Project: **499**

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

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Report for period: **2021-01-01 to 2021-12-31 (submitted on 2021-08-31)**

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)
>
> **TIDUS** ("Improved Tidal Dynamics and Uncertainty Estimation for Satellite Gravimetry", DFG-Geschäftszeichen: TH864/15-1)
>
> **G3P** ("Global Gravity-based Groundwater Product", Horizon2020 program of the European Union, Grant No. 870353)

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. Further simulations focus on the dynamics of the terrestrial water cycle with the Land Surface and Discharge Model LSDM (Dill, 2008).

The work performed during the year 2021 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 (Sliwinska et al., 2020). A final set of atmospheric, oceanic and terrestrial excitation functions has been used to evaluate geodetic processing choices of EOP (Dill et al., 2020). The EOP prediction approach developed with DKRZ resources has been implemented in the Navigation Support Office at the European Space Operations Centre of the European Space Agency. Ongoing developments will contribute to the 2nd International Comparison Campaign of Earth Orientation Parameter predictions, that is currently performed under the auspices of the International Earth Rotation and Reference Systems Service (https://www.iers.org/WGEOPPCC2).

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 GNSS networks (Klos et al., 2020).

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 has been completed (Shihora et al., submitted to Ocean Modelling). Long simulations including SAL have been completed in summer 2021 and the corresponding articles will be submitted in the upcoming months. Results from previous MPIOM experiments performed in the past were utilized in a first scientific assessment of the performance of the GRACE-FO mission (Landerer et al., 2020) and an assessment of future gravity mission constellation concepts (Poropat et al., 2020). The data has been also utilized in a recent multi-model evaluation of high-frequency ocean bottom pressure variability (Schindelegger et al., 2021).

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.

Numerical simulations of global ocean tides:

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 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 (Sulzbach et al. 2020). Further simulations focus on partial tides excited by the 3^{rd} degree of the tide raising potential (e.g., M1, 3MK2, 3MO2, M3) show excellent agreements with tidal constants derived from multi-year records of time-variable gravity observed at the surface of the Earth with superconducting gravimeters (Sulzbach et al., submitted to J. Geodesy). The thoroughly revised TiME model is also being employed to study the evolution of ocean tides in the North Atlantic and Arctic Ocean since the Last Glacial Maximum (LGM), which is important for the interpretation of geologic markers of past sea-levels (Sulzbach et al., in preparation).

The work with the TiME ocean tides model is being continued in the frame of the TIDUS project within the DFG-funded research group NEROGRAV.

Terrestrial Water Storage from GRACE and LSDM:

Time-series of the gravity field as obtained from GRACE and GRACE-FO were newly processed into gridded estimates of time-variable terrestrial water storage, that were subsequently used to quantify the European Drought in 2018/2019 (Boergens et al., 2020a, 2020b, 2020c) and to down-scale the low-resolution GRACE-FO data with the help of deep-learning neural networks (Irrgang et al., 2020). GRACE data also turned out to be suitable to evaluate atmospheric water fluxes as represented by different global atmospheric reanalyses (Eicker et al., 2020) as well as to assess the long-term evolution of the hydro-climate as represented in CMIP5/CMIP6 model experiments (Jensen et al., 2020a, 2020b).

Numerical simulations of the terrestrial water storage with LSDM based on the most recent ECMWF reanalysis ERA5 ideally complement such analyses by providing independent estimates of the expected water storage signals from a physics-based model. Simulations with different forcing data-sets and/or model parameterizations will be subsequently utilized to assess inherent uncertainties in terrestrial water storage at different temporal and spatial scales. The latter work particularly contributes to the development of a global groundwater product based on GRACE-FO data that is currently being attempted within the H2020-funded project G3P.

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

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Boergens, E., Dahle, C., **Dobslaw, H.,** Sasgen, I., Reißland, S., Flechtner, F. (2020c): Globale Massenverteilungen aus Satellitengravimetrie: Das interaktive Datenportal GravIS. - ZfV: Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 145, 5. doi: 10.12902/zfv-0316-2020

Dill, R., Dobslaw, H., Hellmers, H., Kehm, A., Bloßfeld, M., **Thomas, M.,** Seitz, F., Thaller, D., Hugentobler, U., Schönemann, E. (2020): Evaluating Processing Choices for the Geodetic Estimation of Earth Orientation Parameters with Numerical Models of Global Geophysical Fluids. - Journal of Geophysical Research: Solid Earth, 125, 9, e2020JB020025. doi: 10.1029/2020JB020025.

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