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Orbit and Gravity Field Solutions from Swarm GPS Observations

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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. 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 represent a unique observing system raising expectations at least compared to CHAMP derived time-variable gravity field solutions. 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), first results for Swarm orbits, as well as Swarm gravity field solutions are presented. The latter are also compared to GRACE GPS hl-SST solutions based on the same amount of data and processing methods.

Parametrization and Models

Reduced-dynamic and kinematic orbit determination

Data
- Undifferenced ionosphere-free GPS observations
- CODE final GPS orbits and 5 s clocks (Bock et al., 2009)
- Empirical phase center variation (PCV) maps (Jäggi et al., 2009)
- Attitude quaternions

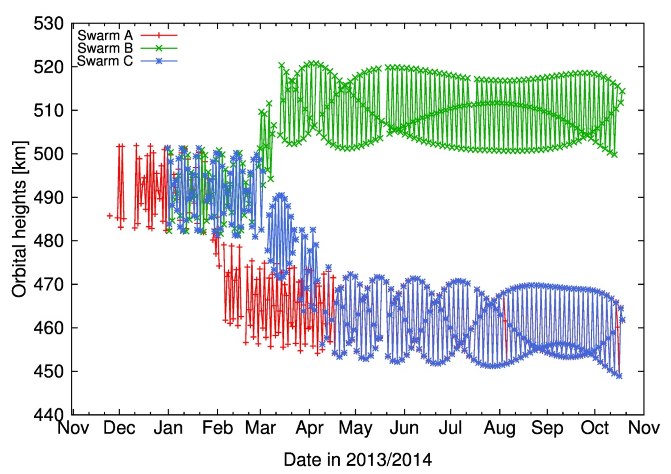
Models (reduced-dynamic):
- Earth gravity: EGM2008 120 x 120
- Ocean tides: FES2004 50 x 50

Gravity field recovery

General aspects
- the Celestial Mechanics Approach is used (CMA, Beutler et al., 2010)
- orbit and gravity field parameters are estimated simultaneously
- CMA is applied to Swarm and GRACE kinematic orbit positions

Models
- same as for orbit determination based on GPS data (see above)

Estimated parameters
- initial state at beginning of 24-hour arc
- constant empirical accelerations over 24hours
- 15-minute piecewise constant empirical accelerations (constrained)
- spherical harmonic coefficients up to d/o 60/60 (coefficients for d/o 61-120 are fixed to EGM2008)



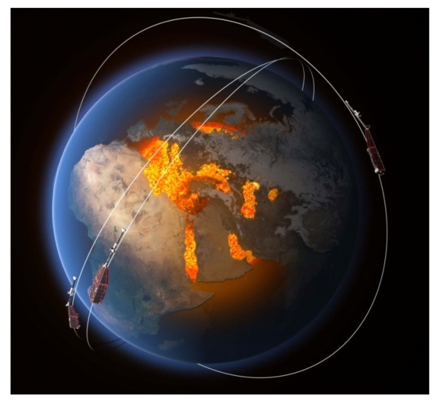


Figure: Orbital heights (left) of the three satellites of the Swarm constellation (right). Osculating semi-major axes are plotted at midnight epochs.

Orbit Solutions

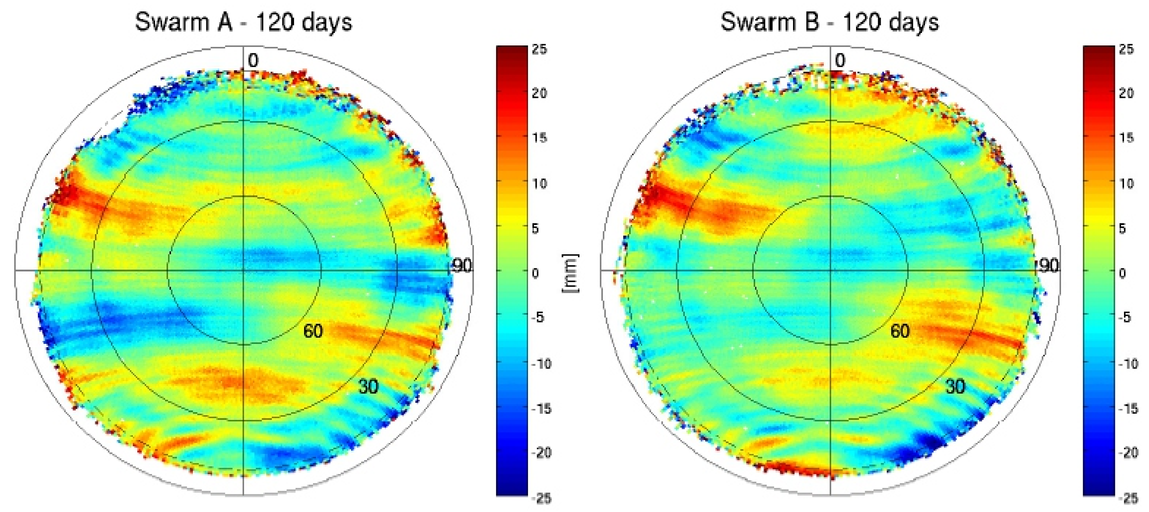


Figure: PCV pattern for Swarm A (left) and Swarm B (right) based on 120 days of GPS carrier phase residuals of the reduced-dynamic orbit determination. Small differences in the PCV maps of Swarm A and B are caused by the currently adopted individual antenna corrections added to the raw GPS observations when generating the RINEX observation files.

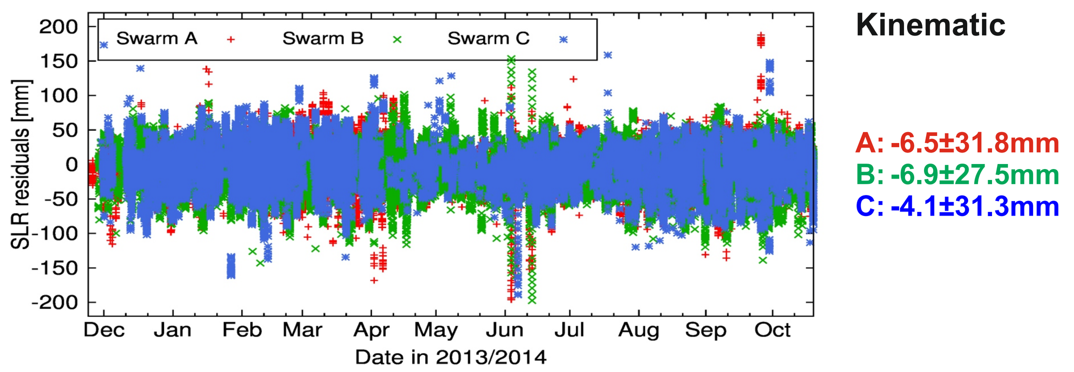


Figure: Independent Satellite Laser Ranging (SLR) validation for kinematic orbits of Swarm A,B,C for the time interval from 25 Nov 2013 to 19 Oct 2014.

GPS Data Screening

Carrier-phase residuals show systematics over the geomagnetic equator. These are related to tracking problems of the GPS receivers when the microwave signals pass regions of the ionosphere with large activity and were present already in GOCE orbits (Jäggi et al., 2014). Since this affects the kinematic orbits, the derived gravity field shows these features as well (see right part of the poster). To reduce these problems, GPS observations related to large ionosphere changes have been removed by analyzing the geometry-free linear combination.

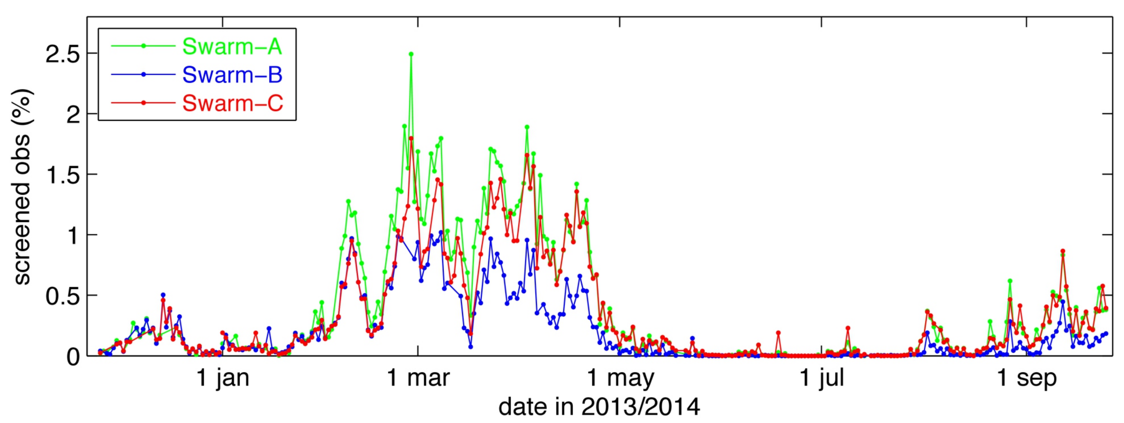


Figure: Amount of screened observations.The larger values in spring and fall reflect the increased activity of the ionosphere over the equator.

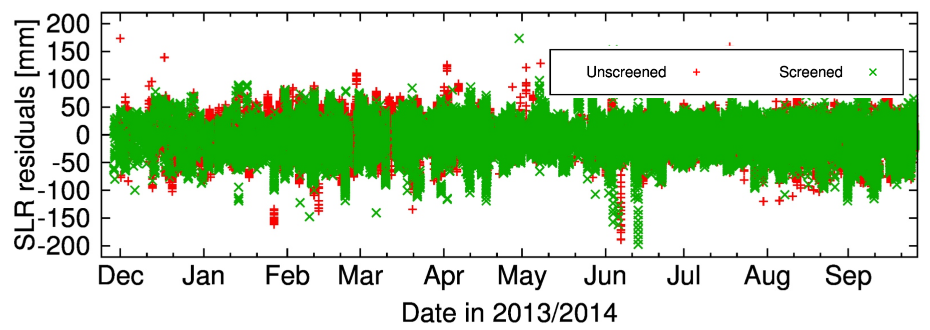


Figure: SLR residuals for kinemtic orbits for Swarm C based on original (red) and screened (green) GPS data. The orbit quality is slightly improved.

Gravity Field Solutions (original data)

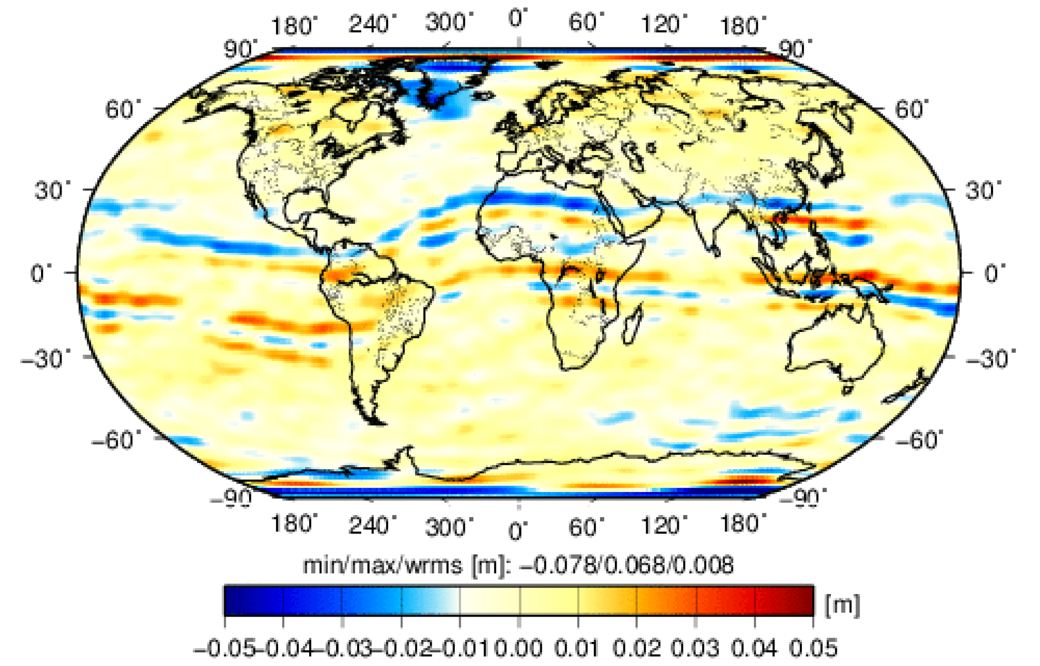


Figure: Geoid height differences wrt EGM2008 (500 km Gauss filtered) of a static gravity field solution based on kinematic positions derived from original GPS data of Swarm A,B,C (2013/12 - 2014/07). Systematic differences along the geomagnetic equator are observed.

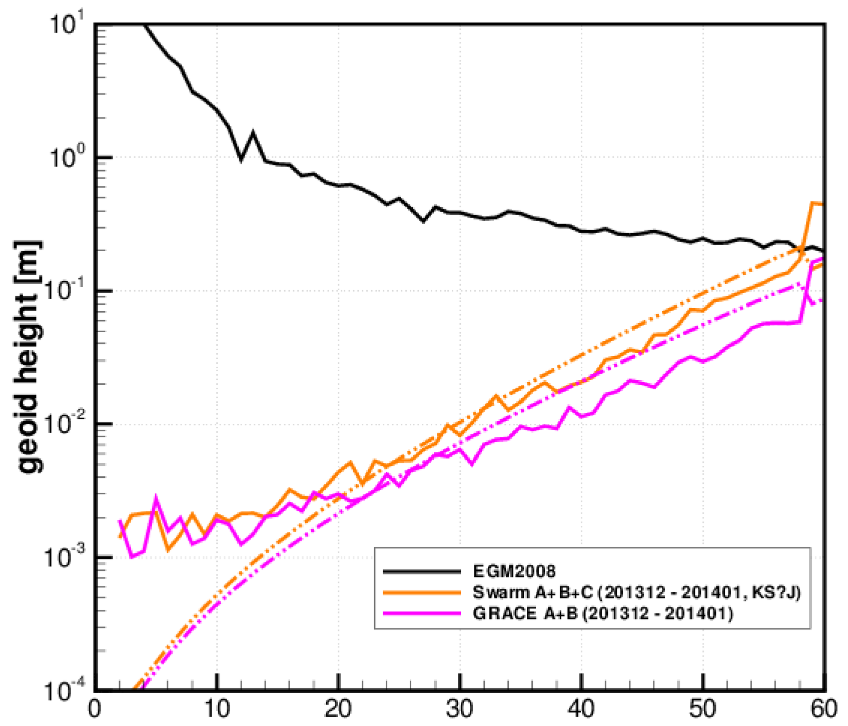


Figure: Difference degree amplitudes wrt EGM2008 and formal errors of static gravity field solutions based on two months of kinematic positions (2013/12 - 2014/07) derived from GPS data of Swarm A,B,C and GRACE A,B. Due to the lower altitude GRACE is superior at higher degrees, but a similar quality is achieved for the low degrees.

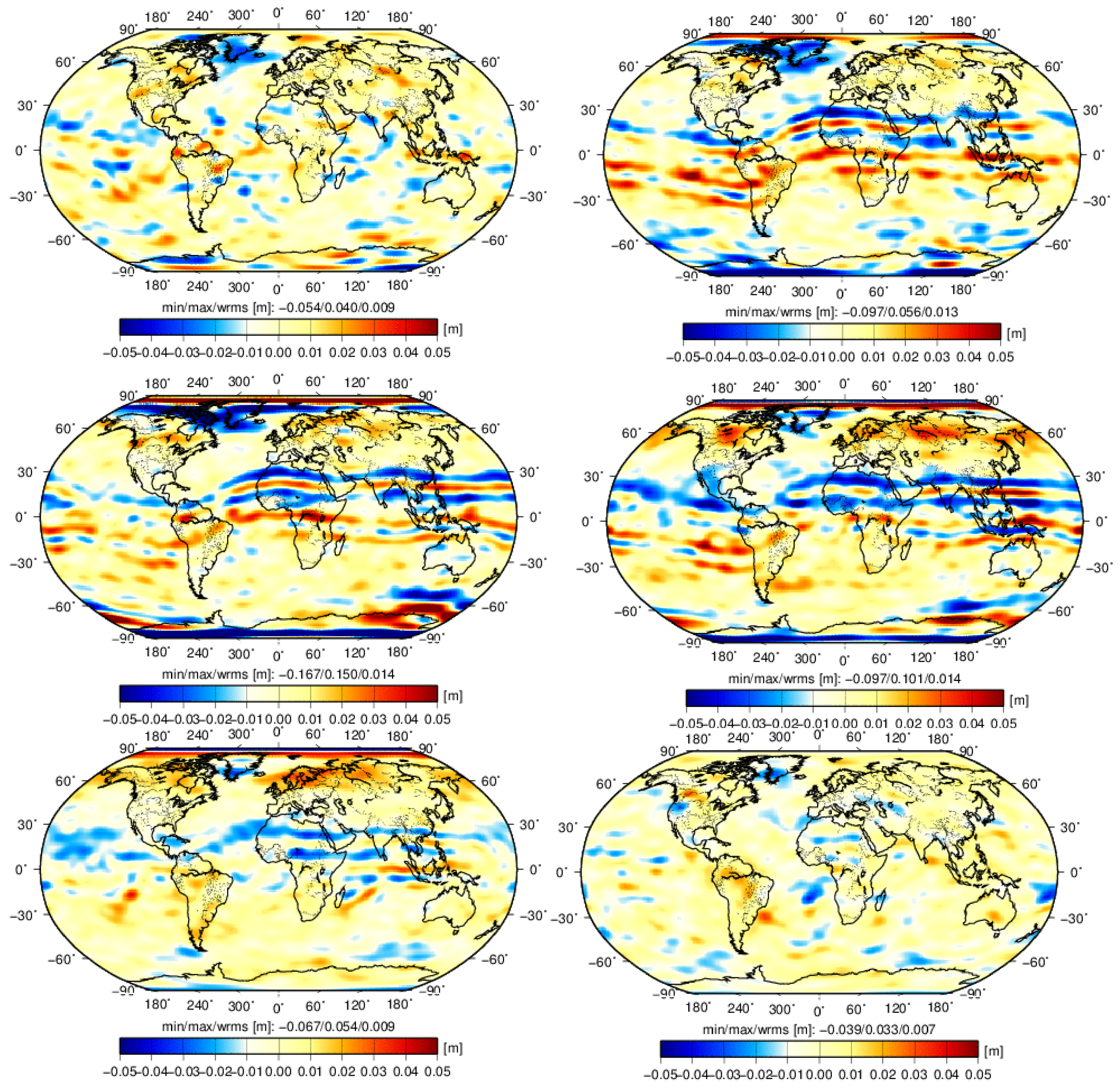


Figure: Geoid height differences wrt EGM2008 (500 km Gauss filtered) of monthly gravity field solutions based on kinematic positions derived from original GPS data of Swarm A,B,C (2014/01 - 2014/06). The presence of the systematic errors is strongly varying.

Gravity Field Solutions (screened data)

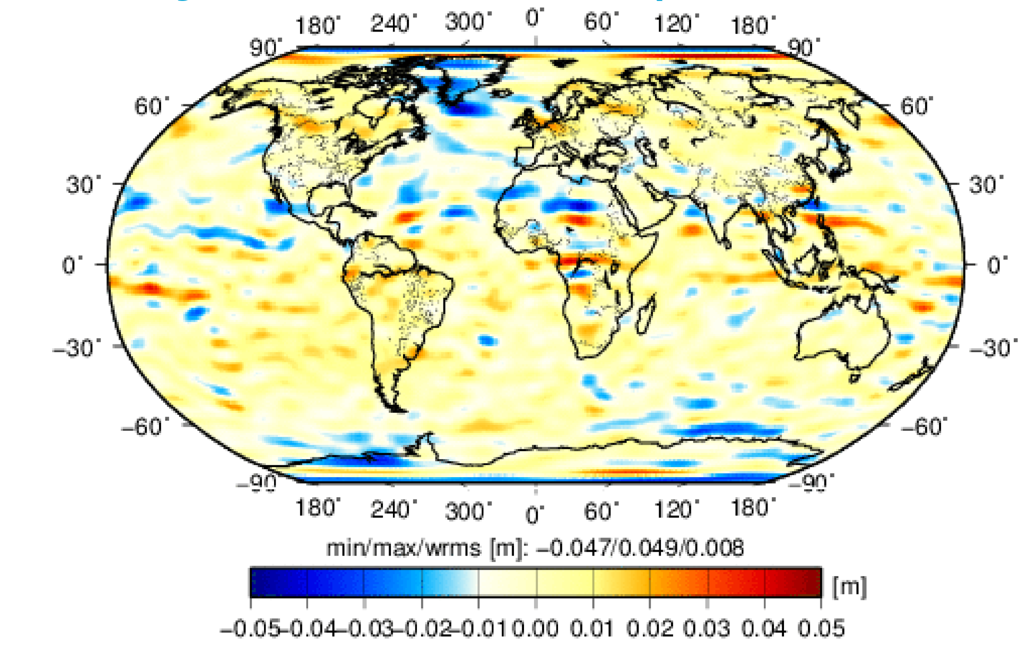


Figure: Geoid height differences wrt EGM2008 (500 km Gauss filtered) of a static gravity field solution based on kinematic positions derived from screened GPS data of Swarm A,B,C (2013/12 - 2014/07). Systematic differences are reduced to a certain extent.

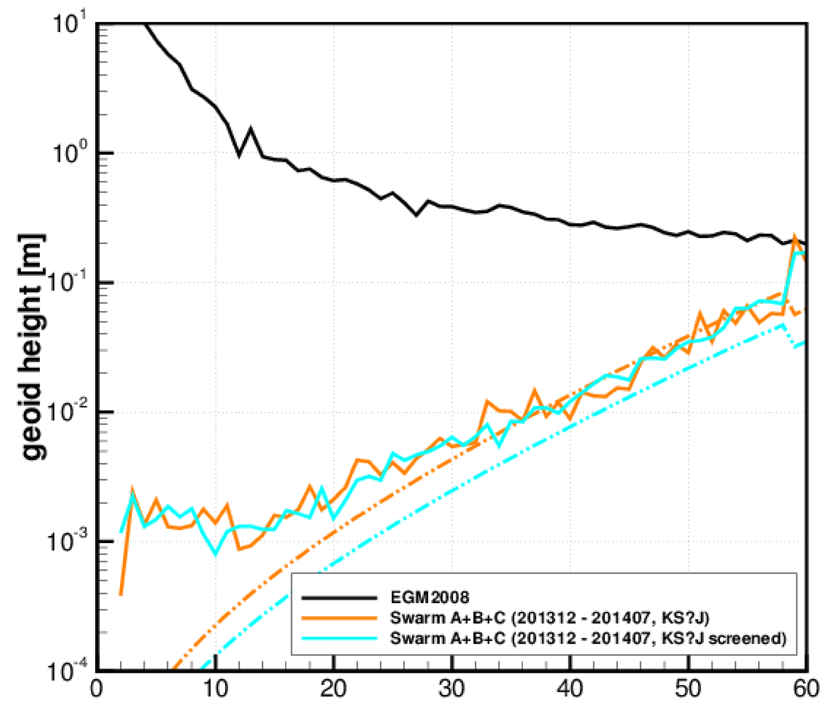


Figure: Difference degree amplitudes wrt EGM2008 and formal errors of static gravity field solutions based on kinematic positions derived from either original or screened GPS data of Swarm A,B,C (2013/12 - 2014/07). No large differences are visible in this representation.

Conclusions

The Swarm GPS receivers deliver high-quality data for orbit and gravity field determination. The quality of the kinematic orbit positions crucially depends on the quality of the empirical PCV maps used, where the validation with independent SLR data currently confirms a quality of about 3 cm SLR RMS. Although not critical for orbit determination, kinematic Swarm positions are affected by systematic errors centered along the geomagnetic equator. The errors propagate into gravity field solutions but show different strengths for different months. They may be reduced to a certain extent by discarding GPS measurements with large ionospheric changes for the kinematic orbit determination. Eventually it could be shown that low degree coefficients derived from Swarm kinematic orbit positions are of a similar quality as derived from GRACE kinematic positions. It is therefore promising to study time variable gravity field recovery from Swarm when longer time series can be processed.

References

Beutler G., Jäggi A., Mervart L., Meyer U., 2010, The celestial mechanics approach: theoretical foundations. Journal of Geodesy, 84(10), 605-624

Bock H., Dach R., Jäggi A., Beutler G., 2009, High-rate GPS clock corrections from CODE: Support of 1 Hz applications. Journal of Geodesy, 83(11), 1083-1094

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