Abstract

Our complex planet is continuously undergoing temporal and spatial changes. In this context, ongoing processes in the Earth subsystems (geosphere, biosphere, cryosphere, hydrosphere, and atmosphere) cause changes in the gravity field of the Earth across a wide range of temporal and spatial scales. Accordingly, by both spatially and temporally tracing our planet's ever-changing gravity field, scientists can better constrain the underlying processes contributing to such dynamic changes of mass distribution within the Earth system.

Monitoring the Earth's gravity field and its temporal variations is essential, among others, for tracking disasters and specifying land areas with a high risk of flooding, earthquakes, and droughts, movements of tectonic plates, and providing accurate positioning through satellite positioning technology. On short-term timescales, temporal variations in the Earth's gravity field are mainly caused by the movement of water in its various forms. Accordingly, sea-level variations and ice-sheet and glacier changes, which are known as critical indicators of global warming and climate change, can be accurately monitored by tracking the Earth's gravity field changes. Since there is a close link between water redistribution and the Earth's energy cycle, climate system, food security, human and ecosystem health, energy generation, economic and societal development, and climate extremes (droughts and floods), it is essential to accurately monitor water mass exchange between the Earth system components.

Among all observational techniques, satellite gravimetry has provided an integrated global view of ongoing processes within the Earth system. The current generation of satellite gravimetry missions (the Gravity Recovery and Climate Experiment (GRACE) mission and its successor, GRACE Follow-On) has dramatically revolutionized our understanding of dynamic processes in the Earth's surface and, consequently, has significantly improved our understanding of the Earth's climate system. By considering different aspects of studying the Earth's gravity field, this thesis brings new insights to the determination and analysis of the mass change in the Earth system.

First, by studying the shortcomings of the common techniques of estimating the geoid potential, a new approach is examined that simultaneously estimates the geoid potential, W0, and the geometrical parameters of the reference Mean Earth Ellipsoid (MEE). In this regard, as the geoid needs to be considered as a static equipotential surface, the sensitivity of the estimations to the time dependent Earth's gravity field changes is studied.

Secondly, relying on the GRACE monthly gravity fields and the complementary observational techniques, and by pushing the limit of GRACE, mass redistribution over land and ocean is investigated. Within the ocean, satellite altimetry and Argo products are utilized along with the GRACE monthly solutions for quantifying the global barystatic sea-level change and assessing the closure of the global mean sea level budget. Over land, a region with relatively high temporal mass change (oil and water extraction) is chosen in which by taking advantage of having in-situ observations and hydrological models, the ability of GRACE products in quantifying the changes in groundwater storage is studied. In this frame, for both the ocean and land studies, different aspects of the processing of GRACE monthly gravity fields are investigated and GRACE inherent errors are addressed appropriately to arrive at reliable and accurate estimates of the Earth's surface mass change.

As the final contribution in this thesis, a rigorous analytical model for detecting surface mass change from the time-variable gravity solutions is proposed and examined in different case studies of surface mass change. Since the launch of the GRACE twin satellites, the GRACE(-FO) time-varying gravity fields are conventionally converted into the surface mass change using a spherical analytical model that approximates the Earth by a sphere. More recently, the analytical mass change detection model has been improved by considering an ellipsoid as the shape of the Earth, which improved the previous estimations of surface mass change, especially over high latitudes with relatively large mass change signals. However, by taking into account the real shape of the Earth and considering more realistic assumptions, a new analytical solution for the problem of surface mass change detection from the time-varying gravity fields is proposed in this thesis. It is shown that the simplistic spherical and ellipsoidal geometries are no longer tenable and the new model surpasses the common spherical approach and its ellipsoidal version.

Keywords: geodetic reference system, geoid potential, global vertical datum, climate change, global warming, mass change, ice melting, sea-level change, remote sensing, satellite gravimetry