CURRENT RESULTS OF GOCE IN-ORBIT VALIDATION VIA THE CROSS-OVER APPROACH

Phillip Brieden[(1)], Jürgen Müller[(1,2)]

[(1)] *Institut für Erdmessung, Leibniz Universität Hannover, Schneiderberg 50, 30167 Hannover, Germany, Email: (brieden/mueller)@ife.uni-hannover.de*
[(2)] *Centre of Quantum Engineering and Space-Time Research (QUEST), Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany*

1. INTRODUCTION

Within the context of GOCE calibration and validation (Cal/Val), a variety of approaches have been developed to assess the GOCE data quality before gravity field processing. One can differentiate between approaches that compare downward-continued gravity gradients to terrestrial data on the earth's surface on the one hand and in-orbit calibration/validation at satellite altitude on the other hand. The approach that will be further investigated here belongs to the second group: the ***cross-over (XO) approach***, in which measured gradients are compared among each other.
Main processing steps of that method are illustrated and addressed in section 2. When working with real GOCE data, some preprocessing has to be done, mainly focusing on the filtering of the gravity gradient time series, which is discussed in more detail in section 3. Finally, section 4 focuses on results and shows the control option which is given with the cross-over validation tool.

2. THE IDEA OF THE XO APPROACH

The simple idea behind the approach is that GOCE crosses the same point above the earth's surface twice on two different orbits. At both particular epochs, the same gravitation should be measured.

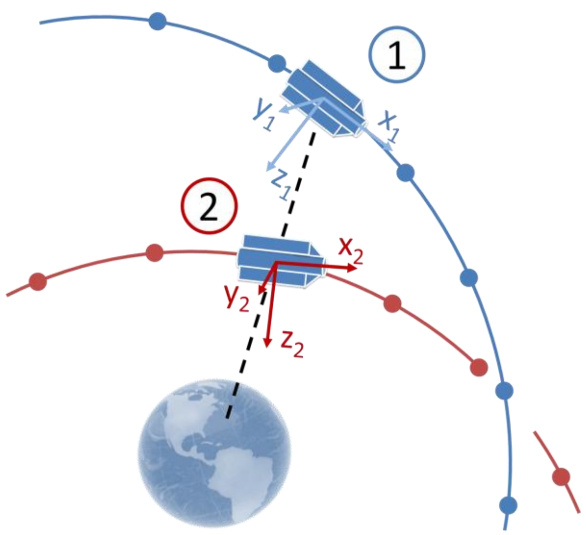

Figure 1: Principle of the XO approach

However, one has to be aware of differences in attitude and altitude that occur (see Fig. 1) and that have to be reduced for the XO analysis.
The reduction process starts with the computation of model gradients based on a global geopotential model in the gradiometer reference frame (GRF) in position 1 (see Fig. 1). This is followed by a transformation process in which the (original) model gradient is rotated from GRF to the local north oriented frame (LNOF) of position 1, downward continued to the altitude of the GOCE gradiometer in position 2 and rotated from LNOF to GRF in position 2. Finally, the difference between the original model gradient in position 1 and the transformation result in position 2 ($\mathbf{V_{ij,GPM}^{orig} - V_{ij,GPM}^{transf}}$) is assumed to be the same as the difference between the GOCE measurements in positions 1 and 2 ($\mathbf{V_{ij,G}^{1} - V_{ij,G}^{2}}$). Based on this assumption, the gradient differences caused by attitude and altitude differences can be reduced by the following relation:

$$\Delta V_{ij}^{XO} = V_{ij,G}^{1} - V_{ij,G}^{2} - (V_{ij,GPM}^{orig} - V_{ij,GPM}^{transf}). \quad (1)$$

The colors chosen in Eq. 1 correspond to the color scheme in Fig. 1.
Finally, the remaining differences ΔV_{ij}^{XO} (Eq. 1) are further analyzed.

3. PREPROCESSING

The main sensor for gravity field determination of the GOCE mission is the gravity gradiometer. Its error behavior is optimized in the frequency range between 5 to 100 mHz, the so called measurement bandwidth (MBW). Obviously, below this frequency band the gradients contain less accurate long-wavelength gravity field information. These can be made visible by a comparison between the GOCE time series and a model gravity gradient time series based on global geopotential model (GPM) information, which is highly accurate especially in long wavelengths. Fig. 2 shows the amplitude spectral densities (ASD) of both time series (GOCE red, model green) and the ASP of their differences (blue). The differences in signal content are of the order of the signal power for long wavelength, which requires a dedicated treatment in the XO approach.

Proc. of '4th International GOCE User Workshop', Munich, Germany
31 March – 1 April 2011 (ESA SP-696, July 2011)

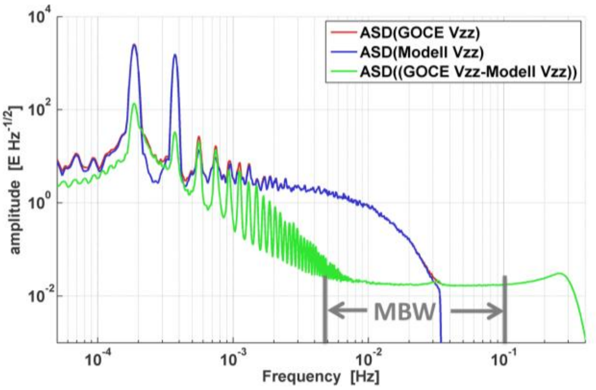

Figure 2: Differences (green) in signal power between GOCE (red) and model gravity gradients (blue) in GRF. The example shows amplitude spectral densities of the V_{zz} component.

To solve this problem, both the model gravity gradient time series and the GOCE gravity gradient time series serve as input for the filtering process that is illustrated in Fig. 3.

3.1. Filtering below the MBW (at 3.5 mHz)

To make use of the positive properties of both time series, the high accurate long-wavelength part of the model gravity gradients and the high accurate short-wavelength part of the GOCE gravity gradients are combined ([1], [2]). Thereby, the selection of the best cut-off frequency is an issue. It has been shown that the GOCE gravity gradiometer provides high-accurate measurements also slightly below the MBW. This, a high accurate model provided, is also shown by the ASD of the differences in Fig. 2. For this reason, the cut-off frequency was set to 3.5 mHz. The next step is the merging of the high-pass filtered GOCE gravity gradient time series and the low-pass filtered model gravity gradient time series.

3.2. Filtering within the MBW (at 33 mHz)

As illustrated in Fig. 3, the combined signal passes a second filtering, namely a low-pass filtering at 33 mHz. This is necessary because the GPM, which is used for the reduction process mentioned in section 2, is the ITG-Grace2010s ([5]) that is complete up to degree and order (d/o) 180, which corresponds to about 33 mHz. As for the reduction of altitude and attitude differences model information is used. The best and most correct reduction can be achieved in the frequency band where both the GOCE and the model gradient time series contain full energy. This assumption restricts the XO approach to the frequency range between 3.5 and 33 mHz. Hence, the quality of the GOCE gradients is monitored only in the MBW, which, however, is the most relevant frequency range of the gradiometer.

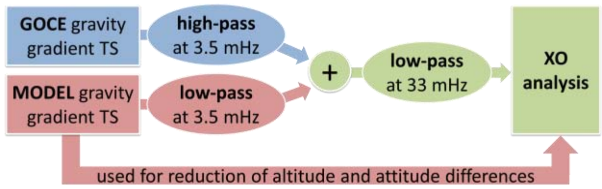

Figure 3: Preprocessing - Filter strategy

3.3. Result of Filtering

The resulting time series that serves as input for the cross-over analysis is a combination of long wavelength model information up to 3.5 mHz and GOCE information between 3.5 and 33 mHz. Above 33 mHz, the signal contains no significant energy. The amplitude spectral density of the resulting time series is illustrated in Fig. 4 (blue). Compared to GOCE (red), the ASD of the differences (green) shows that frequency range where model information was included.

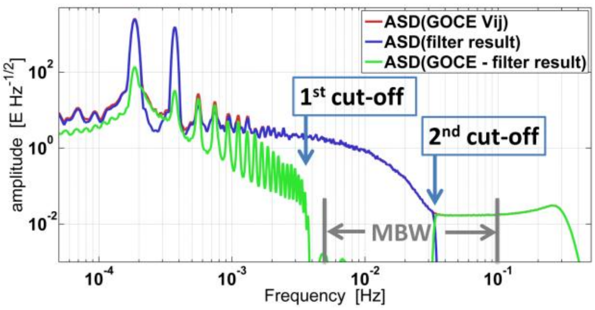

Figure 4: Amplitude Spectral Density (ASD) of the measured GOCE gravity gradient (GG) time series (TS) (red); ASD of TS after passing the filter process (Fig. 3) in blue; ASD of the differences (green) between both TS; here, all results are shown exemplarily for V_{zz}

4. RESULTS AND BENEFIT

Originally, the XO approach was developed for near real-time validation of GOCE gravity gradients ([4], [6]), more precisely the Level 1b gravity gradients (GG). In practice, the Level 1b positions, which are also used for the computation of model gradients in the GRF, has a relevant impact on the quality of the validation results: The restricted accuracy of the Level 1b data in fact limits the actual potential of the validation method, the XO approach. Compared to Level 1b (L1b) data, the use of Level 2 (L2) positions improves the results significantly. That is why L2 positions have been used here. The data covers the period of about one month: April 2010.

4.1. Quality of GOCE gravity gradients using XOs

Fig. 5 shows the remaining differences ΔV_{ij}^{XO} (Eq.1) in about 226 000 XOs, found in the April 2010 data.

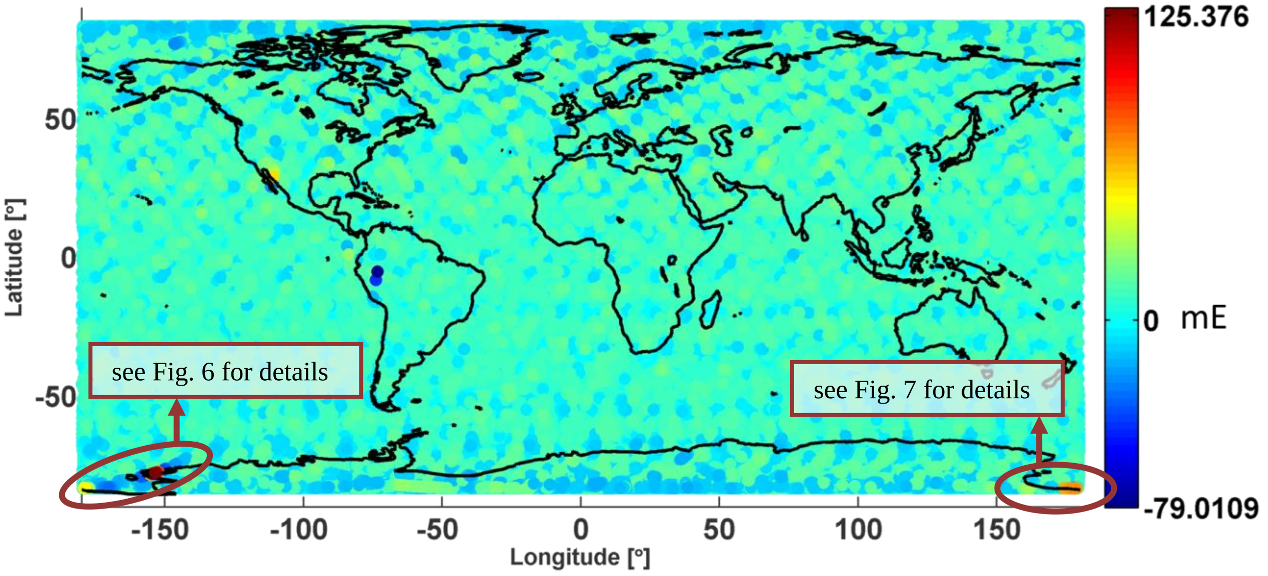

Figure 5: Geographically represented and color-coded cross-over differences ΔV_{xx}^{XO} (Eq. 1) of V_{xx}-component; data base: April 2010

The differences are 95 % below 10 mE for V_{xx}, whereas the other main diagonal components of the gravity gradient tensor show a slightly higher noise level. This is in agreement with results of other validation methods as well as with the general noise level of the main diagonal components of the GOCE gravity gradient tensor.

4.2. XO approach for the control and detection of ‘Special Event’-caused data anomalies

Additional benefit of the XO approach is the detection of data anomalies being caused by so called ‘Special Events’. These are due to hardware effects like ‘Beam-Outs’ of the ion thruster that are still known by ESA ([3]; available at: *http://earth.eo.esa.int*). What is not yet specified is the impact of these effects on the gravity gradient time series, which is investigated here.

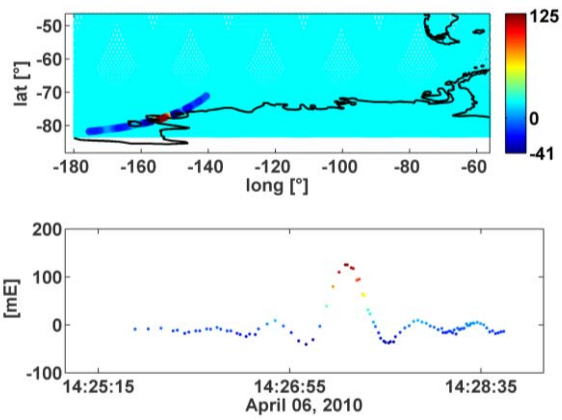

Figure 6: Largest detected XO difference in the V_{xx} component of April 2010 data set, caused by a well-known beam-out of the ion thruster

For the detection of anomalies along the gravity gradient time series with the help of XO results, XO differences along the time series are considered. Accumulations of larger differences are analyzed. In this way, a data anomaly in the V_{xx} component in April 2010 data is detected that is caused by a beam-out on April 06, 2010 at 14:27:08 UTC. This effect results in the largest difference (125 mE) that is identified in the XO analysis in April 2010 data, see Fig. 5. A detailed look into these XO differences along track is given in Fig. 6. The upper figure shows the geographical location of the color-coded XO differences mentioned above. The lower figure shows the color-coded differences with respect to time. A clear oscillation can be detected. Remarkably, the identification of similar effects in the time series of the other main diagonal components fails for this event.

Investigating other clusters of large differences along single tracks, the picture is different: the second event that is highlighted in Fig. 5 for instance is also caused by a beam-out but has an effect on all of the three main diagonal components of the gravity gradient tensor (see Fig. 7). Where the differences in V_{xx} show an oscillation again, the differences in V_{yy} and V_{zz} indicate jumps in the time series that have lower amplitudes compared to V_{xx}.

In addition to ‘Special Events’ that can be attributed to hardware effects like ion thruster beam-outs, other effects can be identified, of which the amplitude is much smaller. The cause of such effects will be subject to future work.

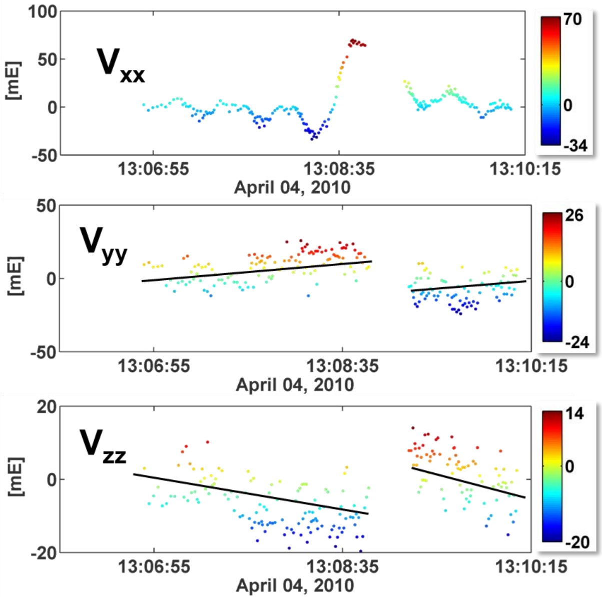

Figure 7: XO differences as function of time; beam-out has individual impact on the main diagonal components of the gravity gradient tensor V_{ii}

In general, when interpreting XO differences along track (or time), one has to have in mind: high quality and correctness of all crossing tracks is assumed. Therefore, a reliable statement can only be made when a sequence of larger differences is identified.

5. CONCLUSION

The XO approach is a suitable tool for the validation of GOCE gravity gradients. More specifically, the gradients are examined in a specified frequency band. This frequency range has currently been selected to be between 3.5 and 33 mHz. Below 3.5 mHz the GOCE gravity gradients contain less accurate long wavelength gravity information and were therefore replaced by a global geopotential model. The upper limit is set to 33 mHz because attitude and altitude differences in the XOs are reduced by using GPM information from ITG-Grace2010s, which is complete up to d/o 180 corresponding to about 33 mHz. For extracting the relevant gradiometer signal, a combination of high-pass and low-pass filters is used.

Based on April 2010 data, the quality of the gravity gradients is assessed in the frequency range between 3.5 and 33 mHz. For the V_{xx} component of the gravity gradient tensor, 95 % of all remaining differences ΔV_{ij}^{XO} (Eq. 1) in the XOs are below 10 mE. For the other main diagonal components, the noise level is slightly higher.

Beyond quality assessment, the XO approach is also used for the control and identification of anomalies in the time series that may have different origin. On the one hand, on the basis of XO differences, the effect of 'Special Events' like ion thruster beam-outs can be analyzed. These are still known be ESA but affect the time series of the main diagonal tensor components differently. On the other hand, additional anomalies can be identified in the data that have smaller amplitudes compared to the previous ones. Understanding the origin of those anomalies is subject to future work.

6. REFERENCES

[1] Brieden, P., Müller, J. (2010): *Two Methods for Quality Assessment of GOCE Gradients.* Proceedings of the ESA Living Planet Symposium 2010, 28 June - 02 July 2010, Bergen, Norway, ESA SP-686 (CD-ROM).

[2] Brieden, P., Müller, J. (2010): *Quality Assessment of GOCE Gradients*. in: Münch, U., Dransch, W. (eds.) Observation of the System Earth from Space, GEOTECHNOLOGIEN Science Report, No. 17, pp. 94-100, Koordinierungsbüro GEOTECHNOLOGIEN, ISSN 1619-7399, 2010.

[3] GOCE newsletter, Issue 2, March 2011. Available at: *http://earth.esa.int*.

[4] Jarecki, F. (2010): *Kreuzungspunktdifferenzen zur relativen Validierung satellitengradiometrischer Messungen*, Wissenschaftliche Arbeiten der Fachrichtung Geodäsie und Geoinformatik der Leibniz Universität Hannover, ISSN 0174-1454, Nr. 286.

[5] Mayer-Gürr, T., Kurtenbach, E., Eicker, A. (2010); *ITG-Grace2010 Gravity Field Model*; http://www.igg.uni-bonn.de/apmg/index.php?id=itg-grace2010, 2010.

[6] Müller, J., Jarecki, F., Wolf, K.I., Brieden, P., (2010): *Quality Evaluation of GOCE Gradients*. In: Flechtner, F.M., (eds.), System Earth via Geodetic-Geophysical Space Techniques, Springer, New York, pp. 265-276.