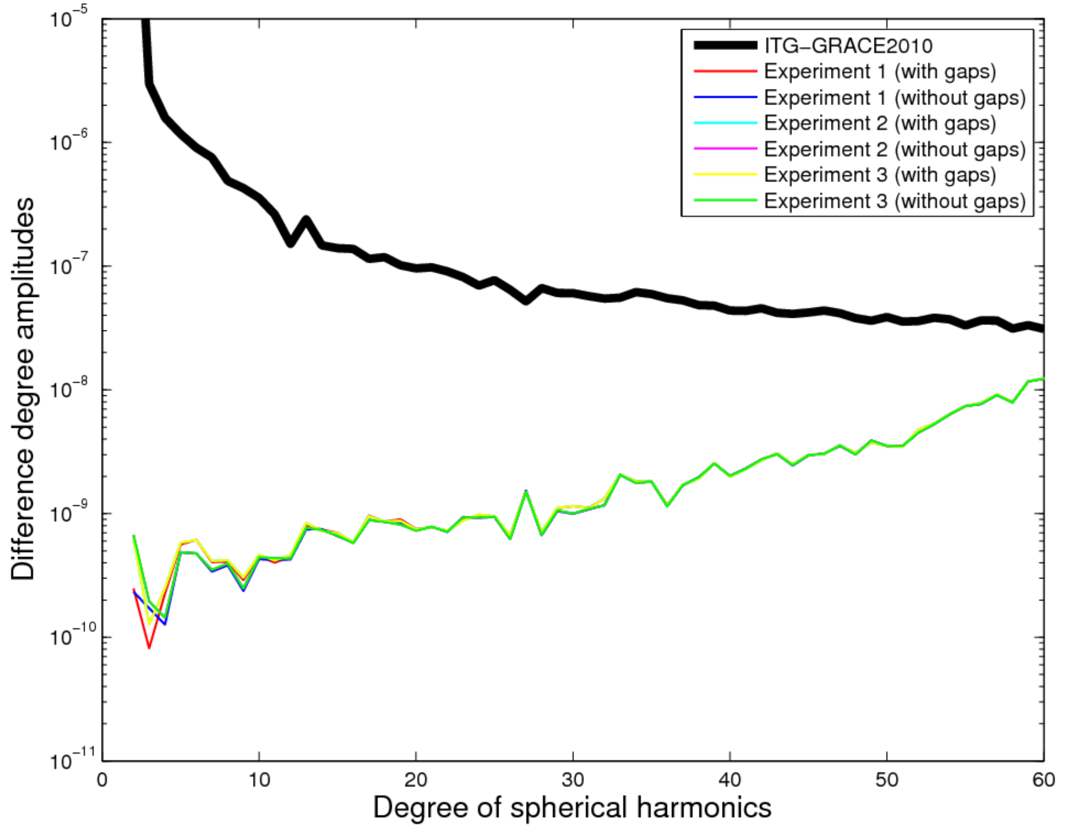
Along-track position residuals for GRACE-A from a combined orbit determination using K-Band and position pseudo-observations with gaps and without gaps. The **EGM96** static gravity field model up to n_{max} = 160 and **no** accelerometer data was used. Large differences are occasionally seen in the positions, but again not in the K-Band residuals.

Gravity Fields from Coverage Experiments



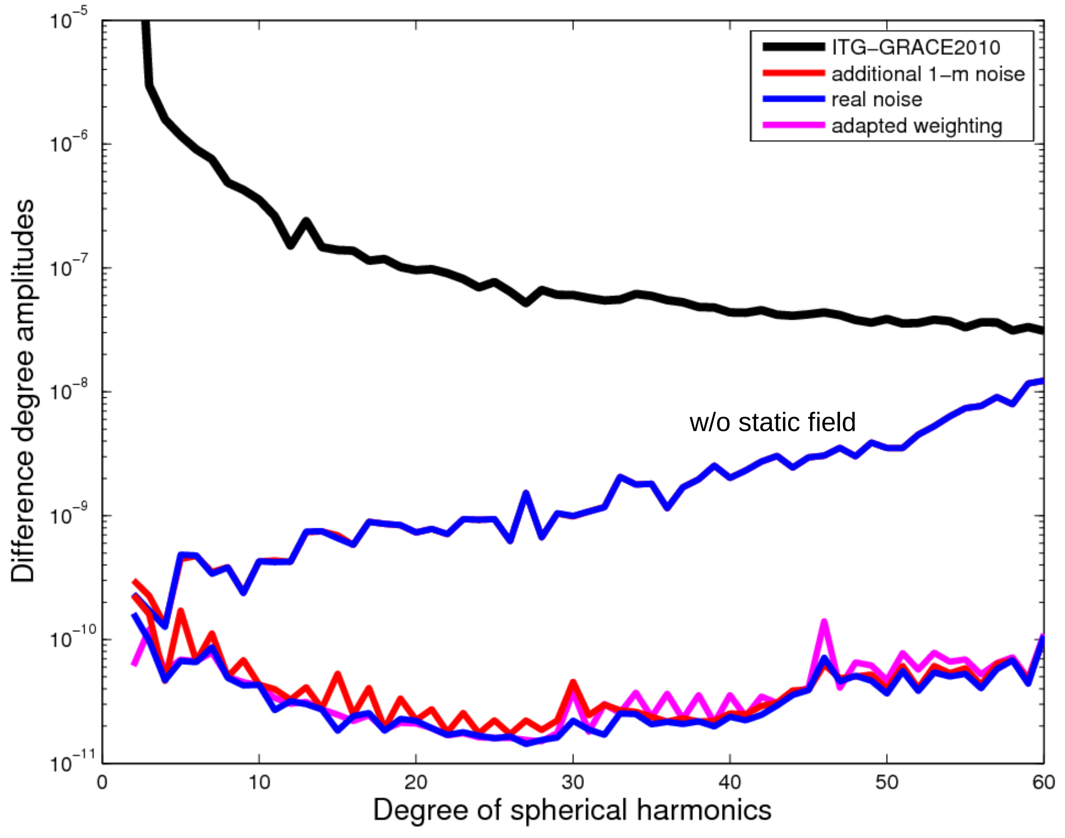
Difference degree amplitudes of a monthly gravity field solution wrt ITG-GRACE2010 when fixing degrees 61 to 160 to the static field AIUB-GRACE03S. Almost no differences are seen in the recovered monthly solution when **using** accelerometer data (experiment 1) or when **not using** them (experiment 2).

Gravity Fields from Coverage Experiments



Difference degree amplitudes of monthly gravity field solutions wrt ITG-GRACE2010 when **not** fixing degrees 61 to 160 to a static gravity field model. Only marginal differences are seen in the recovered monthly solutions when **using** accelerometer data (experiment 1) or when **not using** them (experiment 2), or when starting from EGM96 (experiment 3).

Gravity Fields from Noise-Experiments



Impact of an additional 1-m noise on the positions when not fixing degrees 61 to 160 to AIUB-GRACE03S. Only when fixing the high degress to a superior static field, the impact of the severely degraded positions becomes visible.

Continuation of the talk

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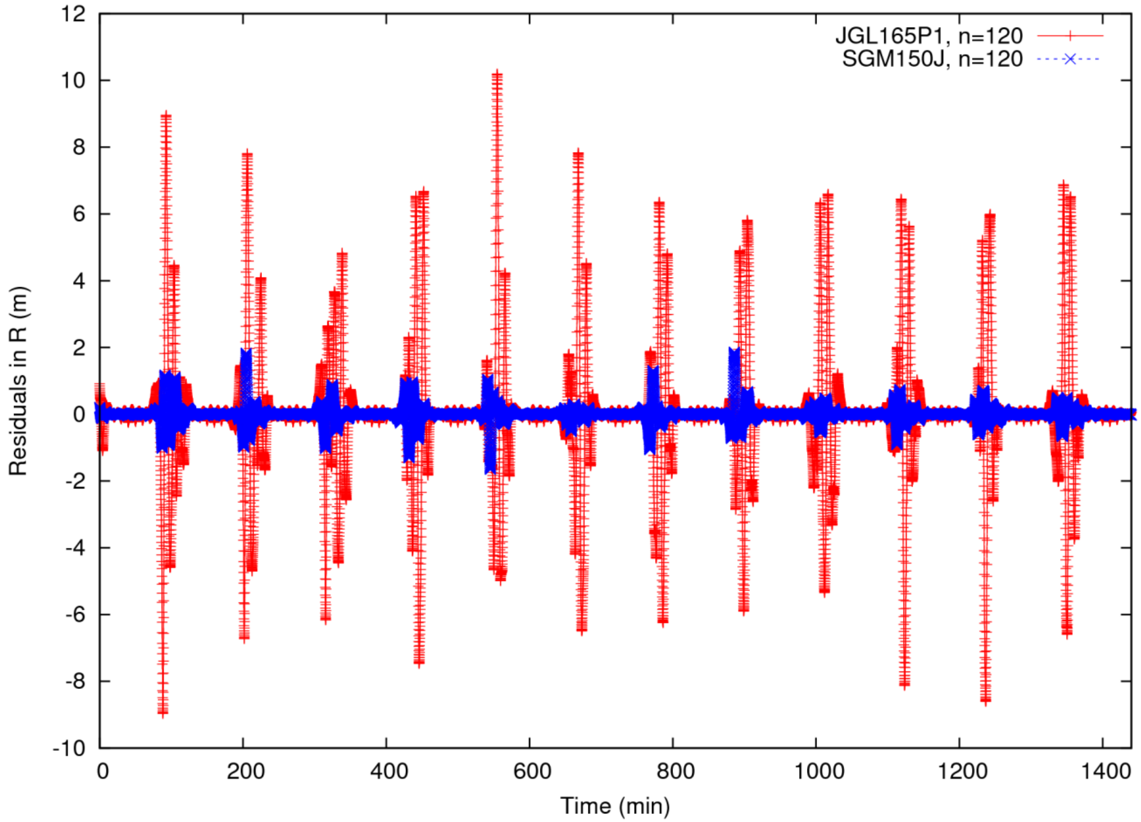
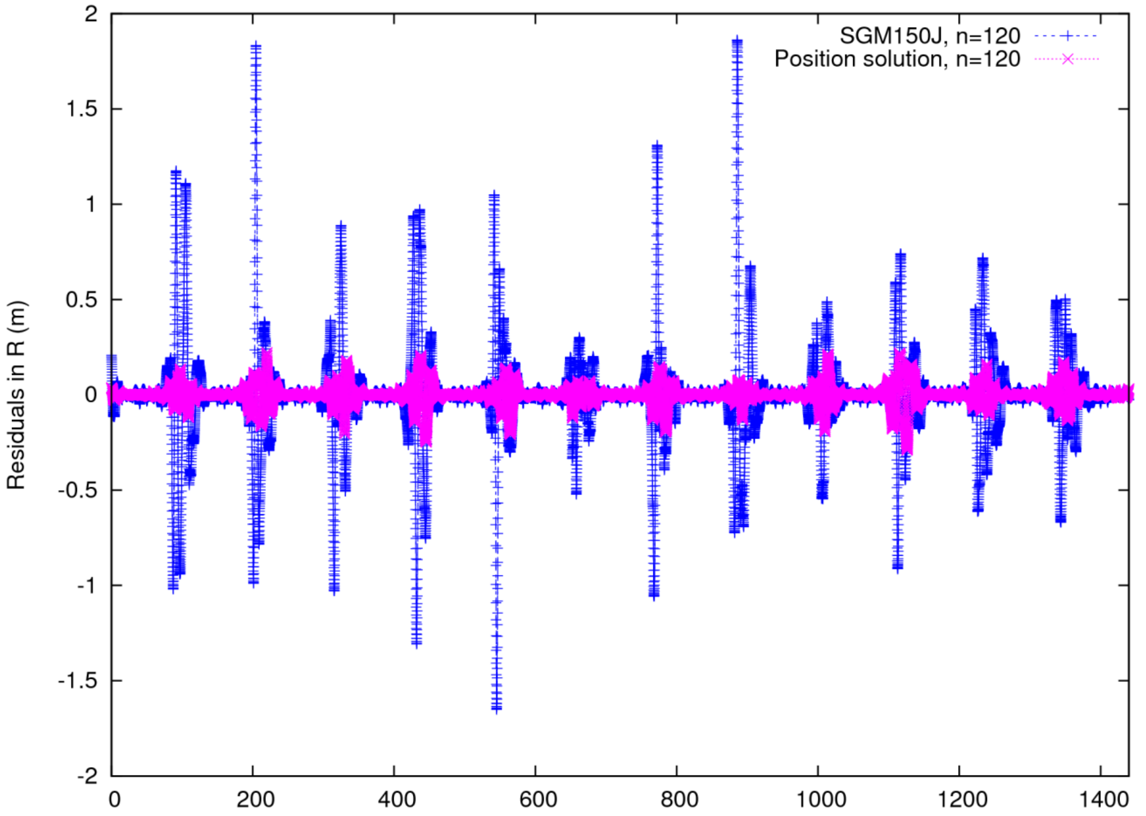
Orbit Determination from Positions



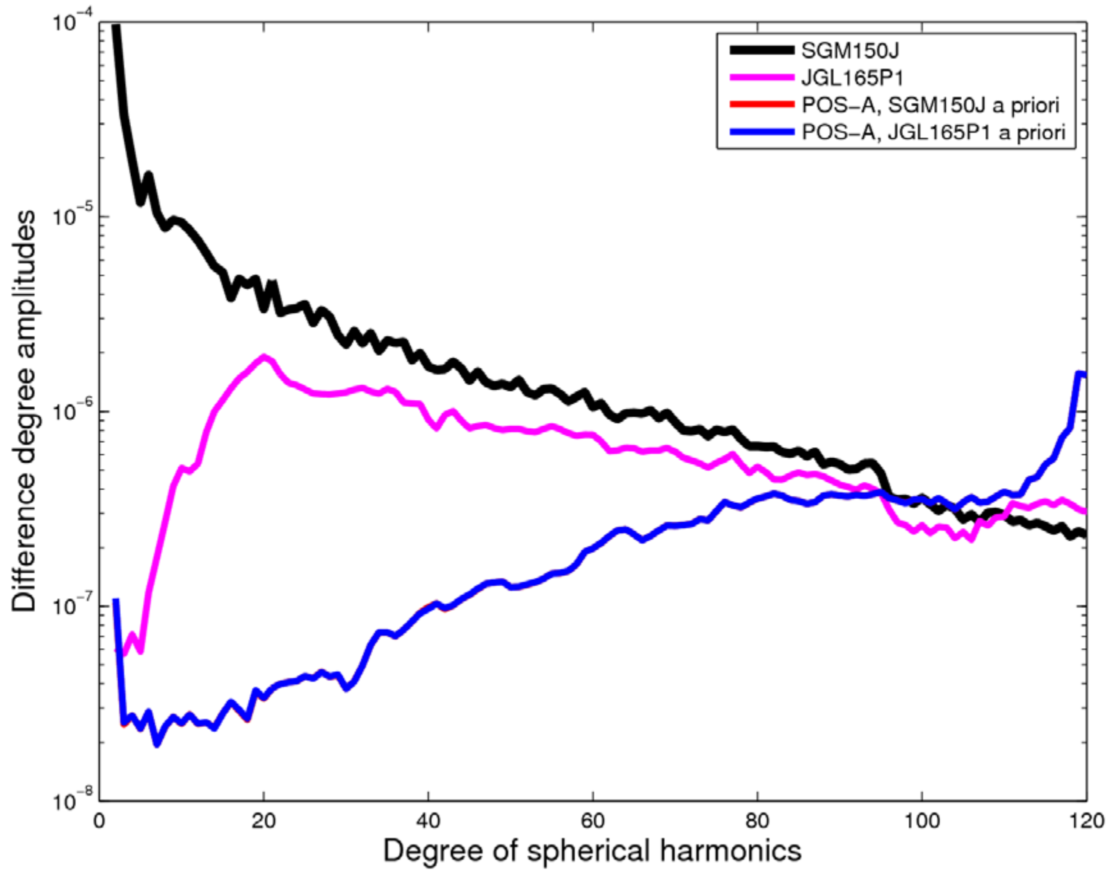
Radial position residuals for GRAIL-A from an orbit determination using position pseudo-observations. The Lunar Prospector and SELENE gravity field models up to n_{max} = 120 were used. Larger residuals on the far-side are clearly visible for both a priori gravity field models.

Orbit Determination from Positions



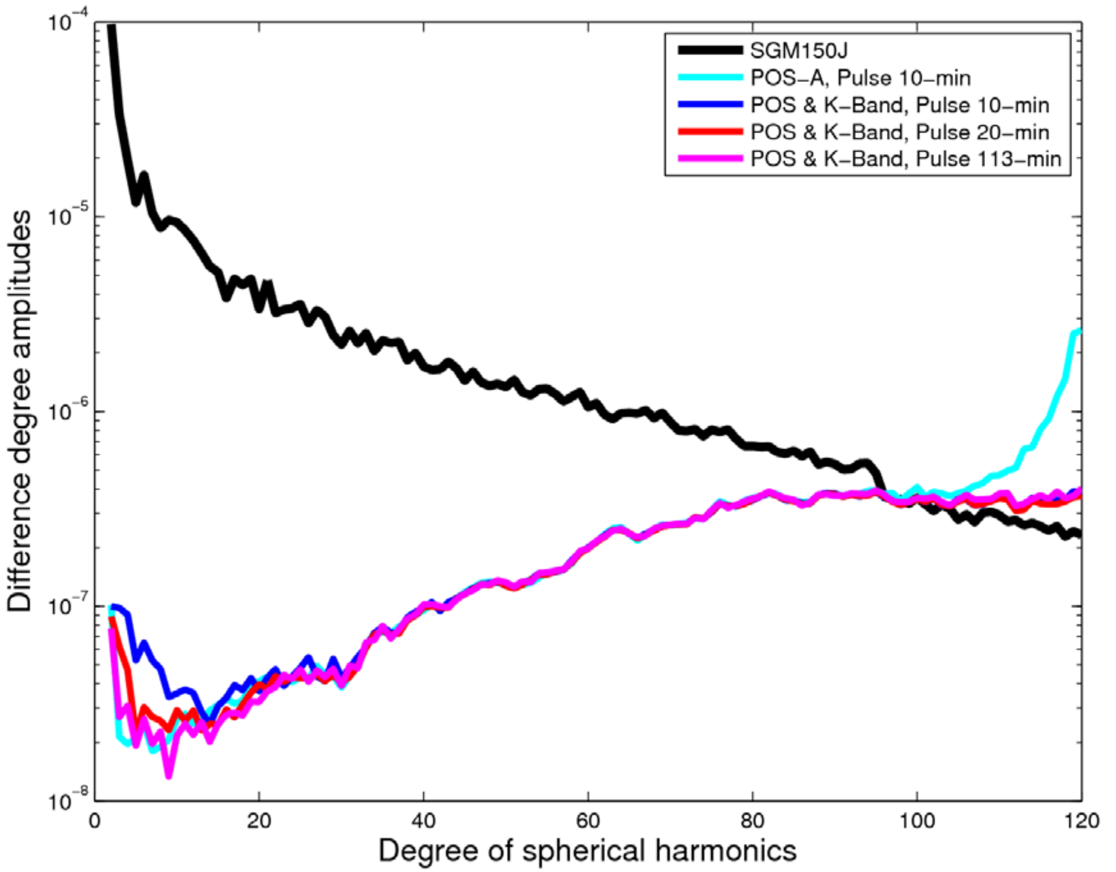
Radial position residuals for GRAIL-A from an orbit determination using position pseudo-observations. The SELENE and an AIUB model based on positions up to n_{max} = 120 were used. Residuals on the far-side are further reduced, but are still larger than on the near-side.

Gravity Field Solutions from Positions



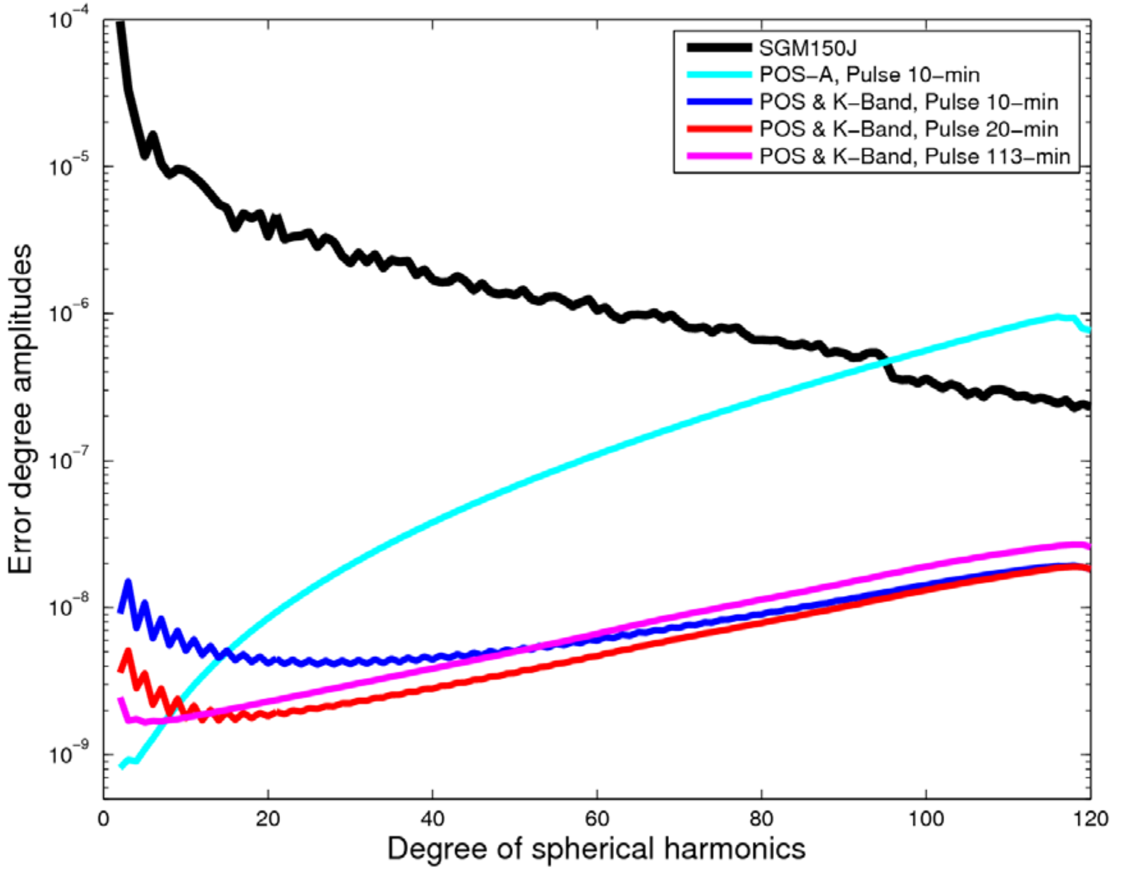
Differences between the Lunar Prospector und the **SELENE** a priori gravity field model are huge. Independently of the used a priori gravity model, the solutions based on GRAIL-A position pseudo-observations match the SELENE solution rather well.

Solutions from Positions and K-Band



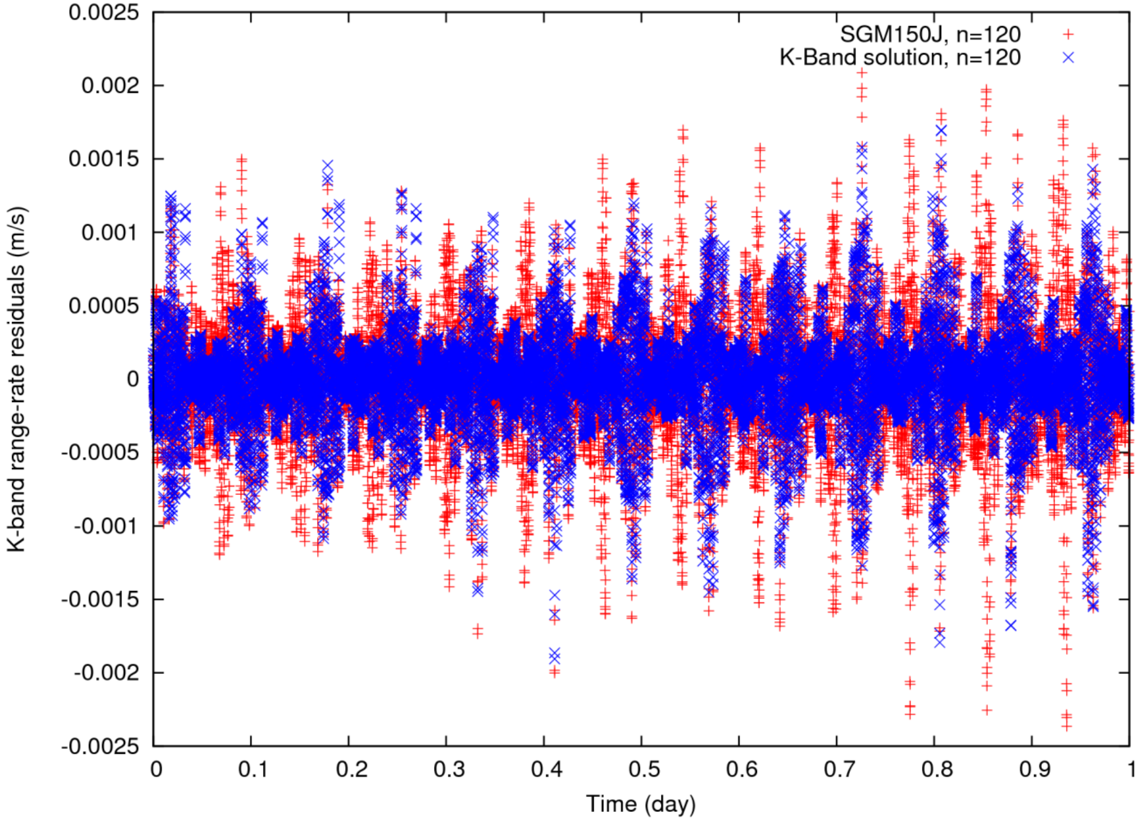
The additional use of the K-Band data illustrates that 10 min empirical parameters already absorb too much gravity signal. Almost identical differences above degree 35 illustrate that the **SELENE** reference field is no longer able to indicate the differences between the different solutions.

Solutions from Positions and K-Band



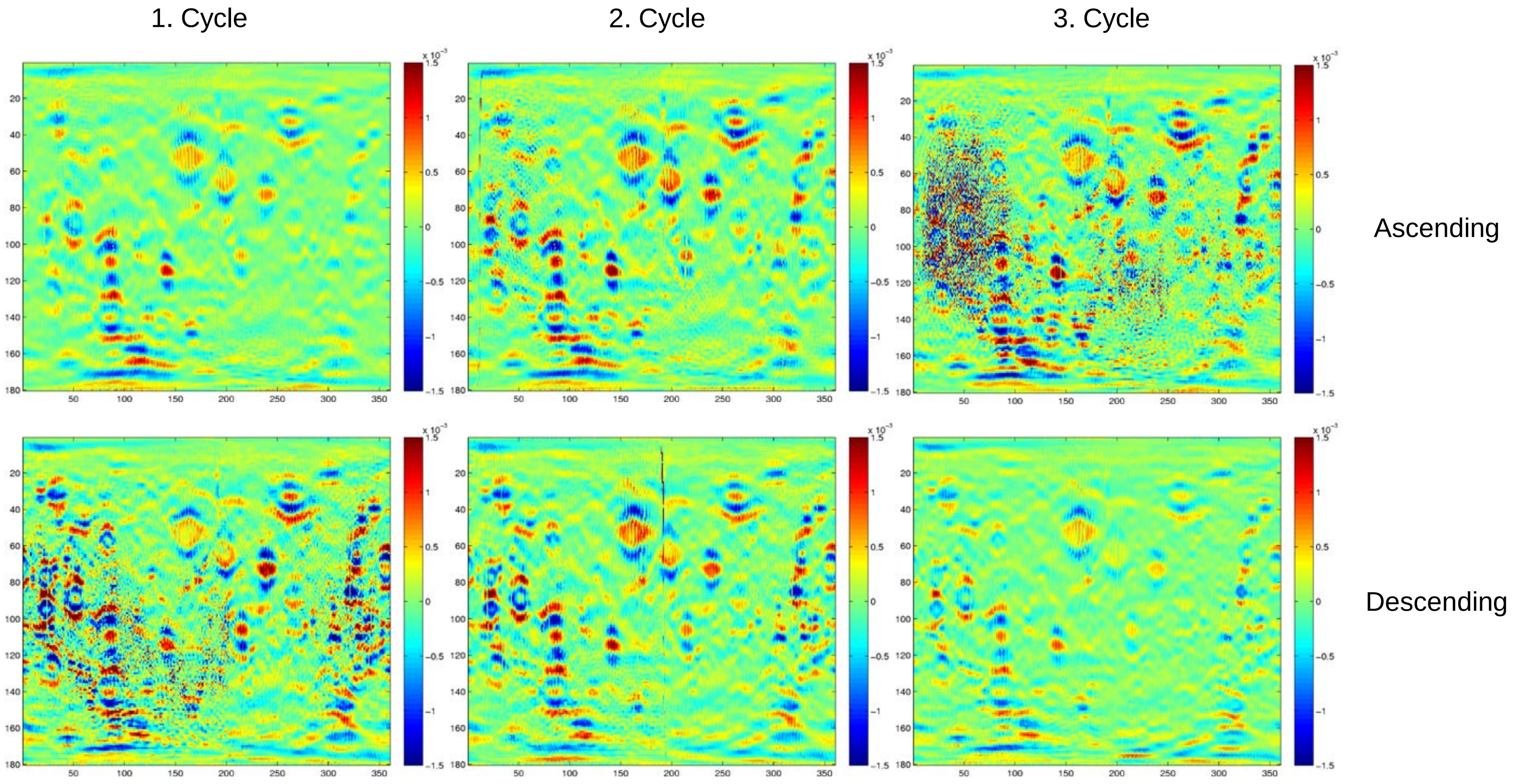
The formal errors indicate that 20 min empirical parameters is currently a reasonable choice to absorb deficiencies of the orbit model.

K-Band Residuals



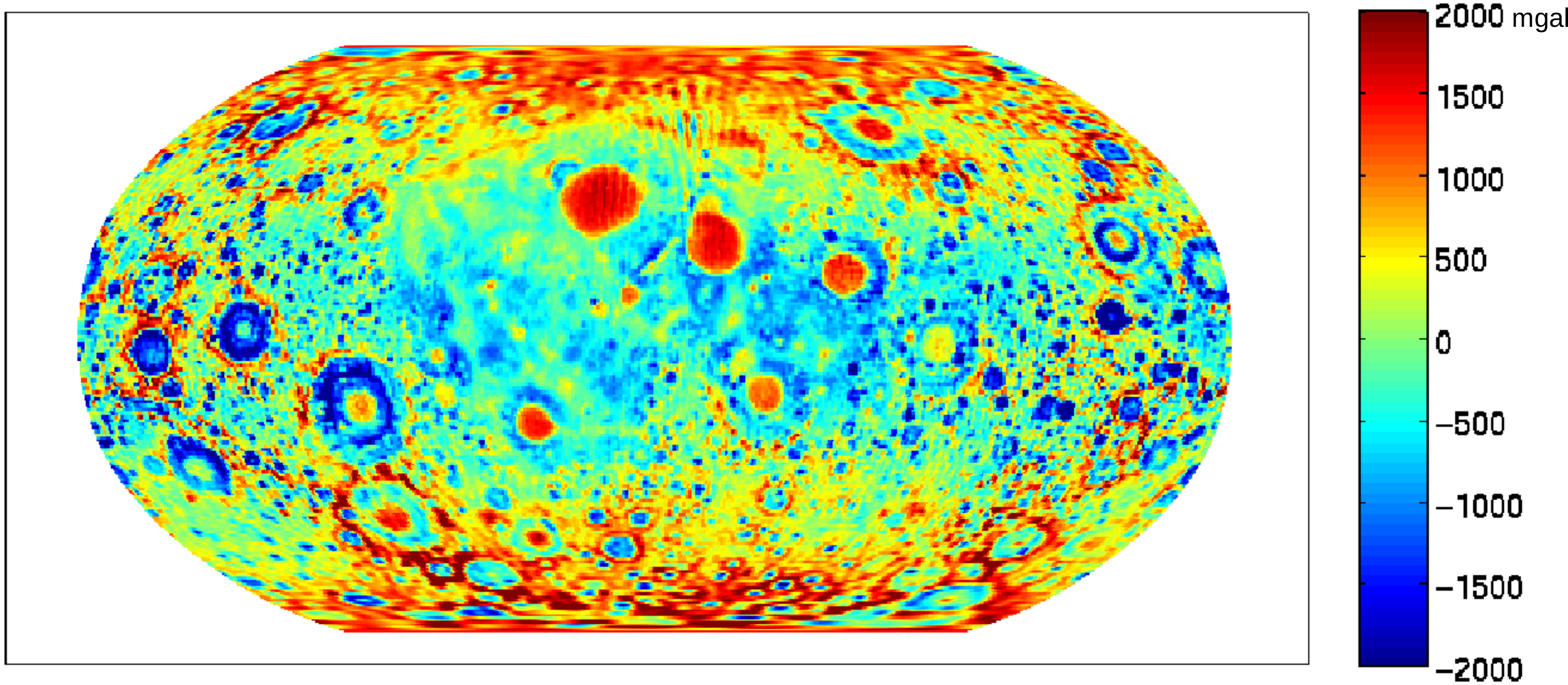
K-Band residuals of the combined gravity field solution. An improvement with respect to the SELENE solution can be seen, but the residuals still contain a lot of systematic signal …

K–Band Residuals



…, which is, fortunately to a large extent, related to yet unmodeled gravity field signatures. The different sensitivities observed for the ascending and descending orbital arcs are related to the varying orbital altitude.

Gravity Anomalies up to degree 120 and 160



Gravity anomalies from the combined gravity field solutions up to n_{max} = 120 bzw. 160. For the higher resolution solution, however, not only additional details but also artifacts (stripes) start to appear. Their origin needs to be further investigated.

Conclusions

- **Biased solutions when using reduced-dynamic orbit positions as pseudo-observations for GOCE long-wavelength gravity field recovery**

  => Implementation of DSN analysis is a must for GRAIL

- **Almost no degradation of GRACE gravity field recovery when kinematic positions are used with**
  - artificially reduced geographical coverage
  - artificially reduced accuracy

  => Encouraging for GRAIL

- **First GRAIL results are very promising**
  - Very high sensitivity to small-scale structures
  - ...