GOCE gradient validation using in-orbit comparison along collinear / repeating tracks

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Introduction

The GOCE (Gravity field and steady-state Ocean Circulation Explorer) mission had been very successfully operated between 2009 and 2013. GOCE's main measurement quantity is the gravitational gradients. To ensure high qualitative final GOCE products including highly accurate gravity field models, various methods are examined to assess the gradient quality. At IfE in Hannover, two in-orbit validation methods have been developed: the comparison of gravitational gradients in satellite track cross-overs and their comparison along collinear or almost repeating tracks.

The latter is discussed in more detail here:

- The basic idea and the processing steps for comparing satellite observations along collinear tracks are explained.
- This includes the 'adjustment' of the observations along both tracks due to differences in altitude and attitude.
- The orbit of GOCE was lowered stepwise in the last months of the mission from about 260 km down to 229 km. Finally, collinear-track results are given comparing the data quality of different altitude levels.

Comparison of gradients in collinear tracks: basic idea + 'adjustment' of the V_{ij} to be compared

The basic idea of the comparison is that the gravitational gradient tensors (V_{ij}) measured along collinear tracks are almost identical, which is used for quality checks.

Collinear tracks are satellite tracks of which their projection in the (earth fixed) latitude/longitude plane leads to almost parallel, closely spaced or even almost identical tracks. The 'closeness' finally depends on the orbit and thus the satellite altitude. Here tracks are considered as 'close' as long as they are less than ± 0.5° apart (in terms of longitude).

The closest tracks occur after a repeat cycle of the mission, which is 61 days (at a mean altitude of 260 km, Figure 1: period A). Further close tracks arise after sub-cycles, which is strongly altitude dependent (see Table 1).

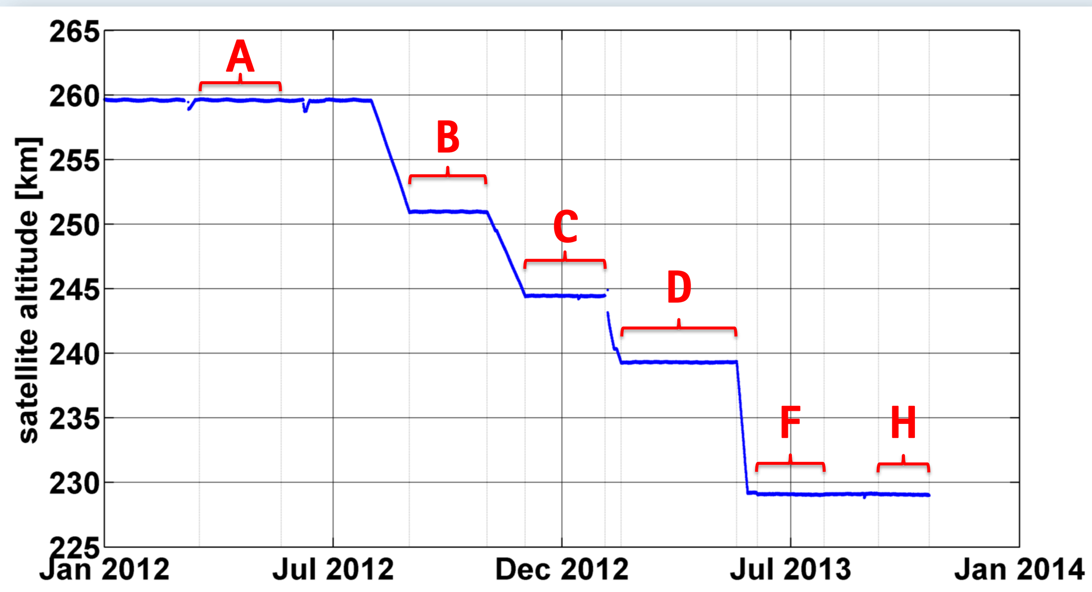

Figure 1: Orbital mean satellite altitude derived from its spherical radius minus Earth radius of 6378 km; analysis periods are A,B,C,D,F,H

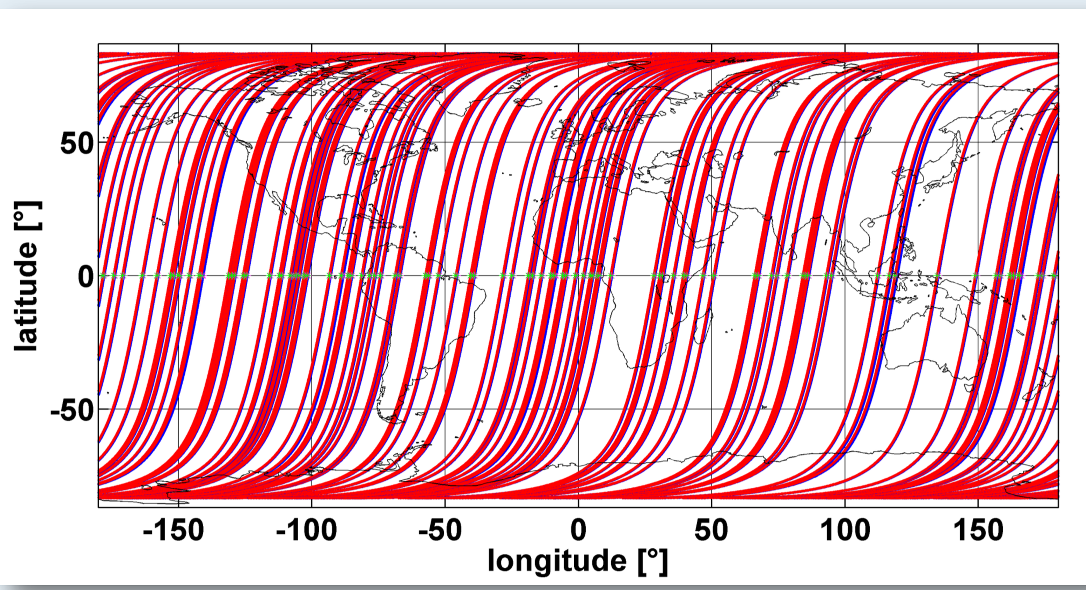

Figure 2: 79 pairs (red+ blue) of descending (dsc) satellite tracks from data period A with a 61 days repeat cycle and a mean longitudinal distance of 0.015° respectively 1.5 km at the equator.

For comparison purposes, the 'measured' gravitational gradient tensors $V_{ij}^{track\ 1}$ and $V_{ij}^{track\ 2}$ along the two tracks have to be 'adjusted' which means, that the observations have to be brought into identical coordinate systems. The most important steps are (see also Figure 3):

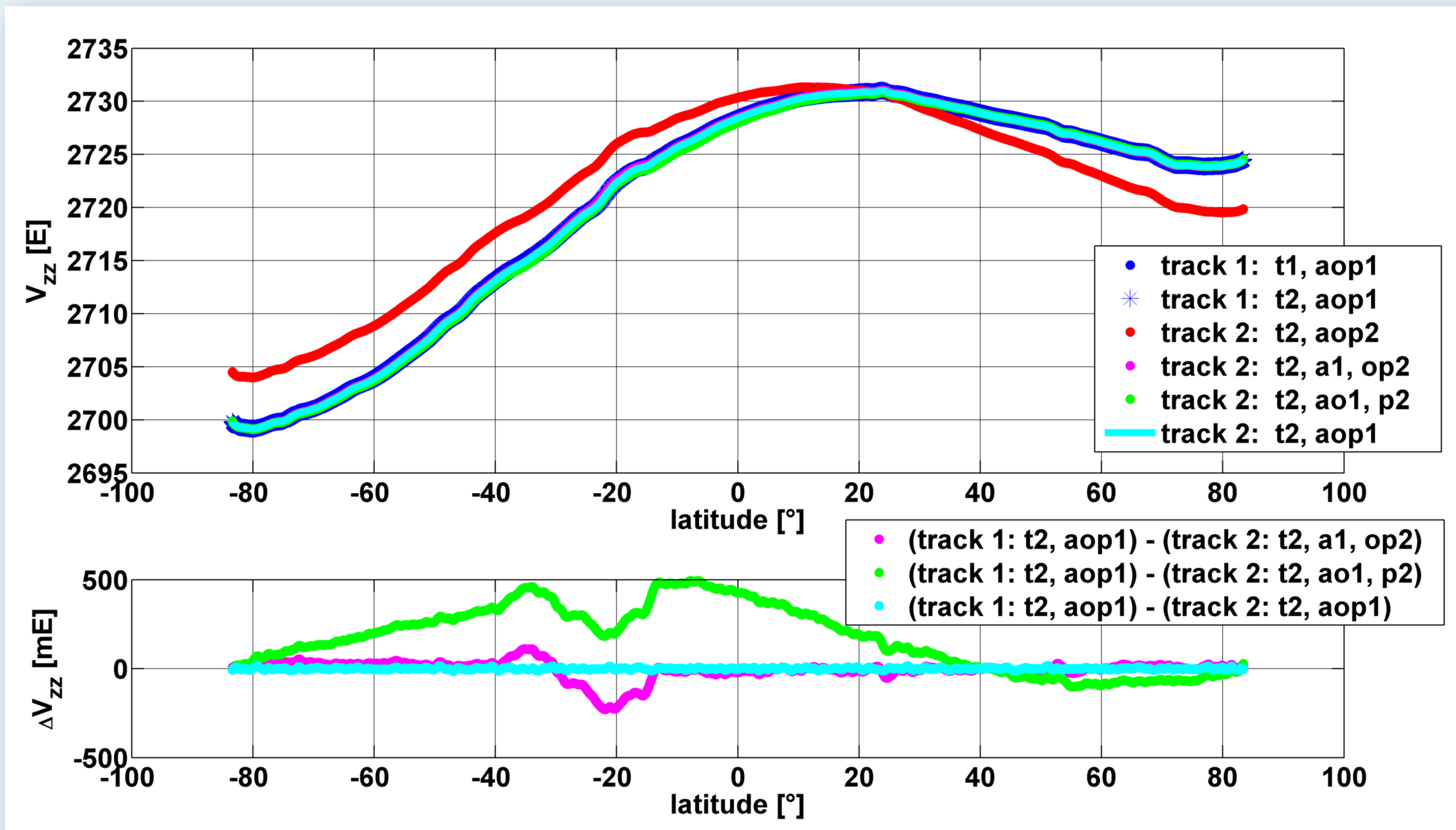

Figure 3: 'Adjustment' of V_{ij} along both tracks; necessary steps are explained below

1. Interpolation of V_{ij} along track 1 to latitudes (t) of observations along track 2
   → track 1: t2, aop1
2. Reduction of differences in altitude (a) with the help of - gravity field model(*) derived - gradient differences $\Delta V_{ij}^{altitude} = V_{ij,a2}^{model} - V_{ij,a1}^{model}$
   → track 2: t2, a1, op2
3. Rotation(**) of V_{ij} along track 2 to orientation (o) of V_{ij} along track 1
   → track 2: t2, ao1, p2
4. Reduction of differences in position (p) with the help of - gravity field model(*) derived - gradient differences $\Delta V_{ij}^{position} = V_{ij,p2}^{model} - V_{ij,p1}^{model}$
   → track 2: t2, aop1

Finally, the residuals

$$\boxed{\Delta V_{ij} = (\text{track 1: t2, aop1}) - (\text{track 2: t2, aop1})} \qquad (1)$$

are analyzed.

(*) gravity field model used here: ITG-Grace 2010s up to d/o 180

(**) to allow for rotation of the gravitational gradient tensor, GOCE V_{ij} is partly complemented with Vij derived from gravity field model(*):

- Long-wavelength signal information of V_{xx}, V_{yy}, V_{zz}, V_{xz} is replaced below 0.004 Hz, and
- V_{xy}, V_{yz} have completely been replaced by model information.

Results of collinear-track comparison

Period (see Fig.1)	Length of dataset [days]	Altitude [km]	Pairs of # ascending tracks + # descending tracks (Sub-)Cycles [days] ($\Delta\lambda$ < ±0.5° longitude) Mean distance [°] and above equator [km]				RMS ΔV_{xx} [mE]	RMS ΔV_{yy} [mE]	RMS ΔV_{zz} [mE]
A	66.1	260	712 acs + 717 dsc 20 0.37° ↔ 43 km	391 acs + 393 dsc **41** 0.36° ↔ 41 km	80 acs + 79 dsc 61 0.015° ↔ 1.5 km		3.04 3.01	6.03 4.26	4.92 4.92
B	63.0	251	548 acs + 542 dsc 25 0.36° ↔ 42 km	369 acs + 368 dsc **37** 0.36° ↔ 42 km	13 acs + 13 dsc 62 0.006° ↔ 0.75 km		3.08 3.05	8.10 6.34	5.08 5.04
C	63.0	244	658 acs + 653 dsc 19 0.34° ↔ 39 km	226 acs + 223 dsc **48** 0.32° ↔ 37 km			3.04 3.06	5.33 4.10	5.05 4.97
D	93.0	239	1106 acs + 1109 dsc **8** 0.31° ↔ 36 km	340 acs + 341 dsc 65 0.26° ↔ 30 km	224 acs + 226 dsc 73 0.06° ↔ 7 km	162 acs + 163 dsc 81 0.37° ↔ 43 km	3.09 3.05	9.95 6.90	5.09 5.03
F	54.0	230	223 acs + 232 dsc 25 0.48° ↔ 55 km	175 acs + 174 dsc **31** 0.30° ↔ 34 km			3.13 3.11	17.15 13.34	5.69 5.60
H	41.0	229	191 acs + 192 dsc 25 0.47° ↔ 54 km	127 acs + 128 dsc **31** 0.31° ↔ 36 km			5.55 4.01	13.91 12.12	5.42 5.32

Table 1: Statistics of collinear-track residuals related to 6 data periods A-H in the last months of the GOCE mission; RMS values on the right (upper – ASC, lower – DSC) correspond to the sub-cycles of the red-framed cells

The residuals ΔV_{ij} according to equation (1) are shown as cyan colored dots in the lower part of Fig. 3. Due to the fact that within the analyzed data period up to 1109 pairs of collinear tracks arise per sub-cycle with more than 2600 data points per track, RMS (root mean square) values are used as a simple method for the quantification of the residuals.

In order to compare the residuals between different data periods, one RMS value per sub-cycle is computed from all residuals along 100 arbitrarily chosen collinear-track pairs (if there are at least 100 available).

RMS values for ΔV_{xx}, ΔV_{yy}, ΔV_{zz} for the red-marked sub-cycle are given in the right part of Table 1. The sub-cycles are chosen to be similar (close to 37 km here).

Conclusions:

- The lowering of the orbit leads to an increase of the noise level, very clearly seen in ΔV_{yy}.
- RMS values of ΔV_{ij} along descending tracks are smaller compared to those along ascending tracks.
- Collinear-track residuals between different sub-cycles ($\Delta\lambda$ < ±0.5°) - not shown here -, do not show any track-distance dependency.

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esa living planet symposium 2016
PRAGUE, Czech Republic, 09-13 May 2016

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