ESTEC Contract
No. 14986/01/NL/DC

GOCE: Preparation of the GOCE Level 1 to Level 2 Data Processing

Executive Summary

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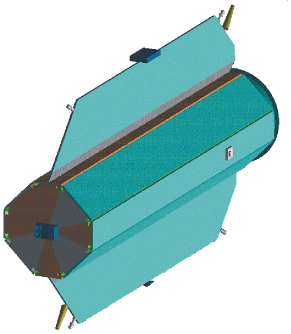

Graz, May 2002

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Prepared by
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Introduction

The Earth's gravity field is the response to the internal mass density distribution of the Earth and its rotation. Mass density anomalies are mapped onto gravity field anomalies. While the rotational contribution to gravity is very simple, the gravitational part is extremely difficult to model and not known with sufficient accuracy and resolution on a global scale. This gravitational field is the focus of attention of the currently planned dedicated gravity field satellite missions CHAMP, GRACE and GOCE.

The gravitational field is harmonic outside the Earth's surface and can be conveniently represented by a series of solid spherical harmonics. In order to model all its irregularities (which are due to the irregularities of the Earth's mass density distribution), strictly speaking an infinite number of parameters (harmonic coefficients, for example) would be required. The estimation of these parameters requires data which are sensitive with respect to these parameters. Any (finite) data set can only provide an approximation to reality. The data type, data quality, and the spatial distribution of the data control the degree of approximation.

The GOCE mission, as one of the dedicated gravity field satellite missions - is based on a sensor fusion concept: satellite-to-satellite tracking (SST) in the high-low mode using the GPS (plus GLONASS) system, plus satellite gravity gradiometry (SGG). The planned GOCE mission will provide a huge data set consisting of tens of millions of orbit data (derived from SST) plus very precise in-orbit gravity gradiometry data. This data contains abundant information about the gravity field of the Earth on a global scale, from very low to high frequencies. This gravity field information is represented by harmonic coefficients up to about degree and order 300 which corresponds to shortest half wavelength of less than 70 km.

The quality of the global gravity field is usually expressed in terms of standard errors of an individual geoid height or a mean gravity anomaly. From the GOCE mission the geoid will become known with an accuracy of better than 1 cm at a resolution of about 70 km half wavelength, and the gravity anomalies with an accuracy of better than 1 mGal within the same resolution bandwidth on a global scale with some degradation over the polar caps.

Previous Studies

In previous investigations, such as the CIGAR I - IV studies, and the study „From Eötvös to Milligal" several fundamental problems regarding gravity field determination from GPS-SST/SGG were investigated. In the course of these research and development activities several problems were identified and were successfully solved such as the contribution of GPS-SST to a dedicated SGG mission, the very efficient processing of SGG data for both the ideal case of a polar and circular orbit with constant sampling rate and a realistic sun-synchronous orbit, the processing of quasi-realistic missions by taking advantage of powerful numerical solution techniques for SGG data, supplemented by SST normal equations, the regional recovery problem, the investigation of significant temporal variations, and other related problems.

These studies were fundamental for the understanding of the capabilities of a GPS-SST/SGG mission and provided a deep mathematical insight into the relation between mission, instrument, and gravity field parameters. These studies did also contribute very significantly to the identification of possible and useful mission scenarios and were essential for the fine-tuning of a realistic mission profile.

The European GOCE Gravity Consortium (EGG-C)

The declared primary goal of the GOCE mission is the determination of the best possible global model of the Earth's gravity field, based on the pre-processed data of the GOCE mission of ESA. Part of this product are derived grids of geoid heights, free-air gravity anomalies, and geoid slopes supplemented by their respective error estimates.

In order to accomplish this goal and to link with international teams who conduct similar tasks in context with other dedicated gravity field missions, especially the GRACE mission, the European GOCE Gravity Consortium (EGG-C) was established. It consists of the following 10 teams:

Name of team/organisation	Country	Acronym	Team leader
Dept. of Theoretical Geodesy/Graz Univ. of Technology & Space Research Inst./Austrian Academy of Sciences	A	TUG/AAS	H. Sünkel
Inst. of Astron. and Physical Geodesy/ Techn. Univ. Munich	D	IAPG	R. Rummel
Inst. of Theoretical Geodesy/Univ. of Bonn	D	UNIBONN	K.H. Ilk
Division 1/GeoForschungsZentrum	D	GFZ	Ch. Reigber
Astronomical Institute/ Univ. of Bern	CH	AIUB	G. Beutler

Dept. of Geophysics/Univ. of Copenhagen & National Survey and Cadastre	DK	UCPH & KMS	Ch. Tscherning
Groupe de Recherches de Geodesie Spatiale/ CNES	F	GRGS	G. Balmino & R. Biancale
DIIAR/ Politecnico di Milano	I	POLIMI	F. Sansò
Delft Inst. of Earth Oriented Space Research	NL	DEOS	R. Klees & P. Visser
Space Research Organisation Netherlands	NL	SRON	R. Koop

Table 1: The GOCE Gravity Consortium (EGG-C)

Scope of this Contract

The focus of attention of this contract is GOCE, the proposed Gravity Field and Steady State Ocean Circulation Explorer mission of ESA. Until its approval in November 1999, GOCE was one out of four candidate missions within the Earth Explorer Program. It will be the first dedicated gravity field mission of ESA, the launch of which is to be expected in spring 2006. GOCE has a long history which is very well documented by a series of investigations, conducted by academic institutions, by space research oriented enterprises, by the space industry and by ESA. In the course of these investigations an ever increasing interest and a strong demand of the international geoscientific community for a dedicated gravity field mission became evident. As a result of these activities a European cluster of competence centers emerged that represents a very capable international scientific community, speaking a common scientific language and having a common goal in mind: the optimal realization of the GOCE mission goals.

The GOCE mission is designed to map the Earth's gravity field with both a very high and rather homogeneous accuracy and very high resolution on a global scale. An indirect and a direct gravity field sensor ideally complement each other. The GOCE spacecraft will be tracked by the global positioning system GPS (and eventually also by the global navigation satellite system GLONASS) which will provide the orbit with an accuracy in the centimeter range. A three-axis gravity gradiometer as the core instrument on board the satellite will provide local gravity field information in terms of second order derivatives of the gravitational potential along the orbit, plus linear and angular accelerations of the spacecraft which will be compensated for by thrusters such that the spacecraft remains in a free fall motion.

The irregularities of the orbit can be converted into gravity field structures with long to medium wavelength, while the gravity gradiometer delivers a map of the gravity field structures with medium to short wavelength.

As a level-2 product the geoid as a unique equipotential surface at mean sea level will be delivered by GOCE with a resolution of about 70 km half wavelength and with a design accuracy of 1 cm on an almost global scale. Converted to gravity anomalies this corresponds to an accuracy of better than 1 mGal.

Objectives of this Contract

The objective of the work in this contract is the design of the overall architecture of the GOCE level 1 to 2 data processing system with special emphasis on the detailed identification and definition of all interfaces. Furthermore, the work covers also the detailed definition of the Level 2 products which are adequate to meet the requirements for further added value products (i.e. Level 3 and beyond). Part of the contract work is the definition of the development plan of the data processing chain. The development plan also identifies critical software modules which have to be developed in context with the GOCE data processing. General support to the Agency has been offered regarding aspects of mission development elements.

Work breakdown structure

According to the statement of work the activities in this contract are broken down into 5 so-called “Slices”. Each slice is coordinated by a slice coordinator:

Slice	Topic	Organization	Coordinator
1	GOCE Products and Standards Definition	GFZ	P. Schwintzer
2	High Level Processing Architecture	IAP	R. Rummel
3	Development Plan	CNES/GRGS	G. Balmino
4	Development and Test of Critical Modules	UCPH	C.C. Tscherning
5	Support Activities for the End-to-end Simulator, Level 0 to Level 1 Processing and for the Definition of the Sat. Calibration and Characterization	SRON	R. Koop

Table 2: Slice Structure

All activity elements in these Slices are also mapped by the “Tasks” as defined in the matrix of competences of the reference document of the European GOCE Gravity Consortium (EGG-C). This document defines 9 tasks as the processing blocks of the level 2 processing:

Task	Topic	Coordinating Organization
1	Standards	CBES/GRGS
2	Database	GFZ
3	Pre-processing	SRON
4	Precise orbit determination	DEOS (4.1), AIUB (4.2)
5	Gravity modeling	CNES/GRGS (5.1), IAPG (5.2), POLIMI (5.3)
6	Solution evaluation	UCPH
7	Public relations	TUG/AAS
8	Science interface	IAPG
9	Regional solutions	UNIBONN

Table 3: Task Structure

Of these 9 tasks only Task 7 is not included in the present contract. Tasks 1 and 2 relate to Slice 1 of the present contract of the above list. Because of the intimate relationship between the contract Slices and the EGG-C Tasks, the output documents of this contract are structured accordingly.

Contract Output

According to the Statement of Work the following documents have to be provided as the output of the contract:

Slice	Acronym	Document
1	**PDD** **StRD**	**P**roduct **D**efinition **D**ocument **St**andards **R**equirement **D**ocument
2	**ADD** **SRD**	**A**rchitecture **D**esign **D**ocument **S**ystem **R**equirements **D**ocument (preliminary)
3	**DP** **DRD** **SWVP**	**D**evelopment **P**lan **D**ocumentation **R**equirement **D**ocument **S**oft**w**are **V**alidation **P**lan Proposal to ESA of modules to be developed
4		Developed and tested modules with documentation and test reports
5		Review of technical notes

Table 4: Documents

Team Structure and Management

The project work was performed by the 10 institutions of EGG-C as listed in Table 1 with Prof. Dr. Hans Sünkel (TUG/AAS) as the prime contractor.

The sub-contractors and local project leaders with the contributing scientists are listed in the subsequent table.

Sub-contractor	Organization	Contributing Scientists
Prof. Dr. G. Balmino	CNES/GRGS	S. Bruinsma
Prof. Dr. G. Beutler	AIUB	U. Hugentobler
Prof. Dr. K.H. Ilk	UNIBONN	W.-D. Schuh
Prof. Dr. R. Klees	DEOS	P. Ditmar, P. Visser
Prof. Dr. Ch. Reigber	GFZ	P. Schwintzer
Prof. Dr. R. Rummel	IAPG	J. Flury, C.Gerlach, Th.Gruber, U. Meyer, J. Mueller, M. Rothacher, N. Sneeuw
Prof. Dr. F. Sansò	POLIMI	A. Albertella, F. Migliaccio, M.Reguzzoni
Dr. A. Selig	SRON	J. Bouman, R. Koop, J.M.Smit
Prof. Dr. H. Sünkel (contractor)	TUG/AAS	K. Arsov, Th. Badura, E. Höck, R. Pail, G. Plank
Prof. C.C. Tscherning	UCPH	

Table 5: The Project Team

Meetings and Documents

The contract was signed by ESA on March 26, 2001. The project was subdivided into four milestone periods. Each milestone was completed by a report at the meetings listed in the subsequent table. Additional "working meetings" in smaller groups have taken place between PM3 and FPM.

Meeting	**Code**	**Date**	**Place**	**Document**
Kick-off	KOM	March 6, 2001	ESTEC, Noordwijk	
Progress Meeting 1	PM1	June 26, 2001	ESTEC, Noordwijk	Progress Report
Intermediate Meeting	IM1	Sep. 14-15, 2001	IAPG, Munich	
Progress Meeting 2 (Midterm)	PM2	Oct. 22, 2001	TUG/AAS, Graz	Midterm Report
Progress Meeting 3	PM3	Jan. 31, 2002	IAPG, Munich	Progress Report
Final Presentation Meeting	FPM	June 4, 2002	ESTEC, Noordwijk	Final Report

Table 6: Meetings and Documents

SLICE 1

GOCE Products Definition Document (PDD)

Prepared by
EGG-C

Compiled by
P. Schwintzer, GFZ

Summary

The PDD document characterizes the GOCE mission generated products within the level 1 to level 2 processing and the required ancillary data from external sources.

According to the GOCE Granada report ESA-SP 1233-1 [1] and the GOCE ESA System Requirements Document [5] the pre-defined GOCE product levels are as follows:

- Level 0 products: Raw measurements (telemetry data)
- Level 1A products: Instrument time series with calibration file attached
- Level 1B products: Calibrated and corrected instrument and satellite sensor data
- Level 2 products: Gravity field models in different representations with quality parameters

Level 3 products, which are value-added products, derived from geoscientific studies and modelling incorporating GOCE products, are not subject of this document.

Here, the list of level 2 products include all calibrated and validated gravity field related products, not just gravity field models. Four level 2 product categories are introduced:

- GOCE core products
- GOCE preparatory products
- GOCE internal products
- GOCE ancillary data

Core products are the fully evaluated reference products of the mission for the users' community (including the selected 'best' gravity field model and precise orbit).

Preparatory products are parallel solutions, resulting from different approaches (space-wise, time-wise, and direct gravity field solution; kinematic and reduced dynamic precise orbit determination) and are the input for the quality evaluation and the final selection. Preparatory products are supplemented by by-products which contain necessary background information for interpreting the core products. Preparatory products shall also be accessible for external users.

Internal products are for internal use only and are relevant internal interface products in between processing steps or among processing groups.

Ancillary data are data sets, series and geophysical models acquired from external sources and international services as needed for the generation of level 2 GOCE products. Ancillary data are related to the GOCE processing standards (cf. Standards Requirements Document, StRD).

For each product and the ancillary data an individual product fact sheet and ancillary data fact sheet, resp. has been prepared. In these fact sheets each individual level 2 product is specified and labeled with a unique identifier. They provide specifications in terms of input/output, standards, format, coverage, resolution, generation schedule, volume, and file attributes.

In the following task requirement matrix the task-specific acquisition (input 'I') and generation (output 'O') requirements are given for all products with the tasks as defined in Table 3.

Product / Task Requirement Matrix (L1 → L2)

TASK	1		2		3		4		5.1		5.2		5.3		6		8		9		
Product	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	**Product ID**
Level 1B Products			X																		
EGG calibrated & corrected gravity gradients, linear accel.					X		X		X		X		X						X		GO-1B-EGG
SSTI calibrated & corrected code & phase observations							X		X				X						X		GO-1B-SST
SSTI position & velocity in an inertial frame													X		X				X		GO-1B-NAV
SSTI position & velocity in an ECEF & inertial frame																					GO-1B-RSO
SSTI time-stamping (S/C time and UTC or GPS time,resp.)																					GO-1B-TIM
SREM e,p,heavy ion accumulation file and total dose																					GO-1B-SRM
Star tracker calibrated & corrected quaternions					X		X		X		X		X		X				X		GO-1B-ATT
Proof-mass DC polarisation (bias) voltage																					GO-1B-PMV
Thruster activity							X		X		X		X		X				X		GO-1B-THR
A priori SGG error model					X						X										GO-1B-EGG+ERM
Level 2 Products			X																		
<u>Core Products</u>																					
Earth gravity field model, harm. coeff., grid values, VCMs																■	X		X		GO-2-EGM
Quality report for global Earth gravity field model																■					GO-2-EGM+QUR
Gradiometer geo-located gravity gradient data, reductions						■			X		X		X				X		X		GO-2-EGG
GOCE precise science orbit											X					■			X		GO-2-PSO+GOC
Quality report for GOCE science orbit																■					GO-2-PSO+GOC_QUR
Regional gravity field model																				■	GO-2-RGM
<u>Preparatory Products</u>																					
Global Earth gravity field model from direct method										■					X						GO-2p-EGM+DIR
Global Earth gravity field from timewise method												■			X						GO-2p-EGM+TIW
Quick-look global gravity field model (timewise FFT)												■									GO-2p-EGM+QLK
Analysis report of quick-look gravity field solution												■									GO-2p-EGM+QAR
Global Earth gravity field model from spacewise method														■	X						GO-2p-EGM+SPW
Global covariance function for the gravity field					X									■					X		GO-2p-EGM+COV
GOCE precise science orbit (reduced dynamic mode)					X			■							X				X		GO-2p-PSO+GOC_RD
GOCE precise science orbit (kinematic mode)								■							X				X		GO-2p-SST+POS
GOCE precise science orbit (dynamic mode)										■					X						GO-2p-PSO+GOC_DY
GOCE rapid science orbit (reduced-dynamic mode)								▨			X										GO-2p-RSO+GOC
Rotation matrices between LORF and RERF						■															GO-2p-REF+LORF2RERF
Updated EGG error model						■					X										GO-2p-EGG+ERM
EGG calibration parameters and errors						■															GO-2p-EGG+CAL

Internal Products																					
GOCE orbit predictions								▨													GO-2i-PRD
Geo-located accelerations from SST data														■							GO-2i-SST+ACC
WOF filtered gradiometer gradient data														■							GO-2i-SGG+WOF
Regional grids of EGG data at mean sat. Alt. (var. Funct.)														▨						▨	GO-2i-RGG
TASK	1		2		3		4		5.1		5.2		5.3		6		8		9		
Product	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O	**Product ID**
Internal Products (cont'd.)			X																		
SSTI pre-processed phase and pseudo-range data								■													GO-2i-SST
Atm. and oceanic temp. Grav. variations (6h-ly)		■			X				X		X		X						X		GO-2i-AOV
Quality report for GOCE science orbit (internal eval.)																■					GO-2i-PSO+GOC_QUR
Quality report for grav. Field sol. (internal eval.)																■					GO-2i-EGM+QUR
Ancillary Data																					
GPS ephemeris and clocks		■					X		X										X		GO-2a-GNS+EPC
GPS ground station tracking data		■					X		X										X		GO-2a-GNS+GST
GPS ground station coordinates		■					X		X										X		GO-2a-GNS+GSC
GPS ground station ancillary data		■					X		X										X		GO-2a-GNS+GSA
Tracking data from the SLR Tracking Network		■					X		X						X				X		GO-2a-SLR
Earth rotation parameters from IERS		■					X		X						X				X		GO-2a-ERP
ITRF station pos. and vel.		■					X		X						X				X		GO-2a-SSC
Sun, moon and planetary ephemeris		■					X		X		X				X				X		GO-2a-EPH
Earth albedo and emissivity		■					X		X						X				X		GO-2a-RAD
Atmospheric density model		■					X		X						X				X		GO-2a-DTM
Solar flux and geomagnetic activity indices		■					X		X						X				X		GO-2a-SGA
Atmospheric pressure grid (6h-ly)	X	■							X										X		GO-2a-ATM
Ocean bottom pressure model	X	■							X										X		GO-2a-OCM
Ocean tide model		■					X		X		X				X				X		GO-2a-OTI
A-priori static gravity field model		■			X		X		X		X		X		X				X		GO-2a-EGM
Temporal gravity field variations (from GRACE results)		■			X				X		X								X		GO-2a-EGT
Terrestrial, airborne gravity data (polar gaps)		■																			GO-2a-GRA
Digital topography/bathymetry model		■			X														X		GO-2a-TOP
Spacecraft parameters (Macro model, COM)		■					X		X						X				X		GO-2a-SCM
Terrestrial and airborne gravity data (evaluation)		■			X										X				X		GO-2a-EVG
Altimetric SSH and SSTop (evaluation)		■													X						GO-2a-EVH
Geoid heights and reg. Models (evaluation)		■													X						GO-2a-EVN
Global gravity field models (evaluation)		■													X						GO-2a-EVM
Satellite orbit tracking & altimeter data (evaluation)		■													X						GO-2a-EVT
Externally computed GOCE orbits															X						GO-2a-EVO

SLICE 1

GOCE Standards Requirement Document (StRD)

Prepared by
EGG-C

Compiled by
S. Bruinsma, CNES/GRGS

Summary

The StRD defines the standards that have to be used for the GOCE mission, in particular for the (precise) orbit determination and gravity field modeling. It includes the physical constants, time systems, coordinate systems, and the force and geometrical models.

The GOCE mission aims at products with utmost accuracy an resolution. Therefore, the latest available a priori information in terms of the static gravity field and the temporal gravity variations should be used as reference. For obvious reasons, the CHAMP and GRACE products will be used as a priori information, provided that the missions will be flown successfully. In particular, the initial static gravity field and the temporal gravity variations due to hydrology and snow cover variations are not presently available with sufficient accuracy and resolution on a global scale. Therefore, the constants and models adopted in the present StRD represent the present state of the art.

The most recent IERS (International Earth Rotation Service) conventions are adopted (IERS-2000 at present), as good as possible, in combination with specific project standards mainly concerning the gravity field modeling. Because this document is written in the early stages of the mission preparation, it is subject to change until the actual launch of GOCE. These conventions are required in all orbit computations and in gravity field modeling.

The following input is required for the GOCE standards:

- ESA System Requirements Document
- Most recent IERS conventions (IERS-2000)
- GRIM5-CHAMP/GRACE standards and initial static gravity field model (from CHAMP-GRACE)
- GRACE temporal gravity field (monthly solutions) and ocean tide solution
- Global and local grids of digital terrain model and free-air gravity anomalies

The definitive standards have to be implemented in the orbit computation/data reduction software for precise orbit determination and gravity field recovery. Presently, the IERS-1996 conventions and GRIM5 standards are available, while the IERS-2000 conventions are nearly completed. The GRACE standards are not yet defined.

A satellite macro-model, and in particular knowledge of the surface materials and reflectivity coefficients, is required in order to accurately model the non-gravitational forces acting on GOCE during periods without linear acceleration measurements. These must be representative of the satellite in launch configuration. (CHAMP, for example, was largely covered with gold foil, rendering the factory reflectivity measurements useless for most of its surfaces.)

Reference System, Reference Frame, and Speed of Light	
TIME	TT (terrestrial time, ex-TDT) or TAI
CCRS CDRS	Mean equator and equinox of J2000.0 (= ICRF) Planetary and lunar ephemerides JPL DE405/LE405 (or more recent), in coordinate time
Precession	IAU 1976
Nutation	IAU 2000 + IERS (EOP05C04) daily corrections, IERS-2000 (or newer) Before 1984
Earth rotation	IERS (EOP05C04) daily Earth orientation parameters
CTRS/F Axis Time evolution	ITRF2000[8]/GRIM5-CHAMP/GRACE IERS reference pole and reference meridian No global net rotation
Origin	Earth's centre of mass
Velocity of light Scale	C = 299792458 m/s Consistent with TT
SRF SARF GRF LORF RERF	Satellite physical coordinate Reference Frame Satellite Alignment Reference Frame Gradiometer Reference Frame Local Orbital Reference Frame Radial Earth-pointing Reference Frame
Dynamical Model	
Earth	R = 6378136, 6 m (Earth's equatorial radius) 1/f = 298.25642 (inverse flattening of reference ellipsoid) □ = 0.7292115.10^{-4} rad s^{-1} (nominal 1994 Earth's mean angular velocity), $\dot{\omega}$ = - 4.5 10^{-22} rad s^{-2} GM = 398600.4418 km^3/s^2 GRIM5-CHAMP/GRACE initial gravity model (epoch tbd) + time variations (GRACE, mean monthly Gravity field up to degree and order 100); associated error estimates. $C_{00} = 1$ $C_{10} = C_{11} = S_{11} = 0$ Global grid (5' x 5') of mean free-air anomalies, with error estimates (for the aid to pre-processing, for some recovery method and for solution evaluation). Local grids (resolution tbd) of free-air gravity anomalies (for tasks 3, 6, 9). Solid tides : anelastic Earth model, permanent tide not removed Ocean tides : GRIM5-CHAMP/GRACE long wavelength solution + most recent FES solution, completed by long period tides Mtm, Mf, Mm, Sa, Ssa, 9.3y, 18.6y equilibrium tides, admittance applied for 60 waves Non tidal atmosphere mass and load deformation potential (from ECMWF pressure data, every 6h). Solid Earth pole tide ($k_2 = 0.3111 + 0.0035i$)
Third bodies	Sun, Moon and planets as point masses, indirect oblateness of Earth/Moon considered, DE405/LE405 ephemerides (or more recent)
Relativity	Schwarzschild correction , Lense-Thirring and geodetic precession (tbd)

Atmospheric drag	DTM 2000 density model[4] (updated with CHAMP data)
Solar radiation	Solar constant 4.5605.10^{-6} Nm^{-2} at 1 AU, exponential regularising function
Earth radiation	Albedo and infrared, daily geographical mean values (ECMWF) Lambert's law
Thermal thrust	Tbd
Empirical accelerations	During data gaps
Spacecraft geometry and thermo-optical properties	
Surface properties	Macro-model (facets) and physical coefficients (for drag and pressure): specular and diffuse reflection coefficients, emissivity, satellite surface temperatures
Mass	Mass history

Geometrical Model	
Station positions	ITRF2000[8] (or updated)
Station velocities	Horizontal : ITRF2000 ($\sigma < 5$ mm/a), NUVEL1A-NNR (or updated) Vertical : ITRF2000 ($\sigma < 5$ mm/a), ICE4G-VM2 (or updated)
Site displacements:	
Geocentre	Empirical annual and semi-annual motions
Earth tides	Anelastic Earth model
Ocean loading	Based on most recent ocean tide models
Atmosphere loading	Based on ECMWF pressure data
Pole tide	$\tilde{h}_2 = 0.5133$[5] (IERS-2000: ?)
Satellite Sensor Position and Orientation	
Center of mass	Position in spacecraft reference frame (SRF)
GPS antenna (phase center)	Position in SRF
SLR retro-reflector array	Position in SRF
Star trackers	Position and orientation in SRF
Thrusters	Position and orientation in SRF
Tropospheric Refraction	
Laser	Marini and Murray or update
GPS	GPS: CNET, Niell (elevation ≥ 12°, or tbd)
Relativity	
	Range and Doppler correction (PPN formulation, Sun-Earth-Moon)
GPS-SST	Clock correction (Martin-Torrence-Misner) Ambiguities, clock offsets, GPS ephemerides (International GPS Service)
Digital Terrain Model	
Global DTM	Grid (5' x 5'), used in Tasks 3, 6 and 9
Local DTM	Resolution tbd, used in Task 9

SLICE 2

GOCE Architecture Design Document (ADD)

Prepared by
EGG-C

Compiled by
Th. Gruber, IAPG
R. Koop, SRON

Summary

The ADD describes the system and software architecture for processing GOCE level 1 data (corrected and filtered observations) into level 2 gravity field and orbit products including their error estimates. The level 2 products are the basic input for the scientific use of GOCE in various disciplines. Therefore the product generation has to be performed with the highest possible quality applying the most up-to-date algorithms and processing techniques. The overall GOCE processing system architecture reflects the common approach and the synergy of expertise of the EGG-C team.

The architecture of the complete system is characterized by several tasks, which can be worked out to a large extent independently, provided that the interfaces between the individual tasks have been clearly defined. Therefore the ADD is also structured into tasks and sub-tasks, defining the architecture of each processing element in terms of the positioning of the individual task/sub-task within the full processing system and its relation to other tasks/sub-tasks, a graphical overview (flow-chart) of the processing tasks showing the individual processing steps and their sequence, a detailed description of the processing steps as given in the flow-chart, the necessary input to perform the tasks, constants to be used for the processing, and corresponding output in terms of the results of the processing task. For these tasks also several sets of ancillary data are necessary which have to be provided.

A similar structure is also used to describe the architecture of the overall processing system, where the interaction between the different tasks and sub-tasks interact and also with external data providers is identified. Therefore the ADD is hierarchically structured with the sub-task structure following the overall structure.

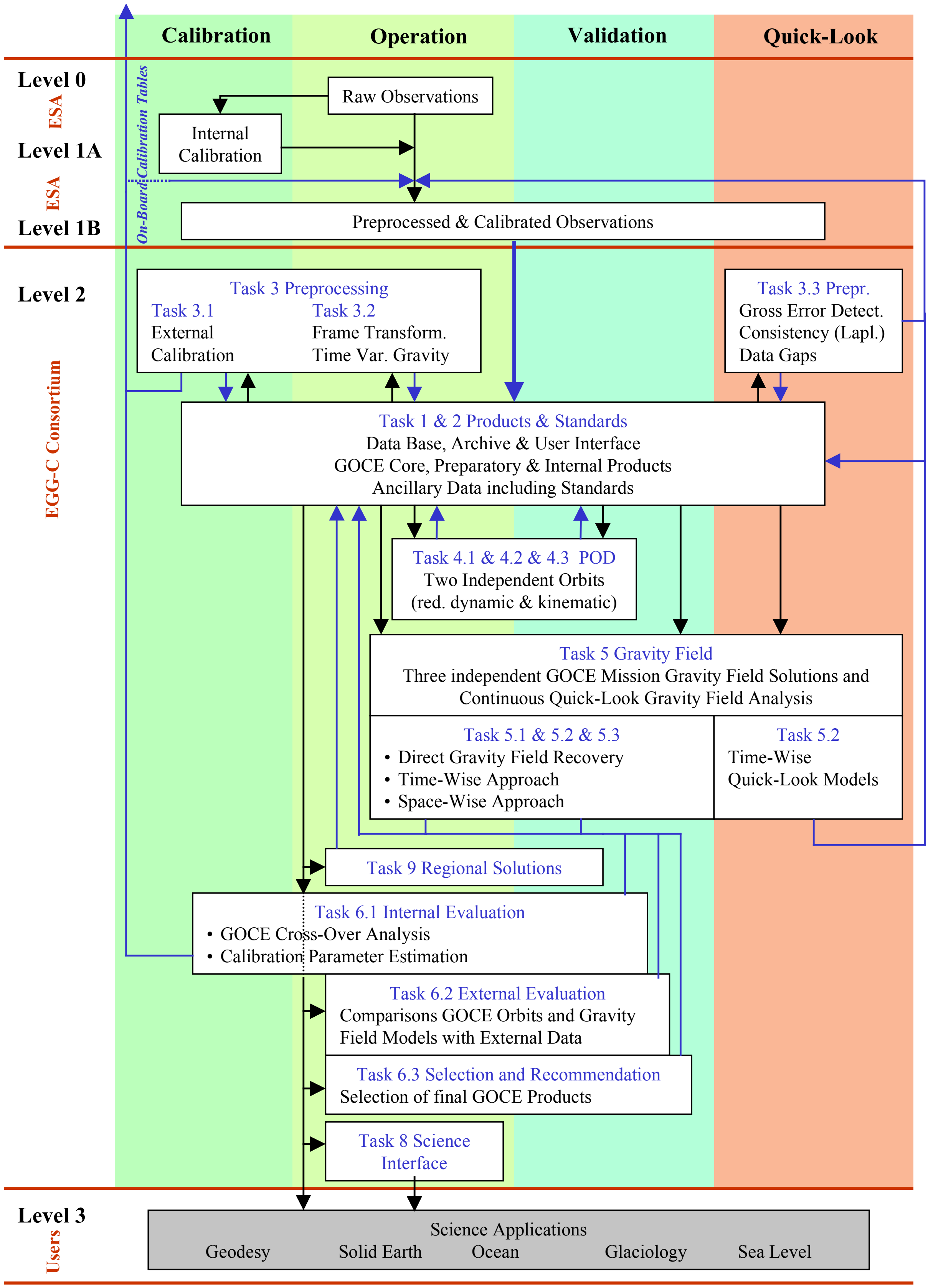

Figure 1: Processing Architecture

The flow-chart shows the interconnection between the different tasks. Also shown are the relation to the ESA level 0 to level 1 processing facility and to the level 3 user applications. Within the level 1 to level 2 processing system also a vertical structure has been introduced in order to separate between the different processing categories: calibration, operation, validation and quick-look. The boxes represent the tasks or sub-tasks. The description of the boxes shows to which categories a task can contribute. The central node of the processing system is the data base. Therefore from various tasks or sub-tasks arrows back to and from the archive are included (marked in blue). Some information in the calibration and quick-look section is also provided to the mission operation and level 0 to level 1 processing system. This indicates a close connection of the level 1 to level 2 processing system with the level 0 to level 1 and the mission operation systems. Each task or sub-task takes the complete information from the data base. This includes internal products as well as ancillary data, which are necessary for the specific task. The flow-chart should not strongly be seen as a timeline for processing level 1 to level 2 data, even if it is true for some tasks.

Task Architecture

The flow-chart clearly shows that the GOCE product generation process is logically structured into three levels:

1. Sensors (level 1 a/b)
2. Orbit and gravity processing (level 2)
3. Science and application (level 3)

The output of level 1 a/b consists of a preliminary GPS orbit, attitude angles, common mode accelerations, the gravity gradiometer components. All elements have undergone on-board calibration and are given at the specified sample rate. They are given with error estimates (stochastic model). The only interface from level 1 to level 2 is through Task 3 pre-processing. There the data is analysed in order to identify gross-errors, data gaps are either flagged or interpolated, data is cross-checked, a qualified information about the spatial orientation of the data is given and corrections for temporal effects such as tides (sun, moon, planets), indirect tidal effects (solid earth and ocean) and atmosphere are made available. Tasks 1 and 2 have been merged to one item products and standards. It contains standards, ancillary data, GOCE core, preparatory and internal products, the user interface, the data base and the archive. These tasks shield all level 2 processing tasks from pre-processing and from level 1 a/b. All data transfer of input and output to or from individual tasks goes via this block.

Precise orbit determination (POD) and gravity modelling runs almost in parallel in tasks (Tasks 4, 5 and 9). POD (Task 4) includes the actual precise orbit computation, either purely kinematical or reduced dynamic, as well as the quality assessment and internal validation of the orbits. Gravity modelling (Task 5) is divided into the computation of a full gravity model, without any simplifications (Task 5.1). It is a combined orbit and gravity modelling. Since SGG is a completely new measurement type, it is important and necessary to apply independent methods directly tailored to GOCE. One method is based on the so-called time wise method (Task 5.2). It comprises a gravity model part, an SST gravity modelling tool and a quick look tool that should be capable to give a feedback about the validity of the SGG/SST data for gravity modelling based on partial data sets. Finally, there is the space-wise method (Task 5.3), which interprets the SGG data as functional of location (and not as an orbit quantity as is the case for Task 5.2).

Global gravity analysis, such as applied in Task 5 has many advantages. Its disadvantage is that, due to the use of base functions with global support, local effects tend to be averaged over the globe. Thus, it is important to provide an algorithm for a so-called regional solution (Task 9) in parallel. It should be able to focus on local gravity features, i.e. extract regional gravity information with highest possible resolution.

Orbits, global and regional gravity models are evaluated in Task 6 solution evaluation. In this segment the previous results are checked employing a series of quality control tools such as determination of orbits of other satellites, effect on altimetry, comparison with terrestrial data sets, such as GPS-levelling profiles and other (Task 6.2 external evaluation). Also included are statistical tests in order to be able to assign quality labels to the standard GOCE products (Task 6.1 internal evaluation). Finally, based on the internal and external evaluation, a third party will formulate a recommendation for selection (Task 6.3 selection and recommendation).

Task 8 science interface is included in order to (1) clarify the use of the GOCE standard products for the users in geodesy, solid earth physics, oceanography and sea level research and (2) to prepare specialised data products tailored to the specific needs of assimilation models.

Task 1: Standards

The standards are described in detail in the GOCE StRD. For this reason and because it is not a proper processing task, no further description is provided in the ADD.

Task 2: Database, Archive, User Interface

The management of GOCE level 1 to 2 products shall be accomplished via an on-line Information System and Data Centre (ISDC) rather than a purely ftp-based directory system. The GOCE ISDC is the focal point for the product data flow among the GOCE processing centres (the product producers) and the only interface for product access by the scientific user community. The outer components of the GOCE ISDC are the product upload directory (for product input), the Clearing House (Web-based product retrieval) and the Data Warehouse (ftp-based product download). The tasks of the GOCE ISDC are product archiving and long-term storage (data centre functions), and running a catalogue system for product retrieval and download, monitoring and reporting of product input/output status, and the user management according to ESA's data policy (information system functions).

Task 3: Pre-processing

Here pre-processing should be understood as “level 2 pre-processing”, which is an EGG-C task and which differs from the level 0 to level 1B (pre-)processing which is performed under the responsibility of ESA/industry. The input for the “level 2 pre-processing” are the level 1B data and other (external) data such as satellite state vectors, existing gravity field information, etc. The sub-tasks of Task 3 include processing steps which are not performed by ESA/industry but which have been identified as required for further level 1b to level 2 processing by EGG-C, like external calibration, temporal gravity corrections and outlier detection. Typically, the processing steps performed here include external or geophysical data (like for e.g. external calibration) and/or geodetic or mathematical methods not used on level 1 (like for e.g. outlier detection).

Related tasks are performed by ESA/industry on level 1, but there the steps include internal calibration and data screening based on GOCE data alone (HK data, payload data, etc.)

The pre-processing task is divided into three sub-tasks with the following functions:

Task 3.1	External calibration: signal calibration and error assessment
Task 3.2	Frame transformation (rotation of the SGG matrix) and corrections for temporal gravity
Task 3.3	Outlier detection and data gaps (quick-look data screening)

It should be made clear that some of these tasks are optional in the sense that not all of Task 4 and Task 5 methods require these pre-processing tasks to be performed before they can use the level 1B data. For instance, when a certain gravity field determination method within Task 5 will estimate calibration parameters and temporal gravity field parameters together with the (static) gravity field model in the level 2 processing, it would not require a separate external calibration and temporal variation correction step in Task 3. On the other hand, one of the outputs of Task 3 will be a level 2 SGG product, i.e. gravity gradients which have been externally calibrated and corrected (for temporal gravity, data gaps, etc.) to be subsequently used in level 3 studies.

Task 4: Precise Orbit Determination (POD)

Precise orbit determination (POD) for GOCE concerns the accurate reconstruction of the position and velocity history of the centre of mass of the satellite in a uniquely defined and well established reference frame. The POD will be based on the Satellite-to-Satellite Tracking (SST) observations, taken by the on-board GPS receiver and the observations collected by a world-wide network of GPS reference stations. Moreover, the POD will be supported by Satellite Laser Ranging (SLR) observations and the gradiometer in the form of common-mode accelerations. In addition, attitude information as derived from the start tracker observations, possibly in combination with the gradiometer observations, is used in the POD. Nominally, an orbit accuracy of a few cm in each direction is aimed at. Currently, it is foreseen that the SLR observations will be used for evaluation purposes only.

It has to be noted that for certain POD tasks, external information from the international GPS service (IGS) is required. This external information can be divided into (1) GPS observations taken by ground stations and (2) derived products such as GPS ephemeris and clock solutions. Concerning (1), it can be noted that these observations are crucial, but a very extensive ground network has been in place already for a long time that provides data on an operational basis and no criticality is foreseen. Concerning (2), a similar statement can be made. However, the EGG-C has the capability internally to produce this information itself, should it be required due to unforeseen circumstances.

A distinction is made between a generic sub-task (Task 4.1), referred to as observation screening, and two independent orbit determination sub-tasks or strategies, referred to as reduced-dynamic (Task 4.2, orbit product “GO-2-PSO+GOC_RD”) and kinematic POD (Task 4.3, orbit product “GO-2-SST+POS ”). The objective of the observation screening is the detection of outliers and the generation of statistical information, including estimates of observation noise levels, stability of the GPS receiver, etc. The observation screening is in this case in support of the POD only. Observation corrections and detailed observation editing algorithms form in general an integral part of POD.

In case of a reduced-dynamic POD strategy, an optimal trade-off can be made between the information content of the tracking observations and a priori knowledge about dynamic models, e.g. for the earth's gravity field, resulting in the ideal case in the best orbit solution possible. Reduced-dynamic POD strategies can be based on undifferenced and differenced GPS observations, where in the latter case additional data have to be provided by terrestrial GPS receivers. In case of kinematic POD, no use is made of dynamic models preventing possible aliasing of dynamic modelling errors in the orbit solution that might for example hamper observability of gravity field perturbations in gravity field recovery schemes that use the orbit solution as the basic observable. Similar to reduced-dynamic POD, the kinematic POD can be based on undifferenced (point positioning methods) or differenced GPS observations.

Currently, it is foreseen that the reduced-dynamic orbit will be the baseline high precision GOCE orbit product. The kinematic orbit has its value in the fact that it will be the result of a purely geometrical solution which might be useful for gravity signal extraction methods based on SST information. Kinematic orbit solutions have no bias with respect to a.o. a priori gravity field models, a risk that can not be completely excluded when computing reduced-dynamic orbits. Therefore, kinematic orbit solutions may eventually be the best starting point in Task 5.2 and 9, whereas the reduced-dynamic orbit solutions may be the best starting point when processing the gravity gradient observations. Moreover, reduced-dynamic orbit solutions are continuous, whereas kinematic orbit solutions might contain gaps in periods where no GPS-SST observations are available.

Two final orbit products will be selected on the basis of a solution evaluation within Task 6.1 from orbits generated with different approaches, namely the reduced-dynamic orbits and the best kinematic orbit.

In addition, the dynamic orbits generated as by-product of the gravity field recovery will be included in the validation Task 6.1. These orbits are supposed to represent the SST observations with reduced accuracy, because dynamic model errors will affect the orbit accuracy. The orbits may, however, be used to cross-check the different POD methods as well as gravity recovery procedures to identify possible problems such as inconsistencies.

Task 4.1: Observation Screening

In principle, observation screening of GPS SST data forms an integral part of the precise orbit determination and is in many cases an iterative process. It has to be noted that nominally no screening of the common-mode accelerometer observations will be included, assuming that this has been done correctly in the generation of the level 1b products. In other words, it is expected that the Level 1b common-mode accelerometer data are well calibrated and checked. Although there are possibilities to screen accelerometer observations in the POD itself, this is not foreseen in the current architecture baseline. A number of fast and efficient methods are available for reliably and automatically detecting tracking observation outliers and also for making a quality check that can be conducted in preparation of the actual POD. Such a screening will result in a more stable orbit estimation and faster convergence of the POD process. In addition, a multi-decadal experience has been built up in the screening of SLR observations. No attention will be paid in the remainder of the Task 4 description to this data type, since in general the quality control is conducted by the individual SLR ground stations and data distribution centres like CDDIS and EUROLAS. It has to be noted that, to ensure the availability of SLR observations, coordination with the International Laser Ranging Service (ILRS) is strongly advised and necessary. The issue of applying observation corrections is addressed in detail in the PDD (Slice 1). Also for the treatment of ancillary data, e.g. GPS observations collected by ground stations, it is referred to the PDD.

In order to facilitate a fast quality check of the GPS SST data, the following methods have been identified:

1. Melbourne-Wübbena editing
2. Assessment of navigation solution

The Melbourne-Wübbena combination is a combination of both carrier phase (*L1* and *L2*) and P-code (*P1* and *P2*) observations. The effect of ionosphere, geometry and clocks is eliminated. This combination enables the detection of outliers and gives an indication of the noise of the code observations. One other possible method can be based on the navigation solution. This method only works at epochs where five or more GPS satellites are in view of GOCE (nominally permanent assuming no outages). Four simultaneous SST observations are sufficient to generate a position fix and the surplus of SST observations can be verified against this fix (different subsets of four or more observations can be used at one epoch).

Task 4.2: Reduced Dynamic POD

Reduced-dynamic POD entails the reconstruction of the satellite's trajectory from GOCE tracking observations, based on GPS SST observations, using an optimal trade-off between tracking observation and dynamic modelling quality. The reduced-dynamic technique allows different approaches with respect to observation data handling, e.g. zero-, double- or triple-differencing of the GPS observations, different combinations of phase and/or pseudo-range observations, and in conjunction flexibility in defining the set of estimated parameters. Nominally, the reduced-dynamic POD will be based on triple differences of ionospheric-free combinations of phase observations. The SLR observations will be used for validation purposes only. IGS products such as GPS orbits and satellite clocks are introduced and fixed nominally. The output will include time series of GOCE positions and velocities in the appropriate reference frames (orbit product "GO-2-PSO+GOC_RD"). The reduced-dynamic orbit determination will be performed with the GEODYN software.

Task 4.3: Kinematic POD

Kinematic POD consists of the reconstruction of the satellite's trajectory from GPS SST tracking information using geometric methods. No dynamic orbit model is used. A distinction can be made between kinematic POD approaches based on undifferenced (in the following referred to as 'A') or differenced ('B') GPS observations. Both approaches promise results of similar quality. The second approach using double-differences, however, allows fixing of phase ambiguities to integer numbers which would stabilise the solution. Since approach A is more straightforward and developments for ambiguity resolution for Low Earth Orbiters have still to be done, A is proposed as the baseline with the option to be replaced by B if the results are more accurate. The two approaches are compared in context with the solution evaluation in Task 6.1.

IGS products such as GPS satellite orbits and clock corrections, station coordinates and tropospheric corrections are introduced as fixed where necessary. Output are kinematic positions at observation epochs, nominally reconstructed from GPS-SST phase observables only (orbit product "GO-2-SST+POS"). Depending on the approach, code observations may be used as well, e.g. for the extraction of GPS clock corrections. The kinematic orbit determination will be performed using modules from the Bernese GPS Software.

Task 5: Gravity Field Modelling

Task 5.1: Direct Method

The objective of this task is the construction of a gravity field model in spherical harmonic coefficients up to degree and order 300. The direct method of gravity field recovery requires the reduction and evaluation of the GPS-SST tracking data or pre-computed precise ephemeris as pseudo-observations and the linear non-gravitational accelerations provided by the gradiometer (common mode), and the employment of gravitational force models in order to compute arcs in a dynamical approach. After the iterative least-squares orbit adjustment procedure has converged to the highest attainable accuracy level, the gravity field normal equations are computed in a subsequent step. The normal equations, representing the long-wavelength gravity field signal, are then reduced for arc-dependent parameters and cumulated over the entire observation period. Secondly, the gravity gradient measurements (SGG) are processed and yield (high resolution) normal equations that are combined with the previous (SST) normal equation set. Finally, the dynamical, gravity field and gradiometer common mode calibration parameters are simultaneously estimated, the errors of which may be estimated through the variance-covariance matrix.

Task 5.2: Time-wise method and semi-analytical quick-look approach

Two categories of gravity field solutions are planned to be processed in this task. The first is the high precision gravity field model based on the time-wise approach including all GOCE SST and SGG observations. The second is the quick-look modelling tool, which uses partial sets of GOCE SST and SGG observations together with simulated data in order to investigate permanently the quality of the GOCE data for gravity field modelling.

Time-wise approach

The objective of this task is to compute a high-accuracy, high-resolution static Earth's gravity field model, including quality estimates, from GOCE SST and SGG observations. The model will be complete (at least) up to degree and order 300. The model is complemented by a set of gravity field functionals (geoid heights and gravity anomalies), including quality estimates, computed on a spherical grid. The time-wise method is used, which was developed in the course of the last 8 years from scratch with the purpose of making optimal use of GOCE SST and SGG data.

The software is a tailored GOCE product and conceived in a modular manner that allows to investigate the behaviour of partial aspects of gravity modelling such as filtering, stability, complementary of SST and SGG data, convergence behaviour, and contribution of a priori information. Besides it supports an adaptation of the software to unforeseen changes in the mission scenario in the course of the mission, because potentially required additional modules can easily be implemented in the processing stream or modifications of already existing modules can be performed locally.

The challenge of the method is on the one hand the exploitation of the high degree of precision and resolution of the data and on the other hand the complications arising from e.g. a non-global data set (polar gap) and the coloured noise characteristics of the gradiometer instrument. The goal is to offer software that is capable of using SST, SGG and their combination for the determination of a set of spherical harmonics including realistic quality estimates.

SST and SGG Quick-Look Gravity Field Analysis

The purpose of the quick-look gravity field analysis is to analyse partial sets of SST and SGG data based on rapid science orbits, and to derive from this analysis a diagnosis of the system performance. The SGG data will be combined with complementary simulated data from an a priori gravity model. If distortions of statistical significance (e.g. systematic errors) are identified, they are reported back to level 0 to 1B processing, and counter measures can be taken at regular intervals.

Task 5.3: Space-Wise Approach

As it is known, gravity field coefficients can be retrieved from observations which are regularly distributed over a “reference” surface (e.g. a sphere, which then constitutes the boundary to which data belong) by space-wise methods. However, the solution by a space-wise approach is not completely independent of the time-wise method: in fact GOCE observations will be taken in a time stream along the orbit with the gradiometer working in a specific measurement bandwidth. Therefore “spatialized” data will be produced using a Wiener orbital filter.

The filtered data will be processed in order to form a regular grid on a reference surface (e.g. a sphere). The approach based on collocation is at the moment considered the “baseline” solution for this purpose, but other interpolation methods are being investigated.

The retrieval of the harmonic coefficients of the gravity field model (which represents the core and final step of the processing chain of the space-wise solution) shall be done by an integration approach and by spherical collocation. Both approaches will be implemented, but only one solution will be provided as the output of Task 5.3. It is proposed that the solution which has the smallest estimated errors is selected: smallest is then measured in an overall sense, as a weighted mean of the estimated errors, the weights being the degree-variances. It must be remarked that additional data to be used in Task 5.3 must come from a known geopotential model, possibly from the CHAMP or GRACE solution.

Task 6: Solution Evaluation

Task 6.1: Internal Evaluation

POD evaluation:

Currently, four methods are foreseen that will be used to assess the quality of the orbits computed in the framework of Task 4:

1. Direct comparison of orbits computed with different techniques and/or approaches
2. Orbit overlap analyses
3. Fitting of satellite positions
4. External validation with SLR observations

Gravity field evaluation:

The GOCE gravity field model as well as the regional solution product quality has to be investigated and monitored for precision, accuracy and possible systematic offsets/effects. In the internal evaluation the GOCE gravity field solutions are compared to each other by the following methods:

1. Direct comparisons of spherical harmonic coefficients and their degree variances (where applicable)
2. Comparison of geoid heights
3. Comparison of gravity anomalies
4. Comparisons of errors of spherical harmonic coefficients and propagated to geoid height errors and gravity anomaly errors.

Task 6.2: External Evaluation

The level 2 orbit and gravity field solutions including their error estimates, which are produced by EGG-C, are externally evaluated by comparisons with independently derived products and external validation data sets. For this purpose existing and new test procedures have to be developed and adapted to the GOCE products and independent comparison data sets have to be acquired and tested if they fulfil the required accuracy and resolution. Generally one can distinguish between orbital and surface/airborne test procedures and data sets, resp.

Orbital test procedures are applied for evaluating the reduced dynamic and kinematic orbit solutions provided by Tasks 4.2 and 4.3, as well as for evaluating the gravity field solutions provided by Tasks 5.1, 5.2 and 5.3, resp. This includes the computation of a set of comparison orbits based on the dynamic approach and its comparison (position and velocity) with the two other operational orbits. SLR data residuals for the different orbits provide additional information about the orbit quality. It is also foreseen to include optional GOCE orbits from other investigators (e.g. IGS LEO) into the external orbit quality evaluation. For global gravity field model testing, orbits for a set of satellites are computed and tracking data residuals (SLR, GPS, PRARE, DORIS, altimeter crossovers) are analysed. By choosing a representative set of satellites with various inclinations and heights (covering a wide spectrum) and with different tracking systems, the long wavelengths of the gravity field solutions can be evaluated very confidently.

Surface/airborne test procedures are used for external evaluation of the medium to short wavelengths of the gravity field solutions and their error estimates. Adequate calibration test sites are selected, taking into account coverage and quality of the available comparison data sets. This includes point-wise comparisons of model derived gravity anomalies, geoid height and vertical deflections with observed surface and/or airborne gravity observations, with independently computed geoid heights (e.g. by GPS and levelling) and with observed deflections of the vertical. Grids of airborne gravity campaigns (e.g. Arctic Gravity Project, specific campaigns for GOCE calibration) and regional geoid solutions can be used for gravity field evaluation over larger regions. A very efficient tool for external gravity field evaluation is satellite altimetry. Crossover difference comparisons after inclusion of recomputed orbits of altimeter satellites as well as direct comparisons of altimeter derived mean sea surfaces with gravity model derived geoid surfaces and general ocean circulation models provide quality estimates over large areas. From the above mentioned comparisons statistical error measures will be derived. These measures are compared with the formal error estimates (delivered by the least squares adjustment process). From the differences even calibration functions for the variance-covariance matrix can be derived to get realistic error estimates.

As additional external evaluation the GOCE gravity field solutions can be compared to gravity field solutions from other gravity field missions such as CHAMP and GRACE. Gravity field comparisons can be performed in the spectral domain by comparing coefficients and derived quantities (e.g. degree and error degree variances) as well as in the space domain by comparisons of global geoid heights and gravity anomalies derived from the models.

The final solution evaluation for an orbit or a gravity field model is performed by the summary of all tests, which cover different spectral ranges or different geographic areas. For the final evaluation also the accuracy and resolution of each test data set has to be taken into consideration. All results should be provided in an external quality report.

Task 6.3: Solution Selection and Recommendation

The final GOCE gravity field and precise orbit products are selected by a GOCE scientific products advisory group based on the internal and external quality reports. The scientific products advisory group should be formed by ESA staff and a few gravity field experts. These experts are external reviewers and members of EGG-C. The formation of the group is done by ESA on invitation only.

Task 7: Public Relation

This task is an element of EGG-C activities, but it is not a part of the current contract.

Task 8: Science Interface

The GOCE standard products will be presented to the users in oceanography, geophysics, glaciology and geodesy together with science user oriented documentation. For some important applications, however, this is not sufficient. Ocean circulation studies showed, that the procedures to integrate (assimilate) GOCE gravity data into the application models are not straightforward. Many applications need gravity field information on regional scale, so the global GOCE products have to be converted into suitable regional representations.

An issue which is critical for the full benefit of GOCE is the correct combination of the GOCE error model (commission and omission) with the accuracy information of the other data (which may be gridded or track-wise) in the application (assimilation) models. To enable an optimal usage of the full information content of the GOCE data, the users will need support and advice in these areas. The aim is to develop and to present, in close interaction with science users, procedures about how to integrate GOCE gravity data and accuracy information into some selected application models and to provide tailored (non-standard) gravity products for these applications.

Science users from all main fields of applications (solid earth, oceans, ice, geodesy, sea level) have to be consulted in order to make a representative inventory of applications that require high resolution gravity field information.

The models of the applications, such as ocean circulation models, lithospheric models or ice flux models, have to be checked (with feedback from users), whether they need non-standard gravity products. Examples of non-standard products are: Gravity data in various gridded structures, along profiles (satellite tracks, ocean profiles), in spectral or other representations, error propagation for these representations, smoothing procedures, omission error models, gravity models combined with ground gravity data, etc.

Studies for the integration of both, standard and non-standard products, into application models have to be stimulated. In case of non-standard products a close interaction with users is recommended for some selected studies (in the sense of benchmark studies). In such studies it has to be specified, how the non-standard products can be derived from the standard products in a correct way. Procedures for the assimilation of these products into selected application models will be developed and tested. The proper interpretation of the oceanographic and geophysical data has to be discussed to understand what the needed input for the models is. Especially the type of the data representation (choice of base functions) and the corresponding error representation has to be checked. One study in each of the main application areas oceanography, solid earth geophysics and glaciology would be desirable, each of them in cooperation with scientists from these areas.

An inventory of existing software for the required transformations and data combination procedures will be collected. Where necessary, new routines will be developed in the studies mentioned above.

Ocean circulation:

The assimilation of a Mean Dynamical Ocean Topography (MDT) deduced from a GOCE geoid and satellite altimetry into ocean circulation models is one of the most important scientific applications of the GOCE data products. To use the full benefit of the GOCE mission, it is important to transform in a well defined manner geoid, altimetric sea surface as well as the corresponding error measures into the spatial or spectral representation of state-of-the-art ocean circulation models. MDT and its associated error measures represent a new and very promising parameter set for assimilation into ocean circulation models, coupled ocean-atmosphere models, ocean transport models and ocean forecast models.

For the assimilation of the MDT into an Ocean model, the location of the model grid points, profiles (boxes) or the type of spectral representation used in the model (principal components, eigenvectors, etc.) have to be discussed and defined. Then the altimetric sea surface, which is in general given along tracks or on grids, and the GOCE geoid have to be translated into MDT in a uniquely defined manner, together with estimates of uncertainties and omission error, into the defined type of representation. Also the error estimates have to be combined in the adopted representation. The most appropriate formats have to be developed in cooperation with oceanographers. They depend on the assimilation approach adopted for the ocean models (such as Kalman filtering, adjoint model, etc.).

For these steps procedures will be developed and provided to users in oceanography. However, one could also consider to provide the MDT as an official product. For this product a mean altimetric sea surface height from a combination of all available altimetric observations for the GOCE mission duration would be a prerequisite, to avoid linking the GOCE geoid to a specific altimetric mission. The altimetry community would have to be encouraged to deliver such a product. This would enhance the value of the dynamic topography information substantially, since users in oceanography would not have to deal with altimetry problems.

Additionally, "oceanographic geoids" resulting from ocean models can be employed for validation of the GOCE geoid. Here the entire argumentation applies inversely.

Solid Earth:

A very promising application in solid earth geophysics is the joint inversion of GOCE gravity anomalies and seismic velocities for the determination of the density and velocity structure of the lithosphere. For this aim a priori density and velocity models with finite element structure have to be built. Then the model influence on both, gravity field and velocity anomalies, has to be computed. Based on this information an inversion of the observed data can be performed. Simulations show, that the joint inversion is much better constrained than an inversion based on seismic velocities only.

Also for this application the correct error propagation for the gravity anomalies and the combination with accuracies of the seismic data is important. The proper gravity field omission error model has to be taken into account. This will allow to estimate the improvement of the inversion results caused by the gravity data.

In addition, for a range of other solid earth applications the assimilation of gravity data could be tested, including error propagation: Determination of viscosity parameters, impact of glacial isostatic adjustment, in combination with tectonic models, rifting, impact of mantle plumes.

It has to be checked as to what extent additional terrestrial gravity data and terrain models are needed, depending on the required accuracies of the results, the accuracies of the seismic data and the resolution of the lithospheric model parameters.

Ice:

The GOCE gravity field is expected to contribute to glaciology at least in two areas: Estimation of bedrock topography from GOCE data in combination with terrestrial gravity data, and Sea ice freeboard determination from the combination of radar altimetry and the GOCE geoid. However, up to now no actual GOCE specific concepts have been worked out. In the science interface frame, it is intended to get the glaciologists interested in joint studies to develop such concepts.

Geodesy:

The GOCE gravity field will bring important improvements in the following areas: high resolution combined geoid/gravity models from combination with terrestrial data, datum connections and unification of height systems, GPS levelling, inertial navigation, satellite orbit determination.

As the use of the gravity field in global spherical harmonic representation is well established in these areas, no specific activities for the interface are planned so far.

Task 9: Regional Solutions

The primary task of GOCE is to derive a precise global static gravity field covering the complete spectral range down to a resolution of approximately 100 km (shortest half wavelength). A proper representation of the global gravity field is based on a linear combination of base functions with global support. At the present time there is no comparable alternative to a global approximation of the gravitational field in terms of spherical harmonics: fast algorithms for analysis and synthesis have been developed in the past decades, a complete set of spherical harmonic coefficients guarantee consistency and the coefficients represent a well-defined relation to a global terrestrial reference frame. Furthermore, spherical harmonics are very user-friendly: the leading Earth gravity models, as for example EGM96, are applied in many applications and this can be done in a fast and economic way. This is why the main focus is on the development and application of analysis techniques which are based on spherical harmonics in a global context. Therefore, it is justified to ask whether there is a need for a regional focus in addition to a global set of gravity field parameters. Can a regional zoom-in really result in a higher accuracy and/or a higher resolution taking into account that GOCE will provide a uniform redundant set of gravity gradients and high-low SST-data?

The answer is yes. When constructing a spherical harmonic expansion one has to decide as to which degree and order the harmonics should be computed. This decision is based on the assumption that the gravity field is homogeneous, i.e. that the gravity field has the same variation everywhere. However, the gravity variation is much higher in the mountains, both on land or at the ocean bottom. These regions produce a much more favourable signal-to-noise ratio, i.e. the data contains more information than what may be represented by the spherical harmonic series. Because of stability problems it is not possible to adapt the upper limit of the spherical harmonics expansion to those regionally limited signals, available in the observations. A subsequent regularisation would damp these features, because the regularisation needed, when determining the coefficient, is based on a global regularisation parameter. In regional gravity field modelling one may take advantage of the a-priori knowledge of the gravity field variation in a given region, so that a gravity field model may be determined with a higher resolution and with a regionally tuned regularisation parameter.

Two methods, least squares collocation (LSC) and the multi-grid method, had been developed and tested in earlier studies, and prototypes are ready for testing. LSC will be used as an interpolator in Task 5.3. It is pointed out that both, in principle independent approaches, represent a control mechanism for the regional recovery process. One should realise the fact that a regional recovery process has to improve a global solution in specific parts of the Earth with no chance for an alternative rigorous validation of the results. This is a very demanding task. Therefore, in our opinion there is an indispensable need for more than only one recovery procedure.

The gravity field determination method based on base functions with local support (e.g. hierarchical multi-grid-procedures with varying kernel functions in selected discretizations, or alternatively LSC, are flexible recovery techniques to process SGG as well as SST observables to derive the gravity field with regional focus. As reference, a spherical harmonics model is used up to an appropriate degree and order. The spherical harmonics model could come from a prior global solution building the framework where the regional solution can be focused in. The "focus-in" aspect can be understood such, that if signal patterns are visible in the residuals then they can result in improvements of space localising gravity field parameters. These regions will show a much more favourable signal-to-noise ratio than other areas, otherwise a regional focus-in will not result in a regional gravity field improvement. The prior analysis of the data with the aim to detect regionally limited data sets with the potential to improve regional gravity field features is done in the box "data screening, etc.". The residual gravity field part is modelled by a space localising gravity field representation in (preferably) equal area blocks covering regions of special interest or by representers of observation functionals (covariance or kernel functions) at satellite altitude. Not only a flexible grid definition is possible, also the choice of the observations associated with the representers opens a wide range of tailored gravity field representations.

The multi-grid method uses base functions associated with a partitioning of the sphere in the form of (preferably) equal area blocks, composed in a hierarchical order, so that a subsequent densification of the partitioning of the sphere is possible. The processing of the SGG and SST data are based on the same physical principle, so that it is possible to apply consistent (coloured) noise models, based on the orbit-wise procedure the data are collected.

Regional recovery procedures are on the one hand product-oriented. The product will be regionally focussed analytic representations of the gravity field as well as grids of gravity anomalies and geoid heights with a density depending on the regional gravity field variation. On the other hand the regional solution approaches (collocation and integral kernel approach) can be considered as methodologies providing a maximum of spatial resolution and accuracy within selected regions.

SLICE 2

GOCE System Requirements Document (SRD)

Prepared by
EGG-C

Compiled by
Th. Gruber, IAPG

Summary

The SRD specifies the system requirements for the development of the level 1 to level 2 science data processing system for the GOCE mission to be developed by EGG-C. Level 2 processing is defined as the generation of orbits and gravity field and possible other products for further scientific use (level 3) starting from the pre-processed level 1b GOCE products, which are provided by ESA. Level 0 to level 1a/b processing is not the subject of this requirements document. Only possible requirements on level 1a/b products, which have been identified during the pre-EGG-C contract, are included in this document.

According to the space engineering standards on Software development, the system requirements are separated into two main categories. These are:

1. General Requirements, identifying requirements for the whole processing system and also for products generated in the level 0 to level 1a/b processing system.
2. Special Requirements, identifying requirements for specific tasks in the level 1 to level 2 EGG-C processing system.

General requirements are divided into the following specific classes:

- Functional requirements (F)
- Performance requirements (P)
- Operations, maintenance and documentation requirements (O)
- Interface requirements (I)
- Verification and validation requirements (V)

Specific requirements for each task or sub-task are divided into the following specific classes:

- Functional requirements (F)
- Performance requirements (P)
- Interface requirements (I)

Operations, maintenance and documentation as well as verification and validation requirements are described in the overall system architecture. All requirements are uniquely coded and numbered according to their specific category they belong to.

SLICE 3

GOCE Development Plan (DP)

Prepared by
EGG-C

Compiled by
G. Balmino, CNES/GRGS

Summary

The aim of the DP is to identify methods and software (existing, to be upgraded, and to be written) which are necessary to transform the GOCE mission level 1A-1B data into a global solution for the Earth's gravity potential and associated functionals (geoid heights and slopes, gravity anomalies) parameterized as truncated spherical harmonic series, with precise error information, validation procedures and criteria, as well as relevant tools and methods for using this model in the various fields of geodesy and geophysics. Some effort will also be directed at providing the GOCE project with some expertise, methods and prototype algorithms for quick-look data validation and pre-processing.

Three different solution methods will be employed. The direct approach, which has a mature state and benefits from historical developments by European groups, in which the full satellite dynamics on the one hand (which can be monitored thanks to GPS tracking), and the gradiometer observables on the other hand are rigorously combined in an entirely numerical adjustment process. Alternative methods, based on a more analytical representation of the information, called the time-wise approach, and a space-wise method, will be run in parallel.

Therefore, and in the context of Slice 3, the DP addresses all questions related to: inventory, necessary upgrades and developments, prototypes, operational implementation and testing, related to all methods to be used (three independent solutions and also the interface tools for scientific users at level 3). The pre-processing task is dealt with separately in Slice 5, but we have included here what concerns the material that could be used for the operational software, which the project will develop at level 1.

The DP presupposes that the whole level 2 work is broken down into the 9 tasks as defined in Table 3. Task 7 (public relation) is outside the scope of this contract, and Task 3 is the subject of Slice 5. Task 1 is concluded by the GOCE StRD. The GOCE PDD defines all GOCE products at different levels and especially those resulting from the different tasks listed above.

The DP is based on Slice 2 and is taking into account the selection of the "official" product which is a global model of the gravity potential of the Earth (in Task 5) and mean values of gravity and geoid heights, by employing several methods in the accomplishment of this task, as well as others (for instance the precise orbit determination). This has been deemed necessary for the following reasons:

- The type of most data and their processing at unprecedented metrological and parameterization levels will be new to everyone.
- Overlaps in both the development and operational phases will be necessary for safety: unpredictable personal turn-over over seven years, relocation /retirement /illness /accident /decease of key persons, international conflicts or crisis of any sort, etc.
- The quality and reliability of the products, of which the derivation is much more complicated than it is for usual sensors (e.g. altimeter), can only be assessed by having different approaches. No standard software engineering procedures can fully guarantee the quality of the products because we are in a scientific domain where new findings/outputs can only be satisfactorily verified a posteriori (at the end of the whole process) and by running parallel and even redundant methods and software.

For clarity and consistency (within each task) the different components are presented separately for each task (or sub-tasks) in terms of inventory, outstanding items, prototypes, and implementation in the operational chain.

Schedule of development plan and required manpower

The total manpower required in the development and operational phases of the mission are displayed in matrix form, except for Task 7, which is not considered in this contract. The estimations are given in # of personnel/yr (per year), which must be multiplied by the number of years of the activity in question to obtain the estimation of the total number of man-years (m-y).

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Management	2002.5 - 2005	3.25
Software development	2002.5 - 2005	17.83
Mathematical algorithms	2002.5 - 2005	8.5
Data processing procedure	2002.5 - 2005	6.5
Simulation and testing	2002.5 - 2005	10
Documentation	2002.5 - 2005	5.25
		total: 180 m-y
Operational phase (O):		
Management	2006 - 2008	3.25
Data processing	2006 - 2008	12.5
Scientific evaluation	2006 - 2008	7.75
Data base management	2006 - 2008	0.5
Methodology	2006 - 2007	2.5
Software development	2006 - 2007	4
Documentation	2006 – 2007	3.5
		total: 91 m-y

Total (D+O): 271 m-y
(Incl. 136 m-y provided for by EGG-C)

Table 7: Manpower Requirement, Broken down by Activities

In the following table a manpower matrix is given per task, in which the personnel provided by EGG-C is also indicated (D: Development phase, O: Operational phase, T: Total, EGG-C: provided for by EGG-C.

Task	**D / m-y**	**O / m-y**	**T / m-y**	**EGG-C / m-y**
1 Standards	3.50	1.00	4.50	1.00
2 Database	1.75	1.00	2.75	0.00
3 Pre-processing	19.25	10.50	29.75	14.25
4 Precise Orbit Determination	26.25	16.50	42.75	20.75
5.1 Gravity Modeling / Direct Solution	29.75	16.50	46.25	25.25
5.2 Gravity Modeling / Time-wise Solution	31.50	13.50	45.00	21.50
5.3 Gravity Modeling / Space-wise Solution	24.50	15.50	40.00	24.25
6.1 Solution Evaluation / Internal	2.90	0.75	3.65	1.75
6.2 Solution Evaluation / External	7.00	3.00	10.00	0.00
7 Public Relations				
8 Science Interface	7.00	3.00	10.00	1.75
9 Regional Solutions	26.25	9.75	36.00	25.00
Total:	**179.65**	**91.00**	**270.65**	**135.50**

Table 8: Manpower Requirement, Broken down by Task

The DP contains also a time schedule for the software development broken down into tasks. The milestones in this development are the delivery and testing of prototype software, and the Software Readiness Review (SRR) several months before launch in which the operational software is validated and given a version number. A “prototype” is a version of the software defined as follows:

- A version of the final processor, or a subset of modules of it, tested with test data/simulated data under controlled conditions, but it may have lower (but known) performance (in terms of accuracy of the results, character and number of the output data, computation speed).
- The volume of data handled by this version may be reduced compared to the final, operational version; e.g. 2 months instead of 20 months of observations, lesser maximum degree and order of the gravity model.
- Simplified assumptions may be taken.
- Processing may be less automated, simpler MMI (Man-Machine Interface).

The specific tests for each prototype are described in the Software Validation Plan (SWVP). The SRR consists of a final evaluation of the most recent prototype software, which, in case it passes the test, will become the operational software. The test consists of the successful processing and analysis of simulated data, generated by the end-to-end simulator employing the complete and up-to-date error model. The pass/fail criteria for all tests are given in the SWVP, a separate document that comprises the Test Definition Document (TDD) and the Test Procedures Document (TPD). Test Data Sets (TDS), equally defined in the SWVP, will be employed in the validation procedure.

SLICE 3

GOCE Documentation Requirement Document (DRD)

Prepared by
EGG-C

Compiled by
S. Bruinsma, CNES/GRGS

Summary

The DRD specifies the approach to be followed for the generation of the relevant documentation, development of a supporting prototype code and generation of the test data sets required as input for the EGG-C development contract. This documentation, supported by test data and prototype code, shall be sufficient to allow the EGG-C contractor to implement the required PDS operational processing software.

The main activities during the different development steps, which are described in the DP, are outlined and the documentation to be delivered at different stages is specified. The following reference documents are addressed:

- GOCE Products Definition Document (PDD)
- GOCE Standards Requirement Document (StRD)
- GOCE Architectural Design Document (ADD)
- GOCE System Requirement Document (SRD)
- GOCE Development Plan (DP)
- Software Engineering Standard (ECSS-E-40B)

A two phases approach is considered for the processing software development:

1. Definition phase
2. Design phase

Phase 1 serves to perform a critical review and, if necessary, a detailed reformulation of the processor performance requirements that were defined in previous phases. In addition, a first (and possibly incomplete) logical model shall be established and a list of ancillary and external data (i.e. all data not included in the payload data stream) shall be generated. These will be in conformity with the StRD and PDD.

Phase 2 shall include the prototyping of the algorithms, the generation of test data and the provision of all relevant documentation to be delivered to the EGG consortium to produce the final operational software. At completion of the Detailed Definition Phase the following documents shall be delivered:

- Development Plan
- Detailed Processing Model Document
- Computation Resources Requirements Document
- High Priority Studies Document
- Data Processing Performance Requirements Document

The operational environment of the employed prototype software is displayed per task in the following table.

Task	Computer/ # CPU/memory	O/S	Archive / size	Code
3	PC 2 GHz 2 GHz PC/3/2 GB 1 GHz PC/2/1 GB PC Cluster 50 /25.5 GB DEC ALPHA 21246/1 GB	LINUX, UNIX, Windows	2 TB, Netapp 1TB	F90, C++, C, F77, Matlab
4.1	SUN E6500 SGI O2	UNIX	7TB DLT Exabyte 18 D	F77/90
4.2	SGI O2	UNIX	Exabyte 18 D	F77
4.3	SUN E6500	UNIX	7TB DLT	F77/90
5.1	IBM / 16 / 32 Gb SunFire 6800 / 8 / 8 Gb	UNIX Solaris 8	StorageTek / 2 Tb StorageTek / 2 Tb	F90 MATLAB
5.2	PC Cluster 50 /25.5 GB DEC ALPHA 21246/1 GB PC Cluster 10 /10 GB SGI Origin 3800 (up to 256 CPUs / 1 GB per CPU)	LINUX UNIX LINUX UNIX	Netapp 1TB Netapp 1TB RAID/500 GB 10 TB on-line, 100 TB near-line	F90, C F90, C F90 F90
5.3	2 GHz PC/3/2 GB 1 GHz PC/2/1 GB	LINUX UNIX, Windows	2 TB 2 TB	C & F77 C & F77 & Matlab
6.1	SunFire 6800 / 8 / 8 Gb 2 GHz PC Cluster/ 4 / 8 Gb	Solaris 8 LINUX	StorageTek / 2 Tb Raid / 100 Gb	F90 F77,F90, MATLAB
6.2	SunFire 6800 / 8 / 8 Gb 2 GHz PC Cluster/ 4 / 8 Gb	Solaris 8 LINUX	StorageTek / 2 Tb Raid / 100 Gb	F90 F90,MATLAB
8	Platform independent			
9	2GHz PC/3/2GB 2GHz PC/4/2GB	LINUX LINUX	2TB 2TB	C & F77 C++ & F77/90

Table 9: Operational Environment for Prototype Software

SLICE 3

GOCE Software Validation Plan (SWVP)

Prepared by
EGG-C

Compiled by
S. Bruinsma, CNES/GRGS

Summary

The purpose of the SWVP document is to describe the detailed test program to be followed to verify the proper implementation (of parts) of the Detailed Processing Model of the prototypes and the final operational software. The verification is based on a number of simulated processing runs under pre-defined conditions and the comparison of the results with expected output data included in the TDS. The SWVP will therefore in this case be a compilation of a definition of test cases, detailed test procedures, and the test data set, as stated in the DP.

The verification by simulations, which will cover a range from an the ideal situation (no noise) to the most realistic cases, will be performed for each separate software package described in the ADD on a per (sub-)task basis. In the revision 1 of this document shall only be given test cases for the first prototype software, which shall be finished by mid 2003. The definition of a prototype is given in the DP document.

The tests shall be described respecting the following classification:

- Hardware / software environment (SWVP)
- Definition of test cases (TDD)
- Test data sets (TDS)
- Detailed test procedures (TPD)
- Pass / fail criteria (TPD)

SLICE 4

GOCE Development and Test of Critical Modules

Prepared by
EGG-C

Compiled by
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J. Bouman, SRON
R. Koop, SRON

Summary

Slice 4 deals with the Development and test of critical modules. These modules are needed for the development of the first prototype and the final prototype. These modules are initially identified in Slice 2 and more explicitly in Slice 3.

A “Critical Module” is (conventionally) defined as follows: a component of the software which is indispensable to the achievement of the (scientific) objectives.

When setting up the list of critical modules, we add the requirement that it should be a “missing” module, in the sense that there is not a prototype ready yet. So each identified module can be checked against the following criteria:

- is it software ?
- is it indispensable ?
- is it missing ?
- does its development depend on the availability of resources (manpower, time) ?

If all answers are “yes” – then it is a Critical Module.

This puts strong restrictions on what can be characterized as a critical module. A module of which it is known that it may be improved in order to provide faster computations will not necessarily be regarded as a critical module.

Furthermore critical modules should not constitute new developments or new tasks which are not yet sufficiently clear. The only reason why a module may be “missing” is that we have not yet implemented it, but we have to know what we should do. New (scientific) developments and ideas, however interesting they may be, are outside the scope of this report.

There are, however, many issues which are considered as critical, but not in terms of software: missing information, unsolved methodological problems, lack of full understanding of an issue, and missing computational and staff resources. Such items are listed in the contributions to Slice 2 and 3 but will not be dealt with here.

The analysis of Slice 2 and 3 shows that there are very few critical software modules. (There are still critical items of another nature, however.) The technical report contains a (short) list of such critical modules. It shows the advanced status of the project, the important phase now being the development of the few missing modules and the testing of the first prototypes of the software.

Example of Development of Critical Module: Frame Transformation

As an example of the development and test of a critical module (Slice 4) the development of a prototype module for frame transformation is discussed.

According to the DP Document and the SRD, the Frame Transformation Module (FTM) has to transform the gradient tensor from the Local Orbital Reference Frame (LORF) to a Radial Earth-fixed Reference Frame (RERF).

Inputs to the FTM are:

- the angles between LORF and RERF and the rotation axes to which the angles refer
- the gravity gradient time series
- time series of the gravity gradient errors

Outputs from the FTM are:

- the transformed gradients (or actually corrections to the gradients, see the ADD)
- the corresponding error time series
- the total rotation matrix

Such a first FTM prototype was successfully implemented and tested. With the FTM, gravity gradient corrections can be computed to transform the gradient tensor from the LORF to the RERF. The software is validated with a direct and inverse transformation between LORF and RERF. The gravity gradients are affected by computer round-off errors, but are otherwise correct. A second software validation test is the computation of a total rotation matrix for 3 simple rotations around the x-, y-, and z-axis. The computed total rotation matrix is identical to the theoretical total rotation matrix up to computer round-off errors. Finally, it has been shown that the gravity gradient errors in the RERF are at the same level as the errors in the LORF (V_{xx}, V_{yy}, V_{zz}). Errors in the angles are not yet taken into account, and these should be generated and considered before finalization of the first prototype.

SLICE 5

GOCE Support activities for end-to-end simulator, level 0 to level 1 processing, and for the definition of the satellite calibration and characterization

Prepared by
EGG-C

Compiled by
J. Bouman, SRON
R. Koop, SRON

Summary

As part of Slice 5 a number of documents have been reviewed. One document prepared by the ESA GOCE Team and seven documents prepared by Alenia.

GOCE System Requirements Document:

In the context of this Slice 5 it appeared worthwhile to have the EGG-C's opinion on the GOCE System Requirements Document (SRD) for Phase B/C/D/E1. It should be remarked that this is not an official review of this document, since the SRD is an approved document for which formal update procedures should be followed.

Alenia Documents:

The following 7Alenia documents have been reviewed on ESA's request. These documents deal with the GPS and gradiometer ground processing, the gradiometer calibration and the performance requirements and budgets for the gradiometric mission.

[RD3] Gradiometer Calibration Plan, prepared by: S. Cesare, Doc.No. GO-PL-AI-0039, Issue 1, 14 February 2002.
[RD4] Gradiometer Ground Processing Algorithms Specification, prepared by: S. Cesare, Doc.No. GO-SP-AI-0003, Issue 1, 14 February 2002.
[RD5] GPS Receiver Ground Processing Algorithms Specification, prepared by: E. Detoma, Doc.No. GO-SP-AI-0004, Issue 1, 14 February 2002.
[RD6] Performance Requirements and Budgets for the Gradiometric Mission, prepared by: S. Cesare, Doc.No. GO-TN-AI-0027, Issue 1, 14 February 2002.

[RD7] Gradiometer Ground Processing Algorithms Documentation, prepared by: F. Bresciani, S. Byam, S. Cesare and E. Detoma, Doc.No. GO-TN-AI-0067, Issue 1, 28 February 2002.
[RD8] Gradiometer Ground Processing Analysis, prepared by: F. Bresciani, S. Byam and S. Cesare, Doc.No. GO-TN-AI-0068, Issue 1, 28 February 2002.
[RD9] Gradiometer On-Orbit Calibration Procedure Analysis, prepared by: S. Cesare, Doc.No. GO-TN-AI-0069, Issue 1, 14 February 2002.