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The Impact on a Combined Global Gravity Field Model Using Simulated GOCE Data

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Introduction

The main objective is the generation of high-resolution global gravity field models, by combining data from the satellite gravity missions GOCE, GRACE and CHAMP with complementary gravity field information represented by terrestrial and air-borne data, satellite altimetry, and satellite laser ranging. These different data types are complementary with respect to their measurement principle, accuracy, spatial distribution and resolution, and spectral (error) characteristics. By means of data combination, benefit can be taken from their individual strengths and favourable features, and in parallel specific deficiencies can be reduced, leading finally to global models of the Earth's gravity field with high spatial resolution and accuracy. A detailed global map of the Earth´s gravity field contributes to many branches of Earth system sciences, e.g., geophysics, geodesy, oceanography, cryospheric and climate research.

Architectural Design

The final products are a satellite-only model and a combined model in terms of geopotential coefficients and the corresponding full variance-covariance matrices (cf. Fig. 1). The combination strategy is based on a weighted superposition of the normal equation (NEQ) matrices of each data type. Therefore, the NEQ matrices have to be assembled for each observation type. For the following consistent combination of the NEQ's, it is very important that they are based on common standards by means of defined constants, reference frame, background models for the reduction of temporal variations, etc. The key issue of the combination step is the determination of optimum weights for each data type with special emphasis on those spectral regions where the individual observation type contributes most to the optimum final solution. In future, also the problem of regularization has to be addressed because of the spatial data distribution of ,e.g., GOCE.

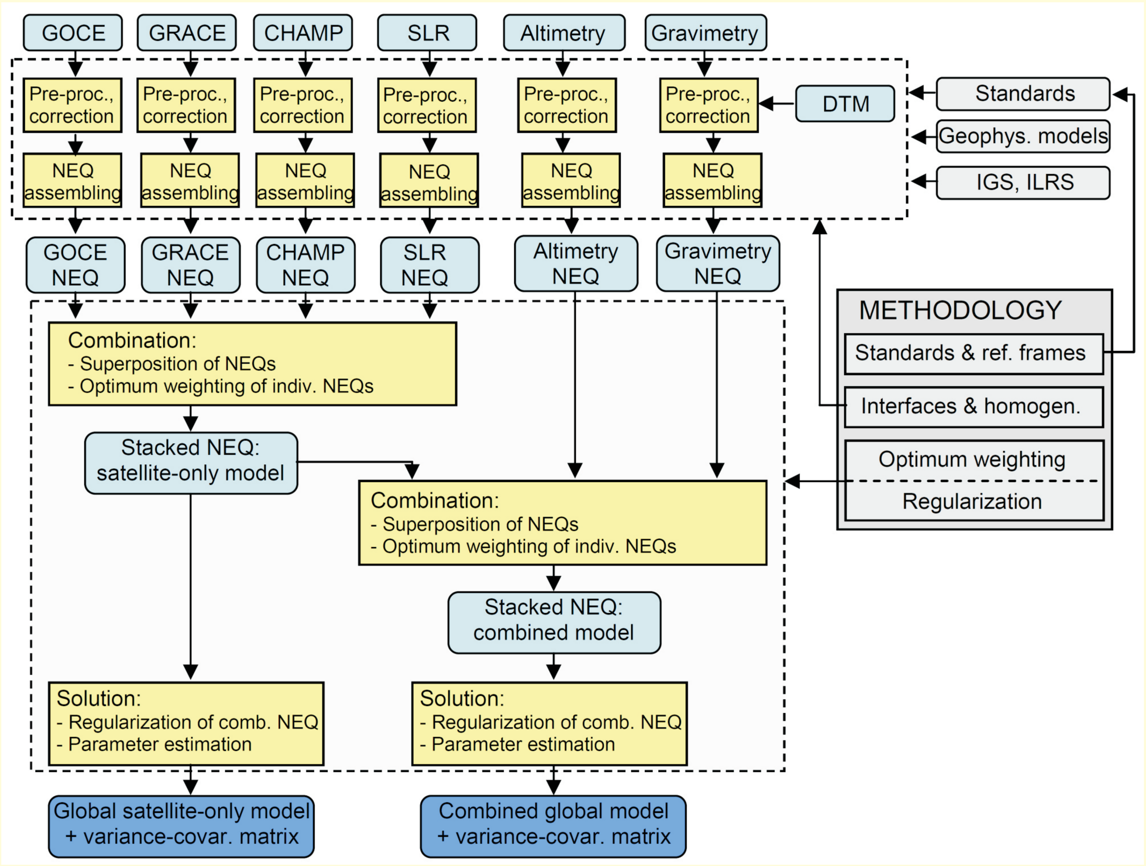

Fig. 1. Software architecture and data flow.

Processing and Results of the Individual Solutions

In this part of the processing chain normal equation systems of each data type are assembled according to the previously described two-step strategy.

CHAMP

The CHAMP-only model is based on precise orbit data for the period of 2004 to 2007 (4 years). To determine the spherical harmonic coefficients to degree and order (d/o) 90, the energy integral approach is applied.

GRACE

The full variance-covariance matrix of the ITG-GRACE03S model has to be inverted to obtain the normal equation matrix. Next, consistent coefficients by using the variance information are generated up to d/o 180 performing the two-step strategy.

GOCE

The GOCE-only model is based on 59 days of precise orbit data, accelerometer measurements and gravity gradients simulated by ESA. Again, for the processing of the orbit data, the energy integral approach is utilized to derive a SST-only (satellite-to-satellite) model to d/o 90. Together with the SGG (satellite gravity gradiometry) normal equations and spherical cap regularization a system up to d/o 204 is assembled.

To get an impression of the characteristics of each data type, the spherical triangles and the gravity anomalies are shown in Fig.2. Comparing the gravity anomaly maps, GRACE and GOCE are able to significantly identify more detailed structures than CHAMP. One has to keep in mind that the GOCE model is based on only 2 months of simulated data whereas CHAMP is based on 4 years and GRACE even on 4.5 years of data.

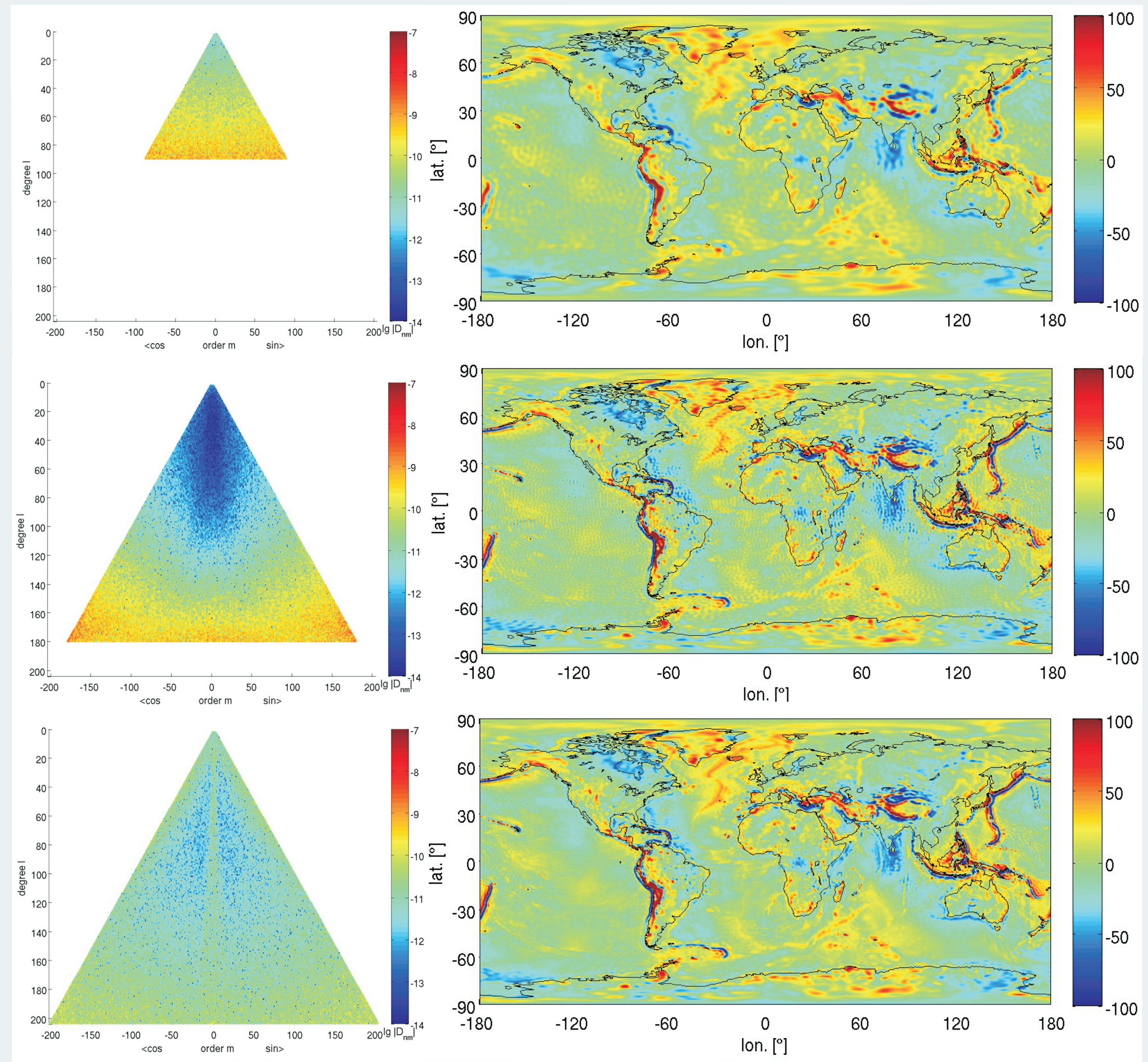

Fig. 2. Coefficient differences of CHAMP (top), GRACE (center) and GOCE (bottom) w.r.t. to EGM96 in terms of spherical triangles (left) and gravity anomalies [mgal] (right) neglecting the zonal coefficients of degree 2, 4, 6, 8.

Test Environment

A test environment was implemented to compute a preliminary combined model and to demonstrate the impact of the different data types.

Data used for a preliminary combination:

- **CHAMP:** 4 years of precise orbit data and acceleration measurements
- **GRACE:** full variance-covariance matrix of the ITG-GRACE03S model available on the website of the Institute of Geodesy and Geoinformation at the University of Bonn. This model comprises 4.5 years of data and has a resolution of degree and order (d/o) 180.
- **GOCE:** 59 days of precise orbit data, accelerometer measurements and gravity gradients, which is an ESA end-to-end simulated data set based on the gravity model EGM96.

Reference frame and standards

Since each data type is observed and computed in its individual reference frame using different standards, the data sets have to be transformed into a common system. In this test environment, EGM96 serves as reference model. Therefore the following two-step strategy for each set *i* is applied:

1. $x_i = x_{EGM96} + \sqrt{trace(\Sigma(x_i))} \cdot noise$

2. $\left(A^T Pl\right)_i = \left(A^T PA\right)_i \cdot x_i$

In the first step the coefficients of the reference model are superposed with noise which is scaled by the standard deviation of the coefficients of each data set to consistently map the error characteristic of the data type to the common system. The second step performs the multiplication of the normal equation matrix with the previously derived noisy coefficients to obtain the right hand side of the normal equation system. In this way consistent normal equation system for further combination purposes can be obtained for each type.

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Processing and Result of a Preliminary Combined Solution

The degree variances plot (cf. Fig. 3) illustrates that, for this test environment, CHAMP has no impact on the combined solution, whereas the coefficients up to d/o 100 are dominated by GRACE and the degrees higher than 100 are mainly determined by GOCE. The weight of each data type is set to one. The spherical triangle (Fig. 4) shows again that the combined model benefits from the high accuracy of GRACE in the lower part of the spectrum and from the high accuracy of GOCE in the upper part of the spectrum.
Figure 5 displays the gravity anomaly differences w.r.t. EGM96 model which have a standard deviation of 0.3 mgal. The maximum differences of +/-6.8 mgal occur at the poles where GOCE can not deliver observations due to the orbit characteristics.

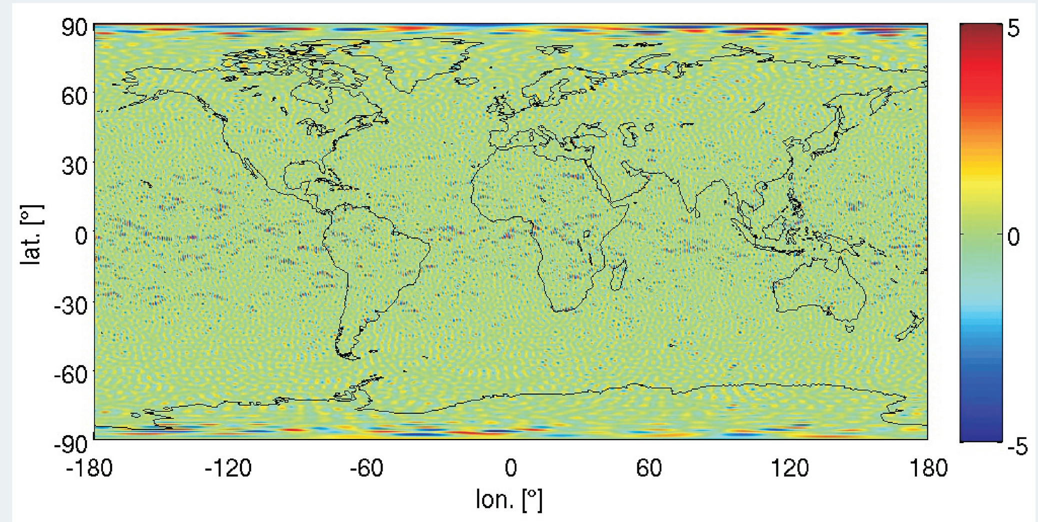

Fig. 5. Differences of gravity anomalies [mgal] derived from the combined model w.r.t. EGM96.

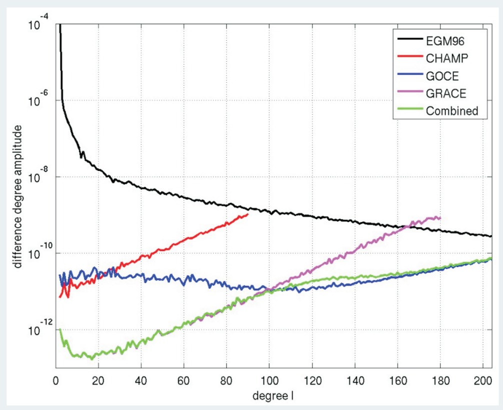

Fig. 3. Degree variances of single solutions and combined solution w.r.t. EGM96.

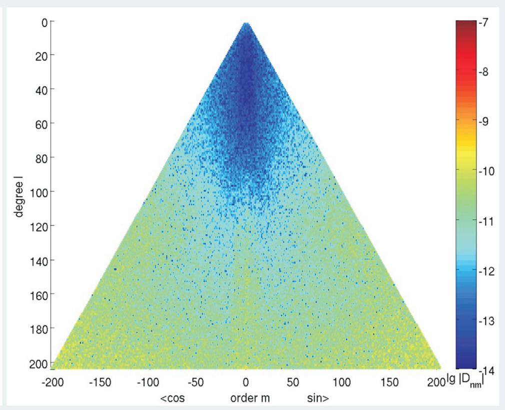

Fig. 4. Coefficient differences of combined solution w.r.t. to EGM96.

Summary and Outlook

The implemented test environment clearly demonstrates the benefits of the different satellite data types and the impact on a preliminary combined solution. The next step will be to update the test environment by using a state-of-the-art reference model and the new ITG-GRACE2010S model. Additionally, also normal equation systems based on SLR observations, altimetry, and terrestrial gravity data will be set up and included into the combination procedure. Additional issues will be the definition of common standards and reference frame and the implementation and study of optimum weighting techniques.