GOCE –

Improving the understanding of high latitude ocean circulation

Introduction

The primary aim of the Gravity Field and Steady-State Ocean Circulation Explorer (hereafter termed GOCE) Mission approved by the European Space Agency (ESA, 1999; Johannessen et al., 2003) is to provide unique models of the Earth's *gravity* field and the *geoid*, on a global scale with spatial resolution of 100 km and to very high accuracies of 1 mGal (1 mGal = 10^{-5} m/s^2) and 1-2 cm. This will provide new and fundamental insight into a wide range of multidisciplinary research and application areas, including solid Earth physics, oceanography and geodesy.

The Earth's geological evolution has resulted in a *gravity* field that departs significantly from an ellipsoid. The differences between the real, measured values of *gravity* and those that would be produced by the idealised ellipsoidal shaped body are denoted as *gravity anomalies*. These anomalies range typically between ± 300 mGal.

The *geoid* is a "level surface" which departs from the Earth's idealised 'ellipsoidal shape of equilibrium' by ± 100 m as a consequence of the topography and density inhomogeneities in the structure of the lithosphere and mantle that result in the *gravity anomalies*. The special significance of the *geoid* is that its shape defines the local horizontal and on land provides the reference surface for topography. Over the ocean it would correspond to the mean sea level if the surface was at rest (absence of tides and currents).

Figure 1b. *GOCE octagonal shaped satellite approximately 5 m long and 1 m in diameter (courtesy ESA).*

The GOCE payload (Figure 1a) consists of an electrostatic gradiometer (3 pairs of 3-axis, servo-controlled, capacitive accelerometers, each pair separated by a distance of 0.5 m), a 12 channel GPS receiver, and a laser retroreflector enabling tracking by ground lasers (Drinkwater et al., 2003). The spacecraft is approximately 5 m long and 1 m in diameter with fixed solar wings and no moving parts (Figure 1b). GOCE is scheduled for launch on 30 May 2008. It will fly in a Sun-synchronous, circular, dawn-dusk low Earth orbit, with an inclination of 96.5˚ and altitude of about 270 km. The nominal mission duration is 18 months, including a calibration phase and two measurement phases of 3 and 6 months duration each separated by a long-eclipse hibernation period.

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Dr. Johnny A. Johannessen has 25 years experience in satellite remote sensing in oceanography and sea ice research. In particular, he has focused on studies with the use of the synthetic aperture radar (SAR). In the recent years he has also been involved in development and implementation of integrated monitoring and operational oceanography systems.

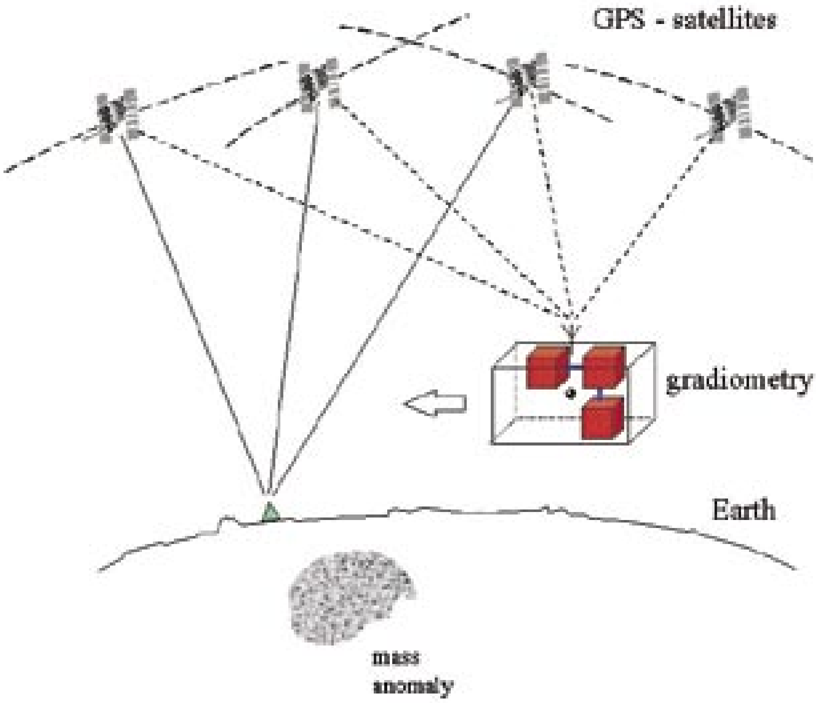

Figure 1a. *Concept of satellite gradiometry combined with satellite-to-satellite high-low tracking with GPS (courtesy ESA).*

In this short paper the research objectives and expected impact of GOCE with focus on oceanography at high latitudes are briefly addressed. The website http://www.esa.int/livingplanet/goce/ gives further details of the current status of the GOCE mission.

Expected impact of the GOCE mission in oceanography

While variations in the sea surface height and thus in the ocean currents can be derived directly from satellite altimeter data, an assessment of the absolute value of the ocean dynamic topography (mean dynamic topography plus sea level anomaly) and hence the surface current requires that the *geoid*, be subtracted from the altimetric mean sea surface height. The typical elevation scale of the dynamic topography is of the order of 0.1 to 1 m. The precision of present *geoid* models is similar on the scale of many ocean-circulation features.

The accurate and high-resolution marine *geoid*, as derived from GOCE, will in combination with precise satellite altimetry enable new estimates to be made of the absolute ocean topography at wavelengths down to 100-200 km (Figure 2). In combination with *in-situ* data and ocean models, this will, in turn, provide a high-resolution "window" on the ocean circulation at depth. Such improvements in estimates of the mean ocean circulation are much needed as addressed below.

Interpretation of Circulation at Short-Spatial-Scales. The mesoscale energy in the ocean topography (height) fields is centred at the 100-250 km half-wavelength band. Knowledge of the eddy statistics of the real ocean from altimetry, together with precise knowledge of the positions of the ocean current fronts from altimetry plus *gravity* will enable a more accurate determination of the role played by the eddies in maintaining the mean current components of the circulation. Fronts are expected to have decimetric signals in sea level relative to the *geoid* at these length scales and will thus be provided by GOCE in combination with altimetry. In turn, more reliable constraints and greater confidence can be placed in the construction and use of ocean and climate models.

Interpretation of Oceanic Flux Estimates. 1 Sv of volume transport (values of ocean volume transports are given in Sverdrup (Sv); 1 Sv = 10^6 m^3/s) corresponds to a heat transport of approximately 5×10^{13} W at mid latitudes, which is of the order of 5% of the total heat transport in a single ocean basin. Present uncertainties in ocean transports are estimated to be approximately 10%. With GOCE data the largest reduction in transport uncertainty is expected to occur in the upper ocean, which is not surprising because reduced *geoid* errors will directly provide precise constraints on upper ocean current estimates. In addition, the positive impact on surface-to-bottom transport uncertainties will also be manifested in regions of marked barotropic character such as at high latitudes. Many of these transports, play a fundamental role in the redistribution of heat from the equator to the poles. As such GOCE will contribute to improvements of our understanding of the role played by the ocean in the global climate system.

In the GOCINA project (Knudsen et al., 2006) the flow of water masses between the Northeast Atlantic and Nordic (Norwegian, Greenland, Iceland, Barents) Seas was examined. The circulation and volume transport between these ocean basins have a profound influence on the water masses leading to a horizontal and vertical density structure unlike any other ocean regions. The question is how the mean dynamic topography (MDT = mean sea surface minus the geoid) reveal this characteristics circulation regime and volume transport. An Iterative Combination Method (ICM) mean was developed combining gravity observations and synthetic gravity data derived from altimetry and several ocean MDT models

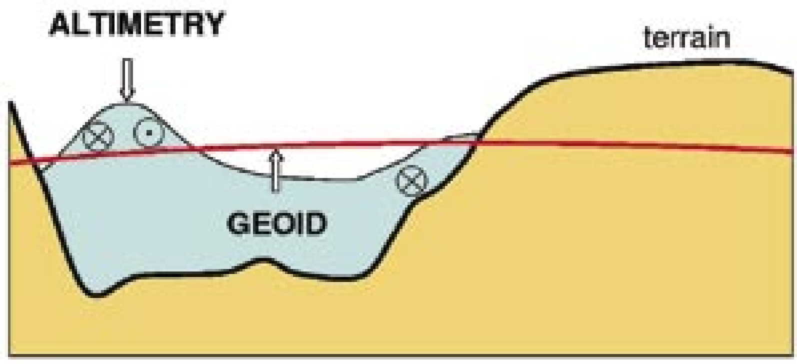

Figure 2. *Conceptual illustration of the relative slope and elevation of the geoid and the sea surface.*

to produce the best possible MDT. This new MDT map is shown in Figure 3 with a maximum elevation difference of about 80 cm. For currents following the western European shelf edge, the ICM solution has a very coherent flow. In the South–eastern Norwegian Sea, the ICM model resolution is good enough to identify the two branches of the North Atlantic water that enters the Norwegian Sea, i.e. the one directed through the Faeroe–Shetland channel and the one flowing eastward along the north side of the Iceland–Faeroe ridge. In the Irminger Sea a low of -17 cm implies the presence of a local cyclonic circulation known to exist.

Furthermore the study showed that the assimilation of SLA referenced to this ICM MDT together with salinity and temperature profiles will improve substantially the dynamic state in ocean models. The results of these simulation experiments suggest that access to the new and high quality gravity field and geoid data from GOCE will lead to more accurate volume and heat transport estimates between the North Atlantic and Nordic Seas.

Global Sea-Level Change. GOCE can also improve our understanding of past sea-level changes, and thereby improve predictions of future changes (Visser et al., 2002). For instance, more accurate models of Glacial Isostatic Adjustment and of local tectonics will result in more precise estimates of the rates of “real” global- and regional-average sea-level changes during the past century by reanalysis of the historical tide-gauge records. Moreover the more reliable determinations of ocean heat and volume fluxes can be used to improve the General Circulation Models (GCMs) employed to determine sea-level change due to thermal expansion.

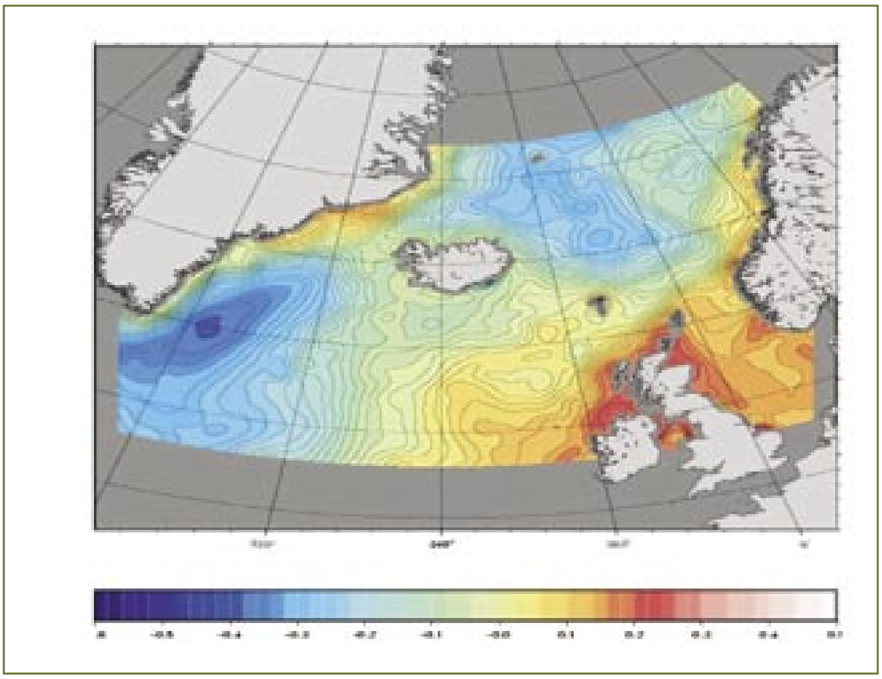

Figure 3. *Simulated mean dynamic topography across the Greenland-Scotland gap obtained from the GOCINA project (Knudsen et al., 2006; courtesy of Roger Hipkins). Maximum elevation change in the MDT of about 70-80 cm is depicted from the isobaths in an east-west direction between the Greenland and Scotland. The color-bar indicates the elevation change in unit of m.*

Summary

Data from the GOCE mission, scheduled for launch on 31 May 2008, will produce a new model of the *gravity* field and the geoid of unprecedented accuracy and spatial resolution. With the corresponding mean dynamic ocean topography derived from the GOCE *geoid* in combination with precise altimetry and *in-situ* observations practically all open ocean current systems from the strongest (Gulf Stream, Kuroshio, greater Agulhas Current regime, Antarctic Circumpolar Current) through to weaker deep-ocean circulations should be better determined in terms of location and strength. In particular, the high-spatial-resolution *geoid* afforded by GOCE is expected to

-reduce the uncertainties in mass and heat transport.

-benefit ocean modelling and forecasting

-facilitate more comprehensive investigation of sea-level changes.

Results from the GOCINA study, complemented by findings from the OCTAS project (Solheim et al., 2007) demonstrate that reliable knowledge of the comparatively high spatial variability of the steric height and MDT within the Nordic Seas and Arctic Ocean will benefit from the precise estimation of the geoid to be provided by GOCE (Knudsen et al., 2006; Siegismund et al., 2007). In addition, the GOCE data is also expected to have very important contribution to and synergy with the Cryosat-2 mission (planned for launch in 2009) for studies of the sea ice thickness in the Arctic and sub-arctic seas as demonstrated by Fosberg et al. (2007) in the ArcGICE project.

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GOCINA (Geoid and Ocean Circulation in the North Atlantic)

As the name indicates GOCINA determines an accurate geoid in the region between Greenland and the UK. The geoid will together with new developed mean sea surfaces and mean dynamic topography improve the analysis of the ocean circulation and transport through the straits in the region.

GOCINA is a joint European project consisting of 6 partners from Denmark, Norway, England, Scotland and France. It started in November 2002 and lasted for a period over three years and has ended now.

GOCINA has developed generic tools to enhance ocean analysis using Earth observation data from ENVISAT and GOCE. The project has examined the mass and heat exchange across the Greenland-Scotland Ridge. This analysis has given invaluable information on the ocean's role in climate. The project will in particular support the GOCE mission with a set of specific recommendation for integrating GOCE in ocean circulation studies and an accurate geoid model for validation purposes.

GOCINA is a shared cost project (contract EVG1-CT-2002-00077) co-funded by the Research DG of the European Commission within the RTD activities of a generic nature of the Environment and Sustainable Development sub-programme of the 5th Framework Programme.

New satellites for Ice and Soil

This year NASA starts planning of the Soil Moisture Active-Passive (SMAP) and the Ice, Cloud and land Elevation Satellite-II (ICESat-II) missions.

SMAP will provide the first-ever high-resolution global maps of soil moisture for early warning of droughts, improved weather and climate forecast and predictions of agricultural productivity.

ICESat-II will precisely measure the heights of ice sheets and sea-ice thickness, and provide estimates of aboveground forest and vegetation biomass.