Time variable Earth’s gravity field from SLR and GNSS satellites

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Introduction
GPS satellites are very sensitive to some of the Earth’s gravity field coefficients, because of the deep 2:1 orbital resonance. The resonant coefficients (Cz, S4, C04, S04, S06) exhibit a saddle drift of the semi-major axes up to 5 m/day (Haugenotter 1998). We processed 10 years of GPS and GLONASS data using the standard orbit modeling from the Center of Orbit Determination in Europe (CODE) with a simultaneous estimation of the Earth gravity field coefficients and other parameters (Tab. 1). The weekly GNSS solutions are compared to weekly SLR and monthly GRACE gravity field solutions.

Figure 2 shows the amplitudes of annual signals of gravity field coefficients from the GNSS, SLR, and GRACE solutions. The median differences are 0.11, 0.12, and 0.09×10^{-4} between GNSS/GRACE, GNSS-SLR, and SLR-GRACE, respectively. The mean amplitude in all solutions is 2.8×10^{-4}, i.e., the amplitudes agree on average at the 30% level.

Figure 3 shows that the sectoral and tesseral coefficients agree very well in the SLR and GRACE solutions, whereas the zonal terms show large variations of Cz are overestimated in the GRACE solutions (Fig. 2), because of the alias with Z tide (Meyer et al., 2012). Cz from the GNSS solutions does not fully agree with the SLR results, but can be improved by changing the orbit modeling (see Sec. 2).

> Cz agrees in the GRACE and GNSS solutions and disagrees in the SLR solution (Fig. 3), because of the correlations between Cz and Csin the SLR solution using spherical satellites (see Sec. 2).

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Figure 4 shows that the variations of Cz do not seem to be fully recovered from the standard CODE orbit parametrization, which is reflected in substantially smaller amplitudes of annual and semiannual signals as compared to the SLR solutions. Figure 4 shows that Cz can be much better determined from the GNSS solutions if the constant and once-per-revolution parameters in the X direction are not estimated: The semi-annual signal is well reproduced, the 3rd harmonic of 118 days disappears, and the correlation coefficient between the SLR and GRACE series increases from 0.02 to 0.28. A very good agreement between SLR and GNSS solutions is observed in particular for the period after 2008 when the contribution of GNSS satellites becomes prominent and the GNSS-observing network becomes more global. It is important to avoid the estimation of both constant z and once-per-revolution parameters in the X direction, because both parameters are correlated with Cz and all solutions with estimating one of these parameters or both show similar results with the inappropriate Coefficients (as in Fig. 4). The spectral analysis shows the 2nd, 3rd, 4th, 5th, and 7th harmonics of the draconic year in most of the GNSS-derived coefficients (Fig. 4, Fig. 7-8). The amplitudes of these harmonics can be reduced for some parameters when not estimating Xc, Xs, Xc (see Fig. 8). The quality of other estimated parameters, e.g., ERPs and station coordinates, are, however, disregarded when Xc, Xs, Xc are not estimated.

The standard errors of GNSS-derived gravity field coefficients are much smaller for degree 2 and for the GPS resonant coefficients than for the remaining coefficients (Fig. 6). The errors of coefficients of degree 2 are at the same level in the GNSS, GRACE, and SLR solutions. The a posteriori errors of GNSS resonant coefficients (Fig. 7) are too optimistic in the GNSS solutions, because the resonant terms are correlated with the solar radiation pressure to a greater extent than non-resonant terms, and thus, strongly affected by modeling issues. The correlation matrix (Fig. 9) shows the correlations between: UTS/UTC & C11, C11, C20, Xc, Xs, Xc, Xs, respectively; D, S, T, Cz, C11, S11, S11, respectively; Xc, Xc.

2. Earth’s Gravity Field from SLR
Most of the low degree Earth’s gravity field coefficients can be determined from the multi-SLR solutions (LAGEOS-1, LAGEOS-2, AIPS, Starfilet, Stella) with a comparable accuracy to the GRAVITY solutions (Fig. 10). Co and Cc can be determined better in the SLR solutions, because of the alias with Z tide in the GRAVITY solutions (Fig. 11, top). On the other hand, Cc cannot be fully recovered from the SLR solution (Fig. 11, bottom), because Co and Cc impose similar orbit perturbations on low orbiting SLR satellites, i.e., on Starfilet, Stella, and AIPS (Cheng et al., 1997). The a posteriori errors of Cc is derived from the SLR solutions, instead. Some of the coefficients from the multi-SLR solutions are affected by the mismodeling of the solar radiation pressure (e.g., Co in Fig. 12), because some progress analysis shows periods related to a draconic year of Starfilet (73 days) and AIPS (89 days), or Starfilet’s revolution of perigee (121 days).

3. Summary
The increasing number of GNSS satellites and a well-distributed network of GNSS stations improve the quality of the GNSS-derived Co and Cc (Fig. 5). Co is correlated with constant and once-per-revolution dynamic orbit parameters in the X direction. Co can be well established from GNSS when these orbit parameters are not set up.

GPS resonant gravity field parameters have very small a posteriori errors, but they are strongly affected by the solar radiation pressure (correlation with Dc). Most of the gravity field parameter levels of low degree can be well established from the SLR solutions with a comparable quality to the GRACE results. The quality of Co and Cc is better in the SLR solutions, whereas Co is better recovered in the GRACE and GNSS solutions.