Project: **499**

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

Principal investigator: **Maik Thomas**

Report period: **2023-01-01 to 2023-10-31**

A central focus of the scientific discipline Geodesy is the precise measurement of the Earth's external gravity field and its time-variable rotation. Beside 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 three peer-reviewed projects

> **NAODEMO** ("Next-Generation Non-Tidal Atmospheric and Oceanic De-Aliasing Models", DFG-Geschäftszeichen: DO1311/4-1 and -2)
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> **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)

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. Further simulations focus on the dynamics of the terrestrial water cycle with the Land Surface and Discharge Model LSDM (Dill, 2008). The work performed in 2022 and 2023 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 various scientific application studies including the assessment of ocean tides excited by the 3rd spatial degree of the tide-rising potential (Sulzbach et al., 2022), the quantification of the atmospheric contributions to global ocean tides (Balidakis et al., 2022), and 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). Experiments from TiME also contributed to a revised quantification of large-scale ocean tide model errors that are highly relevant for satellite gravimetry from GRACE and GRACE-FO (Abrykosov et al., 2022). Preliminary TiME simulations for the North Sea region aided the interpretation of terrestrial gravity observations obtained on Helgoland (Voigt et al., 2023). Dedicated global experiments with TiME were also carried out to quantify the effect of spatially variable elastic properties of the Earth in both crust and upper mantle on geodetically observable ocean tidal loading deformations (Huang et al., 2022). The work on ocean tides is being continued in the frame of the TIDUS project within the DFG-funded research group NEROGRAV.

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 implementation of the explicit feedback of self-attraction and surface loading deformations also into MPIOM (Shihora et al., 2022b). Preliminary experiments were evaluated with along-track GRACE-FO laser-interferometer data (Ghobadi-Far et al., 2022) in order to make processing decisions for the new release 07 of the atmosphere and ocean non-tidal background model AOD1B for GRACE-FO (Shihora et al., 2022a). Subsequently, RL07 of AOD1B has been finally processed for the whole period 1975 until 2022 (Shihora et al., 2023). This GRACE-related work is being continued in the frame of the NAODEMO project as a German contribution to the joint U.S.-German Science Data System of the GRACE-FO mission.

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 to interpret pole position changes observed during dedicated VLBI campaigns (Raut et al., 2022) and also 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 (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 et al., 2022, Kur et al., 2022) organized by the International Earth Rotation and Reference Systems Service. This work is currently being extended within the DISCLOSE project funded by DFG.