Rigorous Fusion of Gravity Field into Stationary Ocean Models (RIFUGIO)

Silvia Becker[1], Grit Freiwald[2], Wolf-Dieter Schuh[1], Martin Losch[2]

[1]Institute of Geodesy and Geoinformation, Department for Theoretical Geodesy, Bonn
[2]Alfred Wegener Institute for Polar and Marine Research, Bremerhaven

Introduction

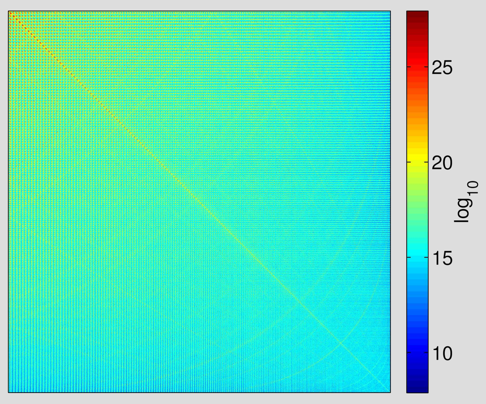
The goal of this study is the integration of a mean dynamic topography model derived from combined gravity field and altimetric information into stationary ocean models and to assess the effects of this data combination on improving estimates of the general ocean circulation. We developed a rigorous combination method to merge satellite-only gravity field models from GRACE and GOCE with a mean sea surface based on altimetric data. This method allows for a direct estimation of the normal equations for the ocean's mean dynamic topography on the ocean model grid by parameterizing the mean dynamic topography with finite elements. A central aspect is the complete and consistent error description of all observations and its rigorous propagation within the developed method. The derived normal equation matrix represents the appropriate weight matrix for model-data misfits in least-squares ocean model inversions. The target grid for the mean dynamic topography is defined by the three-dimensional ocean model IFEOM covering the North Atlantic Ocean. We show results based on a combined GRACE/GOCE gravity field model and a mean profile obtained by Jason-1 and Envisat measurements, for which a full error propagation is implemented.

Geodesy

Gravity field model

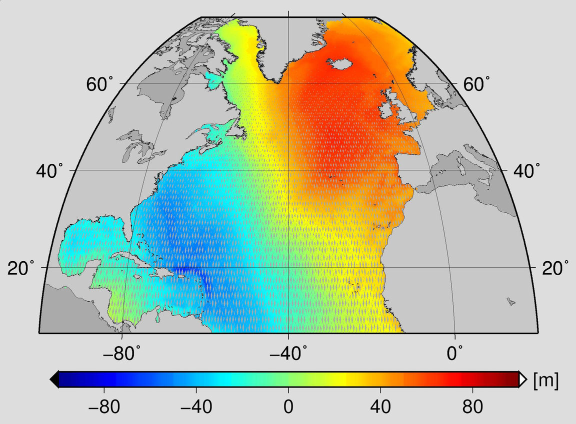
We use the static solution of the GRACE gravity field model ITG-Grace2010 and the GOCE gravity field model TIMrelease3. The full variance/covariance information is provided with these models. This allows for reconstructing the particular normal equations. For our computations we use the combined GRACE/GOCE model.

`www.igg.uni-bonn.de/apmg/index.php?id=itg-grace2010`
`http://earth.esa.int/GOCE/`



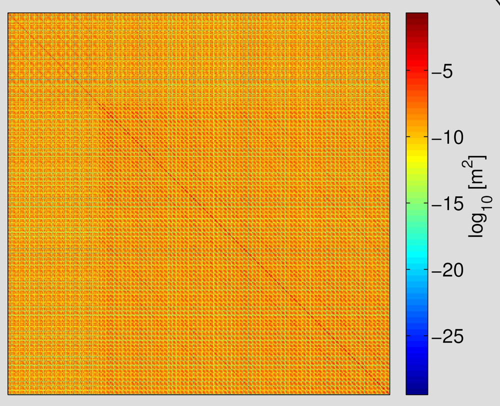
Normal equation matrix of the GRACE/GOCE model

Altimetry



Along-track MSS from Jason-1 and Envisat measurements

A mean sea surface (MSS) based on Jason-1 and Envisat measurements is calculated along the satellite ground tracks including a full error propagation. Considering the MSS as the sum of the geoid (N) and the mean dynamic topography (MDT) yields the observation equations for the altimetry:

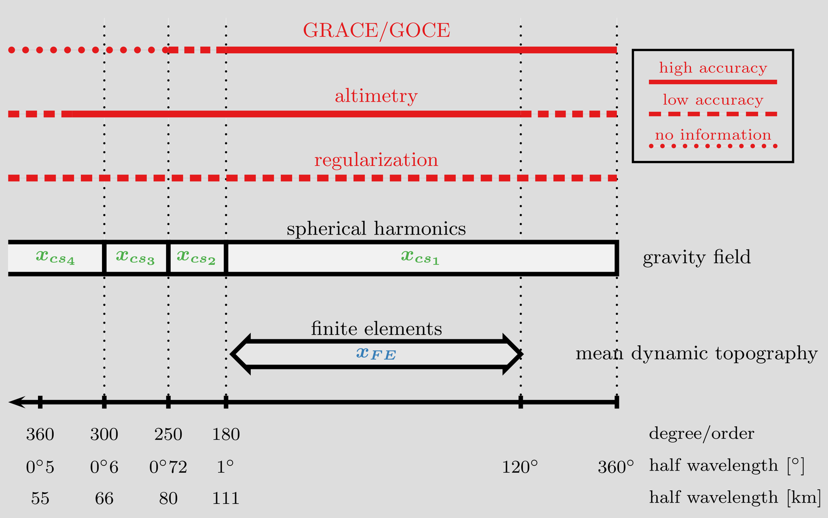


Covariance matrix of along-track MSS

$$MSS(\phi,\lambda) = N(\phi,\lambda) + MDT(\phi,\lambda)$$

The geoid is represented as a sum of spherical harmonics whereas the MDT is parameterized by a finite element method (FEM).

Frequency domains



Separation into different parameter groups

Kaula regularization for the parameter groups x_{cs_2} and x_{cs_3}

Stochastic modeling of the omission domain x_{cs_4} based on a priori information
$\mathcal{S}=A_{cs_4}\,x_{cs_4},\ E\{\mathcal{S}\}:=\Delta l_{\mathrm{MSS}},\ \Sigma\{\mathcal{S}\}:=\Sigma_{\Delta\mathrm{MSS}}$

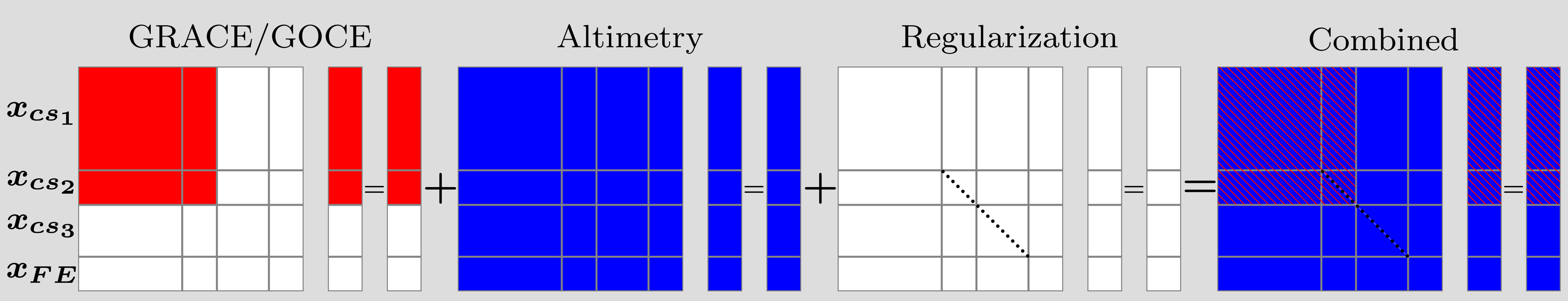
Final altimetric observation equations

$$\bar{l}_{\mathrm{MSS}}+v_{\mathrm{MSS}}=\begin{bmatrix}A_{cs_{123}} & A_{FE}\end{bmatrix}\begin{bmatrix}x_{cs_{123}}\\ x_{FE}\end{bmatrix}$$

with $\bar{l}_{\mathrm{MSS}}=l_{\mathrm{MSS}}-\Delta l_{\mathrm{MSS}}$ and $\bar{\Sigma}_{\mathrm{MSS}}=\Sigma_{\mathrm{MSS}}+\Sigma_{\Delta\mathrm{MSS}}$

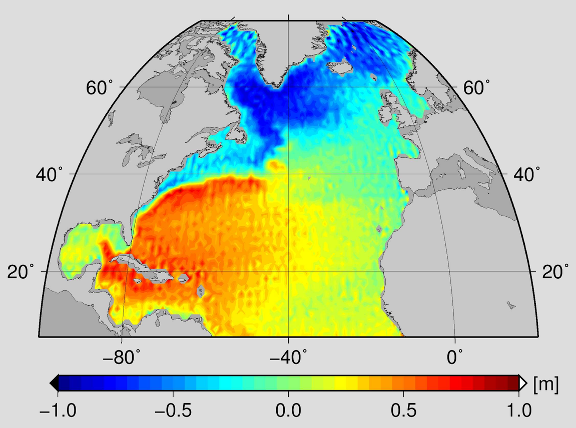
Combination model

Combination of gravity field and altimetric data in terms of normal equations



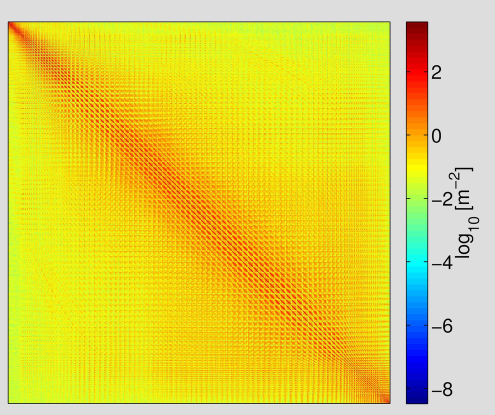
➡ Normal equations of MDT on the ocean model grid

Results



Mean dynamic topography x^{data}

The mean dynamic topography evaluated on the $1°\times 1°$ data grid of IFEOM along with its inverse covariance matrix $\mathbb{C}^{-1}$.



Normal equation matrix $\mathbb{C}^{-1}$ of MDT

Oceanography

Ocean model IFEOM

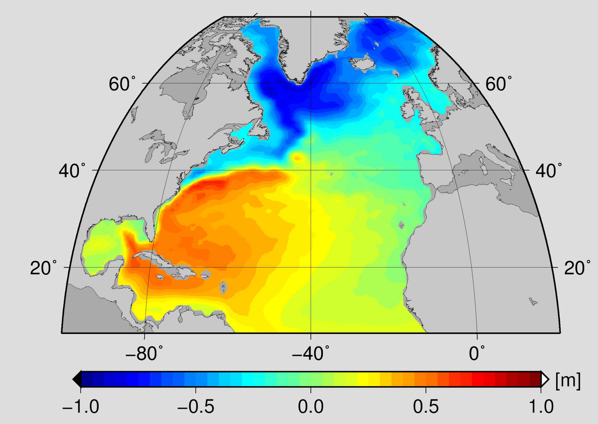
The **I**nverse **F**inite **E**lement **O**cean **M**odel IFEOM computes an estimate of the steady-state North Atlantic circulation. Physical principles are combined with observational data by minimizing the cost function:

$$J=\frac{1}{2}\sum_i J_i \overset{!}{=} \min$$

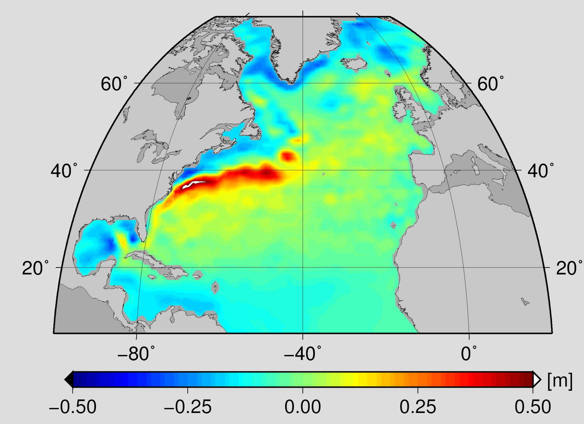
The terms J_i contain quadratic model–data differences weighted by their inverse error covariance matrices, if available. We use temperature and salinity data from a hydrographic atlas (Gouretski and Koltermann, 2004) and the geodetic MDT x^{data}. The MDT term in the cost function reads:

$$J_{\mathrm{MDT}}(x^{\mathrm{model}})=(x^{\mathrm{data}}-x^{\mathrm{model}})^T\mathbb{C}^{-1}(x^{\mathrm{data}}-x^{\mathrm{model}}).$$

Mean Dynamic topography



MDT optimized by IFEOM

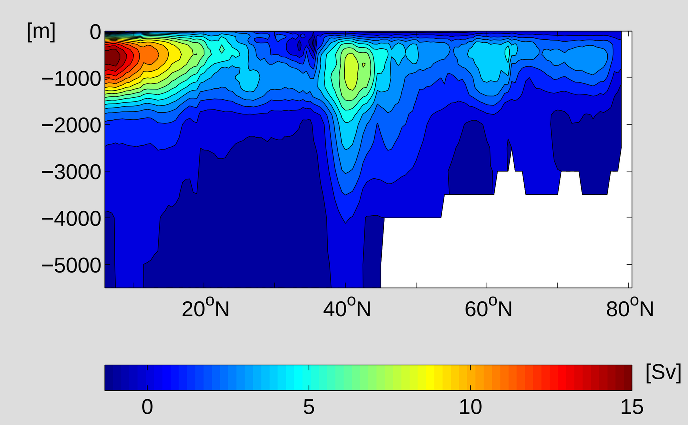


MDT difference: IFEOM with MDT - IFEOM without MDT

Unphysical noise in the MDT has been suppressed by IFEOM. The resulting combined MDT is smooth.

The impact of the MDT data x^{data} is largest in the area of the Gulf Stream and the Mann Eddy.

Overturning circulation

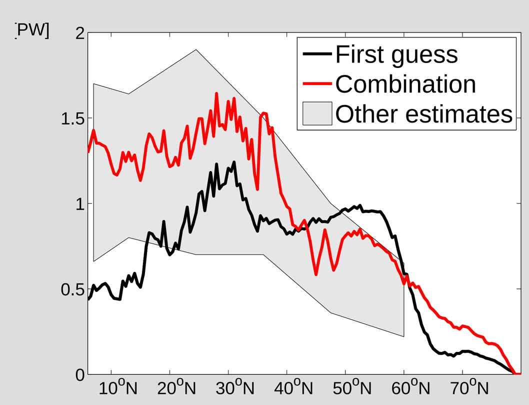


MOC difference: IFEOM with MDT - IFEOM without MDT

The impact of the MDT data x^{data} is also visible in the Meridional Overturning Circulation (MOC) near 40°N. The boundary conditions of the ocean model at 5°N are inconsistent with the MDT data.

Heat transports

Meridional heat transports computed by IFEOM using the MDT data x^{data} agree better with previous estimates than IFEOM heat transport without MDT data. Other estimates include Klein et al. (1995), Lavín et al. (2003), Macdonald and Wunsch (1996), Sato and Rossby (2000), Lorbacher and Koltermann (2000), Bacon (1997), Lumpkin and Speer (2007).



Meridional heat transports by IFEOM

Summary

- A Mean Dynamic Topography and its inverse error covariance matrix were estimated from a combination of GRACE and GOCE gravity field models and Jason-1 and Envisat altimetric measurements.
- The combination with the inverse ocean model IFEOM further improved the MDT estimate.
- IFEOM estimates of the North Atlantic circulation and heat transports improve with the new MDT data combination.

SPP1257

Institute of Geodesy and Geoinformation
Nussallee 17, 53115 Bonn
Alfred Wegener Institute for Polar and Marine Research
Postfach 120161, 27515 Bremerhaven

Contact:
Becker, S.: silvia.becker@geod.uni-bonn.de
Contact:
Freiwald, G.: grit.freiwald@awi.de