GOCE RESEARCH IN GERMANY: FROM SENSOR ANALYSIS TO EARTH SYSTEM ANALYSIS

Reiner Rummel(1), Jakob Flury(1) and Thomas Gruber(1)

Institut für Astronomische und Physikalische Geodäsie, Technische Universität München, D-80290 München
e-mail: rummel@bv.tum.de

ABSTRACT

The mission objectives of GOCE in terms of geoid and gravity accuracy and spatial resolution are extremely high. This poses a great challenge for the development of the on-board sensor systems and spacecraft as well as for data analysis. Current research activities concentrate on the combination of satellite altimetry with the GOCE geoid for a determination of dynamic ocean topography with cm-precision, on problems related to the combination of GOCE geoid and gravity with regional high resolution terrestrial and ocean data sets and on strategies for the validation of the GOCE gravity products employing regional high-precision terrestrial data sets. In Germany these activities are embedded in (1) direct participation in the development of the elements of the ESA GOCE ground segment, (2) research carried out in the context of the Technology Programme for Geosciences of the German Ministry of Education and Technologies, (3) participation in the priority programme "Mass Anomalies and Mass Transport in Earth System" of the German Research Foundation and (4) the establishment of a "Global Geodetic Observing System (GGOS)". These activities are supported by a GOCE project office financed by the German Aerospace Centre (DLR). Additional information in German language can be found at http://www.goce-projektbuero.de.

KEYWORDS: GOCE, gravity, geoid, geotechnology, gravimetry

1. INTRODUCTION

With the launch of the GOCE mission coming closer it seems to be the appropriate time to re-visit the mission and science objectives that were defined in 1998 for the process of mission selection, compare (ESA,1999). The mission objectives of GOCE are the determination of the geoid with a radial accuracy of 1cm, the gravity anomaly field with an accuracy of 1 mGal and to achieve both with a spatial resolution of 100 km half-wavelength corresponding to a surface spherical harmonic series up to degree and order 200. These objectives were based on a thorough analysis of the five primary fields of application, solid earth physics, oceanography, glaciology, geodesy and sea level research. For each of these fields requirements were identified in terms of geoid or gravity accuracy and spatial resolution as shown in Table 1, taken from (ibid) with minor modifications. Some of these science objectives are a serious challenge and are therefore currently subject of research. In the sequel three of these areas of concern will be discussed (chapter 2), before explaining the overall structure of the GOCE related research activities in Germany, the GOCE Grand-II project, the priority program "Mass Anomalies and Mass Transport in the Earth System" (chapter 3) and the role of the German GOCE project office (chapter 4).

Table 1: GOCE science and application requirements

Application	Accuracy: Geoid [cm]	Accuracy: Gravity [mgal]	Spatial Resolution (half wavelength – D in km)
SOLID EARTH			
Lithosphere and upper mantle density structure		1-2	100
Continental lithosphere:			
▪ Sedimentary basins		1-2	50-100
▪ Rifts		1-2	20-100
▪ Tectonic motions		1-2	100-500
Seismic hazards		1	100
Ocean lithosphere and interaction with asthenosphere		0.5-1	100-200
OCEANOGRAPHY			
▪ Short scale	1-2		100
	0.2		200
▪ Basin scale	≈0.1		1000
ICE SHEETS			
▪ Rock basement		1-5	50-100
▪ Ice vertical movements	2		100-1000
GEODESY			
▪ Levelling by GPS	1		100-1000
▪ Unification of worldwide height systems	1		100-20000
▪ Inertial navigation		1-5	100-1000
▪ Orbits		1-3	100-1000
SEA LEVEL CHANGE	Many of the above applications, with their specific requirements, are relevant to studies of sea-level change.		

Proc. 'The 3rd International GOCE User Workshop', ESA-ESRIN, Frascati, Italy,
6–8 November 2006 (ESA SP-627, January 2007)

2. RESEARCH CHALLENGES AND OPPORTUNITIES

GOCE offers the fascinating prospect of a direct global determination of the steady-state dynamic ocean topography. It will be of great importance for an improved understanding of the role of the oceans for our climate and, more specifically, for that of mass and heat transport in the oceans, compare (Wunsch, 1993), (LeGrand, 2001). Dynamic ocean topography is the small deviation of the actual mean ocean surface from the geoid. Typical topography signals in the regions of major current systems are of the order of 30 cm with maximum values of about 1 to 2 m; spatial scales of these quasi-stationary structures range from global or basin scale to about the size of the Rossby radius, say 50 km. If GOCE is to contribute profoundly to the determination of steady-state topography, both the altimetric mean ocean surface and the geoid have to be determined with cm-precision and the two surfaces have to be globally consistent at this precision level. This is all but trivial considering the fact that each of the two surfaces is derived from sensor and satellite systems completely disjoined and technologically very different, the altimetric one scanning a surface track by track and the gravimetric one (GOCE) sensing a field. Even small inconsistencies would result in unrealistic large scale features of the derived ocean circulation. The problem has several dimensions. The two surfaces have to be expressed in one and the same coordinate system at the 10^{-9}-level; the same standards have to apply to both surfaces including items such as the definition of ocean and solid earth tides, zero tide and zero atmosphere and the choice of the adopted geophysical background models. For a draft of the GOCE standards it is referred to (ESA, 2006). It is also to be avoided that the high systematic coloured noise of the gravity gradiometer at low frequencies outside the measurement bandwidth will affect the low harmonics of the derived GOCE gravity model. This requires careful design of filters and is currently under investigation; see (Schuh, these proceedings). Also the combination of GOCE gradiometry with GOCE GPS satellite-to-satellite tracking or with a GRACE a priori field has to be consistent at an extremely demanding level of accuracy. Theoretically both, the GOCE GPS satellite-to-satellite tracking and the available GRACE models, are not extremely stable and accurate in the lowest harmonics. Also this deserves some thought.

The applications of GOCE in the fields of geodesy and sea level research require the combination with high resolution terrestrial gravity material. This implies, on the one hand, an optimal treatment of the GOCE model at its highest degrees of the spherical harmonic series and is related to aspects such as optimal truncation and minimization of aliasing, spectral leakage and of distortions due to regularization. On the other hand, also the terrestrial gravity material will have to undergo a thorough quality analysis before its use. One should realize, for example, that most of the terrestrial gravity measurements refer to reference stations of the international gravity standardization net of 1971 (IGSN71) which was established before the era of high precision absolute gravimetry. Thus, unavoidably, these stations contain systematic distortions. Also, the terrestrial gravity anomalies refer to their respective national height datum and national (horizontal) datum. Correction and unification is difficult and often even impossible because access to the original measurements may not possible anymore. For large parts of the terrestrial material information about the original measurements and the processing is simply lacking. Marine gravity data from the pre-GPS-era is hardly useful anymore because the Eötvös-correction could not be computed with a precision compatible with nowadays standards.

These aspects are also of high relevance when talking about external calibration and validation of GOCE. There the basic question is: How can one validate GOCE gravity and geoid, while they are supposed to be the most accurate ones there are? The only available option is comparison with gravity anomalies, deflections of the vertical, geoid surfaces or ocean topography derived by terrestrial methods that are regionally superior to the corresponding GOCE quantities. The fundamental difficulty with such comparisons is that the GOCE gravity model is given "spectrally", i.e. as a set of spherical harmonic coefficients up to a certain maximum degree (global band-limited representation), while the validation data sets are regionally confined but each value containing a much higher frequency range. The only meaningful comparison of these two types of data is possible by comparing in the region of the terrestrial data set the GOCE based gravity quantities with equally band-limited, i.e. filtered, validation data. To do this filtering with minimum loss of precision is the key to a meaningful validation and is subject to current research.

This all leads to a long list of research topics that need to be addressed:

- take into account peculiarities of the GOCE sensor system,
- get lowest harmonics right,
- get altimetry and GOCE into one consistent reference system,
- ensure the definition and implementation of adequate standards,
- re-visit the theory of geodetic boundary value problem,
- work on the optimal combination of geopotential models and on their combination with terrestrial data,
- develop appropriate validation methods and experiments.

3. GOCE RELATED RESEARCH IN GERMANY

The research activities related to GOCE can be divided into four categories:

- Participation in ESA projects in preparation of the GOCE mission; these are primarily activities for the elements of the so-called GOCE ground segment (PDS, CMF and HPF); there is a strong participation of German groups in the High Processing Facility; also the participation in the GOCE User Toolbox Specification (GUTs) belongs to this category as well as participation in GOCE related ESA studies.
- The GOCE Grand-II project, which belongs to the Technology Programme for Geosciences initiated by the German Ministry for Education and Technology.
- The priority program "Mass Anomalies and Mass Transport in the Earth System" of the German Research Foundation DFG.
- Participation in the establishment of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy.

GOCE Grand-II belongs to theme 2 "Observing Earth System from Space". It has been established in 2002 to support research activities for CHAMP, GRACE, GOCE and other technology related projects. An overview over its results during the first three years is given in (Flury et al., 2006). In the second phase the GOCE-Grand project concentrates on the refinement of the gravity field analysis methods, on the combination with complementary gravity information and on calibration and validation. The structure of this project is shown in Figure 1. All-together seven institutions cooperate in this project. In cooperation of all participating parties the topics described in chapter 2 are studied.

A fundamental break-through is the approval of the priority program "Mass Anomalies and Mass Transport in the Earth System" by the German Research Foundation DFG. This programme, coordinated by KH Ilk, University Bonn, aims at the integrated use of geometric and gravimetric satellite missions for the identification and quantification of mass signals (stationary and temporally varying) for the fields of ocean transport of mass and heat, global water cycle, ice mass transport and sea level and the dynamics of the earth's mantle and crust. Thereby the satellite missions GRACE and GOCE will play a pivotal role.

Finally, German research institutions engage themselves in the establishment of the Global Geodetic Observing System (GGOS). It is the central pilot project of the International Association of Geodesy and will be anchored in the Integrated Global Observing Strategy (IGOS) and in GEO. Its realization will constitute a very fundamental pillar of global change research and natural hazards warning.

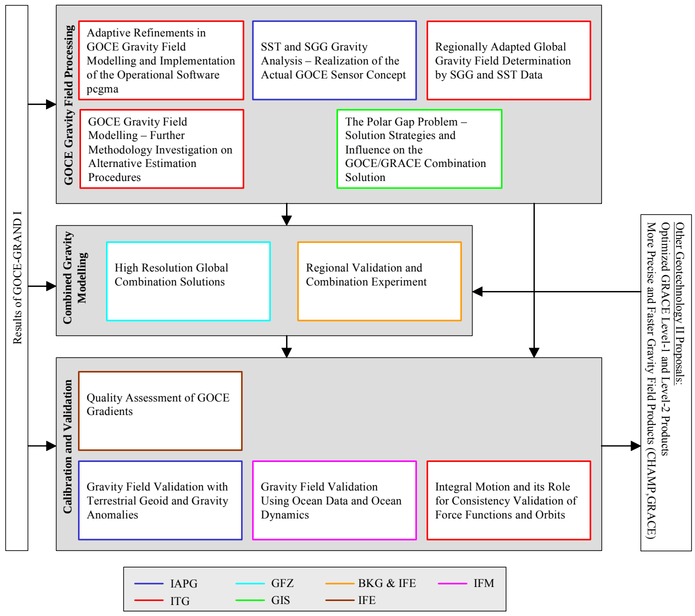

Figure 1: Structure of the GOCE Grand II Project

4. GOCE GERMAN PROJECT OFFICE

The German Aerospace Centre (DLR) is financing a project office at IAPG in support of GOCE activities. Its primary tasks are:

- activation of the user community,
- coordination of GOCE activities,
- public relations (organization of workshops, flyers, brochures, exhibitions etc.),
- contact with industry and funding agencies.

The project office took a prominent role in the coordination of the activities, described in chapter 3. It also tries to initiate the dialog and studies on follow-on gravimetric satellite missions. An important activity was the participation in the technological study "Enabling Observation Technologies for Future Solid Earth Missions", under ASTRIUM, Friedrichshafen. In the context of this study, IAPG coordinated a scientific study into the future science applications of such missions with participation of European scientists from five countries. The results were recently published in Earth, Moon and Planets, (Flury and Rummel, 2005).

5. REFERENCES

ESA (1999) Gravity Field and Steady-State Ocean Circulation Mission, ESA-SP1233(1).

ESA (2006) GOCE Standards, ESA Document GO-TN-HPF-GS-0111, 2006b

FLURY J, R RUMMEL, (2005) Future satellite Gravimetry and Earth Dynamics, Springer, Dordrecht.

FLURY J, RUMMEL R, REIGBER CH, ROTHACHER M, BOEDECKER G, SCHREIBER U, (2006) Observation of the System earth from Space, Springer Verlag

ILK, HK, J FLURY, R RUMMEL, P SCHWINTZER, W BOSCH, C HAAS, J SCHRÖTER, D STAMMER, W ZAHEL, H MILLER, R DIETRICH, P HUYBRECHTS, H SCHMELING, D WOLF, HJ GÖTZE, J RIEGER, A BARDOSSY, A GÜNTNER, TH GRUBER (2005): Mass Transport and Mass Distribution in the Earth System – Contribution of the New Generation of Satellite Gravity and Altimetry Missions to Geosciences, GOCE Projektbüro Deutschland, Techn. Univ. München und GeoForschungsZentrum Potsdam, 2005.

LEGRAND P (2001) Impact of the gravity Field ansd Steady-State Ocean Circulation Explorer (GOCE) Mission on Ocean Circulation Estimates. J.Geophys Res. 106, 19,597-19610.

WUNSCH C (1993) Physics of the Ocean Circulation, in: Rummel R and F Sansó (eds.) Satellite Altimetry in Geodesy and Oceanography, p.9-98, Lecture Notes in Earth Sciences 50, Springer.