GOCE

Mission Requirements Document

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1 Introduction

For the post-2000 time frame two general classes of Earth Observation missions have been identified to address user requirements (see e.g. ESA 1995b), namely:
Earth Explorer Missions - these are research/demonstration missions
Earth Watch Missions - these are pre-operational missions
Nine Earth Explorer missions have been identified as potential candidates for Phase A study (Reports for Assessment: The Nine Candidate Earth explorer Missions, ESA SP-1196 (1-9), 1996). After a selection process four missions were recommended for further study including the Gravity Field and Steady State Ocean Circulation Explorer (hereafter GOCE) Mission. The Phase A for these four missions took place from July 1998 to June 1999. Updated Reports for Assessment, ESA 1233 (1 - 4), were produced. After a second selection process GOCE was chosen for implementation.
The purpose of this document is to define the mission objectives and scientific requirements of the GOCE mission and to provide guidelines for the technical implementation of the mission. The document is divided into 7 chapters addressing the scientific background of the mission (chapter 2), the objectives of GOCE (chapter 3), the observation requirements (chapter 4), the mission elements (chapter 5), the mission products (chapter 6), and the concluding remarks (chapter 7).
The instrument specifications and critical items are included in Annex 1 and Annex 2.

2 Scientific background

The Earth is a dynamic system constantly undergoing changes. The Earth's gravity field reflects the Earth's geological history, formed by processes such as post-glacial rebound and tectonics. Moreover, the impact of processes occurring within the Earth on a global scale is expressed in a variety of ways and on a wide range of temporal and spatial scales, as illustrated schematically in Figure 1. The most significant impact lies in the longer term (i.e. climate time scales of order of 100 years) in which deglaciation and continental rebound (via impact on the marine geoid) influence global sea levels and global ocean circulation. The temporal variations in the sea level and ocean currents on short and medium time scales, on the other hand can de directly derived from satellite altimetry. The unique contribution of a dedicated gravity field mission like GOCE, is its potential for providing a more precise model of the gravity field. This model will provide a steady state reference for oceanography and new data for solid Earth geophsycis
The geoid is a unique surface of constant gravity potential, which corresponds to the hypothetical ocean surface at rest. It is the reference surface to which the actual sea surface may be compared, by means of which the steady state ocean circulation can be inferred. Knowledge of this mean circulation is required by oceanographers and by the builders of models of the Earth's climate system. The geoid is also required to be precisely known by geodesists and surveyors for transforming GPS heights to "levelled" heights and for worldwide unification of height systems.
For this reason the Earth's gravity field and geoid surface, determined uniformly and globally with significant improved spatial resolution and accuracy, are of fundamental importance. Only by the use of satellite missions can these requirements be met.

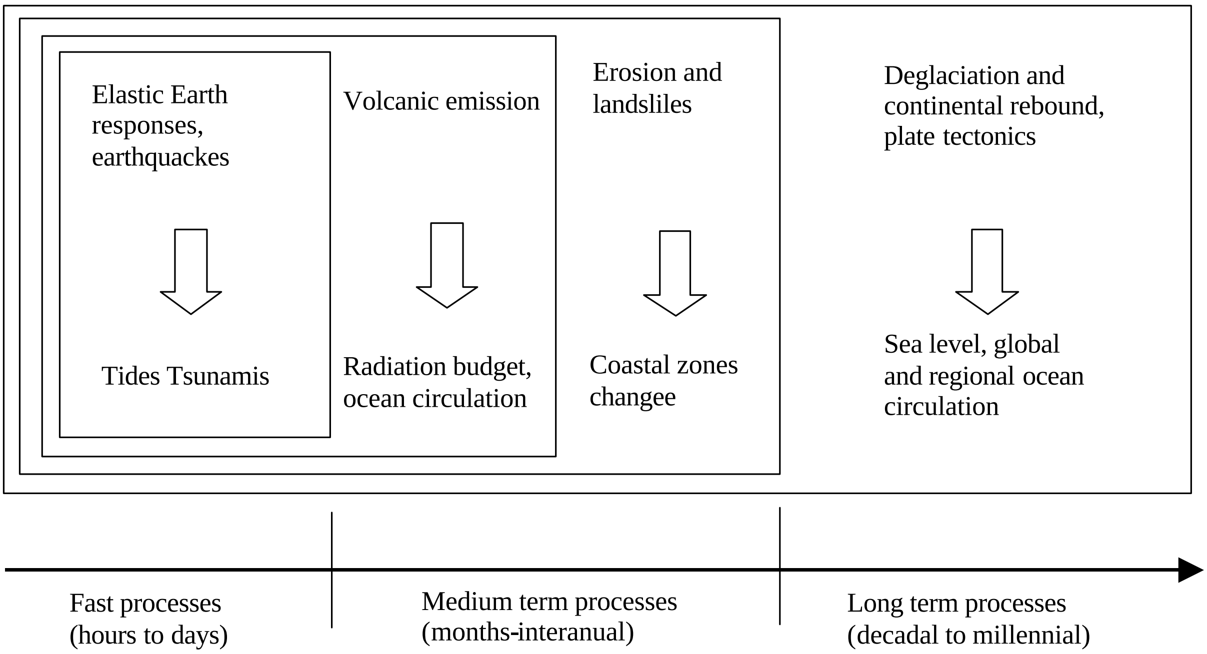


Figure 1. Examples of the impact of processes occurring within the Earth on the global ocean (From ESA SP-1227, 1998).

Marine Geoid and its Impact on Ocean Circulation – The absolute value of the ocean dynamic topography requires the determination of the 'hypothetic' ocean at rest, i.e. the marine geoid. This is the basic requirement for modelling ocean circulation and interpreting satellite altimeter data. Unfortunately, current geoid uncertanties and their impact on the absolute dynamic topography are large, particularly at shorter wavelengths less than 2000 km. Given the continuing need to study and predict climate variation and climate change by the combined use of altimetry, global ocean circulation models, and high-quality global in-situ data, it is thus essential to significantly reduce errors in our knowledge of the geoid, in particular, at shorter wavelength. A similar requirement also applies to the growing field of operational oceanography for which radar altimetry is an important data source. This could be achieved once and for all through a single dedicated gravity field mission. The need for this has been strongly articulated in international scientific programmes including the World Ocean Circulation experiment (WOCE), the Climate Variability and Prediction program (CLIVAR) and the Global Ocean Observing System (GOOS).

Gravity Field and Solid Earth Processes – Specific issues to be addressed by an accurate and detailed determination of the gravity field includes discrimination between active and passive models of rifting; identification of anomalous mass which may drive basin subsidence; and determination of the deep density structure beneath the continents and of the mechanical strength of the continental lithosphere.
Understanding of mantle processes, in particular convection patterns, and of post-glacial mass readjustment, will greatly benefit from improved and more detailed knowledge of the Earth's gravity field. Moreover, the accurate and detailed determination of the anomalous gravity field plays a key role in advancing understanding of the dynamics of the continental lithosphere. It is also necessary to identify the contribution of post-glacial rebound to sea level change, and the impact of Solid Earth processes on the global ocean. Further progress in the understanding of these processes and improvement in geopotential models require global determination of the gravity field, at a spatial resolution down to half wavelengths of between 50 and 400 km.

Geodesy – With a high resolution and precise geoid ellipsoidal heights, as provided by GPS, can be directly translated into orthometric (pseudo-levelled) heights, a perspective of high relevance for cartography, mapping, surveying, navigation and exploration. At present, the different orthometric height systems (national datum) differ by the order of decimeters between islands and between islands and continents, over distances of a few 100 km. Between continents these differences may be as large as a metre. Sea level in one part of our planet can therefore not be properly compared with sea level in other parts, nor can changes be precisely separated into sea level rise and vertical land uplift or subsidence respectively. One of the key objectives in geodesy is therefore to improve and unify the different orthometric height systems using high quality gravity field data.

Present situation – In recent years several concepts have emerged for dedicated gravity field missions. The GPS receiver and a micro-accelerometer will make CHAMP (Challenging Mini-satellite Payload for Geophysical Research and Application planned for launch in late 1999, Reigber et al., 1996), primarily a magnetometry mission, a good candidate for gravity field mapping at degree and order below 40-50 (wavelength of about 1000 km). Currently, NASA is implementing a dedicated gravity field mission named GRACE (Gravity Recovery and Climate Experiment, NRC, 1997) with the aim to retrieve very accurate observations of the time variations of the gravity field at long and medium wavelengths (to degree and order 60). Beyond this degree and order we have to rely mostly on current knowledge from terrestrial data which cause the degree error rms to become too large. For example, at long wavelengths (degree less than 14) the ocean dynamic topography signal is separable from the geoid. However, the geoid error becomes comparable to the dynamic topography signal around degree 14, that is at wavelength of about 3000 km whereas at scales of 1000 km and less geoid error dominates. A detailed and consistent examination and intercomparison of the performance specifications in respect to the observation requirements of GOCE and GRACE is provided in Balmino et al., (1998).

3 GOCE Mission Objectives

The aim of the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) Mission is to provide global and regional models of the Earth's gravity field and of the geoid, its reference equipotential surface, with high spatial resolution and accuracy. Highly accurate measurements of the Earth’s gravity field with appropriate spatial sampling are essential to better understand the processes that take place within the Earth, and on and above its surface as illustrated in Figure 2. Better gravity field models would be used in a wide range of research and application areas, including global ocean circulation, physics of the interior of the Earth and unification of height systems. In oceanography for instance, it would contribute to the recomputation and correction of a major deficiency which is the lack of an accurate and precise reference surface for the interpretation of the mean sea level as mapped by satellite altimetry, allowing longer term studies of the variations of the sea surface. It will moreover benefit to all missions which require highly accurate orbits. It will also make it feasible, should it become necessary, to lower the altitude of future altimeter satellites, since the orbital error due to gravity field knowledge will be considerably smaller. Furthermore, it will impact on the reliability of topography studies from SAR interferometry, where the orbit errors are presently posing a limitation.

3.1 Marine Geoid and its impact on Ocean circulation

The main objective of the GOCE mission for oceanography is a better understanding of the mean (or 'absolute') ocean circulation via an accurate determination of the geoid. At the present time, the mean sea surface (MSS) is known to several centimeters accuracy, owing to the high precision of recent altimeter missions, specifically TOPEX/POSEIDON. However, the configuration of the ocean dynamic topography or sea surface topography (= MSS - Geoid height) is limited because of the multi-decimeter errors in the geoid. If, through GOCE, the dynamic topography can be determined at the centimetric level, then the mean strengths of the main ocean current can be inferred with major benefits to several areas of oceanographic research.

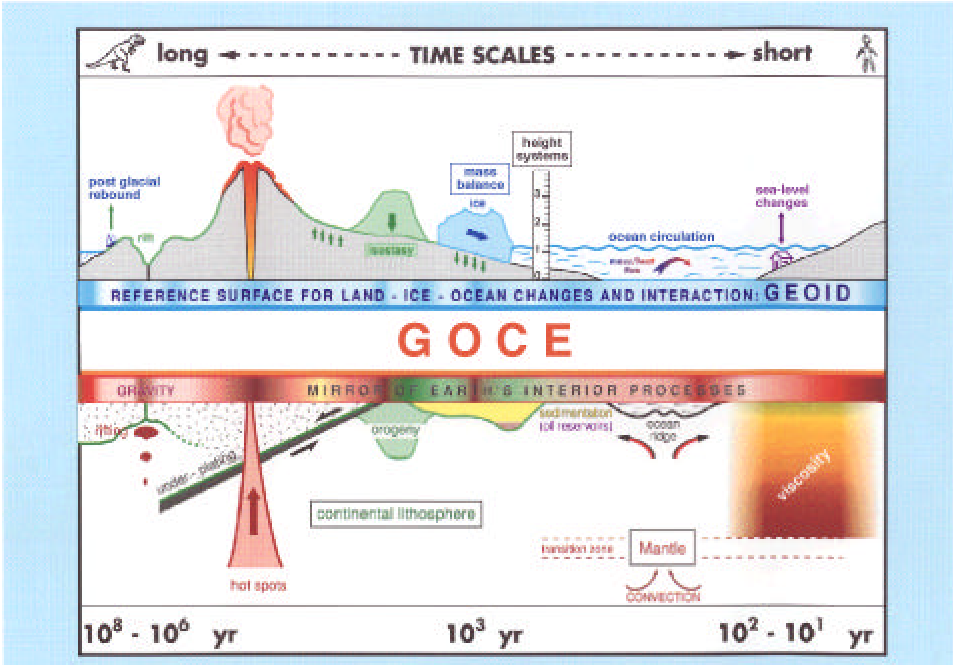


Figure 2. The Earth as a dynamic system. The geoid excursions (bluish colour) integrate the density variations of the interior. These are more directly reflected in the gravity anomalies, hence the use of the conventional "warm" colour (From Balmino et al., 1998).

A comprehensive impact study demonstrated the essential benefits of improved geoid knowledge for ocean circulation modelling (Le Provost et al., 1999). Different scenarios and model assumptions were investigated to quantify the impact on assimilation schemes of altimeter data in meso-scale quasi geostropic models, to investigate the benefits for determination of large-scale oceanic fluxes using a 1 deg inverse model and a linear box inverse model. A spectral analysis of typical spatial scales of the mean sea surface topography demonstrated that for the North Atlantic 15-30 % of the signal between 200 and 500 km will be extracted from altimetry only with a GOCE type geoid. In terms of associated surface transports this implies an improvement of the order of 25-30 % for a detailed quantification. The large-scale study showed that the major reduction in transport uncertainty will occur in the upper-ocean, which is not surprising because reduced geoid errors will directly provide precise constraints on upper-ocean velocities. The overall reductions are very significant, reaching up to 50% for the top 100 m of a short transect thru the Antarctic Circumpolar Current and up to 40% for the top kilometre. Regions of intense oceanic fronts in the North Atlantic can reach reductions up to 60%. In the deep-ocean, the relative impact of GOCE is also significant, with a 30% transport uncertainty reduction in the Circumpolar Current. For eddy resolving models GOCE data will allow a better prediction of the eddy field by about a 15 % of the signal variance for a 7 day prediction.
As regards climate-oriented research, a better knowledge of the ocean circulation will lead to significantly improved estimates of transports of the huge amounts of heat, fresh water and salt, and of dissolved quantities including pollutants, and to improved knowledge of the carbon cycle essential to climate studies.

3.2 Geodynamics

The open questions, that in order to be solved require a high resolution gravity mission are related to the structure and composition of the continental lithosphere, where mineral resources of strategic importance are located, and to the dynamics of the oceanic lithosphere at ocean ridges and subduction zones where the interaction between plates is responsible for dynamic processes that control the evolution of important tectonic structures. New achievements in the comprehension of the tectonics of plate interiors and plate boundaries will allow to understand the impact of tectonic forces on the stress field in active seismic regions and to improve the knowledge on the seismic risks in areas where earthquakes cause human and economical losses. The application of a 2D viscoelastic dynamic model for an active region in central Italy demonstrated the need for more precise gravity data (Sabadini et al., 2000) Such modelling requires knowledge of the density anomalies in the lithosphere and upper mantle, which petrology and seismic tomography alone cannot provide. Only from the inversion of the gravity data from GOCE, will it be possible to derive the worldwide pattern of the density structures in the uppermost portion of the planet with sufficient accuracy and spatial resolution.

In addition this mission will also allow a substantial improvement of the knowledge of the rheology of the mantle that controls the dynamics of the interior and of the whole Earth; mantle rheology impacts not only the long-time scale convective pattern of our planet but its comprehension also enables the interpretation of post-glacial rebound data and of present-day sea-level changes.

3.3 Geodesy

The gravity potential provides the foundation for all practical height determinations, since the surface of zero height - the geoid- is a surface of constant potential. The knowledge of the height of the geoid above the ellipsoid is important, because heights provided by GPS are refered to the ellipsoid and have to be converted to height above the geoid in order to yield orthometric heights. This conversion requires the knowledge of the geoid. The practical determination of the geoid is nowadays conducted using the long wavelength information provided e.g. through a spherical harmonic expansion (SHE) combined with local gravity and topographic information. This determination is currently disturbed by errors in the longer wavelengths, often of the order of 0.5 - 2.0 m. The goal is to enable the computation of geoid height differences to better than about 0.03 m for distances of 100 to 200 km. This can be achieved if local gravity data is combined with an improved SHE.
Geodetic height systems have currently their zero-values fixed through a mean sea level as calculated at or near tide-gauges. Due to changes in the sea surface topography this means that the height systems at present differ with values of the order of decimeters between two islands and between an island and a continent having distances up to a few hundred km. Between continents the differences may be up to a meter. These height systems (national datum) should be unified (by determining the differences relative to an accurate geoid) based on data from a gravity field mission enhanced with local data. Such a geoid surface would in turn serve as a stationary reference for the study of all topographic processes, including dynamic ocean topography (and therefore ocean circulation), the evolution of the ice sheets and land surface topography.

4 Observational requirements

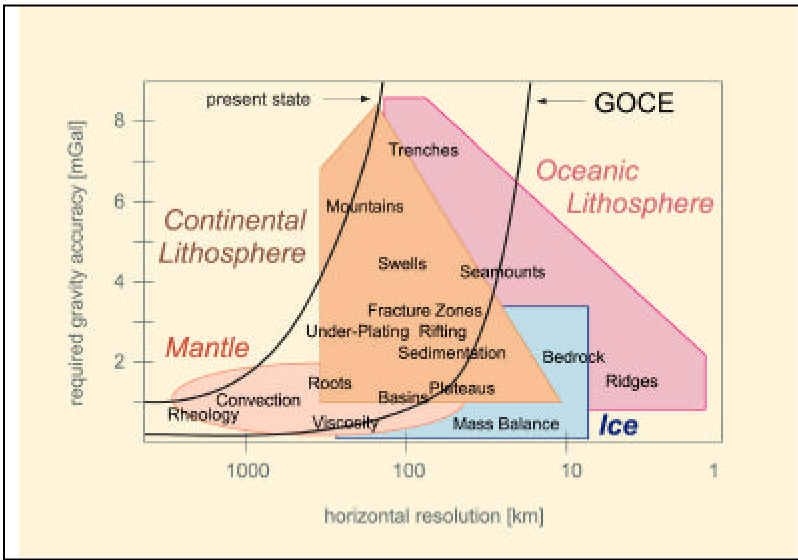
The quantitative requirements for the different scientific goals are derived from the arguments developed in the previous chapters . They are expressed in terms of geoid-height and gravity-anomaly accuracies as shown in Table 1, linked to the corresponding spatial resolution to which they apply (expressed in half-wavelengths). The values shall be understood as 'most likely' values i.e. as equal to the standard deviation assuming a normal distribution. Specifically, in the context of meeting the scientific objectives addressed under solid-Earth physics, oceanography and geodesy, the key requirements can be summarized as:

- to measure the Earth's gravity anomaly field with an accuracy of better than 1 to 2 mgal (or 10^{-5} m/s^2)
- to determine (from the measured gravity anomaly field) the geoid with an accuracy better than 1 cm radially, and
- to achieve these measurements at a length scale of 100 km or less.

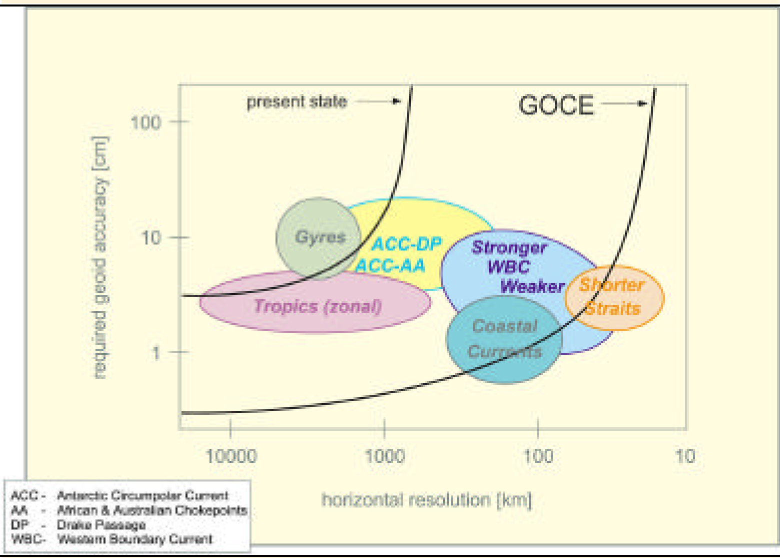
The gravity field recovery shall be achieved on a global scale, with the exception of a limited area in close proximity of Earth's poles. Note that ocean circulation derived requirements do not apply to the polar gaps. Anyway the effect of the polar gaps will be minimized by, for instance, including long wavelength information from present or future global model data and recent release of gravity field data from several sources.
There is no need for a repeat orbit. Actually a constantly drifting ground track that ensures a uniform coverage is desirable. A polar orbit would certainly be ideal but sun-synchronous orbits are acceptable.

APPLICATION	ACCURACY		SPATIAL RESOLUTION (half wavelength – D) [km]
	Geoid [cm]	Gravity [mgal]	
SOLID EARTH			
1. Lithosphere and upper-mantle density structure		1-2	100
2. 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			
3. Short-scale	1-2		100
	0.2		200
4. Basin scale	~ 0.1		1000
ICE SHEETS			
5. Rock basement		1-5	50-100
6. Ice vertical movements	2		100-1000
GEODESY			100-1000
7. Levelling by GPS	1		100-20 000
8. Unification of worldwide height systems	1		100-1000
9. Inertial Navigation System		~1-5	100-1000
10. Orbits *		~1-3	
SEA-LEVEL CHANGE	Many of the above applications, with their specific requirements, are relevant to studies of sea-level change.		

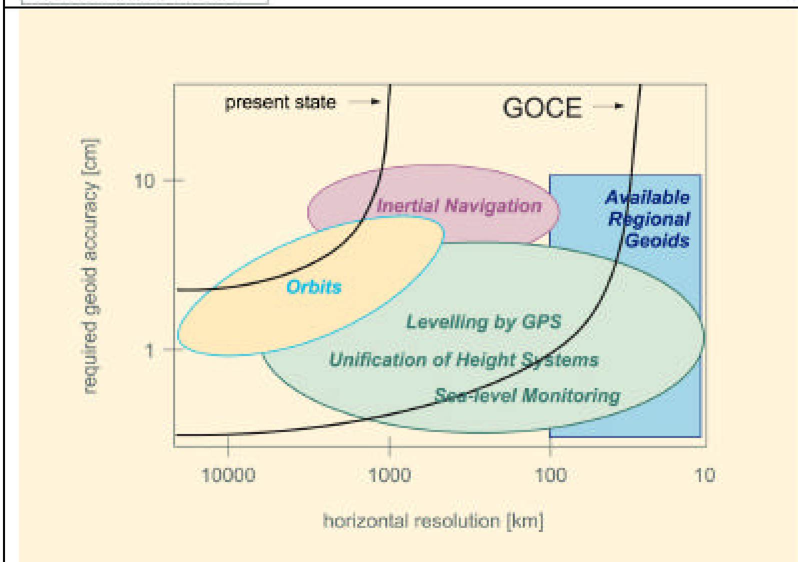
Table 1. The requirement expressed in terms of geoid height and gravity anomaly accuracies. (Orbits*: 1 cm radial orbit error for altimetric satellites).



Required accuracy (estimated at approximately 10% of the gravity signal) as a function of spatial-scales necessary to resolve the quoted geodynamical and tectonic features. The two curves represent the present and the potential accuracy from GOCE



10% of the dynamic topography signals of selected ocean circulation features (10% representing order of magnitude knowledge of the mean flows) and geoid accuracy as a function of spatial-scales obtainable from present models and after GOCE



required accuracy (estimated at approximately 10% of signal strength and all expressed in terms of geoid requirement) as a function of spatial-scales necessary to resolve the specific geodesy areas of application. The two curves represent the present and the potential accuracy from GOCE.

Figure 3. Schematic description of the required accuracy's for different application in geophysics, oceanography and geodesy.

5 Mission Design

Considering the scientific requirements four fundamental criteria can be defined to be accomplished by any future dedicated satellite gravity mission:

1. Uninterrupted tracking of the satellite in three spatial dimensions
2. Measurement or compensation of the effect of the non gravitational forces
3. Orbital altitude as low as possible
4. Enhance the strength of the high frequency component of the signal by differentiation

The first criteria can be met by exploiting the concept of satellite to satellite tracking in the high-low mode including in the mission a GPS-GLONASS receiver.
The second criteria can be met by placing in the satellite accelerometers and proportional thrusters. They will measure and compensate the non gravitational accelerations.
To fulfil the third criteria, it will be necessary to optimize the satellite to fly at low altitude. This requirement shall be balanced against the mission danger associated to having system failures at low altitude.
To fulfil the last criteria the mission will include a three axes gradiometer.

Further important design parameters can be summarized as follows:
Orbit **:** The reference orbit is a dawn-dusk sun-synchronous orbit at a design altitude of 250 km. The nominal overall mission duration is at least 20 months.
Launch: The envisaged launch date is 2004.
Satellite: GOCE will be implemented as a single satellite system configured to minimize aerodynamic drag. Some of its subsystems are conventional but others have uncommon designs due to the special needs of the mission.
Instruments: The payload of GOCE includes two instruments, which provide complementary measurements of the gravity field:

- a gravity gradiometer that measures the gravity gradients, from which the medium and short wavelength terms of the field can be derived.
- a GPS/GLONASS receiver from which the precise satellite position can be obtained and from which the long wavelength terms of the field can be derived.

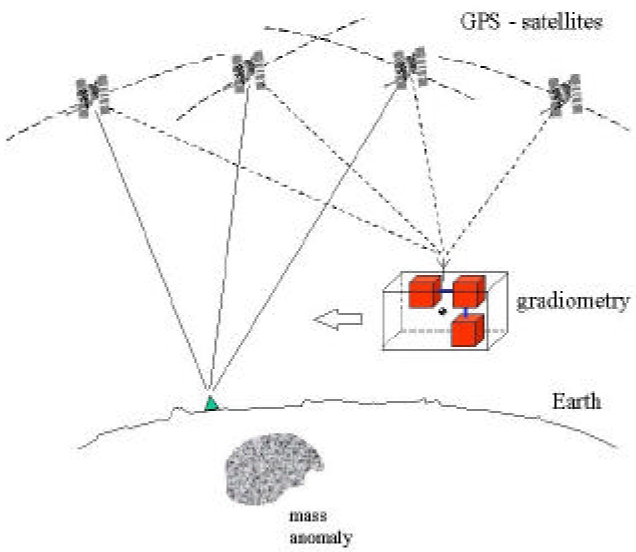


Figure 4: Conceptual illustration of satellite gradiometry gradient (SGG) and satellite-to-satellite (high-low) tracking.

A schematic illustration of the satellite concept is shown in Figure 5. The instruments are described in detail in Annex 1 of this document.
Ground Segment: It includes a dedicated single ground station at Kiruna. ESOC will be in charge of mission and satellite control. The corrected and calibrated output will be provided to a science data centre or a consortium (for example as done in the Hipparcos project) which will be responsible for verification and qualification of the data as well as the generation of the final (global) geophysical data products.

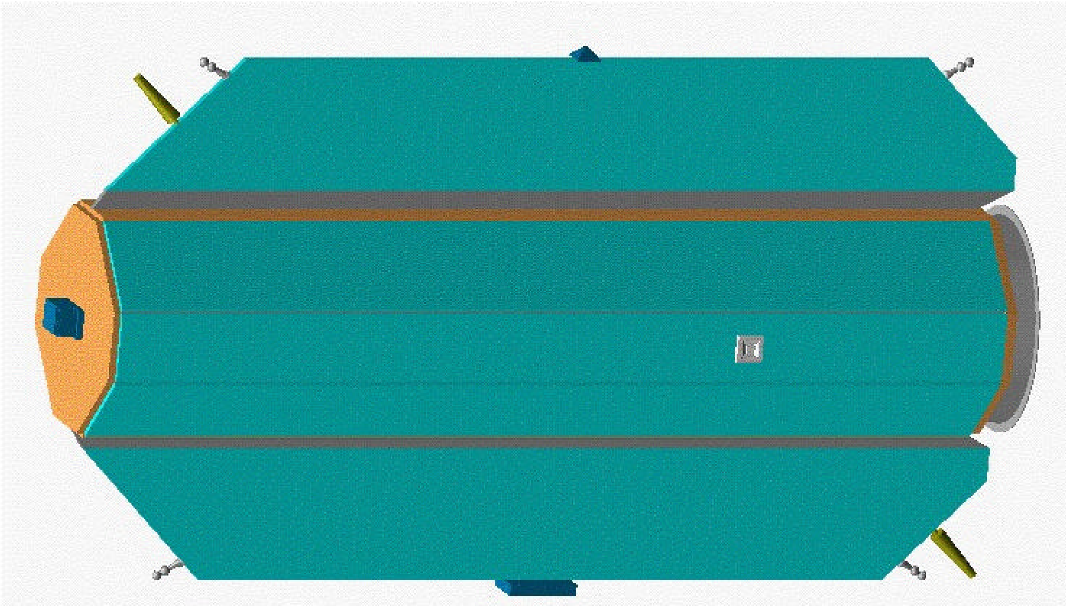


Figure 5: Illustration of the satellite concept.

The whole data reduction process is not time critical. Data and certain products will be archived and will be retrieved and provided to users on request. Ground support requirements for tracking will be satisfied with the availability of the International Geodynamics Service (IGS) network of GPS receivers.
Synergistic Observations: Some scientific studies running in parallel to the definition of GOCE are investigating high accuracy ground knowledge of the geoid (and use of upward continuation) to help in the calibration of the instruments. Although the fulfilment of the scientific requirements may not need such a 'ground truth' calibration, if implemented it could simplify the in-orbit calibration
GOCE does not fly over the poles. The final processing of data after the execution of the mission will make use of any existing gravity data over the poles. The availability of data produced by, e.g. a campaign using aircraft, will improve the performance of the mission. The mission performance figures quoted in this document have assumed that polar data are not available.

6 Data Products

6.1 Scientific Data Processing

The level of data to be produced will be the following:
<u>Level 0:</u>

- satellite and instrument housekeeping data and ancillary data
- accelerometer output at 1 Hz (3 axis for all 6 accelerometer)
- GPS/GLOSNASS receiver data at 1 Hz

<u>Level 1a:</u>

- a time series of relevant instrument parameters including calibration and satellite ancillary data

<u>Level 1a to 1b:</u>

- Calibrated and corrected data on gravity gradients in three directions with an accuracy of 4 mE at 1 Hz provided in local orbital satellite reference frame.

<u>Level 1b:</u>

- time series along the orbit consisting of calibrated and corrected data, sorted in files, including gravity gradients and SST positions, linear accelerations, thruster activity parameters, attitude control data and orbit data

Level 2

- final geophysical data output including global gravity potential, modelled as harmonic coefficients, and global gridded values of geoid heights and gravity anomalies. (Also regional models are available as appropriate.)

The pre-processing, essentially consisting of channel decommutation and reformatting, will not contain any scientific evaluation. The raw data will contain the readouts from the instruments together with calibration, time attitude and other housekeeping information like temperatures as required. After validation of the satellite data, the scientific data will be pre-processed and stored as level 1a data on appropriate media as they are generated during the mission. Data will be calibrated and corrected to provide the level 1b product of the gradiometer. The output will be gravity gradients at the satellite orbit for maximum precision but already referred to an Earth reference frame if all gradients can be derived with sufficient reliability. This data shall also include the attitude, angular velocity and angular acceleration history of the satellite. These processing tasks will require the development of special algorithms which will be part of the general industrial development of the satellite and which are needed to verify the gradiometer.
GPS/GLONASS receiver data will be provided as level 0 data in addition to auxiliary data to the scientific consortia responsible for the higher level data generation. To accomplish this it will be necessary to use the IGS. This service routinely computes high accuracy ephemeris of the GPS satellites and has recently started to produce GLONASS orbits on an experimental basis.
In addition to SST level 0 data the gradiometer level 1a and 1b data products will be transferred to a science data centre that will perform the final data reduction. The delivery will be done by any suitable media. A delivery rate of once a week can be used as a guideline. The algorithms required to convert the data from level 1 to 2 are, thanks to the work of the CIGAR consortium, quite mature. The level 2 final mission products as provided by a data processing centre or consortium will include:

- a global gravity potential model represented by its harmonic coefficients, for most general use, together with error estimates,
- a global gravity anomaly grid for geodesy and geophysics and
- a global geoid height grid for oceanography.

Regional models will be provided as requested. Further processing of GOCE data will also provide better models of atmospheric density.

6.2 Scientific Data Validation

The accuracy and reliability of the different levels of GOCE products have to be validated and assessed. A basis for this is provided by the calibration procedures of each instrument. Concerning the gradiometer observations a further check on the calibrated and corrected gravity gradients can be performed by making use of the traceless property of the gravitational gradient tensor. In addition gradiometer observations at crossing tracks can be compared with each other after transforming to a common attitude.
Although the GPS/GLONASS receiver observations are sensitive to long wavelengths and the gradiometer to short ones, there is an overlap where both instruments provide adequate accuracy. In this range, the output can be compared and validated with respect to each other.

7 Instrument description

The possible instrument layout is described in the following chapters.

7.1 Capacitive Gradiometer

This gradiometer is based on ambient temperature, closed loop, capacitive accelerometers. The principle of operation is based on the measurement of the voltages needed to maintain a proof mass at the centre of a cage. A six degrees of freedom servo controlled electrostatic suspension provides control of the proof mass on translation and rotation. Any movement of the proof mass will produce differences in capacitance between the branches of a capacitance bridge. This difference will be sensed amplified and corrected. The correction is done by adjusting the electrical potential of electrodes that act upon the proof mass until the difference in capacitance is reduced to zero. The present concept of the gradiometer has six accelerometers with one pair located along each main direction: X (velocity) Y (perpendicular to orbit) and Z (Earth). This configuration is able to recover the three diagonal terms of the gravity gradient matrix. It will also provide —but with degraded performance— the non diagonal terms and the angular velocities and accelerations of the satellite. The separation between each pair of accelerometers, which defines the gradiometric base, will be around 0.5 m. The basic instrument characteristics of the capacitive gradiometer are specified in Table A1

Mass (kg)	Power (w)	Data Rate (Kbps)	Volume (m)	Calibration	Bandwidth (Hz)
137	65	1	1.32×0.9×0.9	10^{-5}	0.005-0.1

Table A1: Instrument charateristics

The expected final in-orbit gradiometer accuracy will be **3 mE/ Hz** (1 E = 10^{-9} s^{-2})
The gradiometer is also used for the determination of the non gravitational accelerations acting upon the satellite A performance value for the linear accelerations on all axes is 10^{-9} m/s^{-2} integrated from the upper limit of the measurement bandwidth to 3 times the orbital period.

7.2 GPS-GLONASS Receiver

Two off-the shelf GPS-GLONASS receivers are available in Europe. The following information corresponds to one of them called GRAS. It is under production at Saab Space.
GRAS is a geodetic quality GPS/GLONASS receiver, i.e. it provides measurements at two frequencies for ionospheric corrections to be applied. The main interface characteristics of GRAS are provided in Table A3.

Mass (kg)	Power (w)	Data Rate (Kbps)	Volume (m)	Effective Carrier phase noise (mm)
5.5	38	1 to 10	0.3×0.15×0.2	2 mm @ 1 Hz

Table A3. GRAS characteristics

For satellite to satellite tracking, an antenna looking to the zenith is sufficient. The mass of this antenna is 3 kg and its volume 0.1×0.3× 0.3 m
Being a differential device, the gradiometer is unable to provide absolute scale factors. The SST receiver is used to complement the gradiometer measurements. It will provide an absolute calibration for the gradiometer

8 Mission assumptions

The values in this attachment are not a list of specifications. They are the industrial assumptions taken in the elaboration of the error budget of GOCE and they are provided for information only.
Most of the time, it is necessary to specify the performances on different frequency domains:

- The frequency range from 0.005 to 0.1 Hz is going to be indicated by 'w' (inside the measurement bandwidth)
- The frequency range from 0 to 0.005 Hz is going to be indicated by 'o' (outside the measurement bandwidth). Sometimes this frequency domain will be subdivided into a constant mean value plus frequency dependent variations below 0.005 mHz

8.1 Density parameters

The satellite attitude and drag control devices will be dimensioned against the atmospheric density corresponding to a 95 % confidence solar activity probability at the design altitude given above (250 km) and for the nominal launch date. This will define the worst case design altitude
Taking into account the definition of scientific performances, they should be calculated with respect to the altitude at which the density corresponding to the 50 % confidence solar activity is equal to the dimensioning density defined in the paragraph above. This will define the most likely altitude
The corresponding solar activities and altitudes are:

- 95 % probability: F10.7 = 120 Ap = 22 Design altitude: 250 km
- 50 % probability: F10.7 = 96 Ap = 16 Most likely altitude: 240 km

8.2 Gravity Tensor:

Assumptions on the range of values to be measured are necessary to perform an adequate error analysis of the mission. The gravity gradient tensor as provided by OSU91A completed up to degree and order 360 has been run during 29 days with a time step of 5 s. The resulting values have been obtained

Maximum Gravity gradient tensor in the range 'o':

$$\begin{bmatrix} -1371 & 1.1 & 11.5 \\ & -1361 & 2.5 \\ & & 2723 \end{bmatrix} E$$

Gravity gradient tensor in the range 'w':

$$\begin{bmatrix} -1.301 & 0.655 & 1.364 \\ & -0.765 & 1.024 \\ & & 1.855 \end{bmatrix} E \Big/ \sqrt{Hz}$$

8.3 Gradiometric error allocation

The gradiometric errors have been divided in four categories: Instrument, satellite, coupled (function of the satellite and the instrument at the same time) and post-flight (recovery of the centrifugal acceleration). The allocation for each one of these categories is the following:

- Instrument 3 mE√Hz.
- Satellite 2 mE√Hz.
- Coupled 1 mE√Hz.
- Post-flight 1 mE√Hz.
- R.S.S. total 4 mE√Hz.

9 Concluding Remarks

The satellite gradiometry technique which will be applied to GOCE is the measurement of the relative acceleration, not between free falling test masses like satellites, but of test masses at different locations inside the satellite. Each test mass is enclosed in a housing and kept levitated (floating, without ever touching the walls) by a capacitive feedback mechanism. The difference in feedback signals between the two test masses is proportional to their relative acceleration and exerted purely by the differential gravitational field from which the medium to short wavelength terms of the field can be derived. In addition the GPS/GLONASS receiver precise positioning system which provides satellite to satellite tracking in a high-low altitude configuration will ensure that the long wavelength terms of the gravity field are derived with sufficient accuracy.

Since non-gravitational acceleration of the spacecraft affects all accelerometers inside the satellite in the same manner it ideally cancels out during differencing. The rotational motion of the satellite, in contrast, affects the measured differences. Due to ground testing needs, the gradiometer does not recover with the same level of accuracy all the differences between read-outs, i.e. it does not provide full tensor gradiometry. However, the quality of the recovery of the angular velocities and accelerations, allows the separation of the centrifugal accelerations from the three main diagonal terms of the gravity gradient.

The Earth is a dynamic system in which a large number of interactive processes at a wide span of characteristic spatial and temporal scales take place. It has a fluid, mobile atmosphere and oceans, a continually changing distribution of ice, snow and surface water, a mantle undergoing both thermal convection and rebound from glacial loading of the last ice age, and mobile tectonic plates. Earthquakes and volcanic eruption, for example, are tremors in the crust and upper mantle, arising from the quick release of accumulated stresses at the various tectonic interfaces. They are usually very destructive locally at short temporal scales, but can also have global impact at longer temporal scales via interactive mechanisms in the dynamic system. Accurate measurements of the Earth's gravity field at the spatial resolutions specified for the GOCE mission are therefore essential to better understand these processes and their interactions which take place within the Earth, and on and above its surface.

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