COMBINATION OF GOCE DATA WITH COMPLEMENTARY GRAVITY FIELD INFORMATION

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ABSTRACT

GOCO (“Gravity Observation Combination“) is a project initiative in the frame of ESA’s GOCE Data AO. The main objective is to compute high-accuracy and high-resolution static global gravity field models based on data of the satellite gravity missions CHAMP, GRACE, and GOCE, terrestrial gravity field, satellite altimetry, and SLR data. As a first product, the satellite-only model GOCO01S was computed, which represents the first consistent combination of GOCE and GRACE data. These satellite-only models are being successively improved by including more data, but also CHAMP and SLR normal equations, as it was done for the successor model GOCO02S. In the near future, these satellite-only models will be complemented by combined global gravity models also incorporating terrestrial gravity and satellite altimetry data.

1. INTRODUCTION

The Earth’s gravity field reflects the mass distribution and its transport in the Earth’s interior and on its surface. In 2000, the era of dedicated satellite gravity missions began with the launch of CHAMP (CHAllanging Minisatellite Payload; [15]), followed by the launches of GRACE (Gravity Recovery And Climate Experiment; [16]) in 2002, and GOCE (Gravity field and steady-state Ocean Circulation Explorer; [3]) in 2009. Based on data of these missions, global Earth’s gravity field models with homogeneous accuracy and increasingly high spatial resolution could be derived.

The global gravity field model GOCO01S ([12]), including 7 years of GRACE and 2 months of GOCE gradiometry data, represents the first consistent combination of these two data types. It was made publicly available by the GOCO consortium in July 2010.

The new release GOCO02S, which is based on 8 months of GOCE data, shows an improved performance mainly in the high degrees. As additional observation types also GPS satellite-to-satellite tracking (SST) data of GOCE and CHAMP, and satellite laser ranging (SLR) observations to 5 satellites are included.

2. PROCESSING STRATEGY

The Earth’s gravitational potential V is usually parameterized in terms of coefficients of a spherical harmonic series expansion in spherical coordinates (with radius r, co-latitude ϑ, latitude λ):

$$V(r,\vartheta,\lambda) = \frac{GM}{R}\sum_{n=0}^{N_{\max}}\left(\frac{R}{r}\right)^{n+1}\sum_{m=0}^{n}\bar{P}_{nm}(\cos\vartheta)\cdot \left[\bar{C}_{nm}\cos(m\lambda)+\bar{S}_{nm}\sin(m\lambda)\right] \qquad (1)$$

with G the gravitational constant, M mass of the Earth, R mean Earth radius, $\bar{P}_{nm}$ the fully normalized Legendre polynomials of degree n and order m, and $\{\bar{C}_{nm};\bar{S}_{nm}\}$ the corresponding coefficients to be estimated. All observation types are functionals of the gravitational potential V.

Before combination, full normal equations are assembled for the individual observation types. Special emphasis is given to an adequate stochastic modelling

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of the individual components. This is especially important for GOCE gradiometry, because of the colored noise behaviour of the gradiometer. Details on the stochastic modeling of GOCE gradients can be found in [7]. For GOCE gradiometry, the time-wise processing strategy has been applied ([10], [13]).

The combination procedure of the GOCO models is based on the addition of the individual full normal equations. The models are constrained in the high degrees by Kaula regularization towards a zero model in order to improve the signal-to-noise ratio. Relative weighting factors and the regularization parameter are estimated by means of variance component estimation ([6], [2]).

3. INPUT DATA

Table 1 shows an overview of the input data used for the combined gravity field models GOCO01S and GOCO02S. It provides the data volume as well as the maximum resolution of the corresponding normal equations for all observation types.

Table 1: Data used and max. degree of resolution of combined gravity field models GOCO01S and GOCO02S.

	GOCO01S **d/o 224**	**GOCO02S** **d/o 250**
ITG-Grace2010s	d/o 180 7 years	d/o 180 7 years
GOCE gradiometry	d/o 224 2 months	d/o 250 8 months
GOCE GPS-SST	---	d/o 110 12 months
CHAMP GPS-SST	---	d/o 120 8 years
SLR	---	d/o 5 5 years, 5 sats.
Constraints	d/o 170 – 224 Kaula	d/o 180 – 250 Kaula

Compared to GOCO01S, where the GRACE model ITG-Grace2010s ([9]) has been combined with about 2 months of GOCE data (Nov./Dec. 2009), in the new version GOCO02S 8 months of GOCE data from Nov. 2009 to July 2010 (effectively about 6 months after reduction of data gaps and calibration phases), but also 12 months of kinematic GOCE orbits and 8 years of kinematic CHAMP orbits have been evaluated. Additionally, normal equations derived from 5 years of laser ranging observations to 5 satellites (LAGEOS1 and 2, Ajisai, Stella, Starlette) complete to degree/order 5 have been included ([8]).

4. RESULTS AND SOLUTION VALIDATION

Figure 1 shows the resulting combined gravity field models GOCO01S and GOCO02S in terms of degree medians of the formal errors in light blue and dark blue color, respectively. As a reference, also the degree medians of the time-wise GOCE-only models GO_CONS_GCF_2_TIM_R1 (green dashed curve; [10], [11]) and GO_CONS_GCF_2_TIM_R2 (magenta curve; [13]), the gradiometry-only solution (brown curve) included in the first release of GO_CONS_GCF_2_TIM_R1 and GOCO01S, as well as the GRACE-only model ITG-Grace2010s (red curve) which entered both GOCO solutions, are displayed. The performance cross-over of GRACE and GOCE was shifted from degree 150 for the first release to about degree 130 for the new GOCO model, which is due to the inclusion of about 3 times more GOCE data. Evidently, the GOCO solution combines in an optimum manner the strengths of the individual data types, i.e. the superior performance of GRACE in the low to medium degrees and in the polar gaps, and the high-accuracy detail gravity field information derived by GOCE.

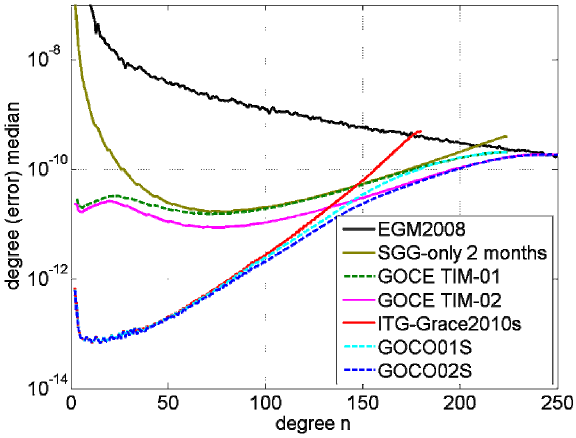

Figure 1. Degree medians of formal errors of GRACE, time-wise GOCE and combined satellite-only GOCO gravity field models.

Generally, the contribution of the additional normal equation systems (GOCE and CHAMP SST, SLR) is rather minor. However, it can be shown that the evaluation of the precise kinematic orbit information of both CHAMP and GOCE significantly contributes to the estimates of (near-)sectorial coefficients.

The improvement of this new combined solution predominantly in the high degrees becomes evident by evaluating geoid height differences to an external reference model. Figure 2 shows geoid height differences of the combined models GOCO01S and GOCO02S with respect to EGM2008 ([14]) for degree/order 180. The noise over the open oceans and regions with high-quality terrestrial gravity field data incorporated in EGM2008 is substantially reduced. In parallel, those regions where the quantity and quality of terrestrial data included in EGM2008 is poor becomes visible even more pronouncedly.

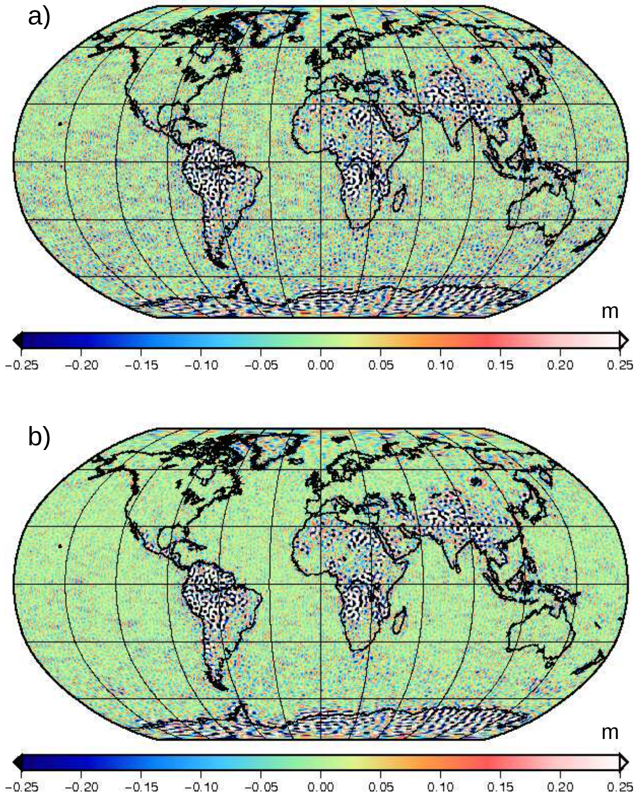

Figure 2. Geoid height differences [m] w.r.t. EGM2008 at degree/order 180: a) GOCO01S; b) GOCO02S.

An interesting detail aspect is shown in Fig. 3, which displays geoid height differences of GOCO02S with respect to the GRACE component ITG-Grace2010s at degree/order 100. Already at this low degree characteristic features which are typical for GRACE errors appear, and correspondingly, it can be concluded that there are significant contributions by GOCE with amplitudes of up to 1 cm (global rms of 1 mm).

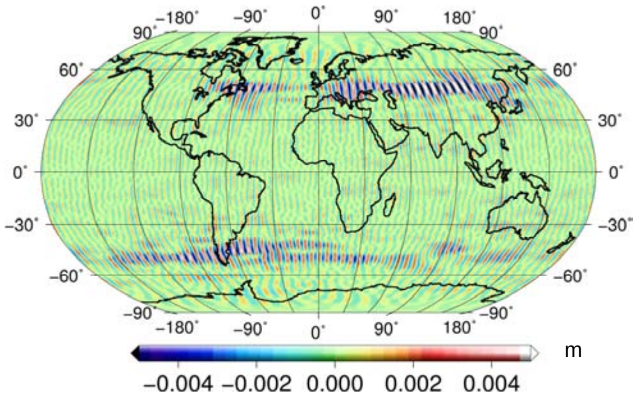

Figure 3. Geoid height differences [m] between GOCO02S and ITG-Grace2010s at degree/order 100.

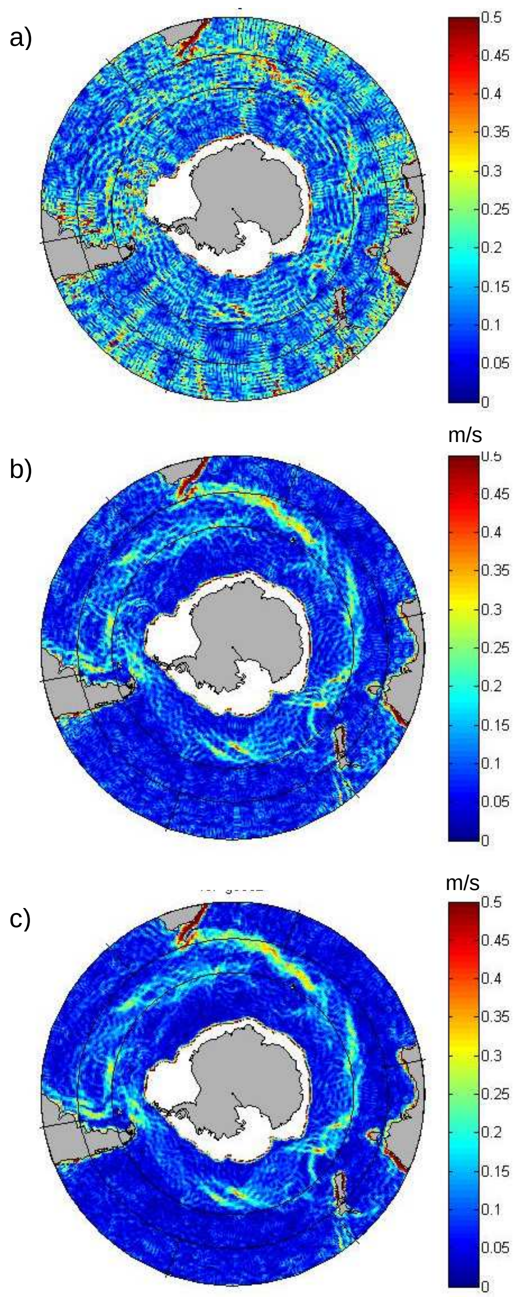

Figure 4. Surface velocities [m/s] up to degree/order 180 from geodetic DOT using mean sea surface derived from 17 years of altimetry, and geoid models: a) ITG-Grace2010s; b) GOCO01S; c) GOCO02S.

One important application of global gravity field models is the derivation of the dynamic ocean topography (DOT), which is defined as the difference of the mean sea surface (MSS) and the geoid. From the DOT, geostrophic ocean surface velocities can be derived. Figure 4 shows these velocity estimates for the Antarctic Circumpolar Current (ACC). The underlying DOT was computed from a MSS derived from 17 years of altimetry processed by DGFI ([1]), and different geoid models, resolved complete to degree/order 180. In Figure 4 a) the ITG-Grace2010s model has been used, leading to a very noisy picture and characteristic striping patterns. When using GOCO01S for the DOT computation, a much clearer picture of the surface ocean circulation can be derived. The noise in these surface velocity estimates can be further reduced when using the new GOCO02S model, clearly demonstrating that this new combined model represents a further significant improvement predominantly in the high degree range.

5. CONCLUSIONS

With the new combined satellite-only gravity field model GOCO02 the performance could be substantially increased, particularly due to the inclusion of more GOCE data improving the high degree coefficients. Also in the future, continuous improvement of combined satellite-only models due to inclusion of more GOCE and GRACE data is to be expected.

In parallel to this continuous improvements of satellite-only models, also combined models including terrestrial gravity and satellite altimetry data shall be computed, in order to further enhance the spatial resolution. First results demonstrate that the assembling and solution of full normal equation systems up to degree/order 600 is feasible ([4], [5]), and the future goal is to achieve even a maximum degree/order of 720.

6. ACKNOWLEDGEMENTS

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