THE NORWEGIAN GOCE INITIATIVE

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INTRODUCTION

National GOCE activities in Norway focus at this stage mainly on establishing and integrating organisational and research platforms. In preparation for this multidisciplinary mission a Norwegian GOCE Group has been formed in order to ensure that coordination and collaboration among candidate Norwegian user groups are established. In so doing it will also increase the knowledge and interest for the GOCE mission both during the pre-launch preparatory phases and during the data collection, analysis and utilisation phases. The multidisciplinary group provides a document that is meant to serve as a guideline for candidate activities that the Norwegian research community, industry, the research council and administration may adopt [1]. Parallel to these activities research programs and proposals at various institutions exist that are directly or indirectly linked to the future mission. The organisational aspects, the planned activities and some selected examples from research will be discussed in the next sections.

THE NORWEGIAN GOCE GROUP

The Norwegian GOCE group is established in order to define and develop necessary coordination and collaboration among multi-disciplinary Norwegian user communities. It has 11 members with expertise in orbit determination, oceanography, sea level, geodesy, solid earth science, glaciology and applied geophysics with J.A. Johannessen acting as leader. The members are representatives from research institutes, university departments, state organisations and commercial companies as indicated in Fig. 1. The group has financial support from the Norwegian Space Centre and Norwegian Research Council. The plans for the Norwegian efforts are scheduled in three phases and the anticipated activities are coordinated with those from the European GOCE Gravity Consortium (EGG-C). The periods are the pre-launch phase up to 2005, the mission phase 2005-2006 and the post mission phase after 2006. The planned activities in relation to these are discussed in the next section.

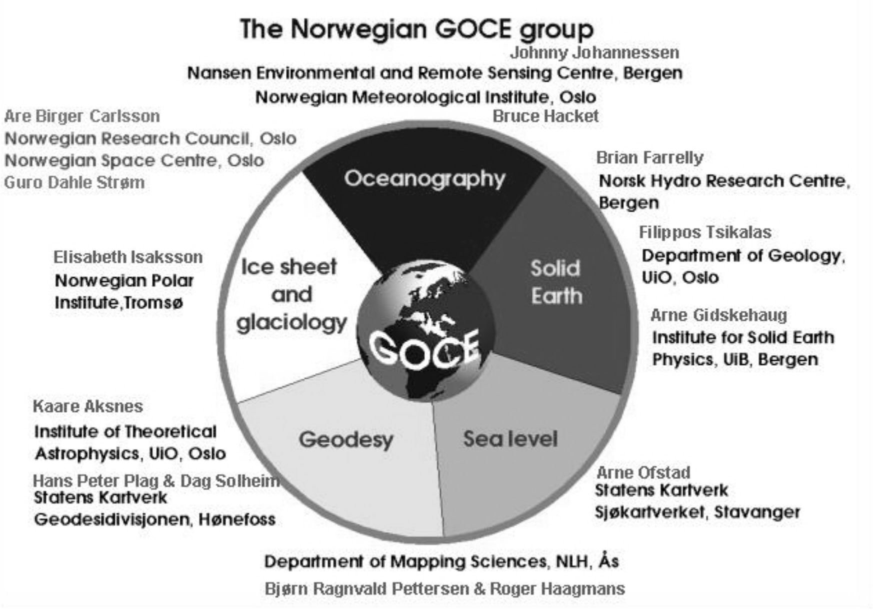

Fig. 1. Members of the Norwegian GOCE group and their affiliation

GOCE ACTIVITIES IN NORWAY

The current and planned activities are closely related to regional phenomena such as post-glacial rebound, the influence of the Gulf Stream on ocean and climate, special coastal conditions set by fjords and islands, and the Artic (and Antarctic) environments that guide research policies in Norway. A full understanding of the Norwegian environment, however, requires studies in a global perspective. Here the main focus is on projects based upon use of so-called level 1 or 2 products. The first group is using level 1 data directly in order to contribute to level 2 products as proposed in by the EGG-C [1]. The second group is relying on level 2 products derived from global geopotential coefficients for science applications. The third group focuses on direct use of level 1 data for science applications. An overview of the specific themes and their relation to fields of research are shown in Fig. 2. The main focus in the next sub-sections will be on some selected items from geodesy with links to geophysical and oceanographic applications.

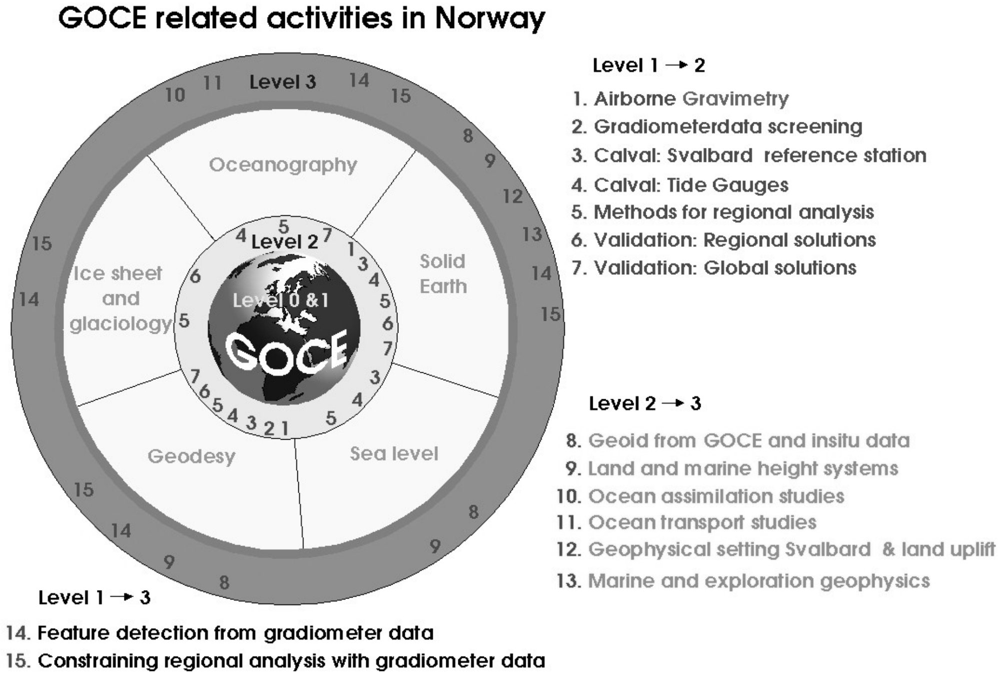

Fig. 2. Ongoing and planned activities related to different level products.

Level 1-2 Examples

Today, the geophysical setting around Svalbard is uncertain and the GOCE level 2 results may unify the observational systems on islands and the main land. Norway operates a geodetic reference station with space techniques and gravity in Ny-Ålesund [2], and a coastal system of tide gauges. These stations yield valuable contributions to calibration and validation in high latitude areas. The reference station is equipped with GPS, VLBI, PRARE, an automatic tide gauge, a tidal gravimeter, a super conducting gravimeter and on regular basis an absolute gravimeter. Furthermore, airborne gravimetric data have been collected over and around Svalbard for example during the AGMASCO project shown in Fig. 3 [3]. Careful integration of these data and the connection to the Norwegian land area can provide a good reference set for the GOCE mission, and contribute to a better regional modelling of the oceanic processes around the Islands and the geophysical processes in Fennoscandia. The airborne gravimetric system can also contribute new data in e.g. unexplored Artic regions. The importance of such supplementary gravity measurements has been underlined recently in the new Nordic geoid computation based upon the NKG airborne campaign in the Baltic Sea [4].

Another aspect is related to data screening of heterogeneous datasets. Methods like cross-validation with least squares prediction, statistical testing with splines or wavelets have been tested and applied to e.g. satellite altimetry data, super conducting gravity data and acoustic multibeam data [5][6]. These need to be modified for gravity gradients and can lead to useful data pre-processing alternatives to those applied in the “From Eötvös to mGal” studies [7].

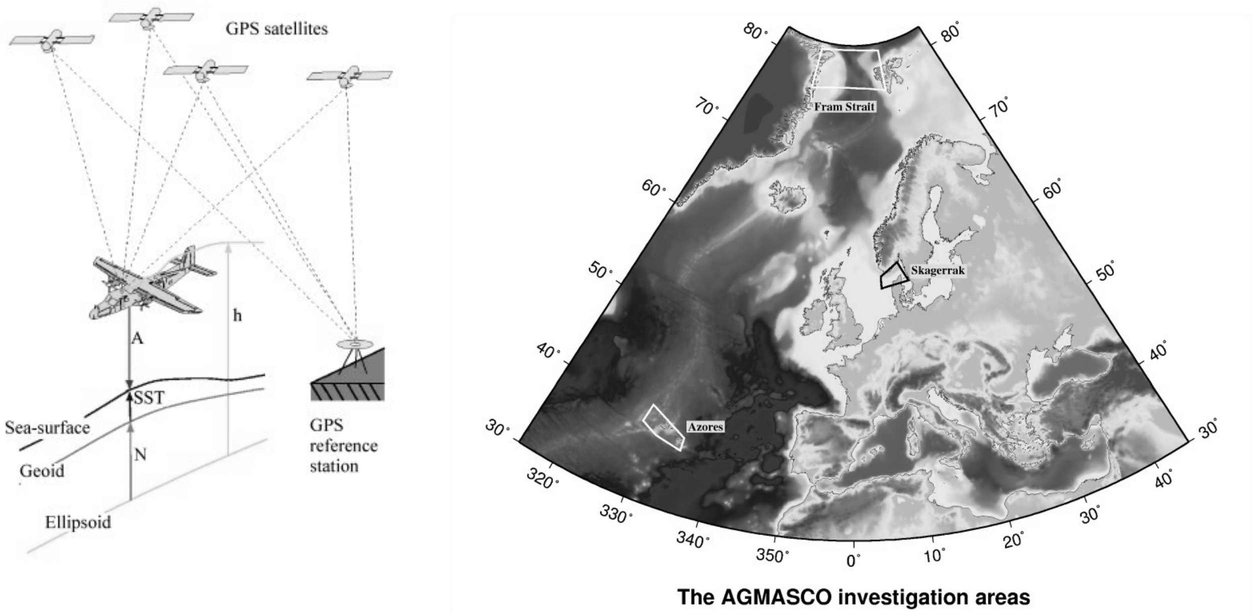

Fig. 3. The observational principle of airborne gravimetry (left), and the AGMASCO project test areas (right).

Level 2-3 Examples

Height Systems

One of the major gains of GOCE is the unification of height systems. Historically, height systems are often linked to local or regional mean sea level. This introduces a difficulty in comparing height systems between different continents, islands and sometimes even neighbouring countries. The mean sea level may deviate up to several dm between various areas in the world. The resulting geoid determined from the GOCE satellite data will allow connection of regional and local height systems in one unique global height datum within a few cm. This will result in a possibility to compare and relate (mean) sea level and sea level changes for example in the North Sea directly with the Mediterranean Sea. The satellite gradiometry mission is expected to contribute to a better height system unification up to spatial scales of ≈200km, which will allow a better integration of GPS/levelling data and local gravimetric geoid results. Especially, the re-evaluation of the national levelling network and the connection of tide gauges is here of great practical interest.

Detailed Geoid Modelling

Also strategies for integrating existing data and GOCE level 2 potential coefficients are developed. This applies both to land and sea areas and will improve ocean modelling, height system unification and operational use of GPS/levelling and offshore surveying. The primary goal is to improve the marine and land geoid to as much detail as possible, adapted to regional inhomogeneities in data, by combining GOCE coefficients and for example land and marine gravity data and heights. Substantial improvements of the geoid models at scales down to 200 km are expected from the satellite gravity missions (CHAMP, GRACE, GOCE). The marine gravity data available in many areas can contribute in an integrated way to a refined modelling process of the satellite gravity observations. Up to now, this refined modelling has received only limited attention, and needs to be fully exploited. A considerable improvement of the marine geoid models is expected from optimal exploitation of regional terrestrial and marine gravity data in combination with the most accurate part of a global geoid model. For this purpose, different methodological approaches need to be tested and additional observational constraints can be included e.g. external data like GPS and levelling [8]. Analysis of the possible characteristics of the geoid error contributions from the global model needs to be carried out [9] [10]. An anticipated improvement in the national levelling consequently changes the terrain correction applied to gravity data in order to achieve the best possible local geoid. The result will be a geoid of rather homogeneous accuracy for spatial scales up to 5-10 km on land and 10-20km at sea based on an optimal combination of the GOCE model and the corrected local data. This offers the opportunity to do levelling with GPS and the geoid model to high accuracy even in a local cadastral survey. At sea, however, it means that one can use instantaneous GPS heights and depth measurements in repeated surveys once these are corrected to refer to the local geoid. The advantage is twofold: on one hand the depth data at sea use the same height reference as the levelling heights on land, and on the other hand the difference between the instantaneous GPS heights and the geoid contains local tidal and meteorological information. This information can for example be used to improve regional tidal or ocean current models. No local tide and meteo measurements on board are necessary to correct the GPS and depth data, which is a great economical benefit in practice. It requires, however, that the GPS height component estimation at sea will improve to the expected accuracy of the geoid in the near future.

Inertial Navigation and Satellite Orbit Improvement

A global gravity model with GOCE quality will also allow improved inertial navigation and leads to improved satellite orbit determination. Adequate suppletion of the GOCE results with local gravity data can even provide more detailed local models, which may improve the independent navigation of ROV's (Remotely Operated Vehicles) that are more and more used in underwater surveys for offshore purposes. A better separation between the local accelerations originating from the gravity field and from the moving ROV allows longer and, maybe of greater importance, deeper surveys with probably less updates with external acoustic systems. Similar conclusions hold of course also for airborne and land surveys.

The improved gravity field also means that all existing and future satellites obtain a new reference model that can be used for improved determination of satellite orbits. This holds for GPS satellites that need to be corrected within the GOCE concept itself, but this is certainly true for all satellite altimeter results. Seasat, Geosat, ERS-1 and ERS-1, TOPEX/Poseidon, GFO, ENVISAT and JASON orbits can all be expressed and linked to each other by means of the GOCE results. This is essential for longer period sea level studies with altimetry and for the comparison with tide gauges in one system.

Fig. 4 contains a flowchart that summarizes how the GOCE data can be used in combinations with other sources of information yielding new and important opportunities in scientific research and practical applications.

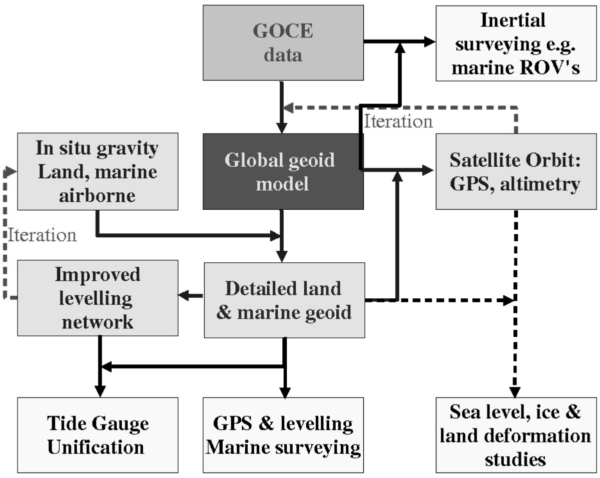

Fig. 4. GOCE data and in situ data use for navigation, the unification of height systems, precise orbits and 'levelling by GPS', with a wide range of applications in practice and science.

Ocean Modelling

In this area many activities are ongoing and planned. For example the DYNTOP project [11] aims to generate improved estimates of dynamic sea surface topography (DSST) as well as estimates of seafloor pressure changes (SFP) in the Northern North Atlantic (NNA) for assimilation in ocean general circulation models (OGCM) [12] and to evaluate the impact of these new observational constraints on model performance, particularly with respect to operational models. DSST data can be derived from satellite altimetry observations, with the accuracy depending crucially on the accuracy of the geoid model used as reference surface. Presently available geoid models are not accurate enough for precise DSST determination. Simulation studies have shown that the use of sufficiently accurate geoid models as reference surface for DSST estimates will improve ocean modelling considerably. The project aims to improve the geoid model for the NNA both on the basis of existing data and the new satellite gravity missions in order to provide an accurate reference surface for DSST determination. It is predicted that SFP can be determined from the dedicated gravity mission GRACE with a high degree of accuracy. In the frame of the project, these new observations will be analysed together with the DSST and other meteorological and oceanographic observations in order to derive separate constraints on steric and non-steric effects. These will be prepared for assimilation in the OGCM. Assimilation of observations in models can be based on different methods. Different methods for assimilation of DSST and SFP will be evaluated with particular emphasis on their suitability for operational models. In the case of operational models used for prediction of ocean state, the latency of observations has a critical influence on the assimilation. Providing better observations for assimilation in ocean models will provide a deeper insight into the processes driving the circulation in the North Atlantic [13].

Level 1-3 Examples

We also plan to design and apply methods for direct use of level 1 data for level 3 products. The applications are primarily in regional geophysical modelling but may also include ocean and ice modelling. The key is direct use of the magnitude of gravity at surface or airborne level, and of the three gravity gradient components at satellite level to constrain geophysical modelling. The latter components have a different constraining effect on e.g. shape than the gravity magnitude, which can be seen from preferences for structures in the gradient components shown in Fig. 5 [14]. The global geopotential models from GOCE, which represent a globally averaged result, do not fully exploit the potential of the local gradiometer data. For this purpose an integrated approach can be developed based upon localizing functions to band-limit the gradiometer signal such that undesired far field effects are eliminated or a global model is correctly weighed and noise is reduced. This requires forward modelling experiments to select the right combination of base functions, which can be used in an integrated approach.

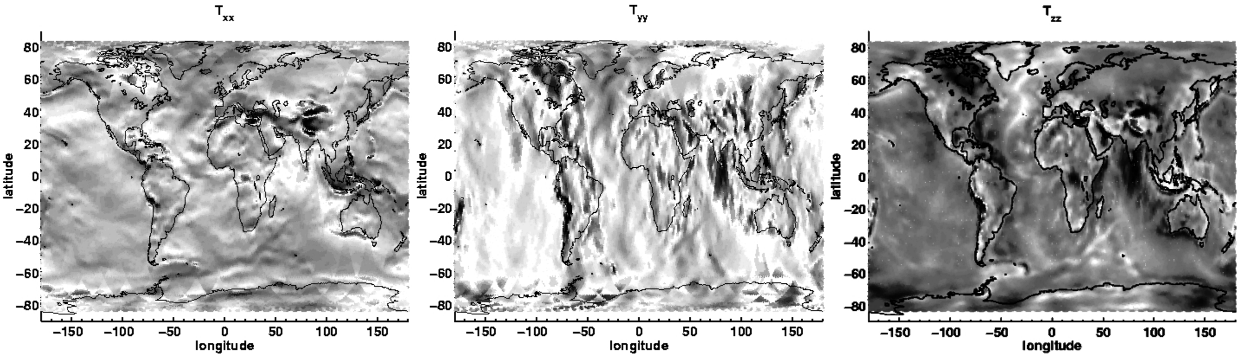

Fig. 5. Simulated GOCE gradiometer data along the orbit: T_{xx}, T_{yy} and T_{zz}.

Another interesting aspect under study is the use of localizing functions and feature detection algorithms directly to the satellite gradiometer data or to a set reduced to a common reference. The same technique can be used on terrestrial gravity and satellite altimetry in order to reveal geological features and possibly for validating GOCE level 2 potential coefficient products. An interesting parallel can be found in the studies performed with the so-called earthworms, or "multiscale" edges [15] [16]. They propose to use the local maxima in the modulus of the horizontal gradient of $\partial T/\partial z$ at multiple upward continued heights, as shown in Fig. 6, in order get an improved geological interpretation based upon the gravity field. It is planned to change the altitude of the GOCE satellite for each phase of the mission, which implies

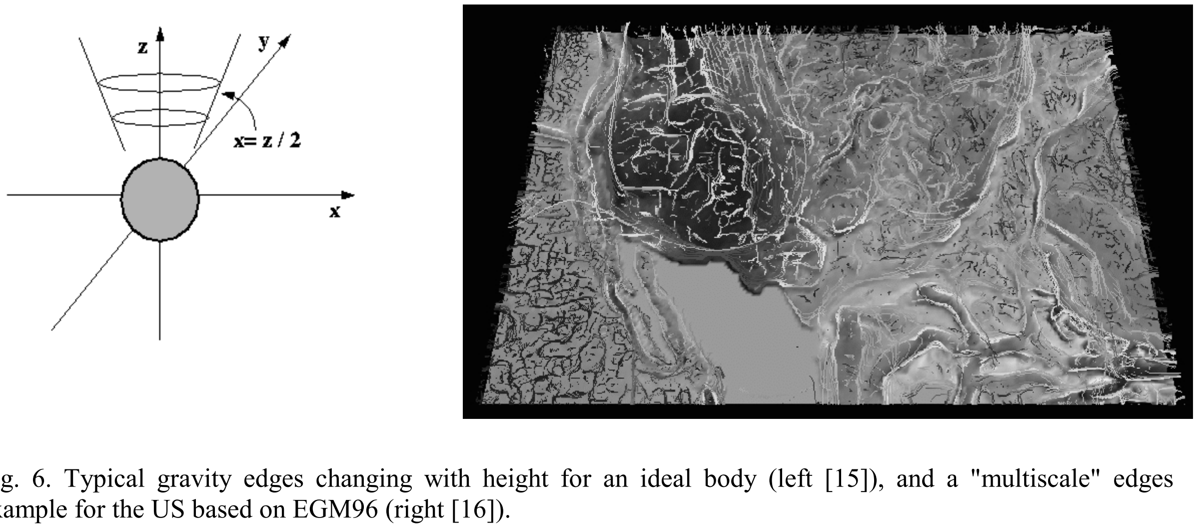

Fig. 6. Typical gravity edges changing with height for an ideal body (left [15]), and a "multiscale" edges example for the US based on EGM96 (right [16]).

that the gravity gradients will be observed at different height levels. This and the combination with other data at flight and terrestrial level can potentially lead to a similar improved geological interpretation, but now directly from observations. This requires an adequate combination of the data of different types at different heights, and the methodology needs to be adapted.

OUTLOOK

The Norwegian effort is a multidisciplinary one that aims at combining expertise and resources in order to be able to optimally exploit the results of the GOCE mission. The on-going and planned activities are performed in close cooperation with the EGG-C and are partly overlapping but largely complementary to those of the consortium. The research described here and in the national plan exhibits different levels of maturity and needs to be stimulated by national and international funding, also for linking the national activities to the international groups.

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