Pre-GRACE Gravity Field Estimation Using SLR and GRACE Data

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The precise monitoring of the Earth's water cycle and the mass balance of glaciers and ice caps has become integral to modern geodesy, with satellite gravimetry playing a critical role in enhancing our understanding of these processes. Since its launch in 2002, the Gravity Recovery and Climate Experiment (GRACE) mission has significantly improved the accuracy of observations related to global hydrology and cryospheric changes, offering essential data that support a wide range of scientific disciplines. This legacy of over two decades of continuous data, with only a brief one-year interruption, has established a foundational framework for studying the global climate system and its interactions with both natural and human-induced factors.

Prior to the GRACE mission, the determination of monthly gravity field models depended on alternative methods such as Satellite Laser Ranging (SLR) to passive spherical satellites. Initially, the application of SLR data was restricted to assessing the Earth's oblateness. However, advances in satellite constellations, observational techniques, and improved orbit and background models eventually enabled the derivation of gravity field models up to degree and order 10 of spherical harmonics based on SLR data. Despite these advancements, the spatial resolution of these models did not match the level achieved with GRACE data. Nevertheless, the long-term gravity field models derived from SLR data provide crucial information about large-scale global changes in ice mass, ocean, and land hydrology, especially for periods before 2002.

In this study, we propose a set of long-term, continuous solutions based on SLR data, aiming to address the challenge of limited high-resolution satellite gravimetry data prior to the GRACE era. The gravity field is expanded up to a degree and order 10 with a monthly resolution from 1995 to 2024. The main solution has been decomposed into solutions expanded to degree and order 4, 6, 8, and 10, and stacked, taking advantage of the stability of the low-degree expansion and the better resolution of the high-degree expansion. By capturing large-scale changes and combining them with GRACE data using an empirical function with stochastic parameters, we enhance the spatial resolution of these observations. Analyzing these integrated datasets allows us to identify global regions experiencing significant accelerations in water storage and determine the dates of the maxima and minima of the function for the period from 1995 to 2024. For instance, in the Svalbard region, our findings indicate that ice mass accumulation peaked in the early 2000s, followed by a pronounced acceleration of ice mass loss due to climate warming, which continues to this day. Such trends, which cannot be detected using GRACE data alone, underscore the necessity of combining SLR and GRACE data. A similar trend is observed in the Gulf of Alaska Glaciers, where ice mass loss has substantially accelerated since the beginning of the observations, with a notable increase after 2012. The results of this study show strong alignment with external validation datasets, including satellite altimetry and climate parameters like Sea Surface Temperature Anomalies.