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Using Inverse GNSS Methods for the Determination of C_{20} and C_{30} Gravity Field Coefficients for the Support of GRACE Solutions

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The distribution of atmospheric, hydrological, and oceanic mass loads on the lithosphere affects the deformation of the Earth's surface over time. Monitoring of the relative displacements of the dense global network of permanent Global Navigation Satellite System (GNSS) stations enables the direct measurement of these loads on a global scale. The application of inverse GNSS methods provides an independent tool to retrieve the time variable gravity (TVG) models of the Earth system and to support hydrogeodesy studies, including the monitoring of the water storage cycle or polar ice mass loss.

The goal of this study is to investigate the effectiveness of using inverse GNSS methods to provide independent C_{20} and C_{30} coefficients. These coefficients are essential for deriving highly accurate Gravity Recovery and Climate Experiment (GRACE)-based TVG models. In this study, surface mass variations of low-degree TVG coefficients are derived from the displacements of continuously tracking GNSS sites based on the 21 years (2000-2021) of the Center for Orbit Determination in Europe solutions of the 3rd data reprocessing campaign of the International GNSS Service in the framework of the preparation of the International Terrestrial Reference Frame 2020. The geometrical displacements of the GNSS stations calculated by inverse methods are compared with changes in the gravity field based on independent estimates obtained from the GRACE and GRACE Follow-On (GRACE-FO) satellite missions and the Satellite Laser Ranging (SLR).

As an alternative to the solutions provided by SLR, it is shown that the C_{20} and C_{30} coefficients can be derived based on GNSS station displacements. The challenge of the inverse GNSS approach is to properly choose the maximum degree of TVG expansion. Compared with the SLR-based solution, the most consistent GNSS estimate of the temporal gravity variation rate of the C_{20} coefficient ($-1.73 \pm 0.10 \times 10^{-11}$/year) and annual variation ($4.7 \pm 0.6 \times 10^{-11}$/$43.9° \pm 7.5°$) was obtained by expansion of the spherical harmonics to degree and order of 8. The GNSS-based C_{30} series is superior to the SLR-based estimates before the launch of the Laser Relativity Satellite. From August 2016, when the C_{30} estimates are essential for correcting the GRACE solutions, the root mean square between GNSS and SLR solutions is 4.2×10^{-11}. GNSS could potentially support GRACE/GRACE-FO solutions that face problems in deriving C_{20} and C_{30}, which are fundamental to estimates of ice mass changes in the polar regions. Recovery of mass change in the Antarctic ice sheet from April 2002 to December 2020 based on the coefficients replaced by GNSS estimates

results in a linear trend of −111 ± 3 Gt/year. In comparison, the trend for the SLR-based replacement from Technical Note 14 shows a trend of −114 ± 2 Gt/year.