GSTM2024-39, updated on 08 Feb 2025
https://doi.org/10.5194/gstm2024-39
GRACE/GRACE-FO Science Team Meeting

How well can we derive the time-variable gravity field before the GRACE mission based on SLR 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 a cornerstone of contemporary geodesy, with satellite gravimetry playing a pivotal role in advancing our understanding of these processes. Before the GRACE era, the determination of monthly gravity field models relied on alternative methods, such as Satellite Laser Ranging (SLR) to passive spherical satellites. While early applications of SLR data were limited to assessing the Earth's oblateness, advancements in satellite constellations, observational techniques, orbit, and background models eventually enabled the derivation of gravity field models to a degree and order 10 of spherical harmonics based on SLR. However, these models still do not match the spatial resolution achieved with GRACE data. Nevertheless, the long-term gravity field models derived from SLR data are a fundamental information source of large-scale global changes in ice mass, ocean and land hydrology, especially for periods predating 2002.

This study addresses the challenge of limited high-resolution satellite gravimetry data available before the GRACE era by leveraging SLR data for large-scale changes and fitting GRACE data using an empirical function with stochastic parameters to enhance spatial resolution. By analyzing these combined datasets, we delimit global areas affected by significant accelerations in water storage and identify the dates for the maxima and minima of the function for the period from 1995 to 2024. We found that in the Svalbard region, ice mass accumulation reached its maximum in the middle of the first decade of the 21st century, followed by a significant acceleration of ice mass loss due to climate warming, which continues to the present day. Such a change in trend cannot be identified using solely GRACE data, therefore, the SLR+GRACE combinations are indispensable. A similar trend is observed in the Gulf of Alaska Glaciers, where ice mass loss has accelerated substantially since the beginning of the observations, particularly intensifying after 2012. In contrast, the Antarctic Peninsula saw a complete deceleration in ice mass loss, with the trend reversing around 2021. The results of our study show strong agreement with external validation datasets, including satellite altimetry and climate parameters such as Sea Surface Temperature Anomalies.