Project: **499**

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

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Report period: **2025-01-01 to 2025-10-31**

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 the 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 two 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)
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> **TERRAQ-C06 (**Collaborative Research Cluster 1464 TerraQ, Project C06 "Atmosphere-Ocean Background Modelling for Terrestrial Gravimetry", DFG-Geschäftszeichen: 434617780)

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 experiments with the barotropic ocean model TiME based on the shallow water equations in a global setting (Weis et al., 2008) describing mass variability to a wide range of ocean tide constituents including over- and compound tides. We also utilized the primitive equations code MPIOM to simulate the general ocean circulation with a particular emphasis on rapid wind-driven variations that are important for both gravity field and Earth rotation studies. The work performed in 2024 and 2025 was in particular focussed on the following topics:

Global Ocean Tides Modelling with TiME:

Substantial 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. During the reporting period, TiME has been utilized to interpret time-variable gravity signals recorded at the German offshore island Helgoland that are closely related to storm surge events in the German Bight (Voigt et al., 2024) and to investigate the appearance of megatides in the Arctic Ocean (Sulzbach et al., 2025). 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 (Esselborn et al., 2025).

Non-tidal Ocean Bottom Pressure Variability from MPIOM:

The latest MPIOM simulations focussed on selecting an optimal model configuration to predict global ocean bottom pressure variability at temporal scales from a few hours to many months including the explicit feedback of self-attraction and surface loading deformations. For the new release 07 of the atmosphere and ocean non-tidal background model AOD1B for GRACE-FO we specifically worked on the long-term stability and the quantification of the remaining modelling errors (Shihora et al., 2024). For the latter, a range of ensemble experiments with the MPIOM TP10L40 configuration were utilized. One of those ensemble experiments is currently also integrated into version 3.0 of the ESA Earth System Model, which is specifically designed for end-to-end satellite gravimetry simulation studies to be coordinated at the European Space Research and Technology Centre (ESTEC). MPIOM results are now also routinely available as correction data-sets for terrestrial gravimetry via the ATMACS Service operated by the Bundesamt für Kartographie and Geodäsie (Antokoletz et al., 2024, 2025).

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 a land surface scheme and discharge model (LSDM) to predict the Earth's rotation variations for up to 10 days into the future (Dill et al., 2025). Prediction results have been evaluated against other internationally available EOP prediction systems within the second Earth Orientation Parameter Prediction Comparison Campaign (Sliwinska-Bronowicz et al., 2024; Kur et al., 2025; Partycka et al., 2025) organized by the International Earth Rotation and Reference Systems Service. Results from this campaign have subsequently triggered AdvEOP study, where refined prediction methods based on MPIOM will be integrated into the operational EOP processing framework at the European Space Operations Center (ESOC).