Project: **499**

Project title: **GFZ - Erdsystem-Modellierung**

Principal investigator: **Maik Thomas**

Report period: **2026-01-01 to 2026-10-31**

A central focus of the scientific discipline Geodesy is the precise measurement of the Earth's external gravity field and its time-variable rotation. Besides large-scale dynamics of atmosphere and terrestrial hydrosphere, the spatially and temporally highly variable ocean bottom pressure plays a major part in determining gravity and rotational variability. Therefore, the processing of global geodetic measurements - including the satellite gravimetry missions GRACE (2002 - 2017) and GRACE-FO (since 2018); Very Long Baseline Interferometry based on a network of globally distributed radio telescopes; and station positions of a permanent network of stations receiving Global Navigational Satellite System (GNSS) signals - requires prior information from numerical ocean models in order to separate signals caused by ocean bottom pressure variability from other geophysical relevant signal sources.

Within a peer-reviewed projects funded by the DFG

> **PROGRESS** ("Pro- and Retrospective Highly Accurate and Consistent Earth Orientation Parameters for Geodetic Research within the Earth System Sciences", DFG-Geschäftszeichen: DI1778/3-1)

and two additional science studies funded by the European Space Agency

> **ESA-NGGM** ("NGGM and MAGIC End-to-End Mission Performance Evaluation study", European Space Agency contract no. 4000145266)
>
> **ESA-AdvEOP** ("Advance Provision of stable Earth Orientation Parameters (EOP) for Reference Frames", European Space Agency contract no. 4000145265)

we performed new simulations of the time-evolution of large-scale mass variations in the Earth's system. This includes short experiments with the global hydrological model OS LISFLOOD, the barotropic ocean model TiME based on the shallow water equations in a global setting and with MPIOM. In addition, a number of data-sets readily stored at the DKRZ were utilized for geodesy-related studies. The work performed in 2025 and 2026 was in particular focussed on the following topics:

Global Ocean Tides Modelling with TiME:

Substantial computation time has been utilized effort has been invested to thoroughly revise and improve the shallow-water equation code TiME (Weis et al., 2008) originally developed by University of Hamburg and DKRZ. The latest version includes flexible rotated grids to avoid numerical singularities in the model domain; the incorporation of explicit feedbacks of self-attraction and crustal surface deformation to ocean dynamics; the consideration of atmospheric forcing like periodic pressure and wind variations; the inclusion of sea-ice drag and ice-drift effects; as well the consideration of energy dissipation due to internal wave drag. Extended experiments have been performed to investigate the appearance of megatides in the Arctic Ocean and on the simulation of minor tides. The TiME model data has been also beneficial to assess the recently available wide-swath altimetry data from the SWOT mission (launched in 2022) to characterize episodic inflow events of Atlantic water masses into the Baltic Sea. Further experiments are ongoing to quantify non-linear interactions among tidal lines and the transient wind-driven circulation with the aim to provide more accurate ocean background models for ESA's Next Generation Gravity Mission (NGGM).

Simulation of terrestrial water storage and surface deformations with OS LISFLOOD:

Numerical experiments have been also performed with the hydrological model OS LISFLOOD to potentially replace the much older LSDM model in geodetic data processing. The model is discretised at 0.05° globally and has been forced with atmospheric data from different atmospheric reanalyses including ERA5, JRA-3Q, and MERRA2. Together with results from MPIOM, the OS LISFLOOD model output helped to explain non-tectonic vertical deformations captured by GNSS

permanent stations. In combination with historical runs from the CMIP6 archive maintained at DKRZ, we used the simulated terrestrial water storage also to characterize return levels of hydrometeorological extreme events and quantified the benefit of future satellite gravimetry missions for the monitoring of such events from space.

Non-tidal Ocean Bottom Pressure Variability from MPIOM:

MPIOM simulations have been performed with ERA5, MERRA2, and JRA-55do to further refine uncertainty estimates on the ocean contributions to variations in the Earth's gravity field necessary for the processing of GRACE/GRACE-FO satellite data. One of those ensemble experiments has been also integrated into version 3.0 of the ESA Earth System Model, which is endorsed by ESA as the new standard source model for end-to-end satellite gravity mission performance simulations. MPIOM results provided by GFZ are also routinely available as correction data-sets for terrestrial gravimetry via the ATMACS Service operated by the Bundesamt für Kartographie and Geodäsie. A high-resolution run with MPIOM has been also used to confirm findings based on an earlier VIKING-20X experiment about (tiny) bottom pressure variations at the shelf slope in the North Atlantic, that are associated with deep southward water transport variations of the Atlantic Meridional Overturning Circulation (AMOC) – a potential target signal for NGGM of exceptionally high societal relevance.

Earth Orientation Parameter Analysis and Prediction:

The rotational speed of the Earth and the position of the rotational pole vary slowly in time caused by angular momentum changes due to mass re-distributions in atmosphere, oceans, and the terrestrial hydrosphere. Short-term forecasts from ECMWF and DWD were used to force MPIOM and LSDM to predict the Earth's rotation variations for up to 10 days into the future. Prediction results have been evaluated against other internationally available EOP prediction systems within the second Earth Orientation Parameter Prediction Comparison Campaign organized by the International Earth Rotation and Reference Systems Service. Results from this campaign have subsequently triggered the AdvEOP study, where refined prediction methods based on MPIOM are integrated into the operational EOP processing framework at the European Space Operations Center (ESOC). Long time-series of angular momentum variations have been also utilized to assess both oceanic and continental contributions of the El Nino Southern Oscillation (ENSO) on the observed Earth orientation parameters.