Orbit and Gravity Field Solutions from Swarm GPS Observations - First Results

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Introduction

Although ESA's Earth Explorer Mission Swarm is primarily dedicated to measure the Earth's magnetic field, it may also serve as a gravity field mission. Equipped with GPS receivers, accelerometers, star-tracker assemblies and laser retro-reflectors, the three Swarm satellites are potentially capable to be used as a high-low satellite-to-satellite tracking (hl-SST) observing system, following the missions CHAMP (first single-satellite hl-SST mission), GRACE (twin-satellite mission with additional ultra-precise low-low SST) and GOCE (single-satellite mission additionally equipped with a gradiometer). GRACE, dedicated to measure the time-variability of the gravity field, is the only mission still in orbit, but its lifetime will likely end before launch of its follow-on mission GRACE-FO in August 2017 primarily due to aging of the onboard batteries after meanwhile more than 12 years of operation.
Swarm is probably a good candidate to provide time-variable gravity field solutions and to close a potential gap between GRACE and GRACE-FO. Consisting of three satellites, Swarm also offers to use inter-satellite GPS-derived baselines as additional observations. However, as of today it is not clear if such information will substantially improve the gravity field solutions. Nevertheless, the properties of the Swarm constellation with two lower satellites flying in a pendulum-like orbit and a slightly differently inclined third satellite at higher altitude still represent a unique observing system raising expectations at least compared to CHAMP derived time-variable gravity field solutions.
Whatever processing method will be applied for Swarm gravity field recovery, its success strongly depends on the quality of the Swarm Level 1b data as well as the quality of the derived Swarm orbits. With first Level 1b data sets available since mid of May 2014 (excluding accelerometer data), some first results for Swarm orbits as well as Swarm gravity field solutions are presented here. The latter are also compared to GRACE solutions based on the same amount of data and processing methods.

Orbit Solutions

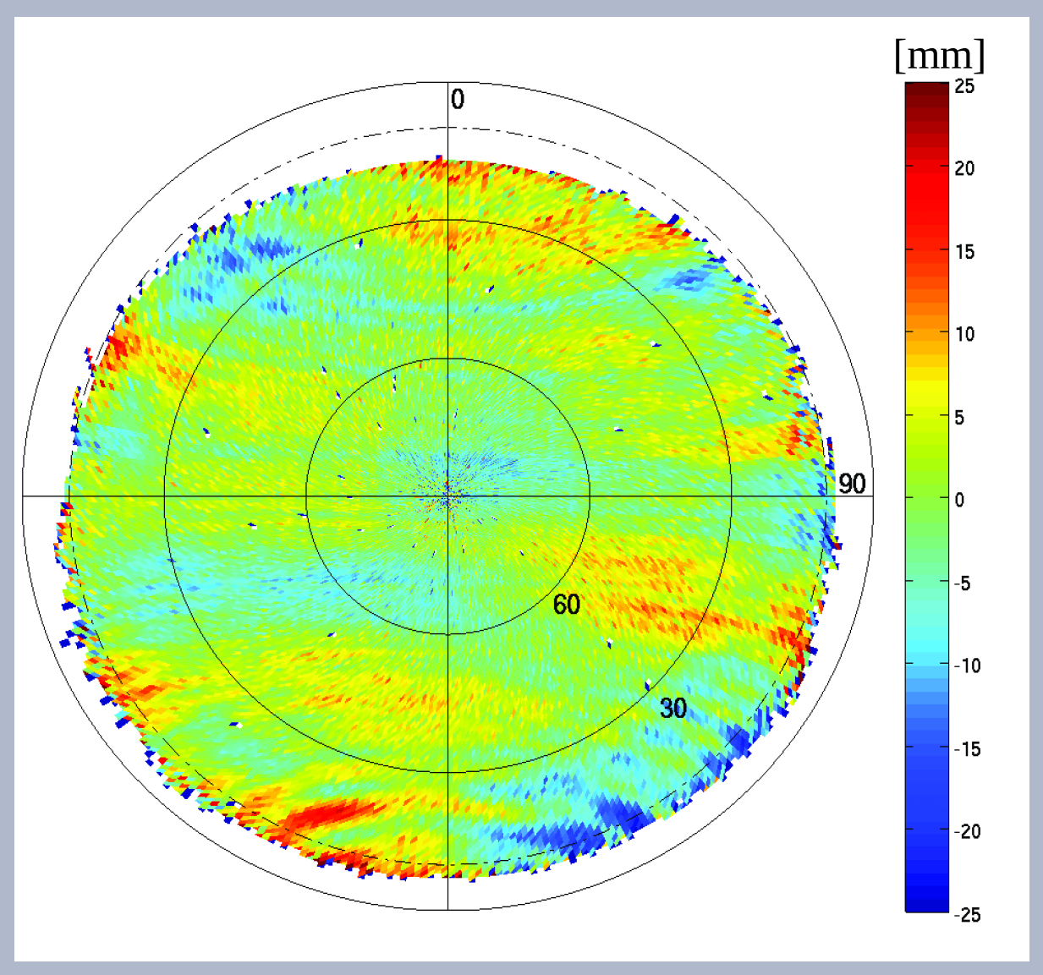

Fig.1: PCV estimation for Swarm C based on 30 days of phase observation residuals of the reduced-dynamic orbit determination. Maps for Swarm A and B look very similar.

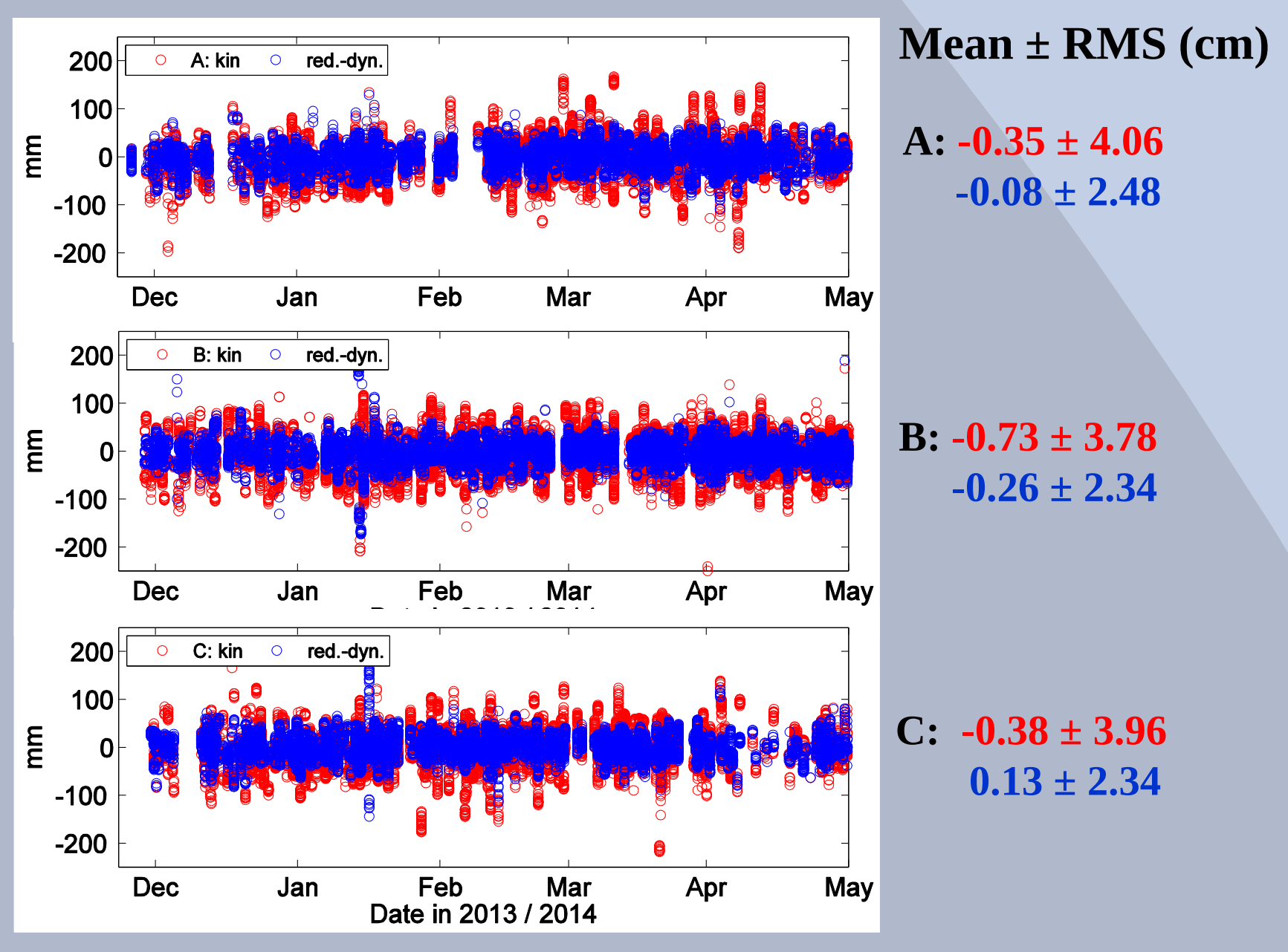

Fig.2: SLR validation for kinematic and reduced-dynamic orbits for the time interval from 25 November 2013 – 30 April 2014 (A:142, B:147, C:130 days).

Reduced-dynamic & kinematic orbit determination at AIUB[1]

Software tool
- Bernese GNSS Software

Data
- undifferenced ionosphere-free GPS code & carrier-phase observations
- final CODE GPS ephemeris and 5-sec clocks
- IGS08.atx GPS antenna phase center variation (PCV) map for GPS satellites
- estimated PCV map for Swarm (Fig. 1)
- attitude from quaternion data

Models
- Earth gravity: EGM2008 120x120
- ocean tides: FES2004

Estimated parameters
- initial state at beginning of 24-hour arc
- epoch-wise receiver clock corrections
- carrier-phase ambiguities
- constant empirical accelerations over 24 hours
- 6-minute piecewise constant empirical accelerations (constrained)

Validation of Swarm orbits against SLR (Fig. 2) yields promising results for reduced-dynamic orbits (~2.5 cm RMS). SLR validation of kinematic orbits is significantly worse (~4 cm RMS), which is probably caused by the receiver limitation to track only 8 satellites simultaneously.

Comparison of reduced-dynamic and kinematic orbits shows:
- differences between both types of orbits are larger than for other LEO satellites[2]
- radial direction shows largest differences (mean of daily RMS: ~10 cm for Swarm A)
- larger noise of kinematic orbit positions around geomagnetic poles (ascending and descending passes) and equator (descending passes only) (Fig. 3)

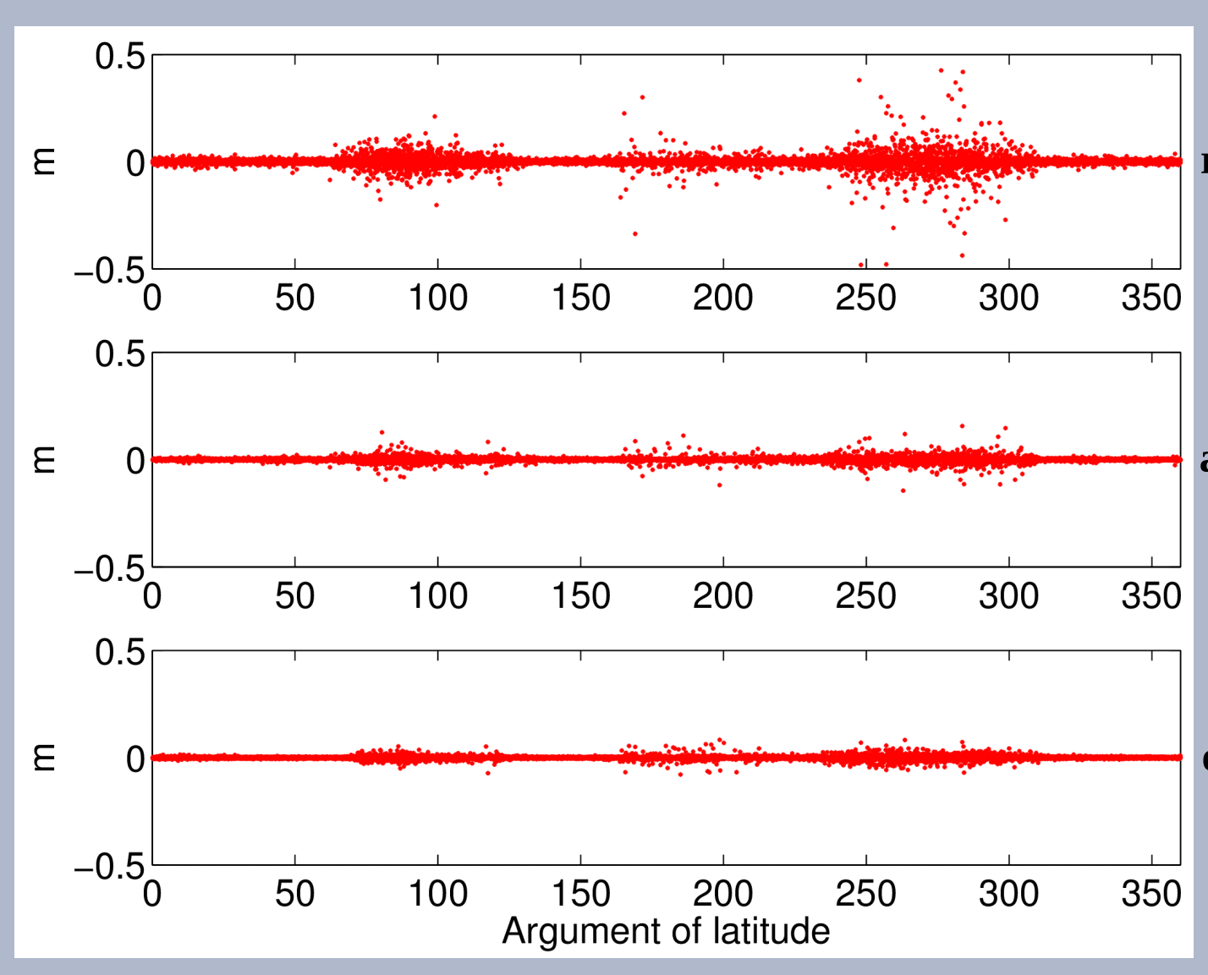

Fig. 3: Time-differenced residuals between reduced-dynamic and kinematic orbit positions of Swarm C w.r.t. argument of latitude (90/270: poles; 0/180: equator).

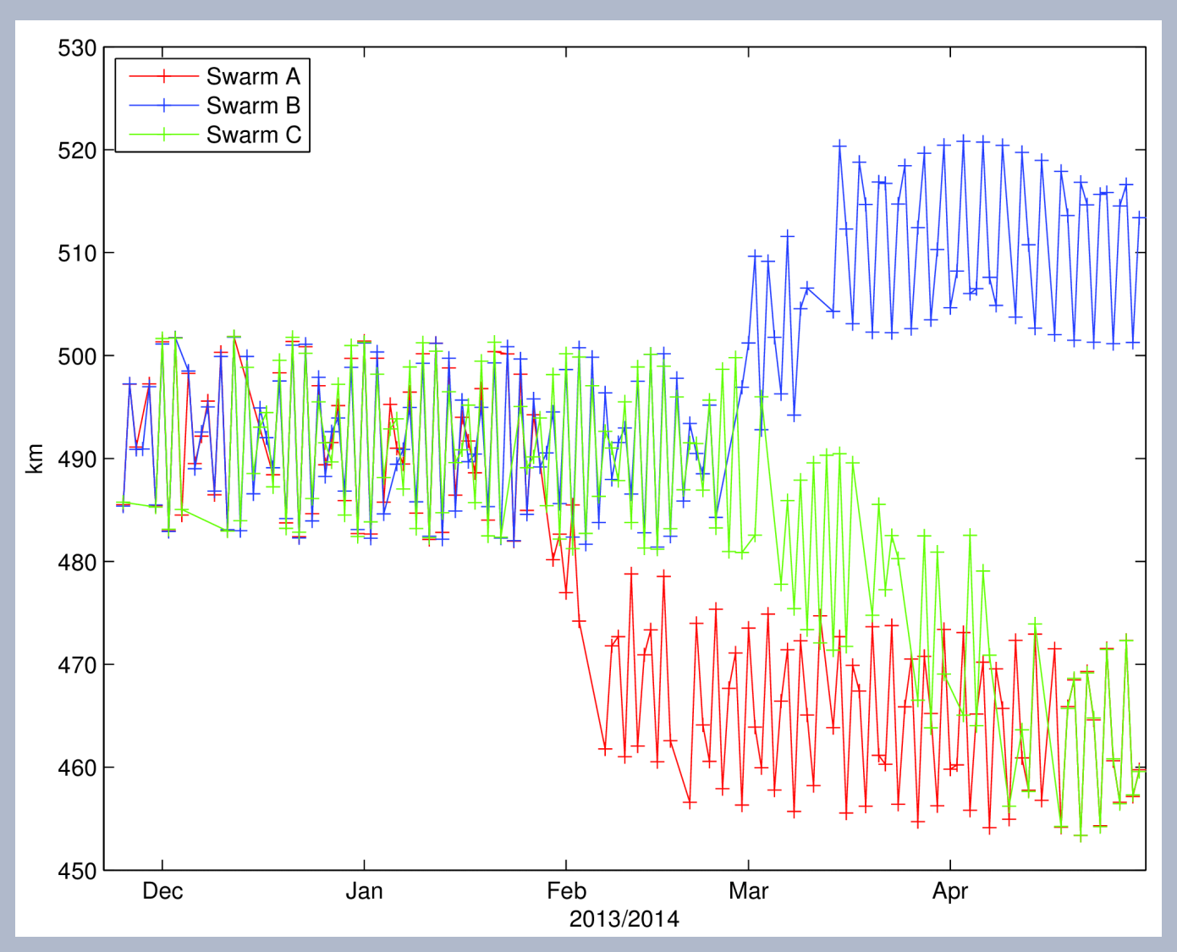

Fig. 4: Oscullating semi-major axis at midnight for Swarm A, B and C.

Dynamic orbit determination at GFZ[3]

Software tool
- EPOS-OC Software

Data
- undifferenced ionosphere-free GPS code & carrier-phase observations
- GFZ-internal GPS ephemeris with 30-sec clocks (interpolated to 1 sec)
- relative PCVs for GPS satellites
- no PCV map for Swarm so far
- no attitude (not yet available)
- preliminary CoG

Models
- Earth gravity: EIGEN-CG01C-2 120x120
- ocean tides: GRIM5-C1 / FES95.2.1
- drag: DTM94bis / CHAMP macro model

Estimated parameters
- initial state at beginning of 24-hour arc
- epoch-wise receiver clock corrections
- carrier-phase ambiguities
- 1 C_r/arc and 4 C_d/arc
- 45-min 1/rev and 2/rev empirical accelerations in along-track & cross-track (constrained)

Time interval
- 25 – 27 January 2014 (Swarm A only)

Results
- SLR fit: 3.62 cm RMS (145 obs.)
- Comparison with reduced-dynamic orbits from AIUB (RMS/Mean [cm], 8631 obs.): 5.47/3.61 (radial), 4.09/1.71 (along-track), 5.96/-4.78 (cross-track)

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Gravity Field Solutions

Gravity field recovery using the Celestial Mechanics Approach (CMA)[4]

General aspects
- the CMA is a generalized orbit determination procedure
- orbit, gravity field and stochastic parameters are estimated simultaneously
- CMA is applied here to Swarm as well as to GRACE kinematic orbits

Pseudo-observations
- screened kinematic orbit positions (weighted according to the epoch-wise covariance information from the kinematic orbit determination)

Models
- same as for orbit determination (see left panel)

Estimated parameters
- initial state at beginning of 24-hour arc
- constant empirical accelerations over 24 hours
- 15-minute piecewise constant empirical accelerations (constrained)
- spherical harmonic gravity field coefficients up to degree/order 60x60 (coefficients for degrees/orders 61-120 fixed to EGM2008)

Results

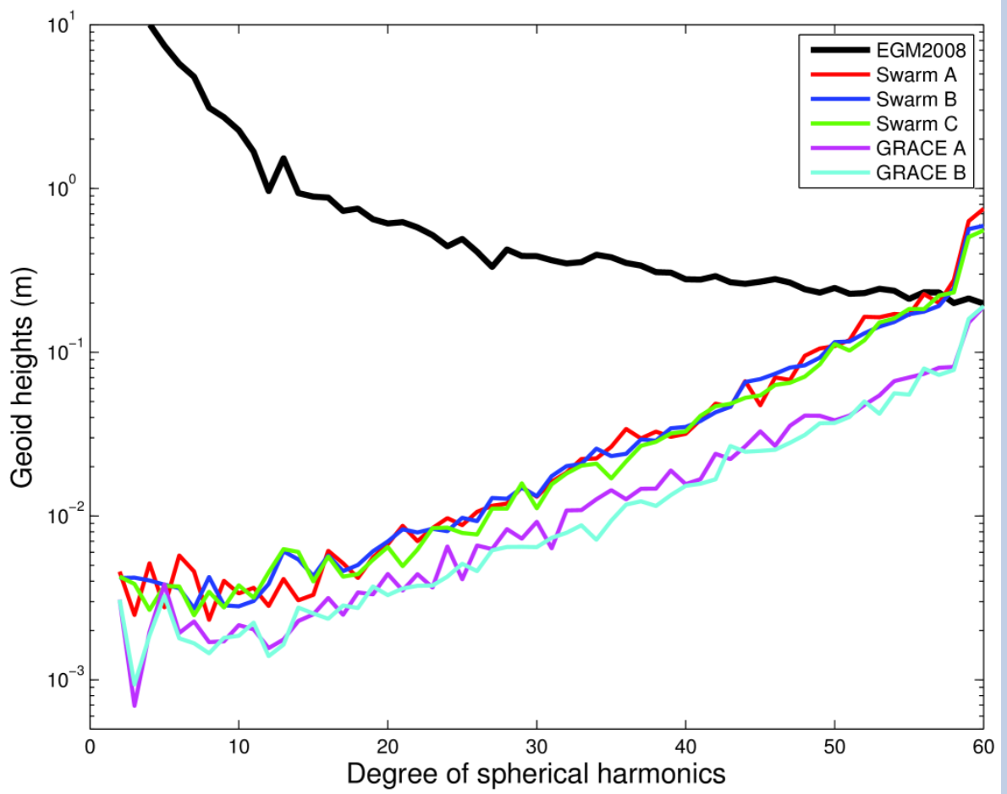

Fig. 5: Difference degree amplitudes w.r.t. EGM2008 in terms of geoid height [m] for individual Swarm and GRACE 2-month solutions.

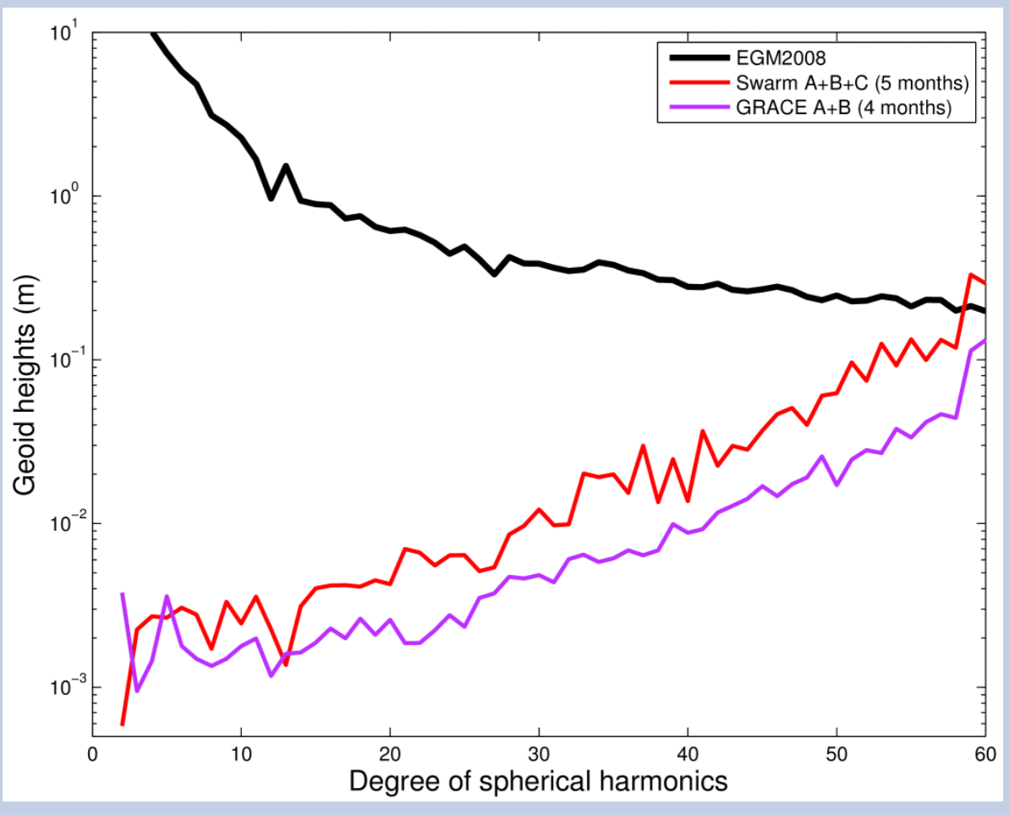

Fig. 6: Difference degree amplitudes w.r.t. EGM2008 in terms of geoid height [m] for a combined Swarm 5-month solution and a combined GRACE 4-month solution.

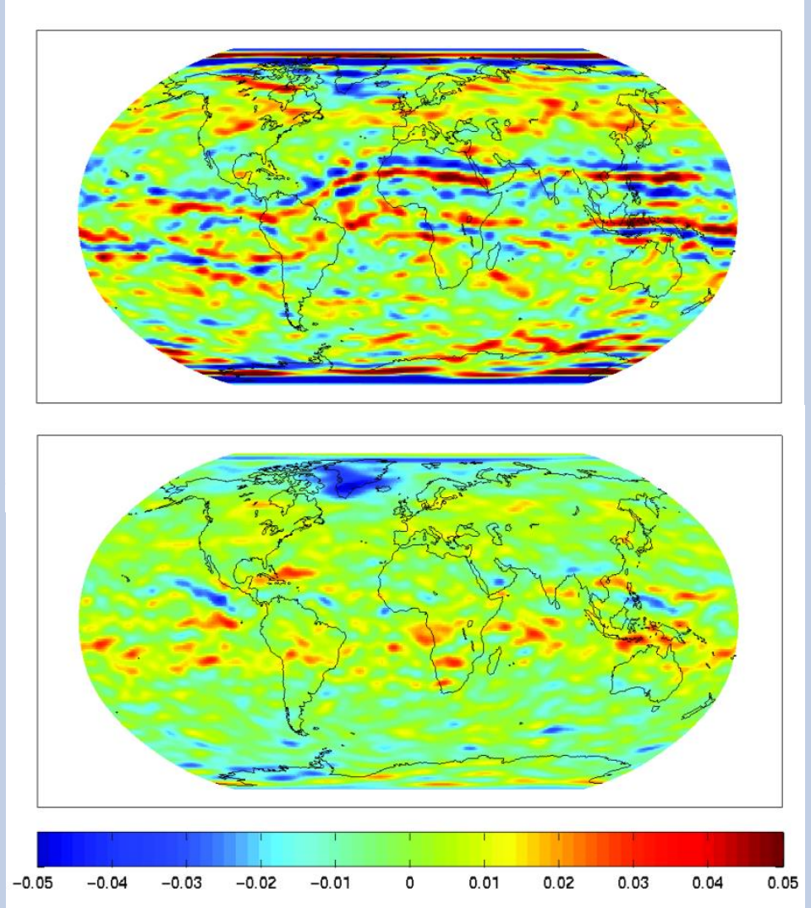

Fig. 7: Geoid differences [m] w.r.t. EGM2008 after 400km Gaussian smoothing for a combined Swarm 5-month solution (top) and a combined GRACE 4-month solution (bottom).

Individual 2-month gravity field solutions (1 December 2013 - 31 January 2014) for Swarm A, B and C are very similar (Fig. 5). This time interval has been chosen as all 3 satellites were at approx. the same altitude during that period (Fig. 4). Fig. 5 also shows that the Swarm solutions are significantly worse than individual GRACE A and B solutions covering the same period. This conclusion can also be drawn from Fig. 6 where combined Swarm A+B+C and GRACE A+B solutions over longer time intervals are shown (combination has been performed on normal equation level). Looking at the spatial domain, Fig. 7 shows that the aforementioned larger noise in the kinematic orbit positions over the geomagnetic poles and equator is propagated into Swarm gravity field solutions. It also becomes obvious that GRACE does not suffer from this feature. Although only some very first results are presented here and further investigations are needed, the following properties of Swarm might additionally explain why the results are worse compared to GRACE: higher altitude, less GPS satellites tracked (8 vs. 10), different elevation cut-off (10° vs. 0°), worse quality of kinematic orbits.

Summary & Outlook

- Swarm orbits from AIUB reveal comparable GPS data quality for all three satellites.
- Swarm orbits from GFZ so far in a very experimental state (mainly due to missing data and information about satellites), but already of promising quality.
- Kinematic orbit positions are systematically degraded over the geomagnetic poles and along the geomagnetic equator which also propagates into gravity fields.
- Individual Swarm gravity field solutions are of comparable quality, but perform significantly worse than GRACE hl-SST solutions.
- Combined Swarm gravity field solutions show quite large improvement for degree 2 and slight improvements for other degrees.
- Use of GPS-based inter-satellite baselines, in particular baseline A-C, as additional observations might further improve Swarm gravity field solutions.

References

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