Spectral Characteristics of GOCE Level 1b Gradiometer Data

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Abstract

Recent studies on the gravity field determination focus on GOCE-based data and global gravity field models. It is known that GOCE data are capable of improving the knowledge of the Earth's gravitational field in some specific spectral domain. However, there are different characteristics of GOCE-derived datasets which are not completely known yet. In this study, two-month GOCE Level 1b gradiometer derived data sets in different directions are investigated in the frequency domain in order to identify the spectral components of the Electrostatic Gravity Gradiometer (EGG) Level 1b data which represent the calibrated common- and differential-mode accelerations and gravity gradients in our case study. The outcome of this study is expected to help us understand the processing stages and models involved in the development of final products of GOCE data, such as spherical harmonic coefficients, global geopotential models and regional geoid models from raw measurements and introduce innovative improvements.

Keywords: GOCE, gradiometer, accelerations, gravity gradients

Introduction

The Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission was launched on March 17, 2009. The objective of the GOCE mission is to model the Earth's static gravity field with an accuracy of 1 cm in geoid heights and 1 mGal in gravity anomalies at a spatial resolution of 100 km (Drinkwater et al., 2007). In order to solely observe the Earth's static gravitational field, the influence of all other gravitational and non-gravitational accelerations should be eliminated or measured and compensated. The measurement of these effects is generally retrieved by using accelerometer observations onboard the satellite. For the previous gravity missions, CHAMP and GRACE, the accelerometers were mounted precisely at the center of the mass (COM) of the satellite. Therefore, the accelerometer, which is rigidly tied to the COM, would sense the non-gravitational forces only (Hoffmann-Wellenhof and Moritz, 2005). In addition to this concept, the core instrument making GOCE special is the Electrostatic Gravity Gradiometer (EGG) which is almost perfectly positioned at the COM. EGG consists of 3 accelerometer pairs which are placed on three mutually orthogonal axes (Fig. 1). The three axes (of the Gradiometer Reference Frame-GRF) can be expressed as X-axis, along track of the satellite, Y-axis, cross track and Z-axis, along the gravitational plumb line. The distance between the accelerometer couples (A14, A25, and A36) is about 50 cm and the distance between the center of the gradiometer and center of each individual accelerometer is about 25 cm. This causes accelerometers to be affected by the gravitational forces differently from each other and helps map the Earth's gravitational field in detail.

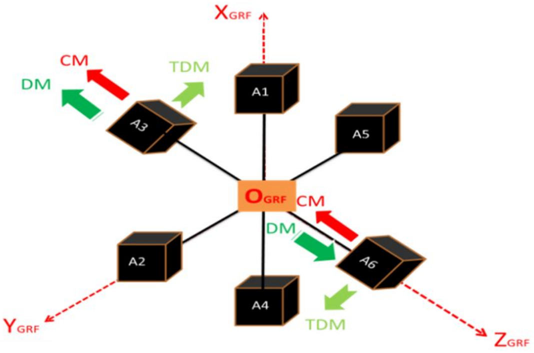

Fig. 1: Configuration of the accelerometers and the axes of the GRF.

Methodology

Data processing and development of the global gravity field models are as important as the development of the mission, its launch and monitoring. Comprehensive investigations are needed both, on the instruments used onboard and ground, communication between these two as well as the methodologies applied in the data processing. The three datasets investigated in this study are common- and differential-mode (CM and DM) accelerations and gravity gradients collected during March and April, 2011. Previous studies (see Stummer et al., 2012) focused on the GOCE EGG measurement bandwidth (5 to 100 mHz) whereas we focus on the lower frequency components (1 to 2.10^{-4} mHz) in order to complement the investigations.

The CM accelerations are of non-gravitational origin acting on the satellite, such as air-drag and solar radiation pressure and these measurements are used in the drag-free control. DM can be defined as the mode where the CM is rejected and the DM accelerations arise from gravitational sources and from angular accelerations of the satellite. The CM and DM accelerations can be expressed by Eqs. (1) and (2), respectively, where *n* and *m* represent the ID number of the accelerometers (cf., Fig. 1) and *i* indicates the measurement direction, X, Y, and Z.

$$a_{c,n,m,i} = \frac{1}{2}(a_{n,i} + a_{m,i}) \qquad (1)$$

$$a_{d,n,m,i} = \frac{1}{2}(a_{n,i} - a_{m,i}) \qquad (2)$$

The CM and DM accelerations should be separated from each other very clearly. In other words, CM should not affect the DM measurements. However, due to small gradiometer imperfections, CMs can leak into DMs which is taken into consideration during the gradiometer calibration process and data processing. These imperfections are due to the scale factor applied in the retrieval of the accelerations, misalignments of the accelerometers and non-orthogonality of the accelerometer axes. More information on the calibration procedure can be found in Mayrhofer, 2008; Siemes et al., 2012 and Stummer et al., 2012.

The main outcome of the GOCE mission is the gravity gradients and they are derived from DM accelerations (Bouman et al., 2004, ESA 2006, and Stummer et al., 2012) by using:

$$\mathbf{a}_d = \mathbf{V} + \mathbf{\Omega}^2 + \dot{\mathbf{\Omega}}, \qquad (3)$$

where $\mathbf{V}$ is the gravity gradient tensor, $\mathbf{\Omega}^2$ is the centrifugal acceleration due to the rotation of the satellite about its COM and $\dot{\mathbf{\Omega}}$ is the acceleration due to the satellite angular acceleration.

Results

Our preliminary spectral investigations of the CM and DM accelerations and each individual gravity gradient tensor component in all three directions (not shown here) show that orbital and semi-orbital periods are the common spectral characteristics of the EGG data. It is also observed that there are different characteristics of different components in various directions. Moreover, there are various unknown non-gravitational sources affecting the accelerations in the Y direction, which made us focus our study on the components of Y-axis which are derived from the accelerometer pair 2 and 5 (A25). It is worth mentioning here that the most accurate CM and DM accelerations on the Y-axis can only be retrieved from A25 pair due to the configuration of the ultra- and less-sensitive axes of the accelerometers. The V_{yy} component is important as it is one of the diagonal tensor elements and used in the development of its trace ($V_{xx}+V_{yy}+V_{zz}$) (see ESA, 2006). The trace of the gradient tensor is a very useful quantity to check the instrument performance and data quality. Fig. 2 shows the V_{yy} component derived from the DM observations during March and April, 2011. One can notice that V_{yy} shows an increasing error during the two months and has gaps.

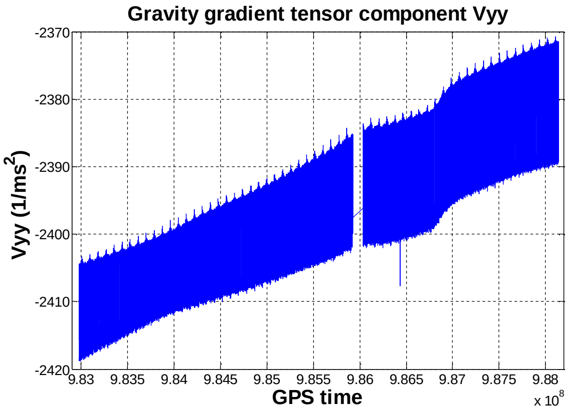

Fig. 2: Vyy collected during March-April, 2011.

Geographic positions of ascending tracks of the CM and DM accelerations and V_{yy} gravity gradients filtered and decimated to 10 seconds interval are shown in Figs. 3, 4 and 5, respectively. One can notice that there are some signatures displayed in Fig 3. Some of these signatures are related to the atmospheric dynamics over the specific regions. The DM accelerations obtained for the same period are displayed in Fig. 4. Similar signatures are observed around the same regions in both, CM and DM acceleration data along the meridian of 120°E, the region below Australia and over auroral regions in the north. The results shown in this paper indicate that there is a coupling between the CM and DM accelerations which needs to be resolved. Previous studies also suggested that there is a wind effect in the North and South Pole, auroral ovals, and ionospheric turbulences around the magnetic equator (Peterseim et al., 2011). Our further analyses suggest that the reasons of these clear signals shown in Fig.3 are most probably related with the magnetic field of the Earth (see Finlay et al., 2010).

The V_{yy} gravity gradients derived for the same period are shown in Fig. 5. In Figs. 4 and 5, it is possible to see that there are some other common characteristics. These components show a strong pattern along the longitudes and show a change in the magnitude from equator to the Polar Regions. These effects are related to the shape of the Earth and can be expressed by the effect of the second zonal term, J_2.

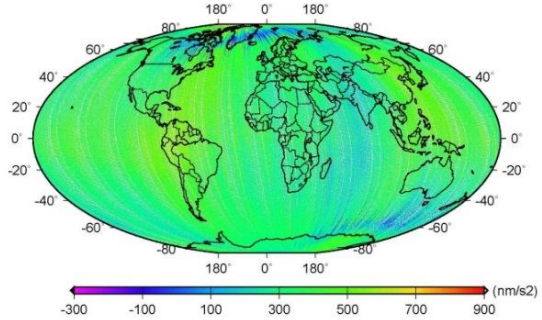

Fig. 3: CM accelerations, March-April, 2011.

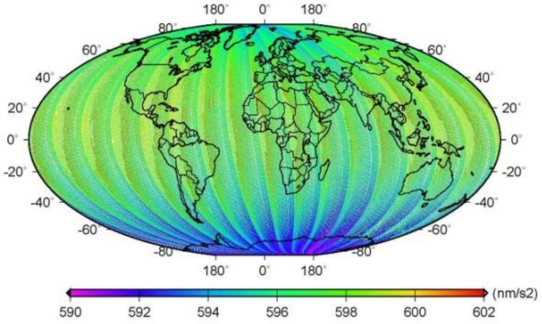

Fig. 4: DM accelerations, March- April, 2011.

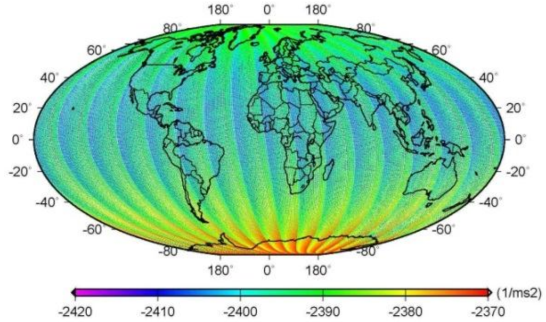

Fig. 5: V_{yy}, March- April, 2011.

Spectral analyses performed on the same datasets show that the orbital (~5386s) and semi-orbital periods (~2691s) are dominating spectral characteristics of the gravitational and non-gravitational accelerations as well as of the gravity gradients.

The power spectral densities (PSD) of the three datasets are shown in Fig 6. The PSD of the CM accelerations is higher than the one of the DM accelerations. This is not true for the other axes, X and Z. It is worth mentioning that the ion thruster assembly of GOCE keeps the mission drag free in the X direction; however, these effects of the drag compensation are not applied to the cross-track components (see Fig. 3).

The PSDs of DM acceleration and V_{yy} are at about the same level for the higher frequencies whereas, the difference increases for the lower frequency components. This might be an indication that the effect of the centrifugal acceleration is higher for the lower frequency components. The dominating components detected (see peaks in Fig. 6) are summarized in Table 1. It is noted that our results are consistent with the investigations of simulated GOCE data given in Bobojc, 2008.

Table 1: Spectral components of the EGG data.

Data	Period (s)	Source
CM	5386, 5067, 4784, 2778, 2691, and 1346	Non-gravitational sources
DM	5386 and 2691	Gravitation of other planets, geopotential
Vyy	5386, and 2691	

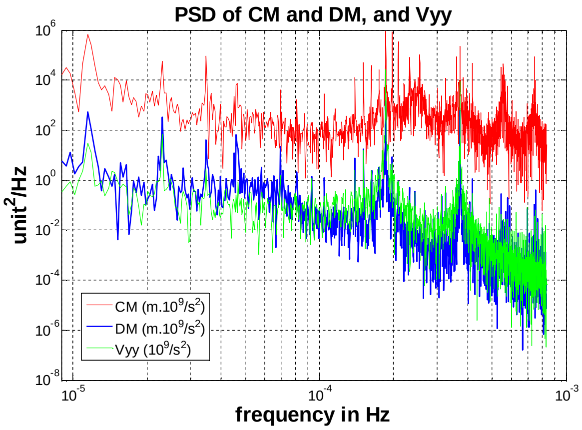

Fig. 6: PSDs of CM and DM accelerations and V_{yy}.

Discussions and Future Work

Our ultimate goal is to develop improved regional static geoid models from GOCE Level 1b data. A combination of well treated satellite observations with accurate regional terrestrial gravity data may lead to accurate regional geoid models.

The aim of this study was to understand and identify the characteristics of GOCE EGG derived Level 1b datasets. Spectral analyses show that the orbital and semi-orbital periods of GOCE dominate other spectral components. These two periodicities can be related to the gravitational attraction due the ellipticity of the Earth. Other periodicities, still to be investigated, contribute to higher frequency characteristics of the gravitational field.

It is observed that the CM accelerations are affected by atmospheric dynamics and the geomagnetic field, which leak into the DM accelerations due to the insufficient calibration parameters. The results indicate that a revision of the determination of the calibration parameters is necessary.

Further studies on the CM and DM accelerations and gravity gradients will be performed by comparing with the datasets obtained for other epochs (2 month length) and also with global gravitational models developed from other gravity missions, such as GRACE. Moreover, comparison between the ascending and descending ground tracks will be studied in order to investigate the systematic differences between the two which might be useful for the improvement of the data processing.

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