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# D2.3.3: Gridded time series of GRACE-based Greenland mass changes


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***SUMMARY***

The joint American-German GRACE satellite mission has since 2002 provided very valuable data for ice sheet mass balance studies.

We use a generalized inversion method to estimate the Greenland ice sheet mass change from the monthly global gravity solutions, provided by one of the GRACE data processing centres (CSR).

We apply several corrections to the monthly GRACE gravity models prior to the inversion. These include e.g. the GIA contribution, de-striping and corrections of some of the low-degree Stokes coefficients.

We derive monthly mass change grids of the Greenland Ice Sheet, and these are all given in the file GRL_MC_GRACE.grd

## *MONARCH-A CONSORTIUM*

| Participant no. | Participant organisation name | Short name | Country |
|---|---|---|---|
| 1 (Coordinator) | Nansen Environmental and Remote Sensing Center | NERSC | NO |
| 2 | The University of Sheffield | USFD | UK |
| 3 | Universität Hamburg | UHAM | NO |
| 4 | Centre National de la Recherche Scientifique | CNRS | FR |
| 5 | Scientific foundation Nansen International Environmental and Remote Sensing Center | NIERSC | RU |
| 6 | Universitetet i Bergen | UiB | NO |
| 7 | Danmarks Tekniske Universitet | DTU | DK |
| 8 | Institut Francais de Recherche pour l'Exploitation de la Mer | IFREMER | FR |

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## 1.1 Grid file

Gridded time series of GRACE-based Greenland mass changes.
Time spans from April 2002 to July 2010.

The gridded mass changes are provided in one file: GRL_MC_GRACE.grd
**Available at: ftp://ftp.spacecenter.dk/pub/MONARCH-A/D.2.3.3/**

File format: GRAVSOFT gridded data consecutively written for each time.

For each time there is a GRAVSOFT block of row-wise data (from north to south) starting with a line containing the coordinates bounding the grid and the grid spacing all in degree:

[ latitude 1 ] [ latitude 2 ] [ longitude 1 ] [ longitude 2 ] [ delta lat ] [ delta long ]

[ value n1 ] [ value n2 ] ... [ value nm]
.
.
[ value 11 ] [ value 12 ] ... [ value 1m ]

The gridded data has been written with the following FORTRAN format:
FORMAT(60(/,8f9.2))

The first data value in the grid is thus the NW-corner and the last the SE-corner. The number of points in the grid file is thus:
n=1 + (lat2-lat1)/(delta lat)
m=1 + (long2-long1)/(delta long)

The time (decimal year) of each grid is written in the file GRL_MC_GRACE.time. The time stamp indicates the middle of the GRACE measuring period for each GRACE solution. Note that the grids provided here are averaged monthly solutions so each time stamp serves only to indicate the month which the solution is referring to.

The value 9999.00 stands for NAN (for grid points outside the ice covered area).

## 1.2 GRACE data

This analysis is based on the monthly GRACE level-2 gravity field models (release 4) provided by the Centre for Space Research, University of Texas (Bettadpur, 2007). It is available to the public via the PO.DAAC system (ftp://podaac-ftp.jpl.nasa.gov/allData/grace/).

The monthly model consists of assets of fully normalized spherical harmonic coefficients, also called Stokes coefficients. CSR provide both formal and calibrated error estimates on the Stokes coefficients.

# 2 Method

An inversion method is used for determining the monthly mass changes from the monthly GRACE data. The inversion method is described in Sørensen and Forsberg (2010).

Prior to the inversion, some corrections and filtering are applied to the GRACE data; these are described in the following

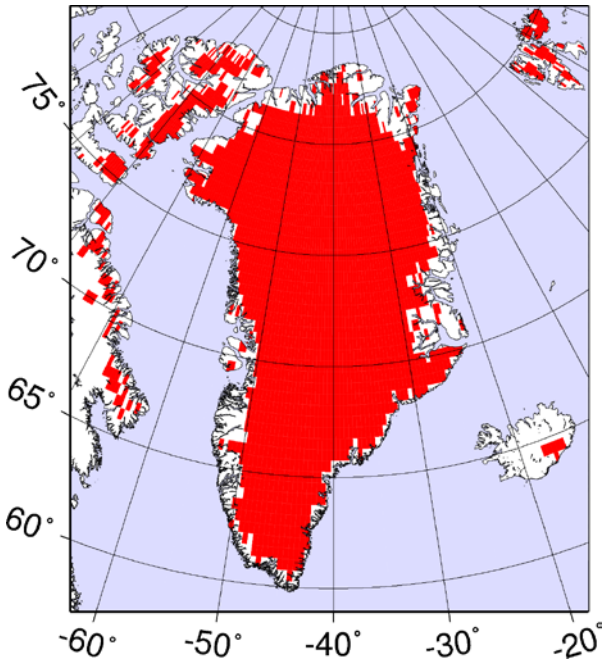


Figure 1: *Solution area for the inversion, in Greenland. The surrounding ice covered areas are included to reduce leakage.*

## 2.1 Glacial Isostatic adjustment

GIA is an on-going Earth's response to changes in ice load geometry during the last glacial cycle. The GIA processes is modifying both the Earth's topography and gravity field, hence the GIA contribution must be estimated and corrected for in studies of ice sheet mass balance.

On the NASA GRACE Tellus site (http://grace.jpl.nasa.gov/data/pgr/) a GIA model is available, calculated by Paulson et al. (2007), which they recommend as “best” model with an uncertainty of +/- 20%. This model is based on global ICE-5g ice history, deglaciation model of Peltier (2004), and on a simplified VM2 Earth model: a 4-layered approximation to Peltier's (2004) VM2 viscosity profile.

This model also includes the rotational feedback based on the formulation of polar wander described by Mitrovica et al (2005). Through the sea-level feedback the centre-of-mass motion is also taken into account.

We used this model to calculate GIA Stokes coefficients to correct the GRACE ones.

## 2.2 De-striping

A well-known problem with the monthly GRACE solutions is apparent linear features (or stripes) in the global fields, generated from the monthly solutions. We apply the de-striping method presented in Kusche (2007) to the CSR models, and provide mass balance estimates based on these de-striped models. The de-striping method developed by Kusche (2007) is a non-isotropic smoothing procedure, based on approximate de-correlation and successive regularization of the GRACE monthly solutions. The results provided here obtained using a weak smoothing (smoothing parameter $a=10^{12}$) also called DDK3 and also available on the web site of GFZ (http://icgem.gfz-potsdam.de/ICGEM/TimeSeries.html). This filter is comparable with a Gaussian filter of 300 km half width.

## 2.3 Low degree Stokes coefficients

The degree 1 ($C_{10}$ $C_{11}$ $S_{11}$) is only corrected with the annual contribution of the geo-centre motion as described in Chambers (2006).

The $C_{20}$ values provided in the level-2 data show anomalous variability. Therefore, the GRACE $C_{20}$ coefficients are replaced with values derived from SLR satellites (Cheng and Tapley, 2004). The SLR $C_{20}$ coefficients and their associated standard deviations are continuously provided in the GRACE project Technical Note 05 (ftp://podaac.jpl.nasa.gov/allData/grace/doc/TN-05 C20 SLR.txt).

We restored the $C_{20}$ $C_{21}$ $S_{21}$ $C_{30}$ and $C_{40}$ coefficient with the reference values of secular changes, reported in the Level-2 Processing Standards Document (Bettadpur, 2007), page 8 section II.2.1.

## 2.4 Error estimates

The error of the mass change estimates derived from each monthly model is estimated by a Monte-Carlo like approach, in which a number of simulations are made. The simulations are created from Stokes coefficients drawn from normal distributions with zero mean, and the standard deviations provided with the GRACE level-2 data (Tscherning et al., 2001).

## 2.5 References

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