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Supporting GRACE/GRACE-FO gravity field products with GNSS-derived data for improved Earth system monitoring

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GNSS-based low-degree spherical harmonic coefficients are an independent source of information for describing mass changes in the Earth system. In this study, we employ the mass load theory by an inverse GNSS approach to determine the changes in the Earth's gravity field with the spherical harmonic expansion up to degree and order 8, using daily station coordinate estimates from the third data reprocessing campaign of the International GNSS Service. Deriving a reliable series of variations in the Earth's dynamic oblateness terms (C_{20}) and C_{30} is essential for supporting GRACE-based time-variable gravity field models. Consequently, our study focused on the comprehensive alternative and validation tool for the widely used Satellite Laser Ranging (SLR) series of C_{20} and C_{30} coefficients.

The global mean sea level has risen significantly since the 1990s, largely due to mass loss from the Greenland and Antarctic ice sheets. This underscores the importance of continued monitoring of the global changes. Therefore, we conduct a detailed analysis of the impact of incorporating GNSS-derived coefficients into the official gravity field products provided by the GRACE and GRACE-FO missions on changes in the ice sheets of these regions. The findings highlight the benefits of the GNSS-GRACE integration as a crucial element in enhancing gravity models and improving the representation of mass changes within the Earth system. The combination of GRACE/GRACE-FO with the GNSS results in a linear trend in Antarctic ice sheets with a rate of -152 Gt/year between January 2007 and December 2020.

Furthermore, we transform GNSS-based gravity field solutions into equivalent water heights and estimate annual terrestrial water storage (TWS) fluctuations in regions that are crucial for understanding large-scale hydrological dynamics, e.g., the Amazon and Brahmaputra river basins. Our solution is validated with GRACE/GRACE-FO data and global hydrological models, i.e., the Land Surface Discharge Model. The results show that the spatial and seasonal patterns of TWS changes derived from GNSS are consistent with GRACE/GRACE-FO and hydrological model estimates at the single-millimeter level within the range of the GNSS-based TVG model spherical harmonic expansion up to degree and order 5.