DFG Research Unit 2736

New Refined Observations of Climate Change from Spaceborne Gravity Missions (NEROGRAV)

Dataset

Regularized Empirical Variance-Covariance-Matrices for stochastic gravity modeling of 8 major ocean tides

Version 1.0 (21 February 2023)

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Individual Project	**Work Packages**
IP1	WP 1.200

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Introduction

This document describes the main outcomes of WP1.200 of Individual Project IP1 and Deliverable D1.1 of the research unit NEROGRAV. The goal of WP1.200 was the realistic representation of modern ocean tide model uncertainties in the form of empirical Variance-Covariance Matrices (VCMs) for the utilization in satellite gravimetric dealiasing. In the following, we describe the dataset generation and format. A more detailed description of the processing strategy of the dataset can be found in Abrykosov et al. (2021).

DataSet Creation

In the first step, tidal solutions from 5 data-constrained ocean tide atlases were fetched and harmonized in tidal notation and grid resolutions (364x182 Gaussian grid, in-phase/quadrature notation). The so-produced ensemble is assumed to be normally distributed around its mean value (see Fig 1a). The intermodel differences show a scatter around this mean value and are a measure of uncertainty, i.e., variance and covariance. Due to the orbits of satellite altimetry missions, which are confined to $\pm 66\,°$ uncertainties are minimal in the equatorial region and enormously elevated in the polar areas (see Fig. 1b).

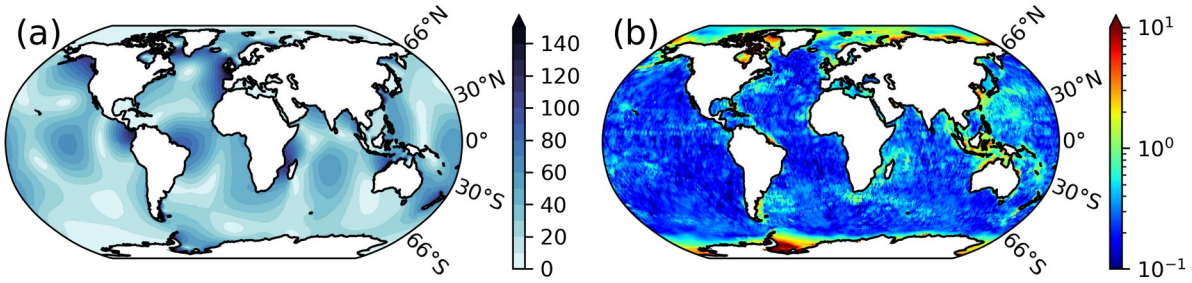

Figure 1: Subplots (a) and (b) show the mean amplitude and standard deviation for the M_2-tide for an ensemble of 5 satellite altimetry data-constrained models (Abrykosov et al., 2021). The logarithmic scale highlights the increased model uncertainty in polar latitudes. Both plots are in cm.

Individually for in-phase (denoted $A_{\cos}$) and quadrature elevation (denoted $A_{\sin}$), the sea surface height is transformed to Stokes Coefficients under consideration of spherical Earth, seawater's constant density, and surface gravity and steady Earth rotation, as well as an Earth flattening correction. Please consider Eqns. (2) + (3) of Sulzbach et al. (2022) for the transformation of surface mass anomalies to Stokes Coefficients. The respective sets of Stokes Coefficients, $C_{nm}^{\cos}$ and $C_{nm}^{\sin}$, are obtained and utilized for further processing. For the dataset at hand, we provide Stokes Coefficients up to degree and order 30.

For each component and tide separately, we use the GLASSO approach of Friedmann et al. (2007) to derive regularized VCMs, where we set the regularization parameter to $\lambda = 0.1$.

Data description

The final data product comprises non-singular VCMs for 8 individual partial tides (the ‚major' tides) up to degree and order 30, which are matrices of size 961x961. As the matrices are symmetrical, the number of elements that have to be stored per tide can be reduced to 2 x 462241 (for in-phase and quadrature components).
The dataset starts with a header (in gray) that is described in the following:

```
--------------------------------------------------------------------------------
PRODUCER AGENCY : GFZ
PRODUCER INSTITUTION                    : GFZ
DESCRIPTION                             : TIDAL ERROR COVARIANCE MATRIX (SHNC)
SHNC-TYPE (complex/real)                : real
```

→ **Normalization of the SH-basis**

```
FILE FORMAT 0=BINARY 1=ASCII        : 1
NUMBER OF HEADER RECORDS            : 22
REFERENCE DOCUMENTATION             : NEROGRAV D1.1 v1.1
PARTIAL TIDE                        : m2
```

→ **Trivial Name of the partial tide of this file. See Sulzbach et al. (2022) for Doodson code**

```
NUMBER OF DATA RECORDS              : 2 x 462241
FILENAME                            : m2_cov_30_lambda_.1.dat
PRESSURE TYPE (ATM OR OCN)          : OCN
```

→ **Refers to atmospheric (ATM) or oceanic tides (OCN). Here always OCN.**

```
MAXIMUM DEGREE                      : 30
COEFF. NORMALIZED (YES/NO)          : YES
```

→ **Normalization of the SH-basis. Here always YES.**

```
CONSTANT GM [M^3/S^2]               : 3.986004418000E+14
CONSTANT A [M]                      : 6.378136600000E+06
CONSTANT FLAT [-]                   : 2.982564200000E+02
CONSTANT OMEGA [RAD/S]              : 7.292115000000E-05
CONSTANT GRAVITY [M/S^2]            : 9.806650000000E+00
CONSTANT RHO(SEAWATER) [kg/m^3]     : 1.024000000000E+03
```

→ **Constants used for computing the Stokes Coefficients**

```
NUMBER OF DATA SETS                 : 2
```

→ **Refers to in-phase (DATA SET 02) and quadrature (DATA SET 01) component**

```
FORMAT (L1,M1,L2,M2,COV(coeff))    : (4(I3,X),E15.9)
```

→ **Data is stored referring to the degree and order of the first SH-function (L1, M1) and second SH-function (L2, M2), which are the base functions of the respective Stokes coefficients. The first four columns store L1…M2 in integer format, while the fifth column contains the respective covariance.**

```
END OF HEADER
-------------------------------------------------------------------------------
```

Following the header, the datasets are listed and follow lines with the keywords **DATA SET 01** and **DATA SET 02**. The data is stored degree-wise as indicated by the FORMAT attribute. L1 runs from 0..30, while M1 takes all possible values between -L1 and +L1. This results in a unique ordering scheme for spherical harmonic functions, i.e. [0,0], [1,-1], [1,0], [1,1], [2,-2], …. Covariances are then calculated for all Stokes coefficients with the same or a lower rank in the ordering scheme. The pursued ordering allows aborting the data-I/O of the file at any maximum degree and order between 0 and 30 and the simple extension of the files to higher degrees without modifying the order of lower degrees.
The first lines of the file thus read:

0	0	0	0	**VCM(0, 0, 0, 0)**
1	-1	0	0	VCM(1,-1,0,0)
1	-1	1	-1	**VCM(1, -1, 1, -1)**
1	0	0	0	VCM(1,0,0,0)
1	0	1	-1	…

Where we have marked **variances** which are always positive semidefinite.

Files are available for the tides M_2, S_2, K_2, N_2, K_1, O_1, P_1, and Q_1 where the respective label is included into the file name: ***{tide}_cov_{lmax}_lambda_{lambda}.dat*** (e.g. `m2_cov_30_lambda_.1.dat`)

References

Abrykosov P., Sulzbach R., Pail R., Dobslaw H., Thomas M., Treatment of ocean tide background model errors in the context of GRACE/GRACE-FO data processing, *Geophysical Journal International*, Volume 228, Issue 3, March 2022, Pages 1850–1865, https://doi.org/10.1093/gji/ggab421

Friedman J., Hastie T., Tibshirani R. Sparse inverse covariance estimation with the graphical lasso. Biostatistics. 2008 Jul;9(3):432-41. https://10.1093/biostatistics/kxm045. Epub 2007 Dec 12. PMID: 18079126; PMCID: PMC3019769.

Sulzbach, R.; Balidakis, K.; Dobslaw, H.; Thomas, M. (2022): TiME22: Periodic Disturbances of the Terrestrial Gravity Potential Induced by Oceanic and Atmospheric Tides. GFZ Data Services. https://doi.org/10.5880/GFZ.1.3.2022.006