

Gravity field products from the GOCE High Level Processing Facility

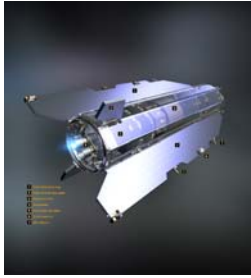


Radboud Koop⁽¹⁾, Thomas Gruber⁽²⁾, Reiner Rummel⁽²⁾

(1) SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands, e-mail: R.Koop@srn.nl

(2) Institut für Astronomische und Physikalische Geodäsie (IAPG), Technische Universität München, Arcisstrasse 21, 80333 München, Germany, e-mail: Thomas.Grubel@bv.tu-muenchen.de

The GOCE satellite



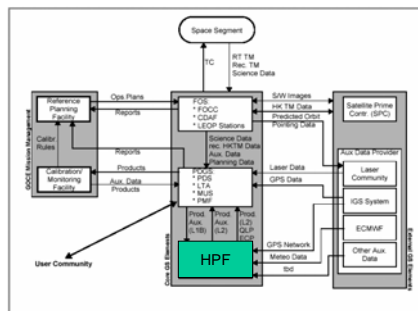
The GOCE gradiometer



The GOCE ground segment

The **High Level Processing Facility (HPF)** is part of the GOCE Ground Segment. Its input products are received from the PDGS (Payload Data Ground Segment) that is in charge of the Level 0 (raw data) to Level 1b (calibrated and corrected measurements) data processing. The HPF will produce systematically GOCE Level 2 products, such as **orbits** and **gravity field models** of different kinds, derived from the highly precise GOCE gradiometry, satellite-to-satellite tracking and additional measurements.

While so-called **quick-look** or **rapid** products are mainly of interest for the GOCE performance monitoring – as done by the Calibration/Monitoring Facility (CMF) – the **final** and **precise** products will represent the official ESA GOCE Level 2 products. They are provided for Level 3 (scientific) processing to the GOCE users (e.g. oceanographers, solid Earth scientists, geodesists and others). The HPF system is specifically developed to be able to process the satellite gravity gradients, which have never been used for gravity field determination before.



The European GOCE Gravity consortium (EGG-C)



GOCE: Gravity Field and Ocean Circulation Explorer

ESA's GOCE mission is dedicated to measuring the Earth's gravity field and modelling the geoid with extremely high accuracy and spatial resolution. It is the first Earth Explorer Core mission to be developed as part of ESA's **Living Planet Programme** and is scheduled for launch in late **2006** into a nearly-polar orbit at an extremely low altitude of **250 km**.

The objectives of GOCE are:

- to determine gravity anomalies with an accuracy of 1 mGal;
- to determine the geoid with an accuracy of 1-2 cm;
- to achieve the above globally at a spatial resolution < 100 km.

The main instruments of GOCE are:

- single, rigid octagonal spacecraft of approximately 5 m long and 1 m in diameter with fixed solar wings and no moving parts;
- **gradiometer**: 3 pairs of 3-axis, servo-controlled, capacitive accelerometers (each pair separated by a distance of 0.5 m);
- 12-channel **GPS receiver** with geodetic quality;
- ion thruster for drag-free control;
- micro-thruster assembly for calibration.

All GOCE Level 2 products will be accessible by the user community via the ESA GOCE Multi-mission User Service (MUS). The products will be provided in XML format in order to enhance the products readability and the in file data definitions. A detailed description of the products will be provided with the Data Exploitation AO (expected release late 2005).

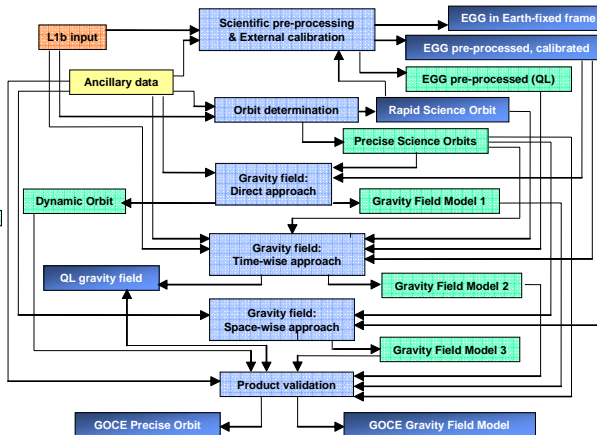
Overview of GOCE Level 2 output products

Identifier	Description	Latency
Pre-processed & calibrated gradiometer data	<ul style="list-style-type: none"> Externally calibrated and corrected gravity gradients in instrument frame Corrections to gravity gradients due to temporal gravity variations Flags for outliers, fill-in gravity gradients for data gaps with flags Statistical information 	2 weeks
Gravity gradients in Earth-fixed frame	<ul style="list-style-type: none"> Externally calibrated gravity gradients in Earth fixed reference frame including error estimates for transformed gradients Transformation parameters to Earth fixed reference frame 	6 months
Rapid science orbits*	<ul style="list-style-type: none"> Rapid science orbit from reduced dynamic approach Rapid science orbit from kinematic approach Rapid science orbit quality assessment 	1 day
Quick-look gravity field models*	<ul style="list-style-type: none"> Quick-look Earth gravity field model from SST only Quick-look Earth gravity field model from SGG only Quick-look Earth gravity field model from SST and SGG combination Diagnosis report sheets for all models Quick-look gravity field quality assessment report 	3 days
Precise science orbits	<ul style="list-style-type: none"> GOCE precise science orbits final product Quality report for precise orbits 	2 weeks
Final GOCE gravity field models	<ul style="list-style-type: none"> Final GOCE Earth gravity field model as spherical harmonic series including error estimates Variance-covariance matrix of final GOCE Earth gravity field model Grids of geoid heights, gravity anomalies and geoid slopes computed from final GOCE Earth gravity field model including propagated error estimates Quality report for final GOCE gravity field model 	9 months

* not foreseen to be distributed to GOCE end users

The GOCE gradiometer is a novel instrument specifically developed for measuring the small scale details of the gravity field, since it observes the **gravity gradients** (2nd order spatial derivatives of the gravity potential). The gravity gradients are sampled at 1 Hz with an accuracy of < 3 mE/Hz^{1/2} (1 E = 10⁻⁹ s⁻²) in the measurement bandwidth (0.005 – 1 Hz). To achieve this accuracy the gradiometer is **calibrated in-flight** by means of a calibration procedure whereby the proof masses of the accelerometers are actuated with a known signal using the sensing coils to determine the quadratic factors – which are then adjusted – and the whole satellite is actuated with a known signal using the micro-thrusters.

Processing Flow from Level 1b observations to Level 2 gravity products



Ten European institutes with complementary expertise, which form together the European GOCE Gravity Consortium (EGG-C), have been contracted by ESA to develop, implement and operate the HPF throughout the whole GOCE mission lifetime. The group is jointly managed by IAPG and SRON. The roles and responsibilities of each participating group is indicated in the table below.

Institution	Activities / Work Packages	Role in Work Package
IAPG	<ul style="list-style-type: none"> Financial, contractual and technical management Scientific pre-processing and external calibration Orbit determination Gravity field determination: time-wise approach Level 2 products validation 	<ul style="list-style-type: none"> Principal investigator & team management Partner institute Partner institute Partner institute Work package manager
SRON	<ul style="list-style-type: none"> Technical and project management Central Processing Facility Scientific pre-processing and external calibration 	<ul style="list-style-type: none"> Team management Work package manager Work package manager
FAE/A&S	<ul style="list-style-type: none"> Scientific pre-processing and external calibration Orbit determination Gravity field determination: time-wise approach Level 2 products validation 	<ul style="list-style-type: none"> Partner institute Work package manager Scientific consultant Partner institute
CNES	<ul style="list-style-type: none"> Gravity field determination: direct approach 	<ul style="list-style-type: none"> Work package manager
TUG	<ul style="list-style-type: none"> Scientific pre-processing and external calibration Gravity field determination: time-wise approach 	<ul style="list-style-type: none"> Scientific consultant Work package manager
POLIMI	<ul style="list-style-type: none"> Gravity field determination: space-wise approach 	<ul style="list-style-type: none"> Work package manager
AiUB	<ul style="list-style-type: none"> Orbit determination 	<ul style="list-style-type: none"> Partner institute
GFZ	<ul style="list-style-type: none"> Gravity field determination: direct approach 	<ul style="list-style-type: none"> Partner institute
ITG	<ul style="list-style-type: none"> Gravity field determination: time-wise approach Gravity field determination: space-wise approach Level 2 products validation 	<ul style="list-style-type: none"> Partner institute Scientific consultant Scientific consultant
UCPH	<ul style="list-style-type: none"> Gravity field determination: space-wise approach 	<ul style="list-style-type: none"> Partner institute

Internal HPF product evaluation

Due to the combination of the specific expertise of the ten different groups into one consortium (EGG-C), the HPF is able to strengthen the quality of the output products by realizing extensive internal evaluation procedures. Multiple orbit and gravity field determination methods – both long-standing, proven methods as well as new, tailored methods – are (developed and) implemented within the HPF. The solutions from the different methods – both for orbits and gravity field models – are extensively evaluated using different methods as shown in the tables below. Then a selection – done by ESA and HPF together – takes place on the basis of the results from the evaluation leading to the final Level 2 products which are to be released to the user community.

Methods for orbit products validation

Method	Test Data	Quality Parameters	Limitations
Overlaps of Orbits	GOCE precise Science Orbits	Position & Velocity Differences at Overlaps	Internal Orbit Consistency Check
Satellite Laser Ranging Residuals	Laser Ranging Data to GOCE Satellite	RMS and Mean of Laser Ranging Residuals	Difficult to track GOCE Satellite with Lasers
Comparisons with internal & external provided Orbits	External GOCE Orbit Solutions	Position and Velocity Differences	Quality of external Orbits not known

Methods for gravity field products validation

Method	Test Data	Spectral Range	Quality Parameters	Limitations
Precise Orbit Determination for other geodetic and Altimeter Satellites	Satellite Laser Ranging, Microwave and Altimeter Tracking Data	Degrees 0-70, Resolution 300-20000 km	Tracking Data Residuals, Altimeter Crossover Differences	Tracking & Altimeter Data Quality; Sensitivity of Satellites; Non-gravitational Force Models applied
Error Propagation of Variance-Covariance Matrix of Spherical Harmonic Series	Variance-Covariance Matrix	Full Spectrum of Solution	Error Degree Variances; Propagated Geoid Height Variances; Correlations of Spherical Harmonic Coefficients	No absolute Error Measure; Dependent on internal Error Calibration of Spherical Harmonic Series
Comparison with independent Geoid and Gravity Observations	GPS-Levelling Geoid Heights; Gravity Anomalies	Full Spectrum of Solution	RMS and Mean of Differences at the Observation Points and of Differences in Slopes	Treatment of Omission Error; Low-pass Filter Model; Sensitivity to long Wavelengths
Analysis of Sea Surface Topography Solutions	Mean Sea Surfaces from Altimetry; Oceanographically derived Sea Surface Topography Solutions	Long and medium Wavelengths with Resolution down to a few hundred km	Differences between geodetic and oceanographic Solutions; Test for remaining oceanographic Signals	Quality of Mean Sea Surfaces and Sea Surface Topography Solutions; Low-pass Filter Models; Treatment of Ocean-Continent Boundaries