Model name	**GO_CONS_GCF_2_DIR_R5**
Producer	- GFZ German Research Centre for Geosciences Potsdam, Section 1.2 “Global Geomonitoring and Gravity Field” - Groupe de Recherche de Géodésie Spatiale (GRGS)/CNES, Toulouse
Method	Direct approach
Data period	01/11/2009 – 20/10/2013 Effective data volume: ~ 19380 orbital revolutions ~ 1259 days
Max. degree	300
Input data	*Orbit data:* - SST_PKI: Kinematic GOCE orbits as positions for the gradiometry observation equations - SST_PRM: Rotations between inertial and Earth-fixed reference frames *Gradiometer data:* - EGG_NOM: Level 2 gravity gradients in GRF - EGG_IAQ: Rotations between inertial and gradiometer reference frames *Other satellite data:* - LAGEOS-1/2 SLR data (measurement period 1985 – 2010) - GRACE GPS-SST & K-band range-rate data (measurement period of ten years 2003 – 2012)
Processing strategy	*A-priori Information used* - The a-priori gravity field for the processing of the GOCE gravity gradients was the GOCE-model 4th release from the direct approach GO_CONS_GCF_2_DIR_R4 up to its maximum degree/order 260 (Bruinsma et al. 2013). *Processing Procedures:* - The GOCE gravity gradients were processed without applying the external calibration corrections. - The observation equations were filtered with a 8.3 - 125.0 mHz bandpass filter. Subsequently "SGG" normal equations to degree/order 300 have been computed separately for 42 continuous time segments of 1259 days totally (identified after the preprocessing of the data) and for each of the gradient components Txx, Tyy, Tzz and Txz. For the period 20120801 to 20120831 Txx has been replaced by linear combination of Tyy and Tzz. Tyy has been replaced by linear combination of Txx and Tzz for the time span 20130530 to 20130731. - The Txx Tyy, Tzz and Txz SGG normal equations were accumulated with the relative weight 1.0. But within the SGG components, all observation equations have been weighted individually according to their standard deviation estimated w.r.t. the a-priori gravity field. *Combination & constraints:* To overcome the numerical instability of the GOCE-SGG normal equations due to the polar gaps and to compensate for the poor sensitivity of the GOCE measurements in the low degrees the following stabilizations were applied:

	- The GOCE-SGG normal equation was fully combined with a GRACE normal equation. Details about this GRACE contribution are given below. - A spherical cap regularization in accordance to Metzler and Pail (2005) was iteratively computed to d/o 300 using the GRACE/LAGEOS data as mentioned below to degree/order 130. - Additionally a Kaula regularization was applied to all coefficients beyond degree 180 *Details of the LAGEOS/GRACE contribution:* The GRACE part is a GRACE normal equation to degree/order 175 for the ten years time period 2003 through 2012 from the GRGS/CNES release 3 GRACE processing. For details of this GRACE release see: grgs.obs-mip.fr/grace/variable-models-grace-lageos/grace-solutions-release-03 In the combination with GOCE, the GRACE contribution was taken only up to degree/order 130. The harmonics of very-low degree, in particular degrees 2 and 3, cannot be estimated accurately with GRACE and GOCE data. Therefore, LAGEOS-1 and -2 normal equations over the time period 1985 through 2010 were used in the combination in order to improve the gravity field solution. *Solution:* - The solution was obtained by Cholesky decomposition of the accumulated normal equations.
Key characteristics	- The model is a satellite-only model based on a full combination of GOCE-SGG with GRACE and LAGEOS, leading to an excellent performance of the long as well as of the short wavelengths. - More processing details are given in Pail et al. 2011 and Bruinsma et al. 2013
References	Bruinsma SL, Lemoine JM, Biancale R, Vales N (2009) CNES/GRGS 10-day gravity field models (release 2) and their evaluation, Adv. Space Res., doi:10.1016/j.asr.2009.10.012 Bruinsma, S., Foerste, C., Abrikosov, O., Marty, J.-C., Rio, M.-H., Mulet, S., Bonvalot, S. (2013): The new ESA satellite-only gravity field model via the direct approach, Geophysical Research Letters, 40, 14, p. 3607-3612. doi.org/10.1002/grl.50716 Dahle C, Flechtner F, Gruber C, König ., König R, Michalak G and Neumayer KH (2012): GFZ GRACE Level-2 Processing Standards Document for Level-2 Product Release 0005, (Scientific Technical Report - Data , 12/02), Potsdam, 20 p. DOI: 10.2312/GFZ.b103-1202-25 Metzler B, Pail R (2005) GOCE Data Processing: The Sperical Cap Regularization Approach, Stud. Geophys. Geod. 49 (2005), 441-462 Pail R, Bruinsma SL, Migliaccio F, Förste C, Goiginger H, Schuh WD, Höck E, Reguzzoni M, Brockmann JM, Abrikosov O, Veicherts M, Fecher T, Mayrhofer R, Krasbutter I, Sanso F, Tscherning CC (2011) First GOCE gravity field models derived by three different approaches. Journal of Geodesy, 85, 11, 819-843. doi: 10.1007/s00190-011-0467-x

Model characteristics

The following table and plots show the main characteristics of GO_CONS_GCF_2_DIR_R5 (DIR-R5) in comparison to the previous releases 2, 3 and 4 of the GOCE direct approach (GO_CONS_GCF_2_DIR_R2 = DIR-R2, GO_CONS_GCF_2_DIR_R3 = DIR-R3 resp. GO_CONS_GCF_2_DIR_R4 = DIR-R4) and EGM2008.

In Fig. 1 the spectral behaviour of DIR-R5 is shown. The formal error of DIR-R5 (blue) is significantly smaller compared to that of DIR-R4 (brown). The step in the DIR-R4 formal error curve at degree 55 corresponds to the transition between the two different contributions in the GRACE normal equation system as used at that time for this model (to degree 54 from GRACE release 2 of GRGS, c.f. Bruinsma et al. 2009 and beyond degree 54 from release 5 of GFZ, c.f. Dahle et al. 2010). This jump of about a factor of 2 is caused by the significantly decreased formal error of the new GRACE release 5 from GFZ w.r.t. the older release from GFGS. In DIR-R5 this jump of the formal errors doesn't exist anymore since this model contains only one individual GRACE contribution (i.e. GRGS release 3). Furthermore, the cumulated error of DIR-R5 at degree 200 (expressed in terms geoid height) is **0.8 cm** (yellow) compared to **1 cm** for DIR-R4 (purple) which means an improvement of about 60% of DIR-R5 versus DIR-R4.

Furthermore, in the short wavelength range between degree 180 and 260 DIR-R5 is also closer to EGM2008 compared to DIR-R4. This means a decrease of the noise (c.f. also Fig. 2, bottom vs. top) as well as an improved signal content in DIR-R5 in comparison with DIR-R4 (c.f. Tab. 1)

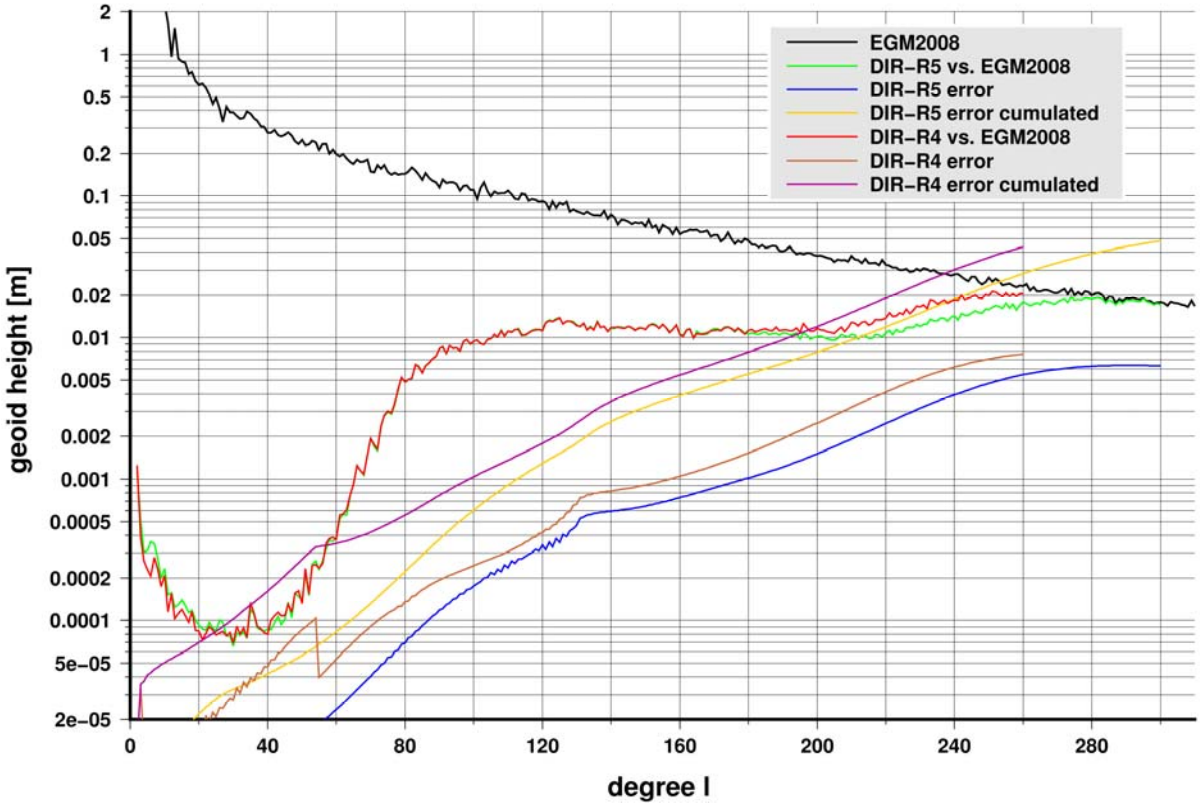

Fig. 1: Spectral behaviour of DIR-R5 in comparison with the model DIR-R4. This plot gives the difference degree amplitudes in terms of geoid heights of DIR-R5 and DIR-R4 to EGM2008 (green resp. blue) and the formal error degree amplitudes resp. the cumulated errors for both models

The comparison of global geoid height differences in Fig. 2 for DIR-R5 (bottom) and DIR-R4 (top) minus EGM2008 shows a significant noise reduction for DIR-R5 versus DIR-R4, particularly over the oceans. This corresponds also to the statistical numbers “wrms about mean / min / max” as given in the plots. Please note that these numbers include the polar caps.

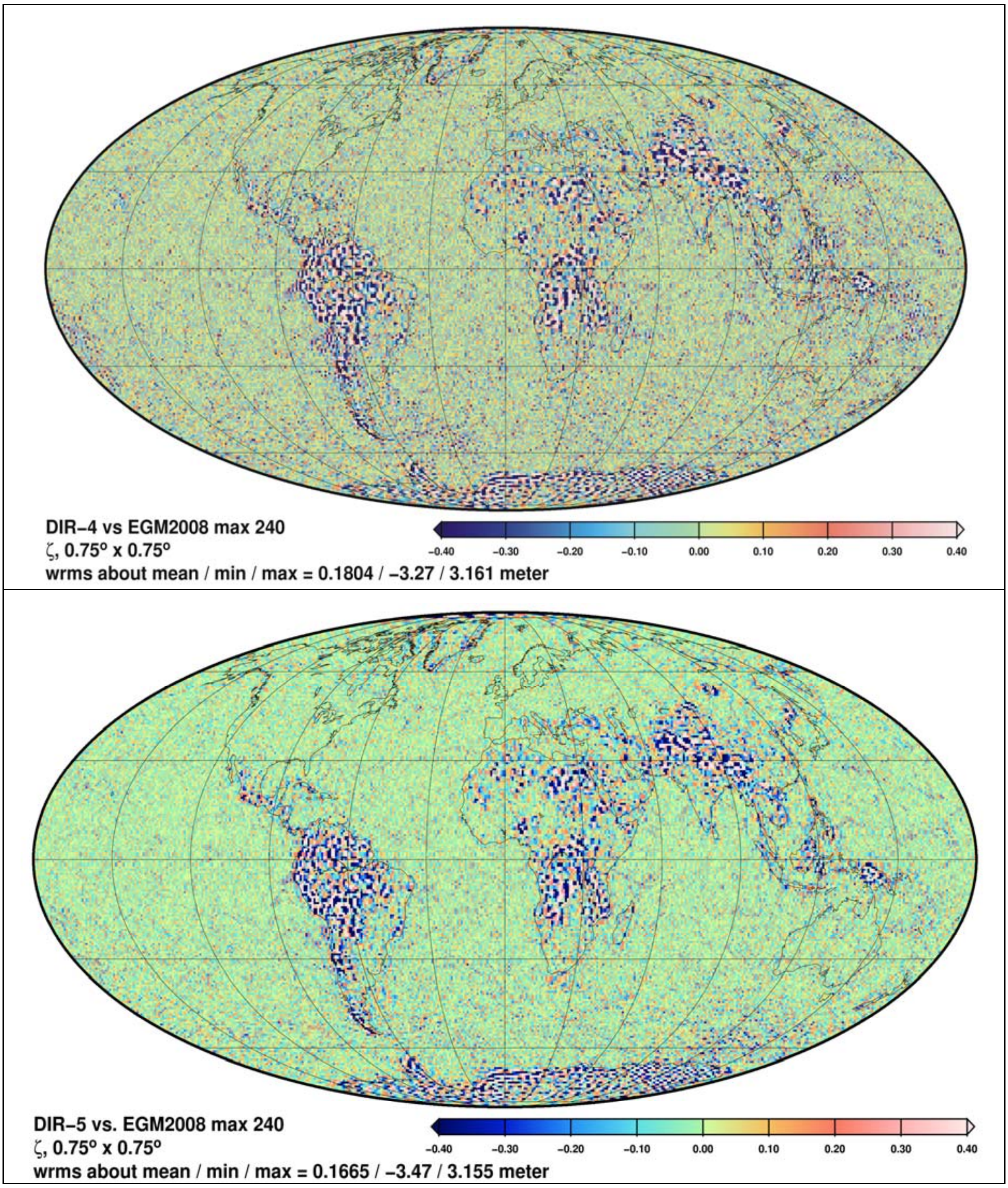

Fig. 2 Global geoid height differences (meter, spatial grid resolution 0.75° x 0.75°, maximum degree/order 240) between EGM2008 and DIR-R4 (top) resp. DIR-R5 (bottom)

Geoid height differences between the two DIR-models themselves are given in Fig. 3. The visible patterns reflect the noise reduction of DIR-R5 w.r.t. DIR-R4 as already indicated in Fig. 2.

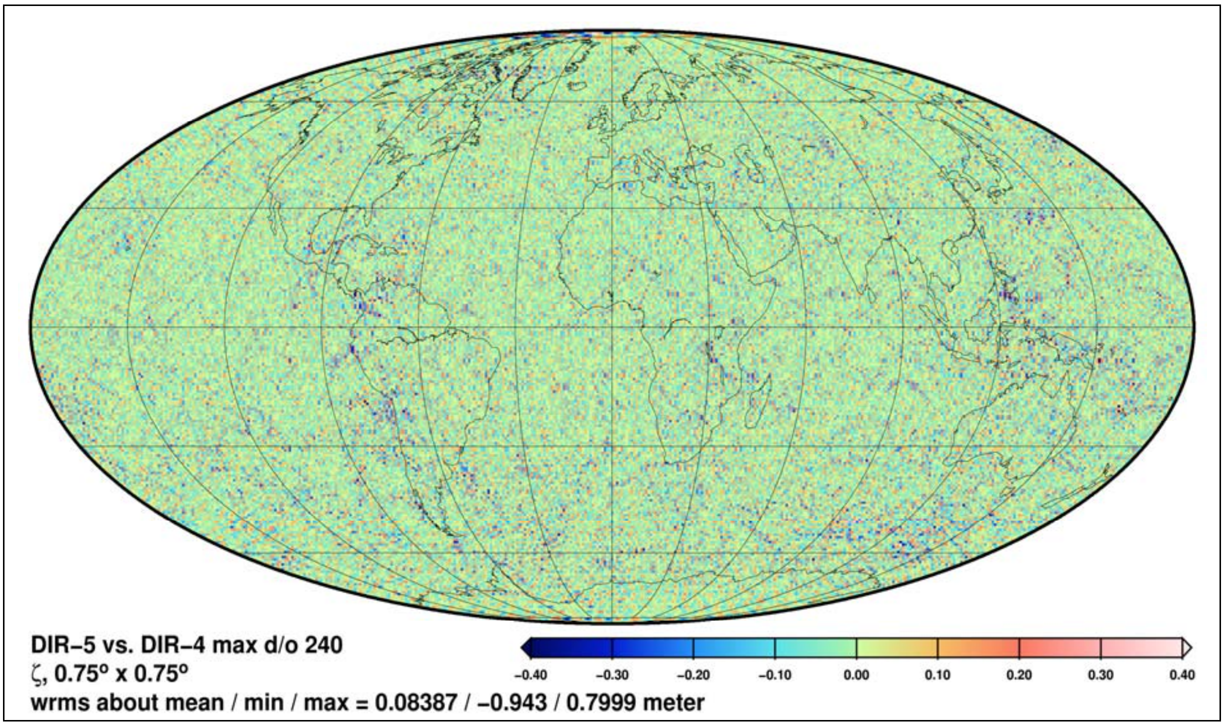

Fig. 3 Global geoid height differences (meter, spatial grid resolution 0.75° x 0.75°, maximum degree/order 240) between DIR-R5 and DIR-R4

The GPS/Leveling comparisons as given in Tab. 1 confirm the significant improvement of DIR-R5 in comparison with the models DIR-R2, DIR-R3 and DIR-4. The obtained GPS/Leveling RMS values for DIR-R5 are significantly smaller than for the preceding GOCE models.

	USA (6169)	**Australia** (201)	**Germany** (675)	**Canada** (1930)	**Europe** (1234)	**Japan** (816)
DIR-R2	**36.8**	**32.6**	**28.5**	**31.0**	**33.6**	**32.8**
DIR-R3	**35.2**	**28.1**	**21.2**	**27.8**	**30.5**	**31.3**
DIR-R4	**32.8**	**26.3**	**16.8**	**24.7**	**28.4**	**30.1**
DIR-R5	**32.4**	**24.9**	**15.2**	**23.7**	**27.8**	**29.0**

Tab. 1: GPS/Leveling tests for the DIR-R5 model versus DIR-R2, DIR-R3 and DIR-R4. This table gives the Root Mean Square values (**cm**) about mean of GPS-Leveling minus model-derived geoid heights for six GPS/Leveling data sets (number of points in brackets). All models were taken up to d/o **240** and filled up by EGM2008 to d/o 360.