EVALUATING GOCE DATA NEAR A MID-OCEAN RIDGE AND POSSIBLE APPLICATION TO CRUSTAL STRUCTURE IN SCANDINAVIA

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ABSTRACT

GOCE gravity fields are assessed in an area around Reykjanes Ridge. Ship gravity measurements were found to be to inaccurate to determine possible improvement of GOCE gravity field models compared to the best available GRACE gravity field model.
Differences between the GOCE gravity field models and EGM2008 does not appear to contain a component of the mid-ocean ridge signal. However the differences follow the Greenland coastline, which could indicate small errors in EGM 2008 there as a result of piecing together different gravity field observations.
A Butterworth bandpass filter was applied to gradiometer observations at orbit height. After filtering, differences between repeat tracks with a magnitude of tens of mE are present, which can not be explained by position or attitude of the satellite. In order to reach the repeatability that can be expected from GOCE measurements, filtering methods need to improve.
It was found that differences between global GRACE and GOCE gravity field models are small compared to uncertainty in crustal and upper mantle structure. Thus, geophysical inversion studies should focus on the gravity gradient observations in the instrument reference frame and at orbit height.

1. INTRODUCTION

With GOCE gravity fields available for some time now, combined GRACE and GOCE gravity fields have been evaluated (e.g. Pail et al. 2010b). However, it is still interesting to know how well the combined GRACE-GOCE models or a GOCE-only model perform in specific areas. In addition, gravity gradients need to be assessed at orbit height, since this data type will likely be used in inversion of geophysical models.

For the comparisons we focus on a mid-ocean ridge area. A mid-ocean ridge is a clear and sharp geophysical signal which is a good test-case for evaluating the GOCE gravity field solutions. We select part of the Reykjanes ridge south-west of Iceland (see fig. 1) as the study region because several ship gravity profiles cross the ridge. Moreover, its high latitude means that many GOCE tracks cross the ridge, although not perpendicularly.

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Three GOCE models are evaluated: the time-wise solution (GO2TIM, Pail et al. 2010a), the space-wise solution (GO2SPW) and the direct method (GO2DIR, Bruinsma et al. 2010). All models are based on two months of observations. The time-wise solution is the only one that can be considered a GOCE-only model, i.e. it does not rely on prior gravity models.

In the next section, we focus on global comparisons in the spectral and spatial domain. Then we zoom in to the area around the Reykjanes ridge. Comparisons will be shown with ship gravity data from NOAA, with the state-of-the-art GRACE-only gravity field model (ITG-GRACE2010s, Mayer-Gürr et al. 2010) and the latest global geopotential model (EGM2008, Pavlis et al. 2008). Subsequently, the gravity gradients in the orbit will be compared for observations in repeat tracks, with global geopotential models EGM2008 and EIGEN05C (Förste et al 2008).

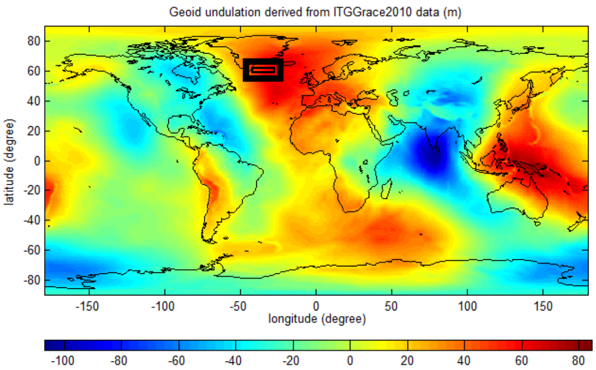

Figure 1: Study area denoted by black box.Colors show the ITG-GRACE2010s geoid height in meters.

2. GLOBAL COMPARISON

To gain insight in the GOCE data, first a global comparison with EGM2008 is performed. The degree difference is calculated according to equation (1)

$$f_l = \sqrt{\frac{\sum_{m=6}^{l}\left(C_{lm}^{\ 2} + S_{lm}^{\ 2}\right)}{2l-11}} \tag{1}$$

Orders larger than 6 are used to mitigate the effect of the polar gap. Fig. 2 shows the degree differences for the three GOCE models and GRACE2010s. The curve for the direct solution dips below the curve for ITG-GRACE2010s around degree 120, while the other two GOCE gravity field models outperform the GRACE model starting at degree 150. In the spatial domain, the RMS of the differences (excluding the polar areas) amounts up to 11 cm in geoid height for the time-wise and space-wise solutions, and 8 cm for the direct solution.

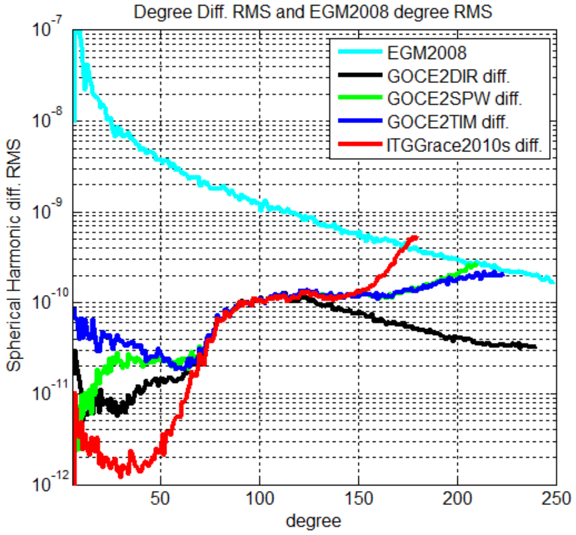

Figure 2: RMS of degree differences with respect to EGM2008, calculated according to equation (1) for orders larger than 6.

3. REYKJANES RIDGE – SHIPBORNE GRAVITY MEASUREMENTS

In the following it will be investigated whether GOCE gravity field models also show improvement in a local area. First we evaluate the GOCE gravity field models against ship gravity data. We used data from the Geophysical Data System from NOAA. 20 ship tracks were selected with a standard deviation less than 10 mGal and were smoothed along the ship track to account for the limited number of coefficients of the satellite gravity models.

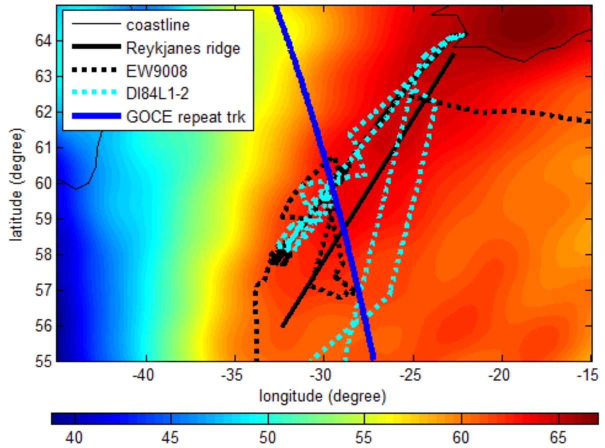

Figure 2: Location of two ship gravity profiles mentioned in table 1 and a GOCE repeat track. Background colors show geoid height from ITG-GRACE2010s.

A second order polynomial was fitted and removed to correct for bias and trend in the shipborne gravity measurements. Table 1 shows the root-mean-square (RMS) of differences between the satellite derived gravity fields and the shipborne gravity fields. It can be seen that the RMS values are very close and the differences are probably not significant. An improvement of the GOCE gravity fields compared to the best GRACE gravity fields (ITG-GRACE2010s) can not be found with the shipborne gravity fields, probably because the ship gravity data are not accurate enough for evaluating the new GOCE gravity fields.

Table 1: Root-mean-square of differences between GOCE and GRACE gravity fields and shipborne gravity measurements.

Ship ID	DIR	SPW	TIM	ITG-GRACE2010s
EW9008	14.7	14.6	14.7	14.6
DI84L1-2	9.7	9.6	9.6	9.5
all	13.6	13.4	13.5	13.1

4. REYKJANES RIDGE – EGM2008

Differences between the GOCE gravity field models and EGM2008 will now be investigated near the mid-ocean ridge. If differences appear in a shape that resembles the gravity signal from the mid-ocean ridge it would indicate that physical signal is contained in the differences at wavelengths where GOCE is sensitive. That would demonstrate improvements of the GOCE gravity field models with respect to EGM2008. In the comparisons, the maximum spherical harmonic degree that is used is 180 and a Gaussian filter with a halfwidth of 150 km is applied to limit the influence of the truncation error.

In fig. 3 it can be seen that the differences appear as elongated patterns that could be geophysical signal but

most likely is mainly noise. Only for the direct solution the pattern appears to follow the mid-ocean ridge.
An interesting signal appears in all sub-figures along the coast of Greenland. A reason for this difference could be that different data sources are patched together to obtain the EGM2008 model: satellite altimetry over the ocean and terrestrial gravity or airborne gravity measurements over land. The only data set that can be used continuously across the coastline are satellite gravity data. The differences between the GOCE gravity field models and EGM2008 could indicate improvement in measuring the gravity field across the coastline. Ocean currents near the coast are of obvious interest because of the large part of the world population living near the coast. In particular ocean currents are important for erosion and sedimentation studies. A current research effort is aimed at extracting more information from coastal altimetry data (Cipollini et al. 2009).

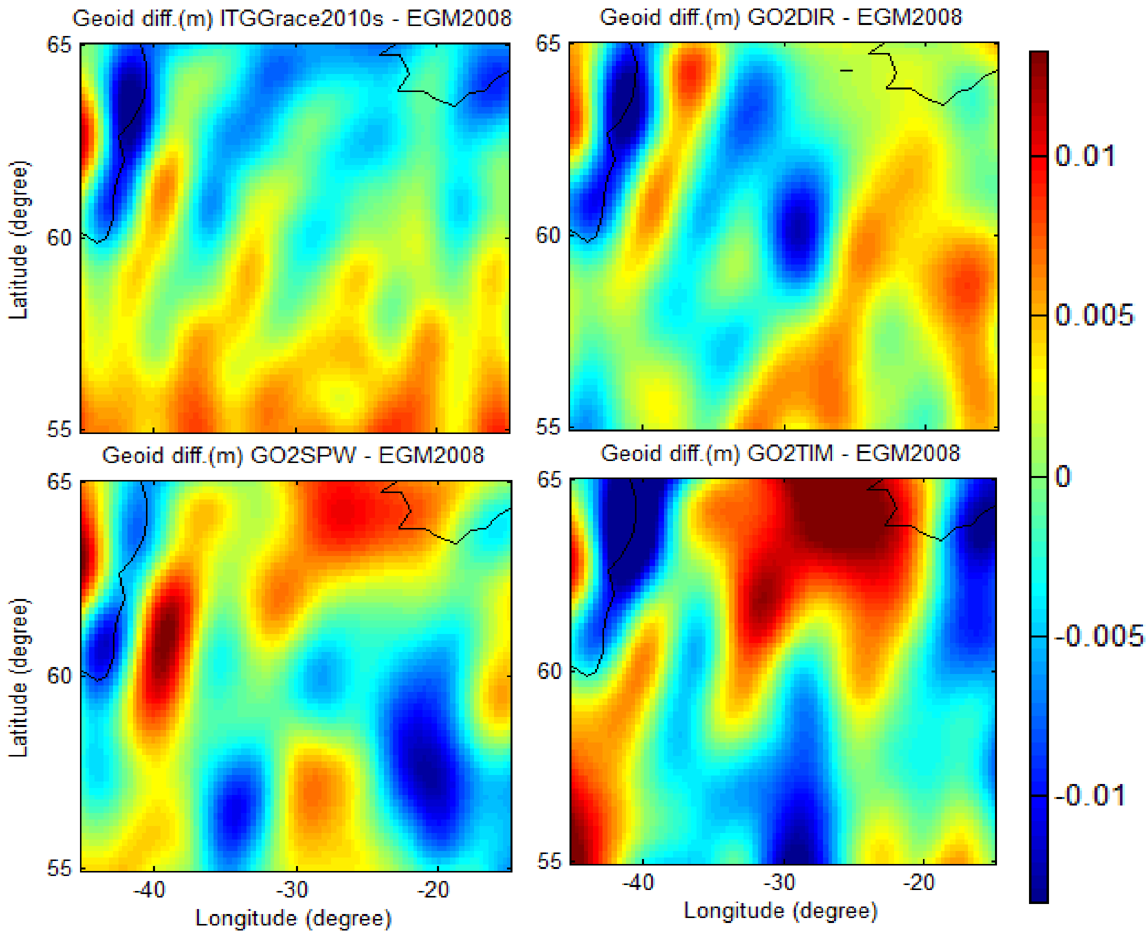

Figure 3: Differences in geoid height between a GRACE and three GOCE gravity field models and EGM2008 in the area shown in fig. 1.

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5. GRAVITY GRADIENTS

In the following, Gravity gradients are assessed in the Gradiometer Reference Frame at orbit height.

5.1. Filtering

Noise is increasing near the edge of the measurement bandwidth. Filtering is done with a Butterworth bandpass filter from the MATLAB signal processing toolbox. Cut-off degree and order are fixed at 5 mHz and 100 mHz (ESA 1999). The degree of the bandpass filter can be varied, which determines the sharpness of the filter at the cut-off frequencies. In order to determine the best value for the degree, filtered observations in two repeat tracks was assessed. Among the values investigated it was found that degree 10 for the Butterworth filter gives the smallest difference between two repeat tracks. The magnitude response function is given in fig. 4.

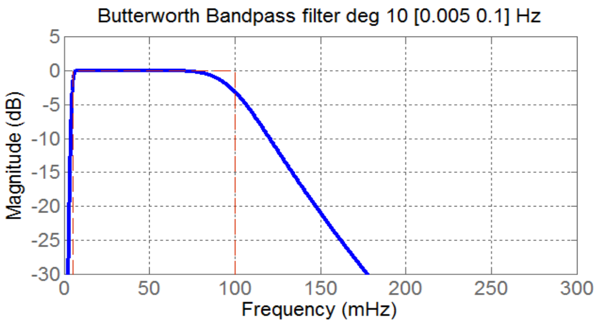

Figure 4: magnitude response of degree 10 Butterworth band-pass filter

The gravity gradient observations after filtering are shown for a single pass across the mid-ocean ridge in fig. 5. The same observations are shown for the following GOCE repeat track (after the two month repeat period). Short wavelength differences between the two tracks can be seen at the level of tens of mE. These are larger than the expected accuracy of GOCE observations. They are likely due to short-wavelength noise that is not filtered out. Filter settings are likely sub optimal and probably more noise can be filtered out. The standard deviation of a set of three repeat tracks was found to be 9 mE, which is closer to the level of accuracy expected for GOCE.

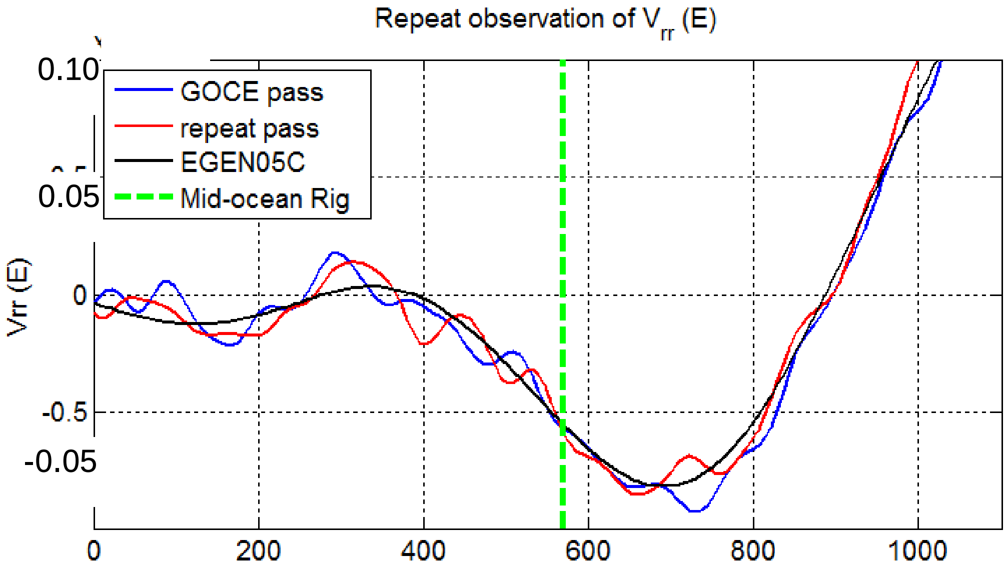

Figure 5: Gravity gradient in the radial direction after filtering for a single pass and a repeat pass. The location of the mid-ocean ridge is also shown.

6. CRUSTAL STRUCTURE IN SCANDINAVIA

An important solid earth application of the GOCE data will be to improve crustal and lithospheric structure. Fig. 6 plots the gravity anomalies from the direct GOCE solution and the ITG-GRACE2010s solution in Scandinavia, a well-studied region where nevertheless the structure of the Earth at depths below the crust is not well known.

In fig. 6, a GIA model was removed from the gravity field models to reveal the crustal structure in the free-air gravity anomaly. Most of the topography signal is removed by cutting at degree 60 and the influence of the Iceland high is removed by starting summing at degree 5.

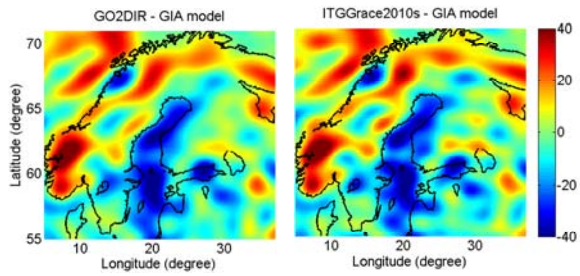

Figure 6: free-air gravity anomalies (mgal) in Scandinavia for spherical harmonic degree 5 to 60 after removal of a GIA model. Top: direct GOCE solution; bottom: ITG-GRACE2010s solution.

It can be seen that the differences between the two residual gravity fields are small. Usually, for geophysical interpretation, the gravity observations are is mostly combined with seismic measurements. The uncertainty in the seismic measurements and corrections (topography, isostasy) is much larger than the difference between the GRACE and GOCE geoids. Therefore, methods for combining gravity and seismic information need to improve, more than the accuracy of the static gravity field itself.

For solid Earth applications it will prove most useful to use the observations of the gradiometer themselves. In the process of rotation, filtering and estimating spherical harmonic coefficients geophysical signal gets lost. However, the tensor observations themselves contain a wealth of observations that should be used directly in geophysical inversion studies.

7. CONCLUSIONS

Significant improvements with respect to EGM2008 can be found for the three GOCE gravity models, compared to the state-of-the-art GRACE gravity field model ITG-GRACE2010s. The direct solution shows improvement for degrees higher than 120, while the space-wise and time-wise solutions perform better than ITG-GRACE2010s for degrees larger than 150.

The GOCE gravity fields measurements were compared with EGM2008 in an area around the Reykjanes mid-ocean ridge, south-west of Iceland. If differences appear in the shape of the mid-ocean ridge at the resolution of the GOCE gravity fields models it could signal that a physical signal is contained in the GOCE gravity field models. Only the direct solution shows differences with respect to EGM2008 that appear to follow the mid-ocean ridge.

For all GOCE models. differences with respect to EGM2008 form a spatial pattern that follows the Greenland coastline with a wavelength that appears to be well within the range at which GOCE (and GRACE) constitute the best measurement technique available. In the creation of EGM2008 several data are patched together: satellite altimetry on the coast with terrestrial data on land. Satellite altimetry data have poorer quality near the coast then in the open ocean. It is possible that the artificial piecing together of the data set results in small errors in EGM2008. GOCE does not have problems crossing a continent-ocean boundary and hence the differences that are visible in fig. 6 might promise a more accurate gravity field along the coast. Such improvement would be welcome for connecting vertical datums from different harbors, as well as helping to improve knowledge of sea-level and ocean currents in coastal areas.

Comparisons with ship gravity data in the Reykjanes area were found to be inconclusive. Many ship tracks are noisy, and all of them require removing a bias and second order polynomial. After selecting tracks with a standard deviation smaller than 10 mGal, RMS differences for GOCE models were close to that of ITG-GRACE2010s, even slightly worse. It is concluded that ship gravity data are not suitable for picking up the improvement presented by the GOCE gravity field models.

Bandpass-filtering of the gravity gradient observations is required to remove noise outside and near the edge of the measurements bandwidth of GOCE. A Butterworth band-pass filter was selected for this study. After determining the cut-off degree and order, the so-called degree has to be defined, which determines the ‘sharpness’ of the magnitude response. By checking the difference between successive repeat periods, the optimal degree was fixed at a value of 10. After filtering, the level 2 GOCE gradients are close to the gradients derived fromEIGEN05C model. However, differences remain between gradients in repeat tracks, which can be probably attributed to suboptimal filtering.

Using the global gravity fields over Scandinavia, small differences between GRACE and GOCE can be found, which are smaller than the current uncertainty involved in modelling the structure of the crust and the lithosphere. Therefore, for solid Earth studies, better techniques need to be developed for combining gravity field information with other observations such as seismic velocity anomalies. Also, much more information can be extracted from the gravity tensor components themselves, which should be used for a geophysical inversion study in their original position and reference frame.

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