Project: **499**

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

Principal investigator: **Maik Thomas**

Report period: **2024-01-01 to 2024-10-31**

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 geophysically relevant signal sources.

Within four peer-reviewed projects

> **NAODEMO** ("Next-Generation Non-Tidal Atmospheric and Oceanic De-Aliasing Models", DFG-Geschäftszeichen: DO1311/4-1 and -2)
>
> **TIDUS** ("Improved Tidal Dynamics and Uncertainty Estimation for Satellite Gravimetry", DFG-Geschäftszeichen: TH864/15-1 and -2)
>
> **DISCLOSE** ("Disentangling Climatic Signals in Earth Orientation Parameters", DFG-Geschäftszeichen: DO1311/6-1)
>
> **PROGRESS** ("Pro- and Retrospective Highly Accurate and Consistent Earth Orientation Parameters for Geodetic Research within the Earth System Sciences", DFG-Geschäftszeichen: DI1778/3-1)

we performed new simulations of the time-evolution of large-scale mass variations in the Earth's system. This includes experiments with the primitive equation model MPIOM (Jungclaus et al., 2013) that focus in particular on the wind-driven circulation with the aim to further improve the standard de-aliasing model for the GRACE mission (Dobslaw et al., 2017), and also experiments with 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. The work performed in 2023 and 2024 was 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 as the consideration of energy dissipation due to internal wave drag. TiME has been utilized recently for the simulation of paleo tides during the last glacial cycle with the aim to support the interpretation of geological sea-level indicators that are susceptible to different tidal levels (Sulzbach et al., 2023). Data from TiME was also utilized to introduce error variance-covariance information on ocean tides into the GRACE gravity field processing (Hauk et al., 2023). Work with the TiME code will be continued in the year 2025 within the frame of the Collaborative Research Cluster 1446 TerraQ.

Non-tidal Ocean Bottom Pressure Variability from MPIOM:

Recent 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 (Shihora et al., 2023). Ensemble experiments with the MPIOM TP10L40 configuration were exploited to characterize residual errors in the atmosphere-ocean background model (Shihora et al., 2024). Both preliminary TiME simulations for the North and Baltic Sea region as well as the MPIOM results aided the interpretation of terrestrial gravity observations obtained on Helgoland for both tidal (Voigt et al., 2023), and later also non-tidal ocean signatures (Voigt et al., 2024). 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). Work with MPIOM will be continued in the next year as part of the ESA-NGGM study.

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. Angular momentum time-series from MPIOM have been used for the evaluation of ocean reanalysis data-sets with respect to their suitability for Earth rotation research (Börger et al., 2023). Short-term forecasts from ECMWF and DWD were further used to force both 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., 2023; Kehm et al., 2023). 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) organized by the International Earth Rotation and Reference Systems Service. This work is currently being extended within the PROGRESS project funded by DFG.

Expired Resources:

We note, however, that a substantial amount of the computing resources granted for the year 2024 has not been used. This is related to the defense of two PhD theses during the reporting period (by Roman Sulzbach and Linus Shihora), which lead to a stronger focus on the consolidation of results instead of performing new numerical experiments. The situation will be much different in 2025, where newly started projects (TERRAQ-C06 and ESA-NGGM) will require the calculation of a wide range of new numerical experiments.