Chapter 13
Global Gravity Field Models from Different GOCE Orbit Products

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Abstract In this contribution, the in-house (processed) GOCE products including precise orbit and Earth's gravity field are compared to the official ESA products. The comparison is drawn on orbit product as well as gravity field level. To ensure comparability, gravity field models from both orbits are estimated in an identical fashion, which is particularly true for the stochastical model. We find that the in-house processed orbit is piecewise rather smooth, but contains jumps like discontinuities in the calculated geometrical point-wise positions. This leads to a degradation of the gravity field solution about by a factor of two in terms of degree variances when compared to the solution from the official orbit product.

13.1 Introduction

The gravity gradiometer on-board the Gravity field and steady-state Ocean Circulation Explorer (GOCE, e.g. Drinkwater et al. 2003; Floberghagen et al. 2011) enables measuring detailed gravity field features with high accuracy. Additionally, GOCE is equipped with a Lagrange GNSS receiver for tracking satellite-to-satellite-tracking observations of the high-low configuration (hl-SST). These data are used to determine the precise orbit of the satellite, which is required for geo-locating the gravity gradients. Furthermore, the precise orbit can be utilized to determine and stabilize

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the spherical harmonic coefficients of lower degrees in the series expansion of the gravitational potential.

Precise orbit determination (POD) is performed by the University of Bern in the frame of GOCE High Level Processing Facility (GOCE-HPF) (cf. Bock et al. 2007). These data are officially published by ESA as the precise science orbit (PSO). Complementary, POD results of an in-house developed software are available. Our processing scheme is summarized in the following Sect. 13.2. Geometrical positions of both products are used as pseudo observations for gravity field recovery, which is dealt with in Sect. 13.3. Section 13.4 discusses the results, while Sect. 13.5 gives the conclusions.

13.2 Precise Orbit Determination of GOCE

The determination of precise positions for the instruments on-board the GOCE satellite is based on POD techniques using the tracking data of the GOCE Lagrange GNSS receiver. In this paper, the sequential time differenced approach (see Shabanloui 2008 for further details) has been applied to the GOCE high-low satellite to satellite tracking GPS observations, and the solution has been denoted as geometrical precise orbit determination (GPOD) (refer to Shabanloui 2008). The geometrical POD solution is based on sequential time differenced hl-SST observations, final International GNSS Service (IGS) GPS ephemerides at the interval of 30 s and GPS clocks from Center of Orbit Determination in Europe (CODE) at the interval of 5 s. The final GPS ephemerides and clocks are fixed during the geometrical (point-wise) computation of the GOCE orbit. The orientation of GOCE can be derived from quaternion information which are observed by star tracker camera. In addition, precise Center of Mass (CoM) position of GOCE can be determined based on attitude data (quaternions) and offset between the center of mass and the Center on Mounting Plane (CMP) of the GNSS antenna.

The estimated GPOD of GOCE results are comparable with results of other groups (see Figs. 13.1 and 13.2); but because of different outliers detection and data processing strategies, the GPOD results presented here are more or less different than the results of the other groups. On the one hand, Fig. 13.1 shows differences between in-house calculated geometrical orbits and reduced-dynamic positions (published by ESA as part of the PSO products) of GOCE. On the other hand, Fig. 13.2 shows the 3D root mean squares (rms) of estimated POD of GOCE based on in-house developed POD software and Precise Science Orbit (PSO). In other words, the red curve in Fig. 13.2 shows the 3D rms which are calculated based on the differences between estimated GPOD orbits and ESA's reduced dynamical orbits and the green one in Fig. 13.2 shows the 3D rms which are calculated based on the differences between ESA's kinematical orbits and ESA's reduced dynamical orbits. The averaged 3D rms of estimated orbits for 71 days isin the range of 2.5 cm; the averaged 3D rms of PSO

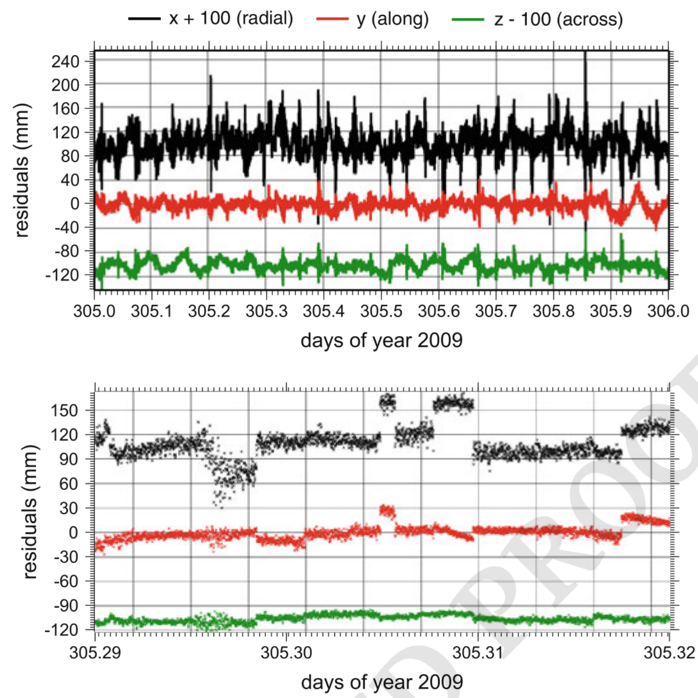

Fig. 13.1 (*Top*) Differences between geometrical and reduced-dynamic positions; (*Bottom*) Jumps like discontinuities which have been caused due to the sequential time difference data processing technique

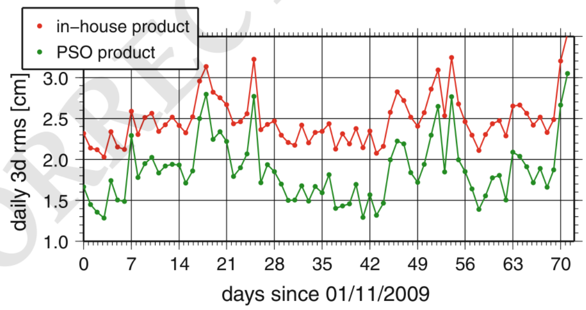

Fig. 13.2 Differences between geometrical and reduced-dynamic positions by means of the daily 3D rms

orbits 1.8 cm. The results show consistency between two orbit products which are estimated with different methods and strategies, but the day to day ‘noise’ level of the in-house estimated GOCE orbits is higher than the official PSO.

13.3 From GOCE Orbits to the Gravity Field

13.3.1 Theoretical Background

Basically, the satellite movement is related to the gravity field by Newton's equation of motion. Depending on whether this relation is used in its raw form or integrated once or twice, a distinction is made between different approaches for gravity field analysis (see an overview in Ilk et al. 2008). Here we make use of an integral equation approach, which avoids any differentiation of the observed positions (for more details see Mayer-Gürr 2006).

Solving Newton's equation as boundary value problem leads to an integral equation of Fredholm type

$$\mathbf{r}(\tau) = \mathbf{r}_A(1-\tau) + \mathbf{r}_B\tau + \int_0^1 K(\tau,\tau')\mathbf{f}(\tau',\mathbf{r},\dot{\mathbf{r}})d\tau', \qquad (13.1)$$

which represents the orbit $\mathbf{r}(\tau)$ at the normalized time τ by the connecting line between the boundary values $\mathbf{r}_A$, $\mathbf{r}_B$ and a correction term integrating the specific forces $\mathbf{f}(\tau',\mathbf{r},\dot{\mathbf{r}})$ with the kernel term $K(\tau,\tau')$ along the orbital arc. The dependency of force on location is no difficulty since the observed positions provide a sufficiently accurate approximation. The velocity only influences surface forces, which in our case are measured by the gradiometer. Discretization of Eq. 13.1 by numerical integration yields the linear observation equations, which are individually established per orbit arc. The results of the POD serve as (pseudo) observations, the spherical harmonic coefficients, which represents the gravity field, are the primary unknown parameters. The exact boundary positions and an offset per gradiometer axis are further arc wise parameters to be solved for in the Gauss-Markov model.

13.3.2 Model Settings

Gravity field models from both products, the PSO and the in-house orbit, are calculated under the same conditions. The data time span is chosen to be the first calibration period from 1/11/2009 till 11/1/2010, which equals 71 days of GOCE orbit data. The data-sets are synchronized and split up in about 3500 short arcs of 30 min arc length. Next, a reference orbit is reduced, which was integrated from ITG-Grace2010s and its background models as specified in Mayer-Gürr et al. (2010). Additionally, disturbing forces measured by the gradiometer as common mode acceleration were taken into consideration. Representation for the gravity models is a spherical harmonic series expansion up to degree and order 110. No regularization is applied. It is worth pointing out that decorrelation is done using the same stochastical model. This clearly does not lead to the optimal solution in a statistical sense, but enables a comparison purely on the basis of orbit observations.

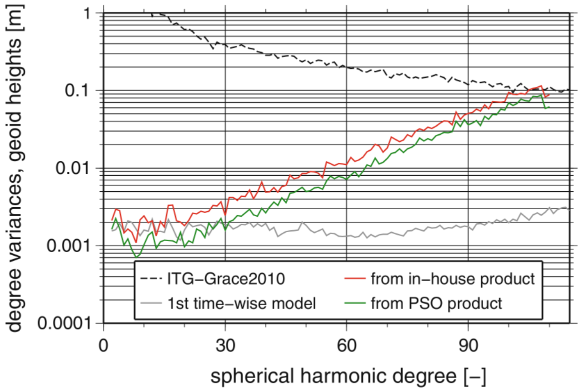

Fig. 13.3 Comparison of GOCE gravity models from different orbit products by means of degree variances excluding low order coefficients. The *dotted line* and the *solid lines* refer to the reference model and difference to the reference model, respectively

13.4 Results

Figure 13.3 shows the gravity recovery results for both orbit products, in-housed processed and ESA PSO, in the frequency domain. In order to keep consistence comparison between different independent gravity models, the first generation time-wise model of GOCE has been added to the Fig. 13.3. The in-house calculated orbit performs worse compared to the official PSO, which is obvious from the up to a factor of two larger differences to the reference models ITG-GRACE 2010s and GO_CONS_GCF_2_TIM_R1 (the first release time-wise of GOCE). This might be explained by the jump like discontinuities, which have already been discussed earlier (see Sect. 13.2). Jumps can be interpreted as high frequency signal, which can not adequately be modeled by a truncated series of spherical harmonics, and leaks therefore into the entire frequency range.

13.5 Conclusion

In this paper, geometrical precise orbits of GOCE based on the sequential time differenced between sequential carrier phase observations are estimated. The results show consistency between in-house estimated POD and official precise orbit (PSO) of GOCE, but the in-house estimated precise orbit performs worse compared to the official PSO. Discontinuities which are caused by the sequential time differenced approach can be interpreted as high frequency signal. These jumps are not adequately be modeled by a truncated series of spherical harmonics to estimate Earth's gravity field, and leaks therefore into the entire frequency range. Due to the discontinuities caused by proposed POD, the recovered Earth's gravity field based on these orbits differs from the up to a factor of two larger differences to the reference model in terms of degree variances. It should be mentioned that both estimated geometrical GOCE orbits, i.e. in-housed processed and official ESA PSO orbits, are independent of dynamical forces acting on GOCE.

References

Bock H, Jaggi A, Švehla D, Beutler G, Hugentobler U, Visser P (2007) Precise orbit determination for the GOCE satellite using GPS. Adv Space Res 1638–1647

Drinkwater MR, Floberghagen R, Haagmans R, Muzi D, Popescu A (2003) GOCE: ESA's first earth explorer core mission. In: Beutler GB, Drinkwater MR, Rummer R, von Steiger R (eds) Earth gravity field from space—from sensors to earth sciences of space sciences series of ISSIKluwer, vol 18, Academic Publishers, Dordrecht, Netherlands, pp 419–432

Floberghagen R, Fehringer M, Lamarre D, Muzi D, Frommknecht B, Steiger C, Piñeiro J, da Costa A (2011) Mission design, operation and exploitation of the gravity field and steady-state ocean circulation explorer mission. J Geodesy 85:749–758

Ilk KH, Löcher A, Mayer-Gürr T (2008) Do we need new gravity field recovery techniques for the new gravity field satellites? In: VI Hotine-Marussi symposium on theoretical and computational geodesy, vol 132. International Association of Geodesy symposia, Springer

Mayer-Gürr T (2006) Gravitationsfeldbestimmung aus der Analyse kurzer Bahnbögen am Beispiel der Satellitenmissionen CHAMP und GRACE. Ph.D. thesis, Rheinische Friedrich-Wilhelms-Universität Bonn

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

Shabanloui A (2008) A new approach for a kinematic-dynamic determination of low satellite orbits based on GNSS observations. Ph.D. thesis, Rheinische Friedrich-Wilhelms-Universität Bonn