Project: **499**

Project title: **Numerical Simulation of High-Frequency Ocean Bottom Pressure Variability**

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Report for period: **2020-01-01 to 2020-12-31**

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 (launched May 22nd, 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.

For three peer-reviewed projects

> **NAODEMO** ("Next-Generation Non-Tidal Atmospheric and Oceanic De-Aliasing Models", DFG-Geschäftszeichen: DO1311/4-1)
>
> **ESAEOP** ("Independent Generation of Earth Orientation Parameters", funded by the European Space Agency ESA, Contract No. 4000120430/17/D/SR)
>
> **TIDUS** ("Improved Tidal Dynamics and Uncertainty Estimation for Satellite Gravimetry", DFG-Geschäftszeichen: TH864/15-1)

we performed new simulations of the time-evolution of the global ocean bottom pressure field. This includes experiments with the current ocean component of the MPI Earth System 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 a global ocean tide model (Weis et al., 2008) describing mass variability to a wide range of ocean tide constituents including over- and compound tides.

The work performed during the year 2020 was focused on the following topics:

Earth rotation predictions:

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 both MPIOM and a land surface scheme and discharge model (LSDM) to predict the Earth's rotation (Dill et al., 2019; Dill and Dobslaw, 2019; Ron et al., 2019; Sliwinska et al., 2020). A final set of atmospheric, oceanic and terrestrial excitation functions has been used to evaluate geodetic processing choices of geodetically observed Earth rotation solutions (Dill et al., 2020).

The Earth rotation prediction approach developed with DKRZ resources has been implemented in the Navigation Support Office at the European Space Operations Centre (ESOC) of the European Space Agency (ESA) within the ESAEOP project.

Elastic Surface Loading Deformations:

Elastic surface loading deformations as calculated based on high-resolution surface mass distributions from MPIOM and LSDM are important for the proper treatment of non-linear motions of geodetic instruments attached to the crust. No new experiments have been performed in 2020, but several studies have been finally published that make use of numerical results achieved at DKRZ in the past. This includes an assessment of the impact of surface loading on the orbit accuracies of altimetry satellites (König et al., 2020), a new strategy to account for surface loading in the analysis of VLBI and GNSS networks (Männel et al., 2019). Data underlying those studies is also distributed via the Global

Geophysical Fluid Centre of the International Earth Rotation and Reference Systems Service (IERS).

Non-tidal ocean bottom pressure for GRACE:

MPIOM simulations performed during 2020 focused on modifying the global ocean bathymetry in particular in polar regions to properly represent also cavities in the Antarctic ice-shelves. The implementation of explicit self-attraction and loading lasted until September 2020 and thereby required more time than initially expected. Consequently, the initially planned long experiments that extend over the full ERA5 period have not yet been performed and will be postponed to 2021. Nevertheless, results from MPIOM experiments performed in the past were utilized in a number of articles including a review of the accomplishments of the whole GRACE mission published in Nature Climate Change (Tapley et al., 2019), and is also part of a first scientific assessment of the performance of the GRACE-FO mission (Landerer et al., 2020). A new release of pre-processed GRACE Level-2 data (Dahle et al., 2019), a first combination of gravity fields from various processing groups in the EGSIEM consortium (Jäggi et al., 2019); and an assessment of future gravity mission constellation concepts (Poropat et al., 2019) also benefited from numerical experiments performed with MPIOM at DKRZ.

By reducing systematic distortions in the finally processed monthly gravity fields, those simulations also enabled a number of further GRACE application studies focusing on the solid Earth response to surface loads of varying size and geometry (Wang et al, 2019a; 2019b). Time-series of the gravity field as obtained from GRACE and GRACE-FO were also analysed to quantify the European Drought in 2018/2019 (Boergens et al., 2020a, 2020b), to evaluate atmospheric water fluxes as represented by different global reanalyses (Eicker et al., 2020) as well as the long-term evolution of the hydro-climate as represented in CMIP5 model experiments with respect to GRACE (Jensen et al., 2019, 2020).

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.

Global ocean tides for GRACE:

Satellite gravimetry is not only affected by non-tidal mass shifts in the oceans and at the continents, but also by periodic variations associated with ocean tides. Substantial effort has been invested in the past 12 months to improve the TiME model (Weis et al. 2008) that implements the shallow water equations at a 1/12° latitude-longitude grid. Improvements include (i) a rotation of the grid to avoid the singularity in the Arctic Ocean, (ii) the implementation of new global bathymetries, (iii) the explicit calculation of self-attraction and loading effects, and (iv) the consideration of topographic wavedrag as an important channel for tidal energy dissipation in the open ocean. Experiments suggest an improvement for the open-ocean rms of the M2 tide from 12.7 cm to 3.6 cm when switching from the original configuration of Weis et al. (2008) to the latest model version. Tailored experiments will be used to explore the effect of lateral variations in upper-mantle rheology on the elastic deformability of the Earth, which is well observed for particular ocean tide frequencies by means of coastal GNSS stations. The results will be also made available to the GRACE processing groups for possible implementation as ocean background models.

This GRACE-related work is being continued in the frame of the TIDUS project as a German contribution to the joint U.S.-German Science Data System of the GRACE-FO mission.

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ISI Publications based on project #499 results from the last two years

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