GLOBAL GRAVITY FIELD DETERMINATION BY COMBINING GOCE AND COMPLEMENTARY DATA

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ABSTRACT

GOCE gravity fields define a new standard concerning spectral resolution of satellite-only models, and provide a very high precision in the long- and medium wavelength part of the gravity field up to a spherical harmonic degree of about 250. Combining GOCE with GRACE data, which gives in addition very accurate information for the long wavelength part, results in the current performance status of satellite-only models. By addition of terrestrial and altimetry data the spectral expansion can be enlarged even further, resulting in high-resolution gravity field models. High-resolution global gravity field determination based on heterogeneous input data puts high demands on computer resources, because full normal equations systems become very large, so that the assembling and solution processes are challenging with respect to memory and computing time. Therefore parallel methods have to be applied. At IAPG computations combining GOCE data with synthetic terrestrial data up to degree/order 600 have been performed. They have shown, that very large normal equation systems can be handled, concerning the processing steps assembling, solving, inversion as well as error propagation. In this study real terrestrial data shall be added consistently to the satellite-only models. Here, further challenges like handling of inconsistent data sets and pre-processing of the terrestrial gravity data occur. This contribution shall present our first results of gravity field determination by using terrestrial, GOCE and GRACE data. The preparation and the relative weighting of the data sources shall be illustrated, analyzed and discussed. The contribution of GOCE to the combined model is explicitly visible.

Key words: GOCE; Combination; High Performance Computing.

1. INTRODUCTION

Since the start of the GOCE mission in 2009 two generations of GOCE gravity field models have been released by the HPF project team, see Pail et al. [2]. This models define a new standard concerning spectral resolution of satellite-only models. Combination with GRACE data increases additionally the accuracy in the long wavelength part so that GOCE and GRACE together define the actual status quo for satellite-only models such as GOCO01S and GOCO02S, see Pail et al. [3]. By inclusion of terrestrial and altimetry data the spectral resolution can be extended even higher. However, with higher resolutions the number of spherical harmonic coefficients is strongly increasing. Therefore assembling and solving of normal equation systems put high demands on computer resources (cf. Figure 1), and the requirements with respect to memory and computing time are immense. In the framework of the GOCO initiative also high-resolution gravity models combining satellite and terrestrial data shall be computed. Therefore this study addresses the following topics:

(1) Overview of the background for the computation of very high-resolution gravity field models.

(2) Combination of GOCO normal equations with full normal equations up to d/o 600 calculated from DTU10 gravity anomalies (compare Anderson et al. [1]) and analysis of the results.

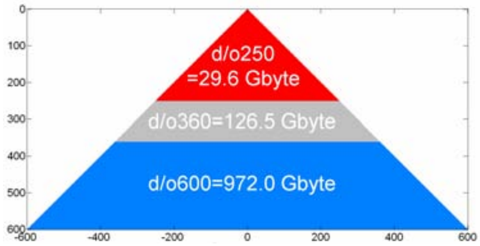

Figure 1. Triangle showing memory capacities needed for full normal equation systems.

2. COMPUTATIONAL BACKGROUND

In the framework of the GOCO project a combined global gravity field model shall be computed based on full normal equations up to d/o 600. This corresponds to a normal equation system with a size of almost 1 TB, thus more than 7 times larger than equations for a system up to d/o 360. Because of the demanding I/O processes, the

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request of random access memory as well as hard disk storage, assembling and solving of such a normal equation system is a computational challenge. The size of normal equation matrices requires the distribution of the normal equation to different processes. Figure 2 shows how a normal equation is assigned to 15 processes during the assembling steps. Here, only the upper triangle part must be held in the kernel. All processes which include blocks with the same row index of the normal equation are summarized in a process grid (here: grid 1-5). An additional process grid contains the normal equation blocks with the diagonal elements. In this grid also the right-hand side of the system of equations is assembled. In this study, computations were performed with more than 40 grids. For the solving process the normal equation is distributed block-cyclical and the full matrix is stored in the kernel. Calculations were performed on the national supercomputer HLRB-II: SGI Altix 4700 of the Leibniz Supercomputing Centre. Different runs have shown, that the system and architecture is able to handle full normal equations up to d/o 600.

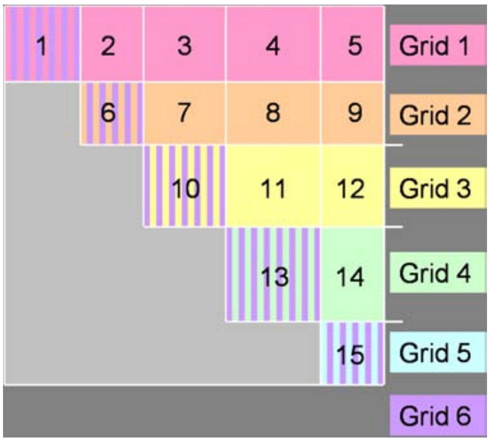

Figure 2. Distribution of normal matrix on different processes.

3. COMBINATION STUDY

First a pure terrestrial solution has been performed by using the DTU10GRA gravity anomalies as observations. The DTU10 gravity anomalies over the oceans are altimetry observations, whereas gravity anomalies over land are calculated from EGM2008 (see Pavlis et al. [5]). For the weighting of the ocean data the DTU10ERR interpolation error has been transformed from a metric scale into weights for the ocean observations. This weights were then converted to standard deviations, which are used in our processing chain. On land the standard deviations were put to constant values, which shall approximately distinguish between areas with good and bad terrestrial data. Figure 3 shows the assumed errors [mgal] of the terrestrial/altimetry data. The error on land sometimes exceeds the maximum value of the colorbar and is in this case printed as black number. For this case study the

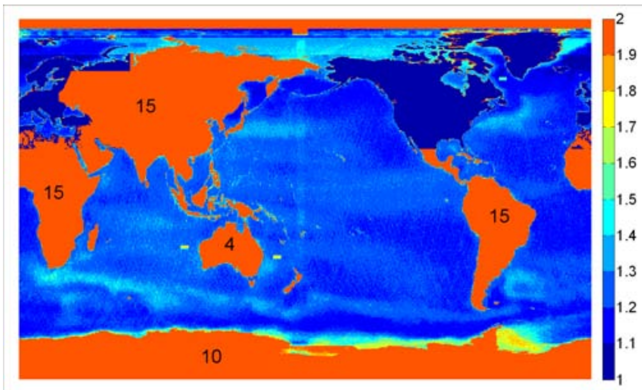

Figure 3. Assumed erros for terrestrial data [mgal].

error in some areas was intentionally chosen quite pessimistically. Before assembling normal equations, the DTU10GRA gravity anomalies were reduced onto a 15' grid and spectral limited to a signal content up to d/o 600. Coefficients up to d/o 600 have been estimated and were used to recalculate gravity anomalies, which were compared to gravity anomalies of EGM2008. Figure 4 shows these differences evidently, the agreement is quite high. Differences occur in arctic regions and in coastal areas due to the improvements in DTU10 compared to EGM2008. In the next step, this terrestrial solution shall

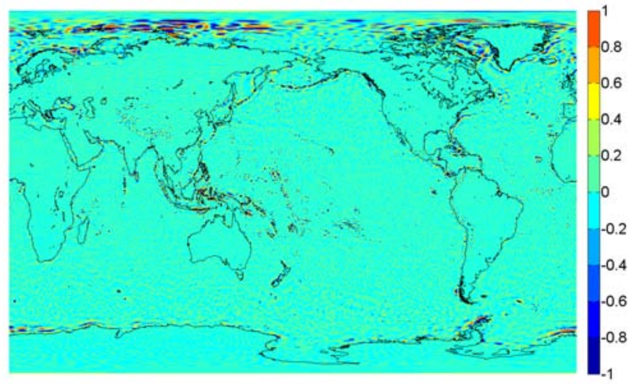

Figure 4. Comparison of terrestrial solution to EGM2008 [mgal].

be combined with a satellite only solution. For this case we use GOCO02S (see Pail et al. [4]) normal equations without regularization. Figure 5 shows the formal error of the combination in terms of degree variances in comparison to the original datasets. Up to d/o 100 the combination result depends almost solely on satellite data, whereas above 250 only terrestrial/altimetry data play a role. It is clearly visible, that the combination merges the very high accuracy of the satellite observations in the lower degrees with the very high spectral resolution of the terrestrial model. To get a better estimation of the contribution of the GOCO02S model to the combined solution, error propagations to geoid heights based on the full variance-covariance matrices were performed for both models. Figure 6 shows the relative contribution of

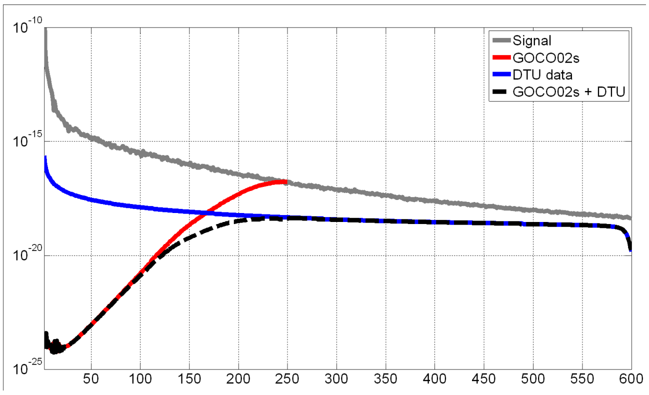

Figure 5. Formal errors of GOCO02S, the terrestrial data DTU10, and the combined solution.

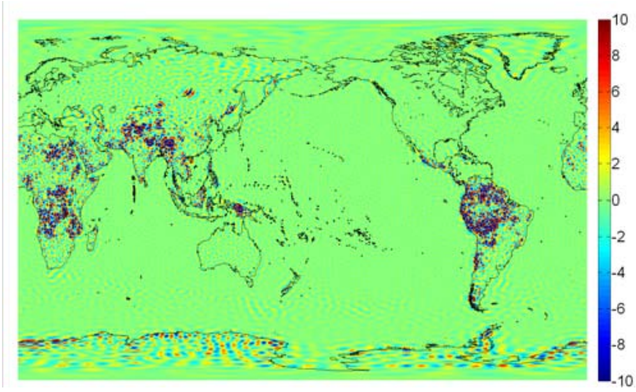

Figure 7. Difference between pure terretrial and combined solution [mgal].

the satellite model to the combination model up to d/o 170 in the spatial domain. The influcence of the satellite model over the ocean is very low, whereas its influence is very high over land areas where a very high error for terrestrial data was assumed. This is logical considering the standard deviations above and confirms, that the combination was sucessful. Figure 7 shows the difference

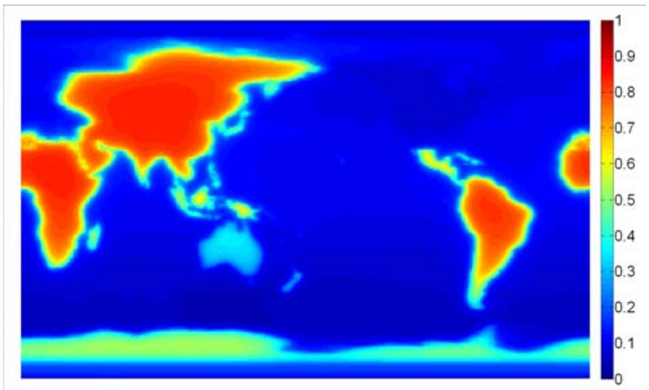

Figure 6. Relative contribution of satellite-only models up to d/o 170 to the combined model.

between the pure terrestrial and the combined solution [mgal]. It can be clearly seen, where GOCE contibutes with new signal, especially in areas where high-quality terrestrial data are not available.

4. CONCLUSIONS

(1) Different runs have shown that the architecture of the system is stable. High resolution gravity fields can be calculated. Here the following challenges must be dealt with: complex I/O processes, high requirements to random access memory and hard disk storage (4 TB hard disk for terrestrial and combination normal equation matrices and the associated variance-covariance matrices), long qeuing time until job starts.
(2) The comparison of GOCE with other gravity field data sources shows that GOCE contributes with new signal. But nevertheless also GOCE benefits from combination with complementary data. The combination with GRACE and terrestrial/altimetry data shows, that a gravity field can be computed with a very accurate long and medium wavelength part and a very high resolution.
(3) DTU10 was not only used over the oceans, but also over land, where it is just a fill-in of EGM08. In the future on land independent datasets shall be used.
(4) In this study the weighting of land data was deliberately chosen quite pessimistic. For the future, when independent datasets shall be used, more investigations have to be done to achieve realistic weighting.

ACKNOWLEDGMENTS

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