**Introduction**

GRACE K-Band is highly sensitive to gravity field variations at low to medium spherical harmonic degrees. But for very low degrees the results are affected by aliasing from slowly varying geophysical signals or tides (Secta et al., 2005). Especially $C_{02}$ shows a spurious signal at a 160 day period. These aliasing effects can be mitigated by the combination of GRACE data with other satellite data sensitive to the gravity field variations, e.g., from Satellite Laser Ranging (SLR).

**GRACE + SLR**

It has been common practice to replace $C_{02}$ in GRACE gravity fields by SLR-derived values (Cheng and Ries, 2007). Combined GRACE / SLR solutions including SLR observations to LAGEOS were generated by GRGS (Brunnima et al., 2010). Later Sońska (2014) and Sońska et al. (2015a, b) showed that a gravity field solution from up to nine dedicated SLR satellites (LAGEOS 1 and 2, Starlette, Stella, AjSIA, LARES, Larets, BLITS and Beacon-C) shows sensitivity to temporal gravity field variations at least up to degree 6. At AIUB these SLR solutions were combined with GRACE GPS and K-Band at the level of normal equations with a relative weight of 1e-2.

**GRACE GPS + SLR**

Since 2011 data gaps are occurring in the GRACE K-Band data due to the aging of the batteries and consequently a shutdown of the onboard accelerometers and K-Band instrument during phases of extended shadow periods (occurring every 160 days). During these times only GPS and attitude observations are available. Lately the sensitivity of monthly gravity fields derived from LEO GPS observations to temporal variations has been studied widely (e.g., Wiegelt et al., 2014). GPS-derived gravity fields may also be used to bridge the short K-Band gaps of GRACE. We therefore also derived monthly GRACE GPS + SLR solutions to show, if the GPS solutions may benefit from the combination with SLR data. The relative weight of SLR in this combination is 1e-2.

**Fig. 1:** Impact of SLR on monthly GRACE GPS + K-Band solutions 2003-2013 (in terms of the RMS of the differences GRACE only - SLR only per coefficient).

**Fig. 2:** Spectra of monthly $C_{20}$ values from 2004-2013. The spurious signal around 160 day period is slightly reduced by the combination.

**Fig. 3:** Example time-series of coefficients from monthly GRACE GPS + K-Band (black), SLR (blue) and GRACE + SLR combined solutions (green). As expected, $C_{02}$ is dominated by SLR, while all other coefficients are dominated by GRACE K-Band. In case of $C_{20}$ the combined solution shows a small bias compared to SLR only, as yet unexplained. A small impact of SLR on other coefficients is only visible at degree 2. Spectral analyses reveal that the spurious signal at 160 day frequency inherent to GRACE solutions may be slightly damped by the combination with SLR. The plots also visualize that SLR is well capable to capture seasonal or secular variations in gravity.

**Fig. 4:** Significance of secular and annual variations per coefficient. GPS is sensitive mainly at low order and sectorial coefficients. SLR does not only contribute to the low degree coefficients, but also increases sensitivity beyond degree 6 due to the different inclination of the SLR satellite orbits that help to de-correlate the coefficients.

**Fig. 5:** Amplitude of annual variations that were fitted to the time series of monthly gravity fields (left) and trends derived from the period 2004-2013 (right), both in geoid heights. The combination of GPS and SLR leads to a slight damping of the observed signals, but also to an improved localization and a reduction of noise.

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