PERFORMANCE ANALYSIS OF GOCE GRADIOMETER MEASUREMENTS

Yi Weiyong, Murböck Michael, Rummel Reiner, Gruber Thomas

Institute of Astronomical and Physical Geodesy, Technical University Munich, Arcisstrasse 21, 80333 Munich, Germany, Email: weiyong.yi@bv.tum.de

ABSTRACT.

Since the launch of the GOCE satellite on March 17th 2009, a large amount of observation has been collected and needs to be analyzed. Of highest priority are the gradiometer measurements. Gravitational gradiometry measured in a satellite is new and many lessons are to be learnt before one can turn to a global gravity field analysis. Of highest priority is an analysis of the performance of (1) all six three-axis accelerometers, individually, (2) the three gradiometer arms, (3) the separation of the rotational signal from the gravitational one and, finally, (4) the complete three axis instrument. We compared a small set of original GOCE measurements with reference values from the EGM08 gravity field model up to a comparable spherical harmonic degree and order. The gradiometer reaches its highest performance in the so-called measurement band width (MBW) between $5 \cdot 10^{-3}$ and 0.1Hz with a 1/f increase at lower frequencies. An ideal check of the overall noise behavior is derived from the trace of the gradient tensor, i.e. from the sum of the three diagonal terms of the gradiometer. It serves not only as a diagnosis tool of the gradients but also of possible influences of the measured angular velocities. In addition to these tests some experiments were carried out with various combinations of the individual accelerometer read-outs and of gradiometer components.

Key words: Gravity field, gradiometry, measurement band width (MBW), GOCE

1 Introduction

The GOCE gravitational gradiometer consists of three pairs of ultra-sensitive accelerometers. Every accelerometer has two high sensitive axes, and one less sensitive axis. In Fig. 1 the high sensitive axes are displayed with solid arrows, and the less sensitive axes with dashed arrows. With the configuration shown in Fig. 1, the gravitational gradient tensor (GGT) components {xx}, {yy} and {zz} as well as {xz} are measured with high precision. The three diagonal elements of the gradiometer are aligned in such a way that the x-axis of the gradiometer reference frame (GRF) is in flight direction, the z-axis is in radial direction, and the y-axis is orthogonal to the orbit plane. The accuracy requirement of the gradiometer in MBW is 11mE. The sum of the three diagonal components has to fulfill LAPLACE condition.

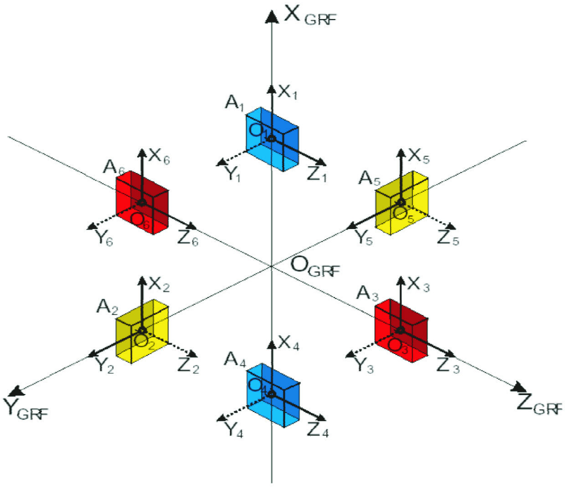

Figure 1 Gradiometer configuration

Since the components of the GGT are not measured with equal precision, the measured GGT should not be rotated. Otherwise the high precise components will be contaminated by the low precise components. Based on the satellite orbit from the SST_PSO_2I product, the reference values from a chosen a priori field can be evaluated along the orbit in either the Earth-Centered-Earth-Fixed (ECEF) frame or in the Local-North-Oriented-Frame (LNOF), and transformed into inertial frame; the reference values in inertial frame can then be rotated to Gradiometer

Reference Frame (GRF) using the orientation information from EGG_IAQ_2C product.

In order to assess the performance of the gradiometer, we analyze the consolidated measurements from the period October 31st, 2009 to December 30th, 2009. The three observed diagonal components are compared with the reference values computed based on EGM2008 as a priori field up to degree and order 250. As an important factor of the gradiometer performance, the trace of the GGT is also analyzed over the same time period.

2. Performance analysis in the frequency domain

The precision of the gradiometer is inferior outside of the so-called MBW, as stated in GOCE technical notes. This can be seen from the Power Spectral Density (PSD) of the trace, see the green curve shown in Fig. 2. The trace should be theoretically zero, or approximately equal to the value of the noise level in practice. However due to the colored noise, the trace of the GGT at low frequency is significantly larger than the noise requirement in the MBW. This tells us that some filtering should be applied outside of MBW. Inside the MBW, the noise of V_{xx} and V_{yy} is within the specification. The noise of V_{zz} is larger by a factor of two than that of V_{xx} and V_{yy}, see again Fig. 2. The reason for this is not yet understood. The signal itself in {zz} is also about two times larger than the signal in {xx} and {yy}. Thus the signal-to-noise-ratio (SNR) is the same for all three components. Fig. 2 shows also that the spectral level of the signal is significantly above that of the noise up to 2 or $3 \cdot 10^{-3}$Hz

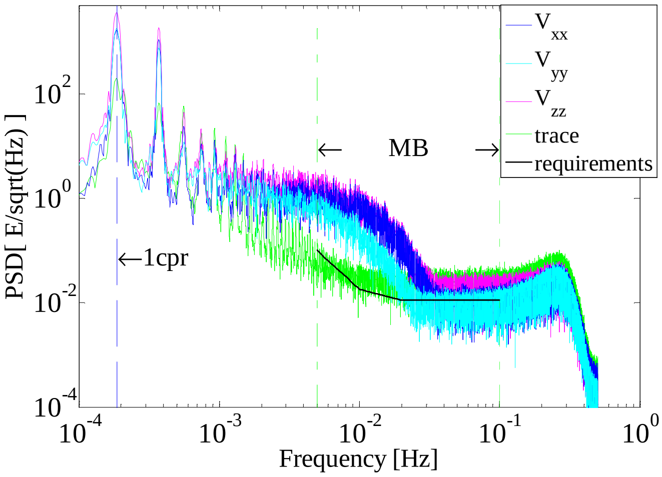

Figure 2 The power spectrum of the diagonal components

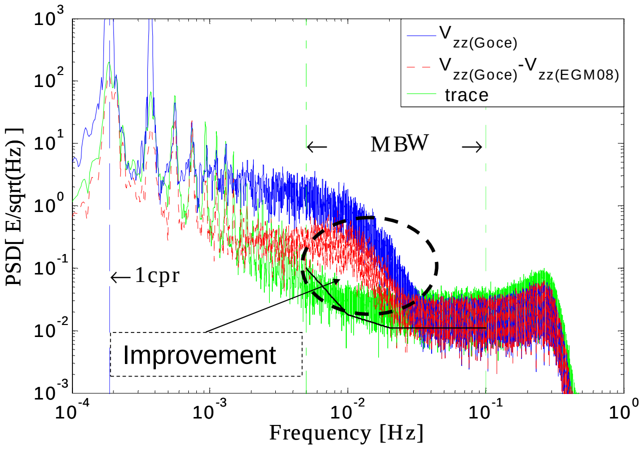

Figure 3 GOCE improvement shown in frequency domain

What is more important is whether GOCE can improve an a priori field. As shown in Fig.3, the PSD of the difference between the measurements and a chosen a priori field is also significantly above the noise level in the MBW. This indicates that GOCE will improve the a priori field (in our case EGM08 to d/o 250).

3. Performance analysis in the space domain

The measured GGT as a time series contains long wave length information such as once-per-revolution (1cpr) and multiples of it, which are mainly due to orbit altitude variation and the oblateness of the earth,

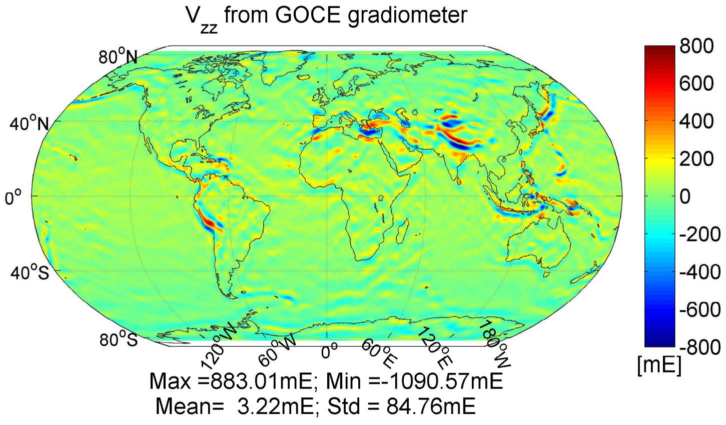

Figure 4 Observed V_{zz}

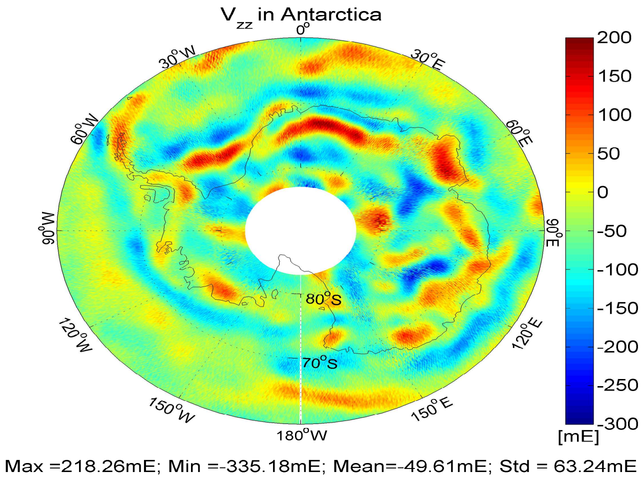

Figure 5 Observed V_{zz} in Antarctica

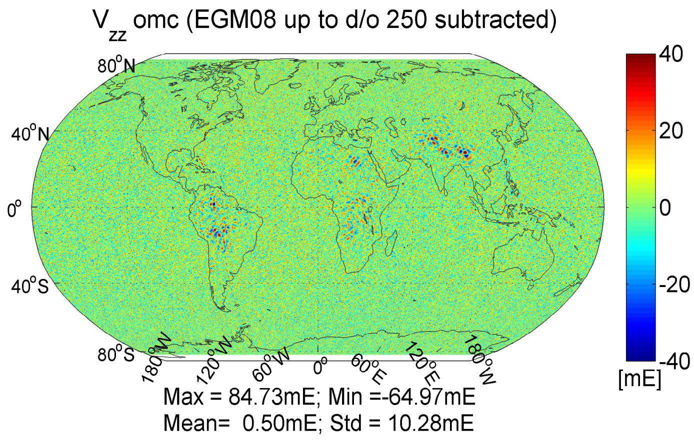

Figure 6 V_{zz} Observed minus computed

as well as some unavoidable drift in the lower frequencies. In order to inspect the data at high frequency, a pre-whitening filter with length of 1801 is used to filter out the coloured noise outside of the MBW. The GGT is shown geographically after geo-location based on the SST_PSO_2I product and filtering. The geophysical features such as Himalaya and Andes as well as Antarctica can be clearly seen from data inspection alone, see Fig. 4 and 5. This shows already that the gradiometer will provide a valuable map of the gravity field. According to our other studies, the other sensitive components have similar behaviour and are consistent with their characteristics.

In order to analyze the measurement more quantitatively, the reference values from EGM2008 up to degree and order 250 are computed along the orbit, and then transformed into the GRF. The same filter is applied to both reference values and observed values. In Fig. 6, differences are shown with respect to GGT values for the {zz} component based on EGM08 up to d/o 250. The possible areas of improvement are Himalaya, Africa, South America, South East Asia, as one can see with naked eyes.

The magnitude of the trace is an important index of the performance of the gradiometer. The trace for ascending passes are filtered and plotted in Fig. 7. The trace is roughly homogeneous globally. There is no obvious dependence on latitude (see left side). Some distortions are found over the magnetic poles for ascending passes. This is due to anomalies in the {yy} component. The standard deviation (std) of ascending passes is 14.73mE, slightly larger than the requirement (11mE). The trace for descending passes

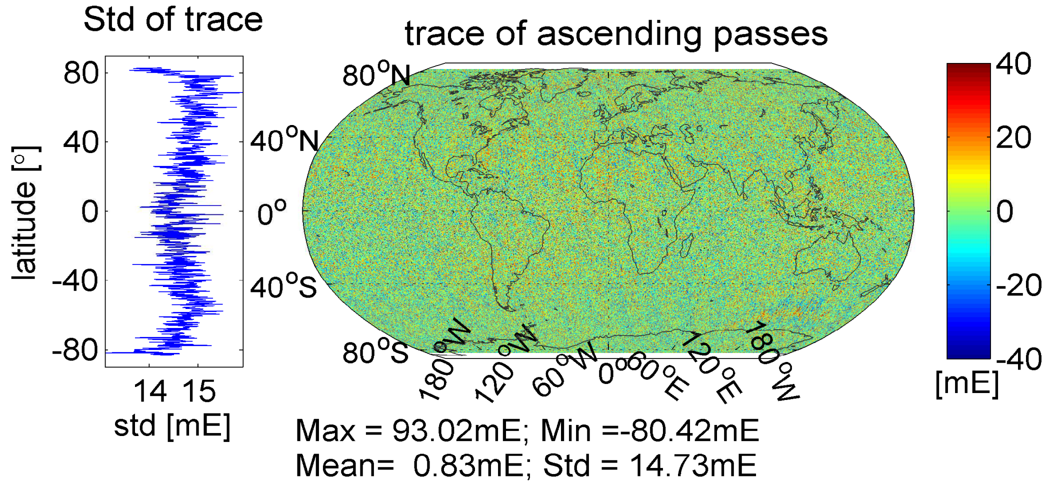

Figure 7 Trace for ascending passes

is similar to that for ascending passes in our other studies, except for no distortions at the magnetic poles.

4. Open questions

Open questions are not only the slightly higher noise level in {zz}, but also some anomalies in {yy} for ascending passes; somehow correlated with the magnetic South and North poles, see Fig. 8. There could be a relationship to attitude control.

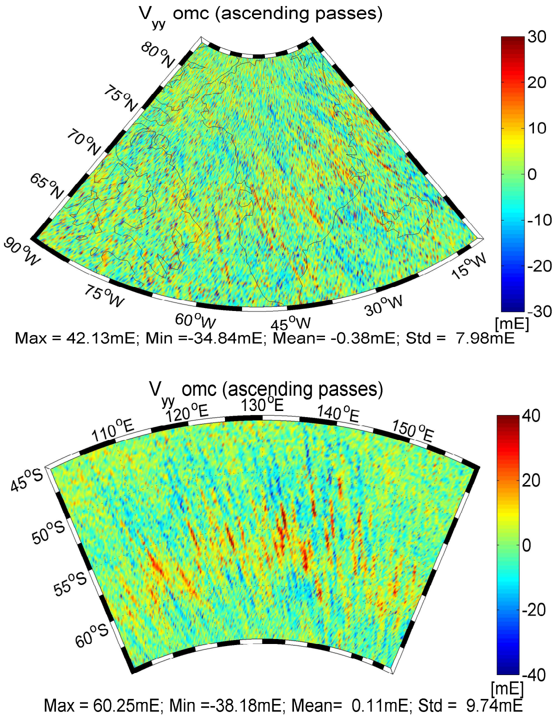

Figure 8 Anomalous observations in {yy}

5. Conclusions and outlooks

The three diagonal components are excellent, except for a slight degradation of {zz}. Due to its high signal content, this component remains however very valuable for spherical harmonic analysis.

The noise of the gradiometer is globally homogeneous, except that there are some anomalies in {yy} in the area close to magnetic poles for the ascending passes. With an appropriate outlier detection algorithm, these observations can easily be eliminated. From our study, we can conclude that the performance of the gradiometer is very high. A gravity field model with high resolution and accuracy can certainly be obtained.

Acknowledgements

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