Introduction

- Gravity fields derived from Swarm GPS data are considered important for bridging the upcoming gap between the dedicated gravity satellite missions GRACE and GRACE-FO.

- Currently, the constellations of the first three Sentinel missions of ESA's Copernicus Earth observation program are being established with the last successful launch of Sentinel-2B on March 7, 2017 from Kourou. There are now five Sentinels in Low Earth Orbits (LEOs), see Table 1.

- Each Sentinel satellite is equipped with GPS receivers (same manufacturer as for Swarm) and star cameras, allowing for the Precise Orbit Determination (POD) of the satellites with cm accuracy.

- At the Astronomical Institute of the University of Bern both (reduced) dynamic and kinematic orbits are computed using the Bernese-CNS.S software v5.3. For kinematic POD the three-dimensional position of the satellite and the receiver clock corrections are estimated at every observation epoch. Since kinematic orbits are fully independent of any dynamical and force models used for LEO POD, they are suitable for a subsequent recovery of the Earth's gravity field.

- We present the quality of the Sentinel-1A, -2A, and -3A (SIA, S2A, S3A) kinematic orbits up to end of 2016.

- We employ the Celestial Mechanics Approach (CMA, Beutler et al., 2010) to compute monthly and static gravity fields from these kinematic orbits, as well as their combination with the corresponding Swarm gravity fields.

**Table 1:** Sentinel and Swarm satellites so far in orbit with their average altitudes, inclination and inclination angle. The satellites with shaded entries were used for this study, the last column indicates the number of months included.

**Kinematic Orbits**

Figure 1 shows the daily carrier phase residuals for the Sentinel and Swarm kinematic POD. For Sentinel maneuver days have been excluded (214 days for SIA, 20 for S2A, and 16 for S3A). A clear correlation with the Total Electron Content (TEC) in the ionosphere is visible.

**Figure 2:** Geographically binned RMS values of ionosphere-free carrier phase residuals of Swarm-A (left) and S1A (right) kinematic POD covering the time span Nov-Dec 2014. The angles of the Sun above orbital planes are ~72.3° ≤ 44.7° for Swarm-A and 75.1° ≤ 44.7° for S1A. Of the three Sentinel LEOs considered only S3A is equipped with a retroreflector for Satellite Laser Ranging (SLR). Figure 3 shows the SLR residuals, i.e., the differences between the computed and the measured range, of the S3A kinematic orbits. 15 SLR stations have been included and an outlier threshold of 30 cm applied, resulting in a total number of 37990 SLR normal points.

**Figure 3:** SLR residuals of the kinematic S3A orbits for the entire time span considered (S3A was tracked by SLR from 01 Apr 2016 on) without maneuver days.

**The Celestial Mechanics Approach**

The kinematic orbits of SIA, S2A, and S3A, as well as the corresponding kinematic orbits of the three Swarm satellites serve as pseudo-observations for the CMA of gravity field recovery. The epoch-wise covariance information of the kinematic positions is introduced for the weighting. Normal Equations (NEQs) are set up for the parameters listed in Tab. 2.

**Figure 4:** Difference degree amplitudes (solid) and formal error degree amplitudes (dashed) of monthly gravity fields for April 2014 recovered from Swarm kinematic orbits computed from original (red) and screened (green) GPS data, as well as the combined Swarm/S1A monthly solutions (blue). For the left plot the coefficients most affected by a polar gap of 8° have been excluded, for the right plot all coefficients have been included.

**Conclusions**

SIA, S2A, and S3A kinematic orbits are shown to be of good quality and not affected by ionosphere-related artefacts along the geomagnetic equator. Despite the fact that they fly at higher altitudes than the Swarm satellites and that their Sun-synchronous orbits lead to larger polar gaps, Sentinel data is shown to significantly contribute to the lowest degrees of the Earth gravity field and capable of reducing degradations introduced by the data screening of Swarm GPS data during times of high ionospheric activity.

**References**


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