ESTEC Contract
No. 14986/01/NL/DC

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

Final Report

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ESTEC Contract No. 14986/00/NL/DC

Slice 0

Project Management

Coordinated by:
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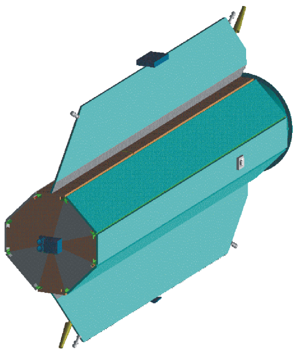

21. May 2002

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 2005. 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.

Some Background on Global Gravity Field Determination

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 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 parameters, instrumental parameters, and gravity field parameters. These studies did also contribute very significantly to the clarification of possible and useful mission scenarios and were essential for the fine-tuning of a realistic mission profile.

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 will also cover 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 will also identify critical software modules which have to be developed in context with the GOCE data processing. General support to the Agency will be offered regarding aspects of mission development elements.

Work breakdown structure

The breakdown of the activities in this contract is according to five so-called “Slices”:
Slice 1: GOCE Products and Standards Definition
Slice 2: High Level Processing Architecture
Slice 3: Development Plan
Slice 4: Development and Test of Critical Modules
Slice 5: Support activities for end-to-end simulator, Level 0 to Level 1 processing and for the Definition of the Satellite Calibration and Characterization

All elements of the work in these Slices are also identified in the “Tasks” which are defined by the matrix of competences in the reference document of the European GOCE Gravity Consortium (EGG-C). This document defines nine Tasks which are the processing blocks of the level 2 processing:
Task 1: standards
Task 2: data base
Task 3: pre-processing
Task 4: precise orbit determination (POD)
Task 5: gravity modeling
Task 6: solution evaluation
Task 7: public relations
Task 8: science interface
Task 9: regional solutions
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. Beacuse of the intimate relationship between the contract Slices and the EGG-c Tasks, the ouput documents of this contract are structured accordingly.

EGG-C teams and coordinators; matrix of competences
The EGG-C consists of the following ten teams:
AIUB, CNES/GRGS, DEOS, GFZ, IAPG, PoliMi, SRON, TUG/AAS, UCPH, UniBonn.
For each Task defined in the EGG-C reference document there is a Task-leader, a particular institute which coordinates the work within this Task:
Task 1: CNES/GRGS
Task 2: GFZ
Task 3: SRON
Task 4: DEOS (4.1), AIUB (4.2)
Task 5: CNES/GRGS (5.1), IAPG (5.2), PoliMi (5.3)
Task 6: UCPH
Task 7: TUG/AAS
Task 8: IAPG
Task 9: UniBonn
Furthermore, the “matrix of Tasks and competences” in the EGG-C reference document defines the contributing teams to each Task.
The work within the slices of this contract is coordinated by:
Slice 1: P.Schwintzer, GFZ

Slice 2: R. Rummel, IAPG
Slice 3: G. Balmino, CNES/GRGS
Slice 4: C.C. Tscherning, UCPH
Slice 5: R. Koop, SRON.

Output of the slices
According to the Statement of Work (SoW) the output of the slices is:

Slice 1:	PDD: Product Definition Document
	StRD: Standards Requirement Document
Slice 2:	ADD : Architecture Design Document
	SWRD: (preliminary) Software Requirements Document
Slice 3:	DP: Development Plan
	DRD: Documentation Requirement Document
	SWPARD : Software Product Assurance Requirement Document
	Proposal to ESA of modules to be developed
Slice 4:	developed and tested modules with documentation and test reports
Slice 5:	reviewing technical notes

Remarks:

- Slice 1: Additionally, within the context of the PDD in Slice 1, there will be made a set of Product Fact Sheets (PFS's) containing a detailed description of all applicable (input and output) products related to this contract.
- Slice 3: SWPARD: as agreed at the Kick-off meeting this document shall be replaced by a SWVP (Software Validation Plan).
- Slice 4: it was agreed at the Slice 4 working meeting not to deliver developed s/w of all the identified critical modules, but instead the output of Slice 4 shall consist of a list of identified critical modules and one example of a module developed along the lines of this contract
- Slice 5: Output technical notes containing review of documents are included on the basis of concrete requests by ESA and the availability of the documents.

Progress after PM3 up to the FM
Documentation:
Slice 1:

The PDD has been fully updated and completed and was brought as close as possible into harmonization with the ADD and SRD of Slice 2 (in the way that all products which are referred to in the ADD are contained and explained in the PDD).
The StRD was updated to bring it into its final stage (no major changes).

Slice 2:

The SRD was updated to bring it into its final stage (no major changes).
The ADD has been updated extensively following the remarks made at PM3 and the requirements of the SoW as it was discussed at the Slice 0 management meeting. ESA has reviewed the first release of the ADD (review dd. 10 May 2002), and many of the comments of this review have been implemented in the final version of the ADD.

Slice 3:

The DP and DRD have been updated and finalized (no major changes).
The SWVP has been fully compiled according to the discussion at PM3.

A list of critical modules was drafted and delivered as input for Slice 4.

Slice 4:
The report for this Slice has been rewritten after a dedicated working meeting on this Slice. As an example, a module for frame transformation (from Task 3) has been developed and included in the report.

Slice 5:
A review was written of 7 documents from the PDR package.

Meetings.
Some extra "working meetings" in smaller groups have taken place between PM3 and FM. At two of these meetings (on Slice 4 in Copenhagen and on Slice 0 at Estec) an ESA representative (R. Floberghagen) was present. Other meetings on specific tasks have been held.

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Slice 2:

Some remarks to ESA's ADD Review

Compiled by: Th.Gruber
IAPG

Reference document:
GOCE Preparation of GOCE Level 1 to Level 2 Data Processing – Review of Architectural Design Document, Prepared by R.Floberghagen, Doc.no. TBD, Issue 1.0, 10 May 2002

Task 5.1: Comments and documentation of changes in the ADD
GRGS and GFZ

4.4.1: Task 5.1: A: Direct method

1. *Abstract: Applying to all methods …*
   Max. degree and order of the recovered field : 300 is OK. I think that, if everything goes well, we will indeed compute the partials (and normal eq.) up to 300*300. Whether the final model will be a full 300*300 solution is another question, and I agree that it could be left to another stage of decision - why not to the Task 6 evaluation group, it being provided with full and various truncated solutions ?

2. *The common mode parameters …*
   If the reduced dynamic (or kinematic) orbit is well computed, the dynamic orbit adjusted on the (x,y,z) GOCE ephemeris should not be better, at most of equal quality if the gravity field and the DFACS data + residual surface accelerations handling is very well done. This I doubt. However, I think that the common mode parameters (biases, scale factors) will be computed together with the adjusted dynamical orbit, as a way to check the consistency of the whole modeling.

3. *Regularisation …*
   This has not been discussed to a full extent and certainly not to reaching a consensus. I think that this is not crucial at this stage : it comes in only at the final resolution step, and the regularizing scheme (and law) can be easily varied for producing several intermediate solutions which can be evaluated within task 5.1 itself.

4. *Output: More products ...*
   The quality parameters for the GOCE gravity field products are independently determined in task 6.1 and 6.2. There is no need to do this job already as part of task 5.1. Some internal quality parameters, which are output of the processing in task 5.1 can be delivered as part of the product. Also derived products are part of the direct solution (as indicated in the output table). The direct gravity field is not only the spherical harmonic series, but includes also derived quantities as well as the variance/co-variances of all resulting gravity field quantities.

Task 5.2: Comments and documentation of changes in the ADD
IAPG, DEOS and TUG

4.4.2: Task 5.2: A: Time-wise approach

1. *Abstract: ESA believes that ...*
   The quality parameters for the GOCE gravity field products are independently determined in task 6.1 and 6.2. There is no need to do this job already as part of task 5.2. Some internal quality parameters, which are output of the processing in task 5.2 can be delivered as part of the product. Also derived products are part of the time-wise product (as indicated in the output table). The time-wise gravity field is not only the spherical harmonic series, but includes also derived quantities as well as the variance/co-variances of all resulting gravity field quantities.

2. *Previous about ...*
   Corrected.

3. *It is assumed that ...*
   Explanation adopted.

4. *Does the polar gap situation ...*
   The polar gap has no direct consequence for the Task 5.2 architecture. Indirectly it is addressed by the regularisation. A corresponding explanation is included in the ADD.

5. *Flowchart/Definition*
   - If we go for the best gravity solution, we depend on the availability of the GOCE precise orbit provided by Task 4.
   - QL analysis will be based on the rapid science orbit.
   - Corresponding clarification is included in the ADD.

6. *SST observations ...*
   The formulation in the ADD was confusing in the sense that we used the term reference (nominal) orbit, which has a different meaning in Task 4. We now refer to it as a priori orbit, computed with an a priori gravity field model. This a priori orbit contains the full error caused by gravity field model uncertainties. Thus, nominally the difference between the a priori orbit and the reference orbit of Task 4 reflects the gravity field model error. The generation of the a priori is an intrinsic job of the Task 5.2 SST solver and thus will be done in the framework of 5.2. A corresponding explanation is included in the ADD.

The latency of the precise orbit and the follow-on time-wise gravity field model were harmonized in the SRD. The precise orbit will be available within 2 months after data release and the latency for the time-wise gravity model has been changed to 4 months in order to avoid conflicts there.

7. *Optimal regularisation ...*
   The work to define an optimal technique is still in progress (cf. DP, Slice 4 – critical modules). Several approaches (deterministic, stochastic) are under investigation, but a baseline approach has not yet been defined.

8. *Under 3., it is understood ...*
   It is possible to develop a specific interface sub-task outside of Task 5.2. However, Task 5.1 and 5.3 may deal with coloured noise in a different way (cf. Slice 4, critical modules). In this case the filter design could remain in the framework of Task 5.2.

9. *Under 3., a more elaborate discussion*
   Discussion is included in the ADD.

10. *Input:*
    DFACS and common mode accelerations are needed for the generation of the a priori orbit as discussed in item 6. Now included in the input table.

11. *Output:*
    The time-wise gravity model contains (as specified above) the mentioned drived products and errors.

12. *In general, it holds ...*
    The only official output will be a combined SGG+SST solution.

4.4.2: Task 5.2: B: SGG and SST Quick-Look Gravity Field Analysis

1. *Flow Chart/Definition*
   Corrected.

2. *Is one of the assumptions ...*
   The concept of the energy integral method is proved on the basis of several realistic simulations, demonstrating that e.g. errors in the DFACS can in principle be detected and identified. The ability to trace systematic errors mainly depends on the noise level of the (pseudo-)observations. Correspondingly, the quality of the feed-back, i.e. the statistical confidence level, is directly related to the accuracy of orbit velocity estimates. This issue is currently under investigation (cf. also DP).

3. *Is there simulation proof ...*
   Simulations on this subject are in an early state.

4. *What is the so-called ...*
   Brief explanation included in the ADD.

5. *Input:*
   Rapid science orbit has now been included in the PDD.

6. *Missing input ...*
   Missing input products are added in the ADD.

7. *Output:*
   The QL analysis is part of the Task 5.2 software package, which checks the input data on the level of the final product (harmonic coefficients) before they are included in the SST+SGG solution process. The interfaces and rules of the feed-back mechanism to the ESA Level 0 to 1 processor still have to be defined, which is considered as a processing management task in the follow-up work on QL-GFA.

Task 6.1: Comments and documentation of changes in the ADD
IAPG

4.5.1: Task 6.1: Internal evaluation

1. *Abstract: Gravity field evaluation ...*
   More details included

2. *Definition: POD evaluation: SLR ...*
   Explanation is included in the document.

3. *Defintion: Gravity field evaluation ...*
   Description is extended.

4. *Input: POD evaluation ...*
   Only 1 dynamic orbit is generated in 5.1, corrected.

5. *Input: DFACS actuation history ...*
   As now explained in the definition section the orbit is not recomputed, but only SLR residuals are computed. Therefore the DFACS history is not needed.

6. *Input. Gravity field evaluation ...*
   As mentioned in the comments to tasks 5.1 and 5.2, we define a gravity field product as a set of the gravity field spherical harmonic series, the derived geoid heights and gravity anomalies grids and also the coefficient and propagated geoid height and gravity anomalies variances and co-variances. This is all behind one product identifier. If one product identifier for one single data set would be defined, a huge amount of additional products would appear. We think that for the moment it is sufficient to identify one product, which contains all sub-products.

7. *Constants: ...*
   Corrected.

8. *Output: Gravity field evaluation: ...*

From the error statistics as output of task 6.1 it can not be decided which of the models is the best solution. The final quality assessment can only be done by combination of the internal (task 6.1) and external (task 6.2) evaluation. Therefore it makes no sense to define here a decision tree for the internal evaluation.

Task 6.2: Comments and documentation of changes in the ADD
IAPG

4.5.2: Task 6.2: Internal evaluation

1. *Abstract: Development effort ...*
   Done

2. *Abstract: Orbital test procedures ...*
   The orbital test procedures are different for orbit and gravity field evaluation.
   For orbits evaluation, direct comparisons of the orbits are performed. To include the possibility of an external orbit evaluation (as addition to task 6.1), orbits from other investigators are included. We don't think that an additional official interface has to implemented for this, because various groups are computing orbits regularly and exchange them for comparisons. This can be done in the framework of scientific cooperation. For example in the IGS LEO group orbits for CHAMP from more than 10 groups are compared on a systematic base.
   For gravity field evaluation, orbits for various satellites are computed and compared in terms of residuals. This gives an estimate how good a gravity field model is for a specific orbit configuration. In summary of all satellites a good overview for the quality of the long wavelengths can be reached.

3. *Abstract: Surface/airborne ...*
   For the test procedures all available external surface test data sets should be used. There are no plans to run specific test campaigns in the framework of task 6.2. But such campaigns would be, without doubt, valuable for the external calibration (see task 3.1) and then could also be used for the external evaluation.

4. *Abstract: Crossover differences ...*
   Yes, this statement is absolutely true. Therefore altimeter test procedures are included in task 6.2.

5. *Flow Chart:*
   As mentioned, interfaces to all these data sets shall be implemented during the next stage of the EGG-C development.

6. *Definition: Oceanographic expertise ...*
   A close link between task 8 and the external evaluation has to be established. Therefore it is foreseen that one group should be active in task 6.2 and task 8 in order to use the established interfaces most efficiently.

7. *Definition: Variance / co-variance evaluation ...*

A more detailed description is provided. It is part of the external evaluation, because external data sets have to be used for the error calibration.

Task 6.3: Comments and documentation of changes in the ADD
IAPG

4.5.3: Task 6.3: Internal evaluation

The chapter has been updated completely. Missing elements have been included and descriptions have been improved.

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

ESTEC Contract No. 14986/00/NL/DC

Slice 4

Final Report

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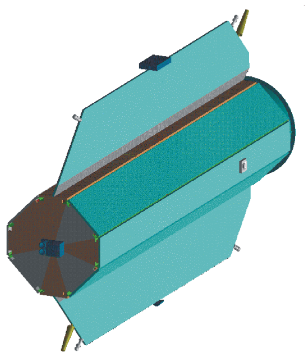

Revision 1.0
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1.Introduction

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

After some iterations we have arrive at the following definition:

A critical module is: 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:

a. is it software?
b. is it indispensable?
c. is it missing?
d. does its development depend on the availability of resources (manpower, time)?

If all answers are "yes" – then it is a Critical Module for Slice 4.

This gives 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 tasks for which we, at this moment in time, do not know what to do. 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.

2 .List of critical modules

A preliminary gross list of critical modules was suggested as part of the output of Slice 3. This list was tested against the criteria mentioned above. After this assessment we concluded that we arrive at the following, rather short list of critical modules:

Task 3.1:

a. GEOCOL: from spherical approximation to no approximation. Atmospheric corrections needed as well as correction for pole-tides.
b. estimation of scale factors in GEOCOL.

Task 3.2:

a. subroutine for the computation of temporal gravity corrections to the GOCE data from external data.

b. frame transformation: subroutine for the computation of SGG tensor in different frames (specifically from LORF to RERF)

Task 5.1:
a. processing of data with coloured noise.

Task 5.2:
a. filter strategies in the case of data gaps in the SGG measurement time series
b. optimal relative weighting algorithm for SGG and SST data.
c. algorithm for the automatic selection of the optimal regularization parameter.
d. incorporation of the estimation of non-geopotential parameters in the software
e. interface module between SST pre-processor and SGG/SST processor
f. pre-conditioner software module for the initialization of iterative procedure for normal equation solution.

Task 5.3:
a. processing of data with coloured noise.
b. error-propagation software module.

3. Conclusion

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.

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

1 Introduction

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 Development Plan Document and the System Requirements Document 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 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 of the FTM are:

- the transformed gradients (or actually corrections to the gradients, see the Architectural Design Document);
- the corresponding error time series;
- the total rotation matrix.

In the Software Validation Plan several tests for the 1st prototype are described and the results of these tests will be given in Section 4. First, however, the FTM algorithm is discussed in Section 2, and its implementation in Section 3.

2 Frame transformation algorithm

In general the rotation of the gravity gradient tensor given in one frame (e.g. LORF) to another frame (e.g. RERF) is: $V_{ij}(2) = RV_{ij}(1)R^T$, with the 'measured' gravity gradients $V_{ij}(1)$ and the total rotation matrix R. The latter is the product of several rotation matrices. According to requirement R-S-32-F-01 in the SRD the GOCE SGG observations shall be transformed from the LORF to the RERF. The full gravity gradient tensor shall be available as well as accurately enough satellite attitude and position information.

The actual/nominal LORF and RERF and the angles between them are defined as follows. The roll, pitch and yaw angles denote the small rotations from the actual to the nominal LORF. These angles can be determined with the star tracker observations. In the nominal LORF the x-axis is exactly in the velocity direction of the satellite and the z-axis is almost radially outwards, the y-axis is in the cross track direction and complements the right handed frame. The RERF is obtained by a rotation around the y-axis over the elevation angle that can be determined from the satellite tracking observations. The z-axis in the RERF is defined to be exactly radial.

The error of the transformed gradients $V_{ij}(2)$ depends on the error of the gradients $V_{ij}(1)$ and the error of the angles that determine R as well as the angles themselves. According to the SRD the accuracy of the gradients after frame transformation shall be compatible with the accuracy level of the original SGG measurements in the LORF (R-S-32-P-01). Since the rotation angles from the actual to the nominal LORF, as well as the rotation over the elevation angle from LORF to RERF are small, this requirement can be met (necessary condition, not sufficient).

The algorithm is therefore feeded with (see also the ADD, section 3.2.2):

- Gravity gradients (full tensor) at times *t*
- The angles to compute the total rotation matrix *R* at times *t*
    - *R* is the product of several rotation matrices which can be computed once the rotation angles and axes are known (based on star tracker and satellite tracking information)
- Error time series of the gravity gradients
- Error time series of the angles

Output of the algorithm is (see also the ADD, section 3.2.2):

- Corrections to the gradients at times *t*
- Rotation matrices at times *t*
- Error time series of the corrected (transformed) gradients

The Frame Transformation Algorithm now looks as follows:

Input (gravity gradients, angles + axes, error time series)
Initialization
Setup rotation matrices: 3 for attitude (actual to nominal LORF), 1 for elevation (LORF to RERF)
$R = R_2(el)R_1(roll)R_2(pitch)R_3(yaw)$
$V_{ij}(2) = R\ V_{ij}(1)\ R^T$
Corrections = $V_{ij}(2) - V_{ij}(1)$
Do error propagation
Output (gravity gradient corrections, rotation matrix R, error time series)

3 Implementation

The transformation part of the algorithm has been implemented and tested, whereas the error propagation part was not fully implemented since we did not (yet) simulate angular error time series. Eventually such data and other simulated data such as gravity gradients etc. will be computed with ESA's E2E simulator. When this data is made available the validation can be completed. The s/w is written in C++ and uses a matrix library for convenience.

4 Validation

4.1 Test data set

Since no simulated data from ESA's E2E simulator is at our disposal, we generated data ourselves. To validate the s/w a time series of gravity gradients in the LORF has been generated along a GOCE-like orbit with a length of 20 days and a sampling interval of 5 s. In addition, the elevation angles, to rotate from LORF to RERF, are generated. In the current simulation these angles are up to a tenth of a degree or less.

4.2 Direct and inverse transformation

A first s/w validation test is to compute gravity gradient corrections based on the simulated elevation angles. These corrections are added to the original gravity gradients and the gravity gradients in the RERF are obtained. With respect to these gradients corrections are computed based on the negative elevation angles. The sum of the former and the latter corrections should of course be zero.

Results:

The relative errors in the gravity gradients are at the 10^{-16} level, that is, computer round off. The only exception is V_{yy} which is errorless since the elevation rotation is around the y-axis. The elements of the two inverse rotation matrices are exactly equal (with a negative sign for the sin elements) for the whole time series.

4.3 Identity test

A second s/w validation test is to rotate the gradients around the z, y and x-axis with an angle of 90, -90 and 180 degrees respectively. The total rotation matrix is

$$R_1(180)R_2(-90)R_3(90) = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

Then the original x-axis becomes the z-axis, the y-axis the x-axis and the z-axis the y-axis.

Results:

The s/w produces exactly 1 for the elements of the total rotation matrix that should be 1, the other elements are zero up to computer round off error.

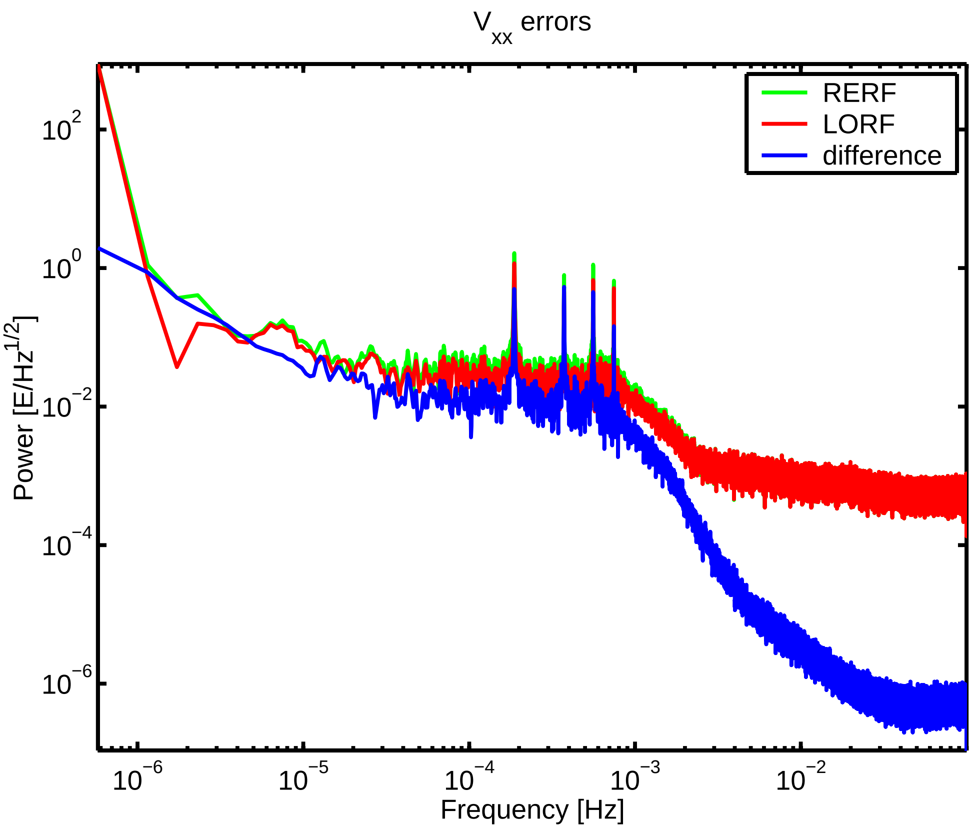
4.4 Error transformation

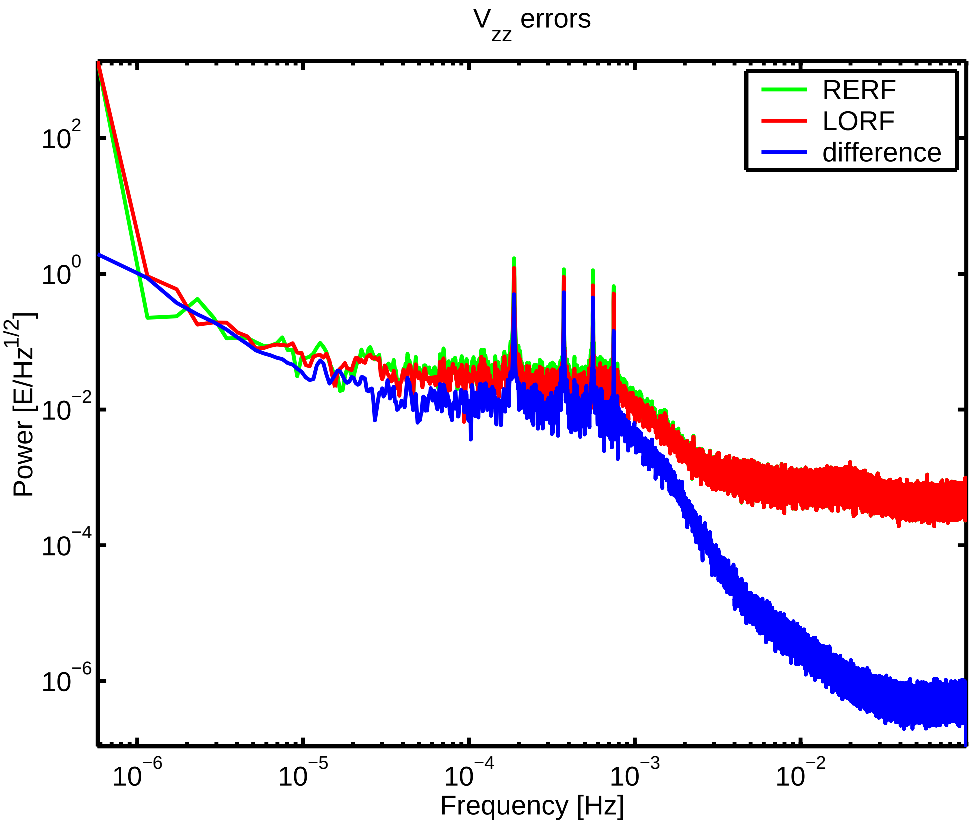
Time series of gravity gradient errors in the LORF have been simulated with the SRON E2E instrument simulator. These errors are rather realistic. The rotation over the elevation angle to compute gravity gradient corrections in the RERF shall not introduce much larger gravity gradient errors (SRD, requirement R-S-32-P-01). Note that errors in the angles are not yet considered.

Corrections to the simulated exact gravity gradients in the LORF are computed as well as corrections to the gradients with errors. With these corrections two time series of gravity gradients in the RERF are obtained. One is errorless, the other is subject to simulated errors. As said before, the difference between these two time series in the RERF shall be comparable to the difference in the LORF for V_{xx}, V_{yy}, and V_{zz}.

Results:

The error PSD's for V_{xx} and V_{zz} are shown in the figures. The gravity gradient errors in the LORF as well as the RERF are almost equal. Especially in the MBW there is no significant difference. In blue the errors due to the rotation are shown, these are the differences between the green and the red curve. Since the rotation for the elevation is around the y-axis, V_{yy} is the same in LORF and RERF and so are the corresponding error PSD's (not shown).


V xx errors
RERF
LORF
difference
Power [E/Hz^1/2]
10^2
10^0
10^-2
10^-4
10^-6
10^-6
10^-5
10^-4
10^-3
10^-2
Frequency [Hz]


V zz errors
RERF
LORF
difference
Power [E/Hz^1/2]
10^2
10^0
10^-2
10^-4
10^-6
10^-6
10^-5
10^-4
10^-3
10^-2
Frequency [Hz]

5 Summary

A first prototype of the Frame Transformation Algorithm 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 s/w is validated with a direct and inverse transformation between LORF and RERF. The gravity gradients are affected by computer round off but are otherwise correct. A second s/w 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.

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

ESTEC Contract No. 14986/00/NL/DC

Slice 5

Final Report

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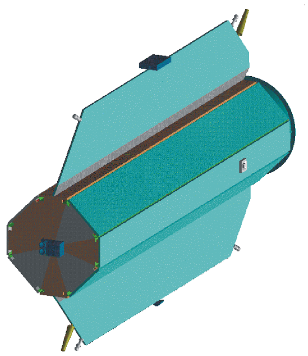

Revision 1.0
17. May 2002

Slice 5: Support activities for end-to-end simulator, level 0 to level 1 processing and for the definition of the satellite calibration and characterization

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. Our comments and questions are listed below.

GOCE System Requirements Document

In the context of this Slice 5 it appeared to be worthwhile to have the EGG-c's opinion on the GOCE System Requirements Document (SRD) for Phase B/C/D/E1 [RD1]. 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. The following analysis of the SRD is merely a collection of remarks addressing only a more or less arbitrary subset of the requirements that are of interest from the EGG-c viewpoint.

Reference Documents:

[RD1] GOCE System Requirements Document (SRD) for Phase B/C/D/E1, prepared by: ESA GOCE Team, Doc.No. GO-RS-ESA-SY-0002, Issue 3, 20 November 2001
[RD2] ESA comments to the midterm study report *Preparation of GOCE Level 1 to Level 2 Data Processing*, draft version, compiled by Rune Floberghagen, November 2001

3.1 Scientific Objectives
This requirement states that one of the objectives of GOCE is to provide regional models of the Earth's gravity field. This requirement therefore relates directly to Task 9 of the EGG-c level 1 to level 2 processing study, and to the discussion on the role of regional solutions, see also [RD2]. So the question should not be whether regional solutions should be included/addressed in the level 2 processing, but should focus only on the "how" of this inclusion.

4.4 Reference frames
Requirement 4.4.1 – R2 lists a number of applicable reference frames. The naming of these frames, however, does not exactly correspond to the names of the subsequent sections 4.4.2 till 4.4.9. This is confusing.

4.4.6 Gradiometer Reference Frame
In requirement 4.4.6 – R1 this is called the "Gradiometer Alignment Reference Frame. Which name to be preferred? Furthermore, in the definition of this frame reference is made to the axes X-GR-ReF etc., the latter which are not defined yet.

4.4.7 Local Orbital Reference Frame
The x-axis of this frame points in the direction of the velocity vector. Should it be the "instantaneous" velocity vector, or the reconstituted velocity vector?

4.4.9 Units Coordinate Frame

What is the role of this frame? In the definition it is referred to the "Unit Inertial Reference Frame". What frame is this?

5.2.2.1 General Orbit Requirements

Requirement 5.2.2.1 – R1 states that "The orbit track repeat period shall be no less than 2 months." Obviously there is no requirement for the maximum length of the repeat, or not even for having a repeat orbit at all. In view of the level 2 processing strategies, in principle, a repeat orbit is not a key issue. However, it may help a lot when the issue of a repeat orbit is clarified. This is not only important for the level 2 processing strategies which may or may not exploit the benefits of having a repeat orbit, but also in view of the discussion on the role of regional solutions (resolution!) and level 2 gravity gradients.

5.2.3.3 Duration of Payload Calibration Phases

The requirement states that the duration of the POP1 shall be shorter than 1.5 months and that of POP2 shorter than 2 weeks. However, in requirement 7.1.2 – R4, a possible re-calibration is limited to one day. How do these durations relate?

5.2.4.5 HOP

Requirement 5.2.4.5.3.1 – R1 states that orbit control during a possible suspension of DFC operation, shall be performed using the information provided by the SST receiver. In what way shall this be done? By using the navigation solution or in another manner?

7.1.1 Satellite Gravity Gradiometry Performance Requirement

These requirements are very important to the EGG-c and should be read and taken into account carefully.

Following requirement 7.1.1 – R4 we see that only for the three diagonal elements of the gravity gradient tensor there is a requirement on the error level of 4 mE/sqrt(Hz) in the MBW in the spacecraft reference frame (and according to R5 also in the LORF). The accuracy of the off-diagonals, so also for the xz-component, is "only" required to be consistent with the error of the diagonal ones.

Requirement 7.1.1 – R6 gives a requirement on the transformation from the LORF to an Earth-fixed reference frame. This is important in the discussion on geo-located gradients and also for regional collocation studies.

Requirement 7.1.1 – R12 states the sampling rate of 1 Hz for all data needed for recovery of the gradiometric performance. Since the gradiometric performance depends on the POD (or at least the performance of the orbit reconstruction and gradiometric inversion are related) does this mean that, implicitly, there is the same requirement for the SST observations?

7.1.1.3 Gradiometer Functional Requirements

R8 states that the gradiometer shall provide the non-gravitational accelerations to satisfy the POD and gravity field retrieval needs. Does this mean that, if we can convincingly argue that for POD we need the common-mode accelerations at e.g. 0.1 Hz, that they will be provided!?

7.1.2 Gradiometric Calibration

R3: "a possible re-calibration shall be required not more often than once a month." Since such a re-calibration takes not longer than 1 day (R4), we may have the situation that one repeat cycle of 2 months (see above) is interrupted by a 1 day calibration (data gaps). This may be not a favorable situation for certain level 2 methods.

7.2.1.2 Receiver configuration
This requirement states that multipath contribution to the total error is negligible. This might be important to take into account in orbit determination simulations.

8.1 General satellite requirements
R2: "the satellite design shall avoid any source of vibrations (switches, relays, etc.) which conflict during measurement phases with the scientific requirements." Does it mean that problems as we see now with Champ will not be present?
Also: requirement 8.4.1 – R4 states that the characteristics of the thrusters shall not cause any deleterious effects on the s/c or the payload. Does this also imply non interference of the measurements by the thrusters? And again: 8.5.1 – R3 states that also the DFACS shall not introduce disturbances.

8.2.5 Ground Alignment Requirements
R4 may be important in view of the accuracy of the internal calibration.

10 Level 0 and level 1a and 1b payload data processing
10 – R2: a RINEX format for gradients is mentioned. This does not make sense. A new format for gradients has to be devised. Also: gradients in the J2000 frame are mentioned, but this also does not make sense.

Review of Alenia documents

As part of Slice 5 seven Alenia documents have been reviewed on ESA's request. The documents deal with the GPS and gradiometer ground processing, the gradiometer calibration and the performance requirements and budgets for the gradiometric mission.

Reference Documents:

[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.

Gradiometer ground processing [RD4, RD7, RD8]

The three documents describe the algorithms specification, the algorithms documentation, and the analysis respectively. What follows are mostly minor comments.

[RD4]: Gradiometer ground processing algorithms specifications

Page 4, section 1.2: Relocate the word ‘orbit’ in the Level 1b description between ‘the’ and ‘consisting’. With respect to the reference frames, see section 3 of this review.

Page 6, 4th paragraph: ‘Actually the GGT expressed in the GGT’. The 2nd GGT should be GRF. First bullet: ‘row’ should be ‘raw’. Above 1st bullet ‘can be are’ should be ‘are’.

Page 7: If external gravity field information is used in the computation of the calibration matrices, then this should be included in the flow chart.

Page 12, section 4.3.1.1, 2nd item: remove one ‘that’.

[RD7]: Gradiometer ground processing algorithms documentation

Page 29, section 6.2.2: ‘the following inputs’ should be ‘the following output’.

Page 31: Between E.3-2 and E.3-3 there seem to be missing equations.

[RD8]: Gradiometer ground processing analysis

Page 5, section 3.1.3: One of the limiting factors is the accuracy by which the reference harmonics of the GGT components can be known before the GOCE mission. Since the orbit is not known a priori, the reference harmonics are unknown before the mission. See also section 4 of this review.

Page 14, section 3.2.2: Instead of the GGT the differential accelerations are used. It makes sense as a first step, but due to the processing the GGT will be contaminated with more errors than the differential accelerations (see section 4 of this review). The analysis should therefore be repeated in a more realistic setting.

Page 17, section 4.1: It is stated that ‘the results are not optimal due to the heuristic approach’. ‘Suitable analysis […] is required to ensure the best performance of the algorithm’. It is unclear what this suitable analysis is.

Page 20: The reason for the higher than the specifications angular acceleration noise are the uncertainties on the noise level about the less sensitive axis of the accelerometer (page 18). The requirements of the rate reconstruction are not met below the MBW. If the noise increase from page 18 is reasonable then this is not an excuse for not meeting the requirements.

GPS receiver ground processing algorithms specifications [RD5]

Page 5, section 1.2: How is CDMU time defined?

Page 9: URA values, which are part of the optional external data, are not defined in the text or in the list of abbreviations in section 10.

Page 10: Text provided in figure 1 is hardly readable.

Page 11, section 4.1.2: In which time reference system is the time stamp T_Q given?

Page 14, section 5.1: Apparently, a list of specified uncertainties is missing from the section.

Page 14, section 5.3: The first sentence in this section apparently aims to specify which earth fixed frame should be used, while the abbreviation given (ITRF-XX) stands for a family of reference frames.

Page 14, section 5.5: The description of how an acceptance window will be realized for outlier rejection is rather confusing.

Page 15, section 5.5: The list of outputs produced by the filter routine contains a smoothed data vector. Are the elements of this vector the raw data elements without the outliers, or are the elements of this vector computed from the last (current) interpolating polynomial?

Page 16: The equation given for $\rho_{iono,\ corrected}$ subtracts variables with different units (meters and seconds).

Page 17, section 5.10: Why should the absolute delay measurement not be added to the receiver time before the navigation solution? During the navigation solution it will become part of the estimated receiver clock offset and should therefore not influence the accuracy.

Page 20, section 5.17: The meaning of the term 'link budget' is not clear in this context and should be explained.

Page 21, section 5.18: Item a) in the list mentions two different estimates of the S/N ratio that can be compared. It is not clear which of the two S/N estimates is referred to in item b).

Page 23, section 6.3: The meaning of the last sentence in section 6.3 is not clear.

General remark: All sum and integral signs are missing from the equations (e.g. in the voltage-to-temperature conversion formula of section 5.4 or in the formulas for the ionospheric phase and group delays on page 16). Some of the formulas contain incomplete closing brackets.

Performance requirements and begets for the gradiometric mission [RD6]

Introduction

In this section we will review [RD6]. Sections 3.2 and 3.3 contain our remarks and concerns with respect to reference frames and requirements + error budgets respectively. In Section 3.4 errors in, or remarks on, the equations are listed, and in Section 3.5 we have made a list of other typos and missing abbreviations. Finally, Section 3.6 contains remarks that do not fit in one of the above Sections.

Reference frames

On page 9, the gradiometric measurements are said to be “reported” to the EFRF. It is unclear what this means. The GPS orbits from the IGS are given in the ITRF2000 (but the broadcast ephemeris in the WGS84). In the last sentence of this paragraph, the last but one ‘EFRF’ has to be replaced by ITRF2000.

The *satellite frame* in which the gravity gradients are said to be given is not defined (Section 3.5, page 24). Moreover, it is unlikely that it is useful to compute gravity gradients in these different frames. J2000 will for example not be very useful. Furthermore, e.g. in the ITRF, all gradients have a strongly reduced accuracy and no transformation parameter helps to recover the original high accuracies! In addition, it makes less sense to transform the gradients in many systems before the temporal variations have been removed?

It is unclear in what reference frame eq. (4.1) and the elements of [U] are given on page 25. Is it the OAGRF for eq.(4.1) and the GRF for [U]?

From the 2nd sentence of Section 4.5, page 41, one could get the impression that the Earth's gravity field can be reconstructed directly from the tensor components in the LORF. This is not necessarily true, an additional transformation to an Earth-fixed frame is required. Furthermore, it seems that the introduction of the GARF makes the GRF obsolete. The three OAGRF's are directly linked to the GARF.

Requirements and error budget

The expected performance of the gradiometer instrument, and the given MBW (which is the result of a trade-off between manufacturing capabilities and mission goals), compared to SST leads to a crossover around degree L=15, not the other way around (pages 8 and 15).

If the gradients would also be delivered in an Earth-fixed frame (apart from the LORF), as stated on page 9, then there is no requirement for the precision in this frame.

On page 11, the power from a continuous integral is directly compared with the discrete power. These two, however, cannot be compared directly. The computation of a PSD (continuous) from discrete points is still subject to discussion. It should be kept in mind that the values of Table 3.3-1 are computed from a simulated time-series along a simulated repeat orbit with 5 sec sampling. This sampling, the repeat condition a.o. influence the PSD computation as it is performed here. As an example, in the MBW the differences in the gradients between OSU91A and, e.g. EGM96, is of the order of the signal itself, which indicates the "roughness" of the values in the table. Any requirement, therefore, based on the values in this Table should be interpreted with care.

On page 28, in the 2nd and 3rd line of eq. (4.6) the acceleration differences are given in different reference frames (in principle), namely 3 different OAGRF's. So when computing the $\dot{\omega}$'s you mix-up quantities from different reference frames, leading to a (possible) error which is not discussed here. Also on page 37 in eq. (4.19) readings from different OAGRF's are combined to determine $\dot{\omega}$. The alignment of two OAGRF's with respect to each other determines the accuracy of this measurement. This is not addressed at in the subsequent error propagation analysis. In particular it is noted that for $\hat{\omega}_x$ and $\hat{\omega}_z$, measurements from less-sensitive accelerometer axes are used, which have higher instrumental noise.

The vector D is to be estimated from the common-mode (page 28, 29). To this end it would be useful that the term with the vector C is neglible. It turns out that to first order the error due to C_X is zero. This is however not true for C_Y and C_Z. It is unclear how large these error terms are compared to D_Y and D_Z which are to be estimated.

On page 37: How is the error propagation in step N.5 performed? (Not discussed here.) Furthermore, in step N.6 the $\hat{U}_{ii}$ are said to be given in the GRF, but this is only approximately true.

At the bottom half of page 42 it is stated that "it is not sufficient to know precisely the rotation angles between the two frames [the GARF and the LORF], but these angles must also be small < 10^{-3} rad)." This is true, but the requirement is too relaxed. Linearisation of (4.36) and subsequent error propagation shows that an angle of 1.3 x 10^{-4} rad gives an error of 1 mE^2/Hz in the diagonal components due to the large uncertainty of the off-diagonal components. 10^{-3} rad would give an error of 60 mE^2/Hz in the diagonal components, which is unacceptable.

Page 43, item d: The GGT is assumed equal in the 3 OAGRF's. This is actually not a requirement, but it suggests that there is not problem.

Section 5.2, 2nd par., last sentence: “can be considered uncorrelated”. Is this proven?

Page 62, Fig: 6-1: How is the stability of the calibration parameters between two calibration phases controlled? How is decided, when the next calibration phase has to take place?

Are there requirements for the calibration parameters below the MBW? How are these met and controlled?

Page 69. The angular velocities $\underline{\hat{\omega}}$ are derived from integration of the angular accelerations $\underline{\hat{\dot{\omega}}}$. Requirements on $\delta\underline{\hat{\omega}}$ hence translate into requirements on the measurement accuracy $\delta\underline{\hat{\dot{\omega}}}$. These are not discussed. The requirements on $\delta\underline{\hat{\dot{\omega}}}$ may derived from

$$\delta\underline{\hat{\dot{\omega}}}(f) = 2\pi f \delta\underline{\hat{\omega}}(f)$$

Taking $\hat{\dot{\omega}}_X^W$ as an example, using the values from Table 6.3-1, we have

$$\delta\hat{\dot{\omega}}_X^W(f) < 2\pi f 10^{-8}$$

The most stringent requirement is set by the frequency $f = 5 \cdot 10^{-3}$ Hz, the lower end of the MBW, which gives

$$\delta\hat{\dot{\omega}}_X^W < 3 \cdot 10^{-10} \text{ rad/s}^2$$

Has it been shown that this accuracy can be obtained, despite the higher intrinsic noise of the less-sensitive axis readouts, the misalignments between two OAGRF's, and the higher non -linearity of the off-line sensitive axis?

Page 87, table 7.3-1: The larger scale factor instability can not be the only reason for the deviations of their simulated error values from the requirements. E.g. the projection of high frequency noise should not depend on the scale factor stability; also not the coupling with the gravity gradient tensor. The reason for the latter effect might be, that the selection of the along track orientation increases, e.g., U_{XZ} which vice versa couples in the others (TBC).

A detailed discussion of Table 7.6-1 is missing, especially because the simulation shows, that the requirements are not kept. The reasons for the differences have clearly to be identified!

Equations

Just below eq. (4.3), page 28, in the definition of *S* and *M* for the common and differential-mode, the - should be + for the common-mode. The first subscript of the first *M* should be a *c*. In equation (4.6), first line, the 2nd term, denominator: L_X should be L_Y.

In (4.15) on page 30, all quadratic terms (like $[dK]_i$ $[dR]_i$) are neglected except for *K2*. A priori this seems to be inconsistent, so it should be explained that this is allowed due to knowledge on the size of all terms.

In the right-hand side matrix $[dM]_{c,ij}$, page 31, the (3,2)-element should have the index *c* (and not *d*).

Are the elements of the *dM* matrices, page 36, really much smaller than 1? The scale factor is 0.01. A test in MATLAB shows that error in the inverse is of the order 10^{-4} for the diagonal elements and 10^{-4} – 10^{-6} for the other elements.

In step N.4, page 37, the common accelerations should be removed (not needed). The vector notation of the differential mode in (4.19) is incorrect. Below (4.19) the subscripts for the OAG's should be 1, 2, 3, instead of 1, 1, 1.

In step N.6 remove the angular accelerations and add the recovered differential accelerations.

In equation (4.27), page 38, the starting point is the estimated U_{XX} gradient.

On page 41, in eq. (4.34), third line, the subscript should be 3 not 2.

Page 42, equ. (4.36): first one has restricted to the linear case (see formula after (4.35)), but in (4.36) quadratic/non-linear terms enter, but not all! That means, (4.36) is not complete, not consistent. Therefore also Laplace equation seems not valid anymore, if used with (4.36), which can never be true. One has to keep the linear approximation or to use the full quadratic level! In the 2nd line of eq. (4.36) the first U_{XZ} should be U_{XY}.

On page 51 eq. (5.1.6): it is $\delta U^{W}_{XX-I.6}$;e q. (5.2.2): top line, right-hand-side, 2nd term: leave out one (.

On page 52/53, C.3: In the derivation the terms with $\underline{C}, \underline{\dot{C}}, \underline{\ddot{C}}$ are left out without notice. In the 4th line of the equation in par.C.3 (starting with =) there should be a factor 2 in front of the term starting with $K2_{d,14,X}$. In the line starting with $\delta\widetilde{U}^{W}_{XX-C.3}$ (and following lines) the ˜ are left out unnoticed.

Remove the ˜ above the *dM* under the root, eq. (5.2.10).

Eq. (5.1.11) should be (5.2.11).

Typos and abbreviations

page 7 In [AD 1] *20001* should be: *2001*
page 8 spherical *harmonicas* should be: spherical *harmonics*
page 11 a period of 10 *orbits* should be a period of 10 *revolutions*
page 24 *either* ultra-sensitive and less sensitive should be: *both* ultra-sensitive and less sensitive
page 33 The bottom table should have a *d* in front of the *M*.
page 36 The inverses of *theses* should be: The inverses of *these*
page 41 *the alignment the individual* should be *the alignment of the individual*
page 42 *though* should be: *through*
page 49 intrinsically *produce* should be intrinsically *produced*
page 55 1st line: noise *and biases are* should be noise *is*.
Section 5.1.3, 1st line *Instrument* should be: *Satellite*.
page 56 first line: *relative* should be: *respective*.

On page 94 the following abbreviations are not listed: LTOAN, DOF, SARF, SSARF, ACF.

Further remarks

The accelerometer biases are not considered in the documents. Are these not part of the calibration parameters?

The angular accelerations as observed by the accelerometers are not considered nor used in the documents. Are these observations not useful to derive the accelerations about the three GRF axes (Equation (4.19), p. 37)?

Are all time series given in 1/0.999360 frequency as written in ESA's document?

It would be helpful, if a summary would be provided indicating the most critical items.

In Figure 3-1 on page 8 of the gravity anomaly, the vector g_r is in the approximate point, which not necessarily has to be on the ellipsoid according to the definition.

Page 8, last paragraph: the sampling distance in orbit (78 km) does not constrain the maximum spatial resolution on Earth surface in that way as it is described. A sampling frequency of 0.1 s would allow to resolve the gravity field up to 35 km (max. resol.), in principle.

Page 9: is the nominal eccentricity really $e=4.5*10^{-3}$? Wasn't the baseline maximum value up to now about $e=1*10^{-3}$? Is the new value somehow driven by orbit dynamics?

On page 15, bottom of the page, the phrase *One of the ultra sensitive axes of the two accelerometers forming a OAG* ... could be misinterpreted as if only one out of four of the ultra sensitive axes is nominally parallel to the OAG baseline. *One of the two ultra sensitve axes of each of the two accelerometers forming a OAG* ... is unambiguous.

Page 26: Is the additional magnetic effect the Lorentz force? How are the magnetic parameters obtained in orbit? From a model or by measurement?

Section 4.3 (p36-38) does not coincide with ESA's GOCE Science and Ancillary Products Description:

- no common-mode accelerations on level 0 in Alenia's description (makes sense)
- no common-mode accelerations on level 1a, only extraction of control voltages and arrangement in ordered time series in Alenia's description (makes sense), but what means 'ordered time series'? Level 0 should already be sorted.
- no conversion to engineering units (decoding) in Alenia's case on level 1a
- Level 1a to 1b includes the following products:
  1. decoding (result: measured acceleration per instrument, no product in ESA's doc.)
  2. computation of common mode and differential mode accelerations (differential mode accelerations are not a product with ESA), (common mode angular accelerations are a product with ESA but not with Alenia)
  3. calibration of (2), excluding bias
  4. computation of angular accelerations about GRF axes from differential mode accelerations and baseline lengths (not a product with ESA)
  5. computation of angular rates from (4) and quaternions (o.k., foreseen also with ESA)
  6. computation of 6 tensor components using the results above (o.k)

Page 56, S.3: still TBD?

Gradiometer calibration [RD3, RD9]

On-orbit calibration without satellite shaking

Our major questions and concerns are related to the determination of elements of the Calibration Matrix using existing gravity field information. [RD9] is used as prime reference below.

Concerns and questions about the procedure

On page 38 it is stated that "Provided that these GGT harmonic components […] can be accurately known before the GOCE mission, … ``. In fact, some of the coefficients of a spherical harmonic expansion of the gravitational potential are accurately known before the GOCE mission but not the GGT components themselves. To compute the GGT components it is necessary to have knowledge about the actual GOCE orbit. It should be analyzed whether the on-orbit navigation solution is accurate enough. An orbit error of 10 m, for example, yields an error of 0.01 E in U_{ZZ}, 1 m orbit error corresponds to 1 mE (roughly). Maybe a precise orbit is needed (cm level) and this will only be available with a time delay of several weeks or months (TBC). Is this a problem?

On page 39 and 40 it is explained that least-squares is not considered due to the fact that the partial derivatives can only be computed numerically. This is, however, not a principle problem.

Unfortunately, we are unfamiliar with the genetic algorithm. Does the genetic algorithm always converge or is there a probability that no solution will be found?

To arrive at gravity gradients the differential accelerations are differenced, integrated, squared and so on. The relation between gravity gradients and differential accelerations is therefore rather complicated and non-linear. Furthermore, the differential accelerations are affected by scale factor errors, mis-alignments and couplings. These errors will propagate to the gravity gradients and in addition the accelerometer mis-positioning and the non-orthogonality of the gradiometer arms will show up in the gravity gradients (but not in the common or differential accelerations). It is therefore possible that in the proposed iterative procedure the updated elements of the Calibration Matrix absorb these and other errors. Even if there is convergence then it is not guaranteed beforehand that the correct Calibration Matrix elements are obtained. Simulations could justify the approach.

The largest peaks in the signal spectrum of the gravity gradients are at 1 and 2 cpr (cycles per revolution). It has to be noted that although J_0 and J_2 (central term and flattening of the Earth's gravity field) are the main contributors to 1 and 2 cpr, other harmonic coefficients contribute as well. The external calibration of the gravity gradients using existing global gravity field models shows that many more coefficients are needed for accurate external calibration results. Moreover, these frequencies are corrupted by a lot of other errors (from drag, from orbit determination, …). Furthermore, 1 and 2 cpr are below MBW. Are the derived Calibration Matrix elements valid in the MBW? Specifically, are the scale factors frequency independent?

What should be the calibration procedure if this method fails?

Consequences for the external calibration

If existing gravity field information is really needed for the on-orbit calibration then this effects the external calibration procedure because existing gravity field information is needed for the external calibration as well. Specifically, existing or near future global gravity field models seem to be suited to recover gravity gradients systematic errors below the MBW (based on simulations with the SRON E2E simulator). Such gravity field information should be independent of the gravity gradients. This condition is violated if the external gravity field information for the on-orbit and external calibration are the same.

So if existing gravity field information is needed to meet the requirements, then this may cause a problem in the level 1 – level 2 processing. With respect to the external calibration it would be better not to use external gravity field information for the on-orbit calibration. If this cannot be avoided, then maybe we should consider an integration of the on-orbit and external calibration. For example, use global gravity field models to determine Calibration Matrix elements and remove systematic gravity gradient errors below the MBW. The gravity gradients could maybe validated using (independent) terrestrial gravity data. However, this needs to be discussed.

Further remarks

Section 3.3, 1st paragraph. Noise SD of 2.2 E/$Hz^{1/2}$. Shouldn't that be mE?

General remark on measurement accuracy, for example Table 3.3-2: These are 3 σ values but this only becomes clear in Section 5. It would be nice to have a more explicit remark on this when the Tables are discussed.

What are the consequences, if the calibration values obtained on ground are not more valid after launch? Is it possible to check these values in orbit? What are the consequences if the behavior of one (or more) thrusters is not appropriate?

What is the error if the shaking generates no clean sine wave, but shows 'abrupt' jumps when the direction changes? Is it critical?

Why is the determination of the k2 parameters and that of the other calibration parameters separated? Are there cross couplings? Is it not possible to use the same calibration signal to adjust some parameters simultaneously?

Does not the dynamic range of the accelerometers change if the k2 parameters are changed?

How well can the amplitudes, generated by the calibration signal at a certain frequency, be extracted, if the noise in reality is higher than assumed?

The shaking duration for several calibration parameters should be quite long to achieve the accuracy aimed for. The compromise is to restrict oneself to 4 orbits (22000 s) and to use a second method for the remaining parameters? Is the selection of 4 orbits arbitrary? Nevertheless, is it realistic that a better performance of the DFACS and the thrusters is required in the calibration phase? Better than the nominal performance? In the beginning of the commissioning phase, where no instruments are calibrated and some sensors behave strange (see CHAMP).

Can it be assumed that the 2nd and follow-on calibration phases need less time than the first one, because the accuracy of the calibration parameters is then always better than at the first time (immediately after on-ground calibration)?

APPENDICES

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

ESTEC Contract No. 14986/00/NL/DC

Slice 1, Work Package 1

GOCE Products Definition Document (PDD)

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EGG-C

Compiled by:
Peter Schwintzer, GFZ Potsdam

Revision 1.0
16 May 2002

Contents

0. Scope

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

1. Introduction

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

- 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 only 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 mission's reference products 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 input for quality evaluation and 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) [10].

2. Product Identification ('Open points' are printed in grey colour)

This chapter identifies the products, which are required and generated by the European GOCE Gravity Consortium (EGG-C) for fulfilling its processing tasks. The list is compiled from the input of the Level 1-2 Study Team and harmonized with [4], the GOCE Architecture Design Document (ADD). The products' identification of levels 0 and 1 is based on ESA's Technical Note [9] and Alenias documents [6]-[8].

As this study deals with the level 1 to level 2 processing, the main focus is given to the identification of level 1B products as input and level 2 products as result. For completeness, also level 0 and level 1A products are reported. Each individual level 2 product is characterized in a Product Fact Sheet.

The individual products are labeled with an identifier specifying the product level, category, type and subtype:

GO-<nx>-<type>+<subtype> …

GO	–	GOCE mission
n	–	'1A', '1B', '2', resp. (product level)
x	–	nothing for core, 'v' for preparatory, 'i' for internal product, 'a' for ancillary data (category)
type	–	three capital letters, e.g. 'EGM' for Earth Gravity Model (product type)
subtype	–	character string characterizing content, processing, observation period, revision number etc.

The sequence of characters after the '+' character is used to discriminate between products of the same type but different content and to uniquely name later on each specific product file.

2.1 Level 0 Products

The Level 0 products consist of time-ordered raw data (telemetry packets) downlinked from the satellite.

<u>Science data</u>

• EGG electrode voltages (6x8) EGG time-stamping (S/C time) EGG engineering packets (EGG mode & configuration parameters, quadratic factor seetings) [Common-mode accelerations (in ESA's but not in Alenia's doc.)]	GO-0-SC+EGG
• SSTI phase observations (L1, L2) SSTI P code observations (L1, L2) SSTI C/A code observations (L1)	GO-0-SC+SST
• SSTI position & velocity in an inertial reference frame (raw navigation solution) SSTI position & velocity in an inertial reference frame (Kalman-filtered navigation solution)	GO-0-SC-NAV
• SSTI time-stamping (S/C and GPS time)	GO-0-SC+TIM
• SREM data	GO-0-SC+SRM
• EGG calibration packets during COP (calibration matrices, thrusters commands), ~1/month	GO-0-SC+CAL

Ancillary data needed for scientific data reduction

• Star tracker quaternions wrt LORF (Alenia: inertial quaternions), and time (from DFACS output)	GO-0-AD+ATT
• Proof-mass DC polarisation (bias) voltage	GO-0-AD+PMV
• Fuel consumption data (number and location of T, P measurements TBC)	GO-0-AD+FTP
• Thruster activity	GO-0-AD+THR
• SSTI S/N ratio, calibration data for SSTI interchannel biases (in Alenia's doc.)	GO-0-AD-SSC

System health & housekeeping data

• EGG-related temperatures	GO-0-HK+EGT
• SSTI-related temperatures	GO-0-HK+STT
• IPA HK data MPA HK data Power consumption data RF data CDMU/DHS HK data	GO-0-HK+SSY

2.2 Level 1A Products

The Level 1A products consist of ordered time series of payload data, with calibration data attached, and satellite ancillary data. In other words, the Level 0 to Level 1A processing does not combine e.g. output voltages with calibration data. It consists solely of TM de-packetting, conversion to engineering units (not quite clear from Alenia's doc., e.g. [7] vs. [6]) and subsequent attachment of CAL files. Therefore, Level 1A products are to 'first order' a straightforwared reflection of level 0.

Science data

• EGG accelerometer output (6x3 single axis accelerations) EGG time-stamping (S/C time) EGG CAL data (applies also to CM) [Common-mode linear and angular accelerations (in ESA's but not in Alenia's doc.)]	GO-1A-EGG
• SSTI phase observations (L1, L2) SSTI pseudo-range observations: P code: L1, L2, C/A code: L1) SSTI CAL data	GO-1A-SST
• SSTI position & velocity in an inertial frame (raw navigation solution) SSTI position & velocity in an inertial frame (Kalman-filtered navigation solutions)	GO-1A-NAV
• SSTI time-stamping (S/C and GPS time)	GO-1A-TIM
• SREM data	GO-1A-SRM

Ancillary data needed for scientific data reduction

• Star tracker quaternions wrt LORF (Alenia: inertial quaternions), and time Star tracker CAL data	GO-1A-ATT
• Proof-mass DC polarisation (bias) voltage	GO-1A-PMV

• Fuel consumption data (number and location of T,P measurements TBC)	GO-1A-FTP
• Thruster activity	GO-1A-THR

System health & housekeeping data

• EGG-related temperatures	GO-1A-AK+EGT
• SSTI-related temperatures	GO-1A-NK+STT
• IPA HK data MPA HK data Power consumption data RF data CDMU/DHS HK data	GO-1A-HK+SSY

2.3 Level 1B Products

The Level 1B products consist of calibrated, corrected and geo-located formatted time series of payload data along the orbit. In going from level 1A to level 1B, all the engineering corrections and calibration information bas been utilised to the maximum extent. The term 'geo-located' means that a position tag is attached to a measurement.

Science data

• EGG calibrated, corrected and geo-located gravity gradients in GRF, satellite, local orbital, inertial and earth-fixed reference frames EGG time-stamping (S/C time and UTC or GPS time, resp.) Calibrated and corrected residual common-mode and differential mode linear accelerations Angular accelerations about the three GRF axes (from common-mode linear accel. & baseline lengths) Angular rates (velocities) about the three GRF axes (integration of angular accel., quaternions)	GO-1B-EGG
• Calibrated and corrected SSTI phase observations (L1, L2) Calibrated and corrected SSTI pseudo-range (code) observations (L1, L2)	GO-1B-SST
• SSTI position & velocity in an inertial frame (raw on-board sol.) SSTI position & velocity in an inertial frame (Kalman-filtered on-board sol.)	GO-1B-NAV (=1A?)
• SSTI position & velocity in an ECEF & inertial frame (kinematic orbit ground processing from pseudo ranges)	GO-1B-RSO
• SSTI time-stamping (S/C time and UTC or GPS time, resp.)	GO-1B-TIM (=1A?)
• SREM e,p,heavy ion accumulation file and total dose	GO-1B-SRM

Ancillary data needed for scientific data reduction

• Calibrated and corrected star tracker quaternions wrt LORF (Alenia: inertial quaternions)	GO-1B-ATT
• Proof-mass DC polarisation (bias) voltage	GO-1B-PMV (=1A?)
• Thruster activity	GO-1B-THR (=1A?)

Model data

- A priori SGG error model (requ. from Task 3.1) GO-1B-EGG+ERM

2.4 Level 2 Products

Level 2 products are orbit and Earth gravity field related scientific products. The term 'geo-located' means that a position tag is attached to a measurement.

Core Products:

- Earth gravity field model, spherical harmonic coefficients and grid values, VCMs GO-2-EGM
- Quality report for global Earth gravity field model GO-2-EGM+QUR
- Gradiometer geo-located gravity gradient data reductions GO-2-EGG
- GOCE precise science orbit GO-2-PSO+GOC
- Quality report for GOCE precise science orbit GO-2-PSO+GOC_QUR
- Regional gravity field model GO-2-RGM

Preparatory Products:

- Earth gravity field model from direct method (spherical harmonic coefficients and grid values, VCMs) GO-2p-EGM+DIR
- Earth gravity field from timewise method (spherical harmonics and grid values, VCMs) GO-2p-EGM+TIW
- Earth gravity field model from timewise FFT-method (Quick look) GO-2p-EGM+QLK
- Analysis report of GOCE quick-look gravity field solution GO-2p-EGM+QAR
- Earth gravity field model from spacewise method (spherical harmonic coefficients and grid values, VCMs) GO-2p-EGM+SPW
- Global covariance function for the gravity field GO-2p-EGM+COV
- GOCE precise science orbit (reduced dynamic mode) GO-2p-PSO+GOC_RD
- GOCE precise science orbit (kinematic mode) GO-2p-SST+POS
- GOCE precise science orbit (dynamic mode) GO-2p-PSO+GOC_DY
- GOCE rapid science orbit (dynamic mode?, task?, for orbit pred., for EGM+QLK: red. dyn.) GO-2p-RSO+GOC
- Rotation matrices between LORF and RERF GO-2p-REF+LORF2RERF
- Updated EGG error model GO-2p-EGG+ERM
- EGG calibration parameters and errors GO-2p-EGG+CAL

Internal Products:

- GOCE orbit predictions (for SLR stations, task?) GO-2i-PRD
- Geo-located accelerations from SST data GO-2i-SST+ACC
- WOF filtered gradiometer gradient data GO-2i-EGG+WOF
- Regional grids of gradiometer data at satellite altitude GO-2i-RGG
- Upward continued EGG observations from ground data GO-2i-EGG+UPC
- SSTI preprocessed phase and pseudo-range data GO-2i-SST
- Gravity corrections for atmospheric and oceanic mass variations (6 hourly spherical harmonic coefficients) GO-2i-AOV
- Quality report for GOCE science orbit (internal evaluation) GO-2i-PSO+GOC_QUR

- Quality report for GOCE gravity field solutions (internal evaluation) GO-2i-EGM+QUR

2.5 Ancillary Data

For generating the GOCE standard products identified above, various ancillary data sets (models and series) from providers outside of the GOCE project are necessary. The following list identifies these GOCE Standards (StRD) [10] related data sets.

Ancillary Data:

- GPS ephemeris and clocks GO-2a-GNS+EPC
- GPS ground station tracking data GO-2a-GNS+GST
- GPS ground station coordinates GO-2a-GNS+GSC
- GPS ground station ancillary data GO-2a-GNS+GSA
- Tracking data from the International Laser Tracking Network GO-2a-SLR
- Earth rotation parameters (pole coordinates, LOD, nutation) and predictions from IERS GO-2a-ERP
- Station coordinates (including velocities) from ITRF solutions (e.g. ITRF2000) GO-2a-SSC
- Sun, moon and planetary ephemeris GO-2a-EPH
- Earth albedo and emissivity GO-2a-RAD
- Atmospheric density model for computation of atmospheric drag forces GO-2a-DTM
- Solar flux and geomagnetic activity indices GO-2a-SGA
- Atmospheric pressure grid values for computation of short term atmospheric gravity variations and the ocean model forcing GO-2a-ATM
- Ocean bottom pressure model for computation of short term oceanic gravity variations (forced by atmospheric pressure data) GO-2a-OCM
- Ocean tide model GO-2a-OTI
- A-priori static gravity field model GO-2a-EGM
- Temporal gravity field variations (from GRACE results) GO-2a-EGT
- Terrestrial, airborne gravity and deflections of the vertical for GOCE data supplement (polar gaps) GO-2a-GRA
- Digital topography/bathymetry model GO-2a-TOP
- Spacecraft parameters (Macro model, surface properties, coordinates) GO-2a-SCM
- Terrestrial and airborne gravity data for GOCE gravity field model evaluation GO-2a-EVG
- Altimetric sea surface height model and sea surface topography model for GOCE gravity field model evaluation and EGG calibration GO-2a-EVH
- Geoid heights from GPS minus leveling and regional geoid modelling GO-2a-EVN
- Global gravity field models for GOCE model evaluation GO-2a-EVM
- Satellite orbit tracking & altimeter data for GOCE gravity field model evaluation GO-2a-EVT
- External orbits from other investigations (for evaluation) GO-2a-EVO

Ancillary data are part of the GOCE Standards. A more detailed description and recipes how these products shall be used for GOCE data processing are described in the GOCE Standards Requirements Document (StRD), which is generated within this contract.

3. Product/Task Requirements Matrix (L1 → L2)

Annex 1 contains the matrix which identifies the requirements for products' acquisition ('in') and generation ('out') per task. These tasks are defined in the 'European GOCE Gravity Consortium (EGG-C)' document [3]:

1. Standards
2. Data bases: Archiving, formats, data dissemination and distribution
3. Aid to preprocessing: Data validation, effect of temporal variations
4. Precise kinematic or/and reduced dynamic orbit determination
5. Global gravity field model: Direct Method (5.1); Time-wise semi-analytic method (5.2); Space-wise method (5.3)
6. Solution evaluation/validation
7. Communication, documentation, publication, public relation (not considered in the matrix)
8. Interface to science use (level 3)
9. Regional solutions

The matrix also makes the main interfaces and relations between the different tasks visible.

4. Product Specifications (Product Fact Sheets)

Annex 2 contains the Product Fact Sheets (PFS) and Ancillary Data Fact Sheets, resp., which specify each individual level 2 product, uniquely labeled with the identifier (cf. Chapter 2) in terms of input/output, standards, format, coverage, resolution, generation schedule, volume and file attributes.
The generation schedule consists of 'Latency' and 'Turn around time'. 'Latency' means the delay of the first issue of a product with respect to the availability of the input products and 'Turn around time' means the rate of product generation (e.g. daily for 24 hour orbits). The 'latency' is harmonized with the GOCE (L1 to L2 Processing) System Requirements Document (SRD) [9].
The 'File attributes' are the minimum retrieval parameters to access a specific product file from the data base.

5. Related Documents

[1] Gravity Field and Steady-State Ocean Circulation Mission; Reports for the four candidate Earth Explorer Core Missions; ESA SP-1233(1)
[2] Mission Objectives and Scientific Requirements Document for the GOCE Mission (MRD), Issue 2, March 2000
[3] The European GOCE Gravity Consortium, Version 9, Feb. 2001
[4] GOCE Architecture Design Document (ADD), Revision 1.0, May 2002
[5] GOCE System Requirements Document for Phase B/C/D/E1, GO-RS-ESA-SY-0002, Issue: Draft 2, June 2001

[6] Performance Requirements and Budgets for the Gradiometric Mission, GO-TN-AI-0027, Draft 2, June 2001
[7] Gradiometer Ground Processing Algorithms Specification, GO-SP-AI-0003, Issue 01, Febr. 2002
[8] GPS Receiver Ground Processing Algorithms Specification, GO-SP-AI-0004, Issue 01, Febr. 2002
[9] GOCE System Requirements Document (SRD) for L1 to L2 processing, Revision 1.0, May 2002
[10] GOCE Standards Requirements Document (StRD), Revision 0.1, Febr. 2002

Annex 1: Product / Task Requirements Matrix (L1 → L2)

Product / Task Requirements Matrix (L1 → L2)

Task	1		2		3		4		5.1		5.2		5.3		6		8		9		Product ID
Product	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	
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. and 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

Task	1		2		3		4		5.1		5.2		5.3		6		8		9		Product ID
Product	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	
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
<u>Internal Products</u>																					
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. altitude (var. funct.)														▒						▒	GO-2i-RGG
Upward continued EGG observations from ground data						■															GO-2i-EGG+UPC
SSTI preprocessed 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
<u>Ancillary Data</u>																					
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

Task	1		2		3		4		5.1		5.2		5.3		6		8		9		**Product ID**
Product	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	
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

Annex 2: Product Fact Sheets

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-EGM
Name	GOCE Earth Gravity Field Model
Definition	Earth gravity field spherical harmonic coefficients, grid values and VCMs (selected 'best' solution)
Basic Input	GO-2-EGM+QUR
Output	selected 'best' model after review and decision by the project
Standards	
Format	
Spatial coverage	
Spatial resolution	
Time coverage	
Time resolution	
Latency	8 weeks
Turn around time	mission phase, whole mission
Volume	
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision
Remarks	for product contents c.f. Product Fact Sheets of GO-2p-EGM+DIR, +SPW, +TIW

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-EGM+QUR
Name	quality report for global Earth gravity field model
Definition	compilation of quality parameters and quality representations from internal quality assessment and external comparisons, calibration of standard deviations, mutual evaluation of gravity models from direct, space-wise and time-wise solutions
Basic Input	global gravity field solutions: GO-2p-EGM+DIR, GO-2p-EGM+TIW, GO-2p-EGM+SPW quality report (internal eval.): GO-2i-EGM+QUR external comparison data sets
Output	statistical parameters, figures, tables, gridded data (differences)
Standards	GOCE Standards
Format	ascii, graphics
Spatial coverage	n/a
Spatial resolution	n/a
Time coverage	n/a
Time resolution	n/a
Latency	2 months
Turn around time	mission phase, whole mission
Volume	10 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-EGG
Name	gradiometer calibrated and geo-located gravity gradient data
Definition	gradiometer data in local orbital reference frame (LORF) and converted to radial earth pointing reference frame (RERF) along GOCE orbit, reductions
Basic Input	gradiometer data in instrument frame (GO-1B-EGG), star sensor attitude data (GO-1B-ATT) GOCE precise science orbit (GO-2-PSO+GOC_RD) Global covariance function for the gravity field (GO-2p-EGM+COV) Rotation matrices between LORF and RERF (GO-2p-REF+LORF2RERF) (GO-2i-AOV, GO-2a-EGT) Temporal gravity field variations
Output	time tag geogr. ellips. coordinates, orientation gravity gradients, and std. dev. reductions: frame transformation, temporal gravity, calibration flags, statistics
Standards	GOCE Standards
Format	tbd.
Spatial coverage	global
Spatial resolution	7 km along-track ($\hat{=}$ 1 Hz observation rate along the orbit)
Time coverage	1 month
Time resolution	1 s
Latency	3 months
Turn around time	1 month
Volume	4 GByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date revision
Remarks	all reductions are not applied but given w.r.t. Level 1B data

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-PSO+GOC
Name	GOCE Precise Science Orbit
Definition	precise restitution of GOCE trajectory (selected 'best' solution from reduced dynamic and kinematic mode)
Basic Input	GO-2-PSO+GOC_QUR
Output	selected 'best' orbit out of GO-2p-PSO+GOC_RD and GO-2p-SST+POS after review and decision by the project
Standards	
Format	
Spatial coverage	
Spatial resolution	
Time coverage	
Time resolution	
Latency	8 weeks
Turn around time	monthly
Volume	
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date revision
Remarks	for product contents c.f. Product Fact Sheets of GO-2p-PSO+GOC_RD and GO-2p-SST+POS

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-PSO+GOC_QUR
Name	Quality Report for GOCE Precise Science Orbit
Definition	collection of results from internal and external orbit quality evaluation
Basic Input	GO-2p-PSO+GOC_RD GO-2p-SST+POS GO-2i-PSO+GOC_QUR ancillary orbit comparison data (SLR, independent solutions) and GO-2p-PSO+GOC_DY
Output	statistical parameters, figures, tables
Standards	GOCE Standards
Format	ascii, graphics
Spatial coverage	n/a
Spatial resolution	n/a
Time coverage	1 month
Time resolution	n/a
Latency	1 month
Turn around time	monthly
Volume	1 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package ----- start date, stop date revision
Remarks	Quality report is basis for selection of 'best' orbit solution

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2-RGM
Name	regional gravity field model
Definition	regional gravity field solutions applying localizing kernel functions and collocation
Basic Input	GOCE precise science orbit (GO-2-PSO+GOC) preprocessed common mode gradiometer data (GO-1B-EGG) gradiometer geo-located gravity gradient data (GO-2-EGG) or preprocessed differential mode gradiometer data (GO-1B-EGG) and star sensor attitude data (GO-1B-ATT), resp. global gravity field model (GO-2-EGM), SGG error model (GO-2p-EGG+ERM) Ancillary data: topography/bathymetry model
Output	gridded disturbing gravity field parameters in satellite altitude and on Earth: gravity anomalies, geoid undulations, deflections of vertical, and gravity gradients, regional covariance functions, standard deviations
Standards	GOCE Standards
Format	grid data format
Spatial coverage	user defined areas of interest (e.g. 20 deg equi-area)
Spatial resolution	user defined ($\lambda/2 > 10$ km)
Time coverage	length of GOCE mission or time window
Time resolution	depends on solutions, observation time difference
Latency	12 months
Turn around time	monthly
Volume	x MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package - - - - - - - - start date, stop date revision lat, extlat, lon, extlon; solution method; surface/flight altitude; functionals
Remarks	global coverage with 22.5 deg equi-areas (2.5 deg overlap) required as input for GO-2i-RGG (task 5.3 'spacewise solution')

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+DIR
Name	Global Earth gravity field model from direct method
Definition	spectral and spatial Earth gravity field model parameters
Basic Input	normal equations from GOCE dynamicly determined orbit (GO-2p-PSO+GOC_DY) preprocessed differential mode gradiometer data (GO-2-EGG) star sensor attitude data (GO-1B-ATT)
Output	1a) spherical harmonic coefficients up to degree/order 300 and standard deviations, quality parameters 1b) correlation matrix of solve-for parameters 2) grid data values: mean geoid undulations, gravity anomalies, defl. of vertical related to an equal angular grid, std. dev. and correlation matrix
Standards	GOCE Standards
Format	1) shm-format (spherical harmonic model) and corregm-format (correl. matrix) 2) grid-data-format, grid-data-correlation-format
Spatial coverage	global
Spatial resolution	1) approx. 80 km (λ/2) 2) x° pixel values (user defined)
Time coverage	length of GOCE mission (and mission phase)
Time resolution	mission phase and time averaged mean (10d for low degree harmonics)
Latency	9 months
Turn around time	mission phase
Volume	shm-format: 5 MByte per model corregm-format: 400 MByte per model (compressed) grid-data-format: e.g. 10 MByte per 0.5° x 0.5° model grid-data-correlation-format: e.g. 4 GByte per model (compressed)
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision parameter type
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+TIW
Name	Earth gravity field model from timewise method
Definition	spectral and spatial Earth gravity field model parameters
Basic Input	GOCE precise science orbit (GO-2-PSO+GOC) preprocessed differential mode gradiometer data (GO-2-EGG) star sensor attitude data (GO-1B-ATT) gradiometer colored noise model (GO-2p-EGG+ERM)
Output	1a) spherical harmonic coefficients up to degree/order 300 and standard deviations, quality parameters 1b) correlation matrix of solve-for parameters 2) grid data values: mean geoid undulations, gravity anomalies, defl. of vertical related to an equal angular grid, std. dev. and correlation matrix
Standards	GOCE Standards
Format	2) shm-format (spherical harmonic model) and corregm-format (correl. matrix) 2) grid-data-format, grid-data-correlation-format
Spatial coverage	global
Spatial resolution	3) approx. 80 km (λ/2) 4) x° pixel values (user defined)
Time coverage	length of GOCE mission (and mission phase)
Time resolution	mission phase and time averaged mean (10d for low degree harmonics)
Latency	8 weeks
Turn around time	mission phase
Volume	shm-format: 5 MByte per model corregm-format: 400 MByte per model (compressed) grid-data-format: e.g. 10 MByte per 0.5° x 0.5° model grid-data-correlation-format: e.g. 4 GByte per model (compressed)
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision parameter type
Remarks	

European GOCE Gravity Consortium (EGG-C)	GOCE Product Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+QLK
Name	Earth gravity field model from timewise FFT-method (Quicklook)
Definition	spectral and spatial Earth gravity field model parameters
Basic Input	GOCE rapid science orbit (GO-2p-RSO+GOC_RD) differential mode gradiometer data (GO-1B-EGG) star sensor attitude data (GO-1B-ATT) gradiometer colored noise model (GO-1B-EGG+ERM, GO-2p-EGG+ERM)
Output	1a) spherical harmonic coefficients up to degree/order 300 and standard deviations 1b) improvement gradiometer noise model 2) point and grid data values: geoid undulations, gravity anomalies, defl. of vertical
Standards	GOCE Standards
Format	1) shm-format (spherical harmonic model) 2) grid, point data-format
Spatial coverage	global
Spatial resolution	1) approx. 70 km (λ/2) 2) 1°, 0.5° (pixel), point data
Time coverage	biweekly
Time resolution	n/a
Latency	2 days
Turn around time	weekly
Volume	shm-format: 5 MByte per model grid data format: 5, 10 MByte per model point data format: 100 KB per model
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision parameter type
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+QAR
Name	Analysis report of GOCE quick-look gravity field solution
Definition	analysis of partial sets of EGG and SST data w.r.t. Drag Free Control (DFC) and EGG noise model
Basic Input	GO-2p-EGM+QLK GO-2p-RSO+GOC GO-2p-EGG+ERM
Output	Analysis report: statistics, figures, tables
Standards	
Format	ascii, graphics
Spatial coverage	
Spatial resolution	
Time coverage	biweekly
Time resolution	
Latency	2 days
Turn around time	weekly
Volume	100 KB
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision parameter type
Remarks	product is designed as feed-back for level 0 to 1B processing

European GOCE Gravity Consortium (EGG-C)	GOCE Product Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+SPW
Name	Earth gravity field model from spacewise method
Definition	fully normalized spherical harmonic coefficients of the gravity potential with error estimates and error covariances
Basic Input	regional grids of gradiometer data and SST data at satellite altitude (GO-2i-RGG), based on data from each phase and from the full mission
Output	1a) spherical harmonic coefficients and error standard deviations, quality parameters 1b) variance-covariance-matrix of solve-for parameters
Standards	GOCE Standards
Format	shm-format (spherical harmonic model) and covegm-format (variance-covariance matrix)
Spatial coverage	global
Spatial resolution	1°x1° (approx., $\lambda/2$)
Time coverage	mission phase and full mission
Time resolution	n/a
Latency	9 months
Turn around time	mission phase
Volume	2 MByte (model up to degree 200) + 6 GByte (variance-covariance matrix)
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGM+COV
Name	global covariance function for the gravity field
Definition	parameters defining a global analytical expression for the gravity field's covariances
Basic Input	A priori global covariance function parameters from ground data and gradiometer WOF filtered gravity gradient data (GO-2i-EGG+WOF), signal and error degree variances from global gravity field model
Output	parameters defining global covariances function
Standards	
Format	GRAVSOFT
Spatial coverage	global
Spatial resolution	80 km ($\lambda/2$)
Time coverage	mission phases, length of GOCE mission
Time resolution	n/a
Latency	1 week
Turn around time	mission phase
Volume	1 Kbyte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date (of input data) revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-PSO+GOC_RD
Name	GOCE precise science orbit (reduced dynamic mode)
Definition	precise restitution of GOCE trajectory in reduced dynamic mode
Basic Input	GPS SST tracking data from SSTI (GO-1B-SST → 2i-SST) common mode gradiometer data (GO-1B-EGG) star sensor attitude data (GO-1B-ATT) thrust history (GO-1B-THR) ancillary data (ground based GPS tracking data, SLR data, IGS GPS products, station coordinates, Earth orientation parameters, tide and loading models, a priori gravity field, Sun, Moon and planetary ephemerides, spacecraft parameters, temp. grav. var.)
Output	time tag position and velocity vectors (center of mass) in terrestrial, mean celestial and true of date system quality parameters: state vectors' standard deviations, rms of orbital fit
Standards	GOCE Standards
Format	SP3 enhanced, SP4
Spatial coverage	global
Spatial resolution	70 km along-track
Time coverage	30 hours (6 hours overlap)
Time resolution	10 s
Latency	2 months
Turn around time	daily
Volume	2 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package - - - - - start date, stop date revision
Remarks	Software package: GEODYN

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-SST+POS
Name	GOCE precise orbit (kinematic mode)
Definition	precise restitution of GOCE trajectory (position only) in kinematic mode
Basic Input	GPS-SST tracking data (GO-1B-SST → 2i-SST) star sensor attitude data (GO-1B-ATT) ancillary data: GPS ephemerides and clocks, ground stations data, station positions, Earth rotation parameters
Output	time tag position and position differences (centre of mass), earth fixed frame standard deviations
Standards	GOCE Standards
Format	SP3 enhanced
Spatial coverage	global
Spatial resolution	70 km along-track
Time coverage	30 hours (6 hours overlap)
Time resolution	10 s
Latency	2 months
Turn around time	daily
Volume	2 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date revision
Remarks	software package: Bernese GPS software

European GOCE Gravity Consortium (EGG-C)	GOCE Product Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-PSO+GOC_DY
Name	GOCE precise science orbit (dynamic mode)
Definition	precise restitution of GOCE trajectory in dynamic mode
Basic Input	GPS -SST tracking data from SSTI (GO-1B-SST) GOCE onboard navigation solutions (GO-1B-NAV) common mode gradiometer data (GO-1B-EGG) star sensor attitude data (GO-1B-ATT) thrust history (GO-1B-THR) ancilliary data (ground based GPS tracking data, SLR data, IGS GPS products, station coordinates, Earth orientation parameters, tide loading models, a priori gravity field, Sun, Moon and planetary ephemerides, spacecraft parameters, temp. grav. var.)
Output	time tag position and velocity vectors (center of mass) in terrestrial and celestial system quality parameters: state vectors' standard deviations, rms of orbital fit
Standards	GOCE Standards
Format	SP3 enhanced, SP4
Spatial coverage	global
Spatial resolution	70 km along-track
Time coverage	24 hours
Time resolution	10 s
Latency	6 months
Turn around time	daily
Volume	2 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date revision
Remarks	Orbits are generated within the GO-2p-EGM+DIR processing chain (by-product) and are based upon the initial gravity field (Type of software package: GINS, EPOS)

European GOCE Gravity Consortium (EGG-C)	GOCE Product Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-RSO+GOC
Name	GOCE rapid science orbit
Definition	Low latency precise orbit restitution of GOCE in reduced-dynamic mode
Basic Input	GPS-SST tracking data from SSTI (GO-1B-SST) ancilliary data (ground based tracking data, IGS products, Earth orientation parameters, Sun, Moon and planetary ephemerides, spacecraft parameters)
Output	time tag position and velocity vectors (centre of mass) in terrestrial, mean celestial and true of date system
Standards	GOCE Standards
Format	SP3 enhanced, SP4
Spatial coverage	global
Spatial resolution	70 km along-track
Time coverage	30 hours (6 hours overlap)
Time resolution	10 s
Latency	1 day
Turn around time	daily
Volume	1.5 Mbyte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package --- start date, stop date revision
Remarks	position & velocity requested for GO-2p-EGM+QLK

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-REF+LORF2RERF
Name	Rotation matrices between LORF and RERF
Definition	Matrices to rotate the gravity gradients from the Local Orbital Reference Frame (LORF = Instrument/Frame) via the nominal LORF to the Radial Earth-Fixed Pointing Reference Frame (RERF)
Basic Input	gradiometer data (GO-1B-EGG) satellite attitude (GO-1B-ATT) gradiometer error model (GO-1B-EGG+ERM) GOCE SST navigation solution (GO-1B-NAV) ancillary data: Earth rotation parameters
Output	time tag 6 matrix elements of anti-symmetric rotation matrix
Standards	GOCE Standards
Format	tbd
Spatial coverage	along orbit
Spatial resolution	7 km along-track
Time coverage	1 month
Time resolution	1 s
Latency	3 months
Turn around time	1 month
Volume	1 GByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package - - - - - - - - - - start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGG+ERM
Name	Updated EGG error model
Definition	Parameter of Error Power Spectral Density (PSD) for EGG channels, within and without the measurement bandwidth
Basic Input	a priori SGG error model (GO-1B-EGG+ERM) gradiometer gravity gradients (GO-1B-EGG) ancillary comparison data and models
Output	frequency, amplitude, slope of PSD per gravity gradient (V(ij))
Standards	
Format	tbd
Spatial coverage	
Spatial resolution	
Time coverage	mission phase, whole mission
Time resolution	1 month
Latency	3 months
Turn around time	1 month
Volume	10 KByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package - - - - - - - - start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2p-EGG+CAL
Name	EGG calibration parameters and errors
Definition	Biases, scale factors, drift and quadratic terms for EGG differential mode observations and standard deviations
Basic Input	gradiometer gravity gradient (GO-1B-EGG) GOCE precise science orbit (GO-2p-PSO+GOC_RD) ancillary comparison gravity data and models
Output	bias, scale factor, drift, quadratic term and standard deviations per gravity gradient (V(ij))
Standards	GOCE Standards
Format	tbd
Spatial coverage	
Spatial resolution	
Time coverage	1 month
Time resolution	depending on EGG performance
Latency	3 months
Turn around time	1 month
Volume	100 KByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = public processing facility software package start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	GOCE Product Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-PRD
Name	GOCE orbit predictions
Definition	GOCE orbit predictions for SLR station
Basic Input	GOCE navigation solution (GO-1B-NAV) SLR data (GO-2a-SLR)
Output	time tag position and velocity vectors (COM) SLR orbit predictions quality parameters
Standards	GOCE Standards
Format	SLR formats, Twoline-Element-Format
Spatial coverage	global
Spatial resolution	210 km along-track
Time coverage	7 days plus 1 day predicted
Time resolution	30 s
Latency	1 hour
Turn around time	8 hours
Volume	20 MByte/file 60 MByte/day
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package --- start date, stop date revision
Remarks	dynamic orbit integration and prediction

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-SST+ACC
Name	geo-located accelerations from SST data
Definition	accelerations from geo-located GPS SST data (positions, position differences)
Basic Input	GOCE kinematic precise orbit (GO-2p-SST+POS)
Output	time tag acceleration vectors (Earth-fixed frame) standard deviations
Standards	GOCE Standards
Format	(time, latitude, longitude, ellipsoidal height or spherical radius, acceleration vectors and error-estimates)
Spatial coverage	global
Spatial resolution	70 km along track
Time coverage	24 hours
Time resolution	10 s
Latency	mission phase and full mission plus 2 months
Turn around time	mission phase
Volume	1 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package - - - - - - - - start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-EGG+WOF
Name	Wiener Orbital filtered (WOF) gradiometer gradient data
Definition	spatialized gradiometer data using a Wiener orbital filter, and covariance function of the estimation error
Basic Input	gradiometer data in instrumental frame (GO-1B-EGG, -2-EGG)
Output	time tag, position (spherical coordinates, Earth fixed) WOF gradiometer gradients in instrumental frame and covariance function of the estimation error, sampled at regular time intervals
Standards	GOCE Standards
Format	tbd
Spatial coverage	global
Spatial resolution	7 km along-track
Time coverage	mission phase and full mission
Time resolution	1 s
Latency	1 month
Turn around time	mission phase
Volume	1.5 GByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package - - - start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-RGG
Name	regional grids of gradiometer data (RGG) at mean satellite altitude
Definition	regionally gridded gradiometer data in an earth-pointing system
Basic Input	Wiener Orbital Filtered (WOF) gradiometer gradient data (GO-2i-EGG+WOF)
Output	gridded gradiometer values in terms of gravity gradients, grav. anomalies and geoid undulations, standard deviations
Standards	GOCE Standards
Format	GRAVSOFT grid format
Spatial coverage	global
Spatial resolution	1/3 degree in longitude and latitude
Time coverage	mission phase and full mission
Time resolution	
Latency	1 months
Turn around time	mission phase
Volume	50 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package
	start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-EGG+UPC
Name	Upward continued gravity gradients
Definition	upward continuation of ground gravity data into gravity gradients (for EGG calibration) synchronized with GOCE observations
Basic Input	ground gravity data (GO-2a-EVG) GOCE precise science orbit (GO-2p-PSO+GOC_RD)
Output	position, gravity gradients along GOCE's orbit
Standards	GOCE Standards
Format	tbd
Spatial coverage	data sets to be selected
Spatial resolution	data sets to be selected
Time coverage	n/a
Time resolution	n/a
Latency	3 months
Turn around time	1 month
Volume	< 4 GByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package --- start date, stop date (of GOCE orbit segment) revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-SST
Name	GPS preprocessed phase and pseudo-range data
Definition	GPS SST data screening, resulting in annotation of outliers with flags and statistical information (number of outliers, noise level)
Basic Input	SSTI calibrated and corrected phase and pseudo-range observations (GO-1B-SST) GPS navigation solution (GO-1B-NAV, in case of Bock-editing); ancillary data: GPS ephemeris and clocks, satellite laser ranging data
Output	GO-1B-SST with outliers flagged, statistical information
Standards	
Format	RINEX enhanced (to accommodate flags and statistics)
Spatial coverage	
Spatial resolution	
Time coverage	24 hours
Time resolution	1 s
Latency	2 months
Turn around time	daily
Volume	100 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package --- start date, stop date revision
Remarks	Melbourne-Wübbena- or Bock-editing

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-AOV
Name	Gravity corrections for atmospheric and oceanic mass variations
Definition	6 hourly spherical harmonic coefficients from atmospheric pressure and ocean circulation model data (time varying geopotential)
Basic Input	Atmospheric pressure grid values(GO-2a-ATM) Ocean bottom pressure model (GO-2a-OCM)
Output	degree, order, fully normalized spherical harmonic coefficients up to l,m=180
Standards	GOCE Standards
Format	tbd
Spatial coverage	global
Spatial resolution	~1° x 1°
Time coverage	1 day
Time resolution	6 hours
Latency	10 days
Turn around time	daily
Volume	4 MByte
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package --- start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-PSO+GOC_QUR
Name	Quality report for GOCE science orbit (internal evaluation)
Definition	Internal evaluation of GOCE precise orbit determination by comparison of different approaches, orbit overlaps, transformations and comparison with SLR
Basic Input	GO-2p-PSO+GOC_RD, GO-2p-SST+POS, GO-2a-SLR, GO-2p-PSO+GOC_DY
Output	RMS values, residuals, transformation parameters, figures, tables
Standards	GOCE Standards
Format	ascii, graphics
Spatial coverage	n/a
Spatial resolution	n/a
Time coverage	1 month of orbits
Time resolution	n/a
Latency	3 weeks
Turn around time	monthly
Volume	
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package --- start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2i-EGM+QUR
Name	Quality report for global Earth gravity field solutions (internal evaluation)
Definition	Mutual comparison of direct, time-wise and space-wise global GOCE gravity field solutions by differencing in the frequency and space domain
Basic Input	GO-2p-EGM+DIR, GO-2p-EGM+TIW, GO-2p-EGM+SPW
Output	difference degree variances, difference grid values, figures, tables
Standards	GOCE Standards
Format	ascii, graphics
Spatial coverage	n/a
Spatial resolution	n/a
Time coverage	mission phases, whole mission
Time resolution	n/a
Latency	1 month
Turn around time	mission phases, whole mission
Volume	
File attributes	generation date (yy.mm.dd) mission (GOCE) Data Access = internal processing facility software package start date, stop date revision
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-GNS+EPC
Product	IGS GPS precise ephemeris and clocks
Spatial resolution	24 GPS satellites
Time coverage	24 hr
Time resolution	15 min. (ephemeris), 10 s (clocks)
Latency	1-2 weeks
Volume	2.5 MB (ephemeris), 1-3 MB (clocks)
Source	International GPS Service for Geodynamics (IGS)
Remarks	10 s clock resolution requires 10 s ground station net data?

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-GNS+GST
Product	GPS ground station tracking data
Spatial resolution	> 100 stations
Time coverage	24 hr
Time resolution	10 s
Latency	< 1 day
Volume	1 MB/station/day for 10 s data, compressed
Source	International GPS Service for Geodynamics (IGS); CHAMP Information System and Data Center (GFZ-ISDC); Jet Propulsion Laboratory (JPL); Bundesamt f. Kartographie und Geodäsie (BKG); European IGS Data Centre (EDC); Scripps Inst. of Oceanography (SOPAC)
Remarks	10 s ground station data presently only provided by CHAMP/GRACE low latency network

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-GNS+GSC
Product	Geocentric coordinates of IGS tracking stations
Spatial resolution	> 130 stations
Time coverage	weekly
Time resolution	n.a.
Latency	12 days
Volume	1 MB
Source	International GPS Service for Geodynamics (IGS)
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-GNS+GSA
Product	GPS ground station ancillary data (tbd)
Spatial resolution	all GPS ground stations
Time coverage	
Time resolution	
Latency	
Volume	
Source	
Remarks	e.g. tropospheric delays (+GSA_MET), antenna phase center variations (+GSA_ANT), differential code biases

European GOCE Gravity Consortium (EGG-C)	GOCE Ancillary Data Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-SLR
Product	Satellite Laser Ranging data
Spatial resolution	< 5 stations/d
Time coverage	24 hr
Time resolution	10 s normal points
Latency	24 hr
Volume	< 200 KB/day
Source	CDDIS at NASA/GSFC, EDC at DGFI
Remarks	

European GOCE Gravity Consortium (EGG-C)	GOCE Ancillary Data Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-ERP
Product	Earth rotation parameters (pole, LOD, nutation) and predictions
Spatial resolution	n.a.
Time coverage	1 week
Time resolution	24 hr
Latency	3 days (IERS bulletin A), 5 weeks (IERS bulletin B, C04 series update)
Volume	< 10 KB/day
Source	International Earth Rotation Service (IERS)
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-SSC
Product	geocentric coordinates and velocities of ITRF Station
Spatial resolution	~ 1000 stations
Time coverage	1 year
Time resolution	secular rates of change in position and height
Latency	yearly updates
Volume	300 KB
Source	IERS ITRS Center at IGN
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-EPH
Product	Sun, Moon and planetary ephemeris (position, velocity, acceleration)
Spatial resolution	n.a.
Time coverage	1599 – 2201 AD
Time resolution	continuous
Latency	available
Volume	2.5 MB
Source	DE 403 / LE 403 ephem. from JPL
Remarks	

European GOCE Gravity Consortium (EGG-C)	GOCE Ancillary Data Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-RAD
Product	Earth albedo and emissivity
Spatial coverage	global
Spatial resolution	0.75ºx0.75º
Time coverage	1 day
Time resolution	6 hr
Latency	1 day
Volume	0.2 MB/day
Source	ECMWF
Remarks	

European GOCE Gravity Consortium (EGG-C)	GOCE Ancillary Data Fact Sheet	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-DTM
Product	Atmospheric density model (DTM)
Spatial resolution	continuous
Time coverage	n.a.
Time resolution	continuous
Latency	available
Volume	< 100 KB
Source	CNES/GRGS, Toulouse; CERGA, Grasse
Remarks	updates of the DTM model are ongoing with CHAMP and GRACE data

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-SGA
Product	Solar flux and geomagnetic activity indices
Spatial resolution	n.a.
Time coverage	1 week
Time resolution	daily / 3-hourly
Latency	24 hr
Volume	< 1 KB/day
Source	International Service of Geomagnetic Indices (ISGI) at CETP, France and US National Geophysical Data Center at NOAA
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-ATM
Product	Atmospheric pressure data
Spatial coverage	global
Spatial resolution	~1.125°x1.123° x N altitudes
Time coverage	6 hr
Time resolution	6 hr
Latency	10 days
Volume	3 MB
Source	ECMWF
Remarks	GRIB format

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-OCM
Product	Ocean circulation model (bottom pressure)
Spatial resolution	1.875º x 1.875º
Time coverage	n.a.
Time resolution	1 hr
Latency	available
Volume	1 MB
Source	Univ. Hamburg
Remarks	model is forced by atmospheric pressure data

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-OTI
Product	Ocean Tide Model incl. long-period ocean tides
Spatial coverage	global
Spectral resolution	spherical harmonics up to l,m=100
Time coverage	periodic
Time resolution	n.a.
Latency	available
Volume	10 MB
Source	IMG Grenoble (FES model)
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-EGM
Product	A-priori static gravity field model
Spatial coverage	global
Spatial resolution	spherical harmonics up to l,m=360
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	5 MByte
Source	GFZ Potsdam; UTEX-CSR, Austin, Tx
Remarks	Latest CHAMP-GRACE gravity field plus surface data incorporation

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-EGT
Product	Temporal gravity field variations
Spatial coverage	global
Spatial resolution	spherical harmonics up to l,m=100
Time coverage	GRACE mission
Time resolution	periods > 1 month
Latency	available
Volume	7 MB per year
Source	GFZ Potsdam; UTEX-CSR, Austin, Tx
Remarks	GRACE monthly gravity field solutions

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-GRA
Product	Surface and airborne gravity data and/or grids (with uncertainties)
Spatial resolution	variable
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	variable
Source	NIMA, KMS, BGI, ...
Remarks	Data to supplement GOCE observations (polar gaps)

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-TOP
Product	Digital topography/bathymetry model
Spatial resolution	2'x2' (ETOPO2 incl. bathymetry), 0.5'x0.5' (GLOBE, land only)
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	distributed on CD-ROMs
Source	National Geophysical Data Centre, NOAA
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-SCM
Product	Spacecraft parameters
Spatial resolution	mm level
Time coverage	n.a.
Time resolution	n.a.
Latency	prior to launch
Volume	1 KB
Source	ALENIA
Remarks	Macromodel, surface properties, antennas and instruments in SRF

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-EVG
Product	Terrestrial, air-borne gravity and deflections of the vertical data for GOCE gravity field model evaluation & EGG calibration
Spatial coverage	variable
Spatial resolution	variable
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	variable
Source	NIMA, KMS, BGI
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier	GO-2a-EVH
Product	Altimetric sea surface heights and sea surface topography model
Spatial coverage	oceans
Spatial resolution	0.5°x0.5°
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	4 MB
Source	NIMA, KMS, GFZ Potsdam, NOAA, Ocean Circulation Model
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Data Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product-ID	GO-2a-EVN
Product	Geoid heights from GPS minus leveling and regional geoid modelling
Spatial resolution	point values ands gridded data
Time coverage	n.a.
Time resolution	n.a.
Latency	available
Volume	1 MB
Source	public (collection of point values available at GFZ), IGeS, Univ. Hannover
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Identifier ID	GO-2a-EVM
Product	Global gravity field models for GOCE model evaluation
Spatial coverage	global
Spatial resolution	'satellite-only' up to l,m=180, 'combined' up to l,m=360
Time coverage	time of comparison
Time resolution	depending on modelled temporal field variations
Latency	available
Volume	1 MB … 5 MB
Source	GFZ/GRGS, UTEX-CSR, GSFC
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product ID	GO-2a-EVT
Product	Satellite orbit tracking and altimeter data for GOCE gravity field model evaluation
Spatial coverage	ground- and space-based
Spatial resolution	depending on measurement frequency
Time coverage	5 arcs of 1 to 10 days per satellite (about 10) incl. GOCE
Time resolution	n.a.
Latency	available
Volume	100 MB
Source	data centers (Laser, GPS, altimeter, DORIS, PRARE)
Remarks	

European GOCE Gravity Consortium (EGG-C)	**GOCE Ancillary Product Fact Sheet**	Doc.: GO-EGG-PDD-1100 Issue: 1.0 Date: 2002-05-16

Product ID	GO-2a-EVO
Product	GOCE precise orbit computations from external investigators
Spatial coverage	
Spatial resolution	
Time coverage	
Time resolution	
Latency	availability uncertain
Volume	2 MByte per 1 day-arc
Source	e.g. JPL, UTEX-CSR, OSU
Remarks	

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

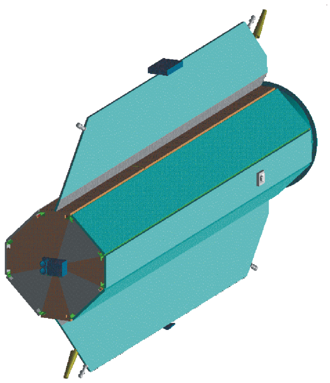
ESTEC Contract No. 14986/00/NL/DC

Slice 1, Work Package 2

GOCE Standards Requirement Document (StRD)

Prepared by:
EGG-C

Compiled by:
Sean Bruinsma, CNES/GRGS



Revision: 1.0
16 May 2002

Contents

0. Summary

The measurement, force, and reference frame models and numerical constants have been taken according to the IERS-2000[1] conventions, the ESA System Requirements Document[A] and CHAMP and (future) GRACE standards and specific results. (Some of) These conventions are required in all orbit computations and in gravity field modelling.

1. Introduction

This document defines the standards that have to be used for the GOCE mission, in particular for the (precise) orbit determination and gravity field modelling. It includes the physical constants, time systems, coordinate systems, and the force and geometrical models. Many elements of the aforecited list are not yet available today, but depend on the success of the CHAMP and GRACE missions. In particular, the initial static gravity field and the temporal gravity variations due to hydrology and snow cover variations are not presently available. The constants and models adopted here are currently state of the art.

The most recent IERS conventions are adopted (IERS-2000[1] at present), as good as possible, in combination with specific project standards mainly concerning the gravity field modelling. Because this document is written in the early stages of the mission preparation, it is subject to change until the actual launch of GOCE.

2. Input

The following input is required for the GOCE standards:

- ESA System Requirements Document[A].
- 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; these are detailed in the following section.
- Global and local grids of digital terrain model and free-air gravity anomalies.

3. Standards Definition

3.1 Reference System

The following table defines the reference system (time systems[1], reference frames[1,A] and speed of light[1]).

TIME	TT (terrestrial time, ex-TDT) or TAI
CCRS	mean equator and equinox of J2000.0 (= ICRF)
CDRS	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	ITRF2000[8]/GRIM5-CHAMP/GRACE
axis	IERS reference pole and reference meridian
time evolution	No global net rotation
origin	Earth's centre of mass
Velocity of light	c = 299792458 m/s
Scale	consistent with TT
SRF	Satellite physical coordinate Reference Frame
SARF	Satellite Alignment Reference Frame
GRF	Gradiometer Reference Frame
LORF	Local Orbital Reference Frame
RERF	Radial Earth-pointing Reference Frame

TAI	International Atomic Time
CCRS	Conventional Celestial Reference Frame
ICRF	IERS Celestial Reference Frame
CDRS	Conventional Dynamical Reference Frame
IAU	International Astronomical Union
IERS	International Earth Rotation Service
CTRS	Conventional Terrestrial Reference System
CTRF	Conventional Terrestrial Reference Frame
ITRF	IERS Terrestrial Reference Frame

3.2 Dynamical Model

The following table defines the dynamical model required in the orbit computation.

Earth	R = 6378136, 6 m (Earth's equatorial radius) 1/f = 298.25642 (inverse flattening of reference ellipsoid) ω = 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 preprocessing, 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[1], permanent tide not removed ocean tides : GRIM5-CHAMP/GRACE long wavelength solution + most recent FES solution[6], 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)[1]
Relativity	Schwarzschild correction , Lense-Thirring and geodetic precession (tbd)
atmospheric drag solar radiation Earth radiation thermal thrust empirical accelerations	DTM 2000 density model[4] (updated with CHAMP data) solar constant 4.5605.10^{-6} Nm^{-2} at 1 AU, exponential regularising function albedo and infrared, daily geographical mean values (ECMWF) Lambert's law Tbd during data gaps

Spacecraft geometry and thermo-optical properties:
macro-model (facets) and physical coefficients (for drag and pressure): specular and diffuse reflection coefficients, emissivity, satellite surface temperatures
mass history

3.3 Geometrical Model

The following table defines the geometrical model in order to correct the measurements for several effects (propagation through the atmosphere, site displacement, etc.).

Station positions	ITRF2000[8] (or updated)
Station velocities	horizontal : ITRF2000 ($\sigma < 5$ mm/a), NUVEL1A-NNR[9] (or updated) vertical : ITRF2000 ($\sigma < 5$ mm/a), ICE4G-VM2[10] (or updated)
Site displacements:	
geocentre	empirical annual and semi-annual motions
Earth tides	anelastic Earth model[1]
ocean loading	based on most recent ocean tide models
atmosphere load.	based on ECMWF pressure data
pole tide	$\tilde{h}_2 = 0.5133$ [5] (IERS-2000: ?)

Satellite centre of mass and other parameters (in SRF):	
	c.o.m.
	position of GPS antenna (phase center) and SLR retro-reflector array
	star trackers and thrusters (position + orientation in SRF)

Tropospheric refraction	Laser : Marini and Murray[1] or update[7] GPS: CNET, Niell (elevation ≥ 12°, or tbd)
Relativity	range and Doppler correction (p.p.n. formulation, Sun-Earth-Moon)[1] clock correction: GPS-SST (Martin-Torrence-Misner)[1]
GPS-SST	ambiguities, clock offsets, GPS ephemerides (International GPS Service)

Digital Terrain Models	global dtm/depth grid (5' x 5'), and local dtm grids (resolution tbd) - used in tasks 3, 6, 9. Information of geometrical nature, but used in terms of its gravitational effect.

4. Status

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[2] conventions and GRIM5 standards[3] are available, while the IERS-2000 conventions are nearly completed. The GRACE standards are not yet defined.

5. Critical Items

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

6. Relation to GOCE Products

Some GOCE products, as defined in the PDD, require knowledge of the standards that are given in this document. These are listed below per product level.

Level 0 Products:
- Spacecraft calibration data (measured on ground or in orbit).
- Spacecraft and instruments reference frames and their relations
- Satellite macro-model

Level 1A Products:
- Star tracker observations (quaternions).

Level 1B Products:
- Calibrated and corrected gravity gradients in three directions provided in the local satellite reference frame (not in Earth-fixed frame !).
- Calibrated and corrected common mode accelerations in three directions provided in the local satellite reference frame.
- Preliminary orbit.
- Satellite linear and angular acceleration vectors
- Satellite attitude, angular velocities and centrifugal accelerations

Level 2 Products:
- Precise orbit and clock solution in Earth-fixed reference frame.
- Coefficients of spherical harmonic series for the Earth gravity field including their standard deviations.
- Map of geoid heights derived from spherical harmonic series and their errors derived from the variance-covariance matrix.
- Map of gravity anomalies derived from spherical harmonic series and their errors derived from variance-covariance matrix.
- Maps of geoid slopes (vertical deflections) derived from spherical harmonic series and their errors derived from variance-covariance matrix.

- Variance-covariance matrix of spherical harmonic series coefficients.
- Geo-located gradiometer and SST data.
- Kinematic and reduced dynamic verification orbits.

7. Related Documents

A – ESA System Requirements Document, GO-RS-ESA-SY-0002, Issue 2, 2001.

8. References

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

ESTEC Contract No. 14986/00/NL/DC

Slice 2

GOCE Architecture Design Document (ADD)

Prepared by:
EGG-C

Compiled by:
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Radboud Koop, SRON

Revision 1.0
17. May 2002

Table of Content

1. Introduction

The following architectural design document describes the system and Software architecture for processing GOCE level 1 data (corrected and filtered observations) to the level 2 gravity field and orbit products including their error assessment. The level 2 products are the basic input for the scientific use of GOCE in various disciplines. Therefore the product determination has to be performed with the highest possible quality applying the most up to date algorithms and processing techniques. The level 1 to level 2 processing system will be implemented by a European consortium called EGG-C (European GOCE Gravity Consortium), which is formed by several groups working since many years in the area of gravity field modelling. The overall GOCE processing system architecture shall reflect the common approach and the synergy of expertise of these groups.

The architecture of the complete system is built by several tasks, which can be worked out to a large extent independently, as soon as the interfaces between the tasks are fixed. Therefore the architectural design document is also separated into tasks and sub-tasks showing the architecture of each processing element. It was agreed within the consortium to describe the sub-tasks architecture by the following elements (if applicable):

- Abstract: Short overview of the task/sub-task and its relation to other tasks/sub-tasks within the full processing system.
- Flow-Chart: Graphical overview of the processing task showing the individual processing steps and their sequence.
- Definition: Description of the processing steps as they are shown in the flow-chart.
- Input: Necessary input to perform the sub-task.
- Constants: Constants to be used during processing.
- Output: Results of the processing task.

A similar structure is also used to describe the architecture of the overall processing system, where it can be identified how the different tasks and sub-tasks interact among each other and with external data providers. The architectural design document therefore is hierarchically structured, providing the overall structure in chapter 2 and the sub-tasks structures in chapter 3.

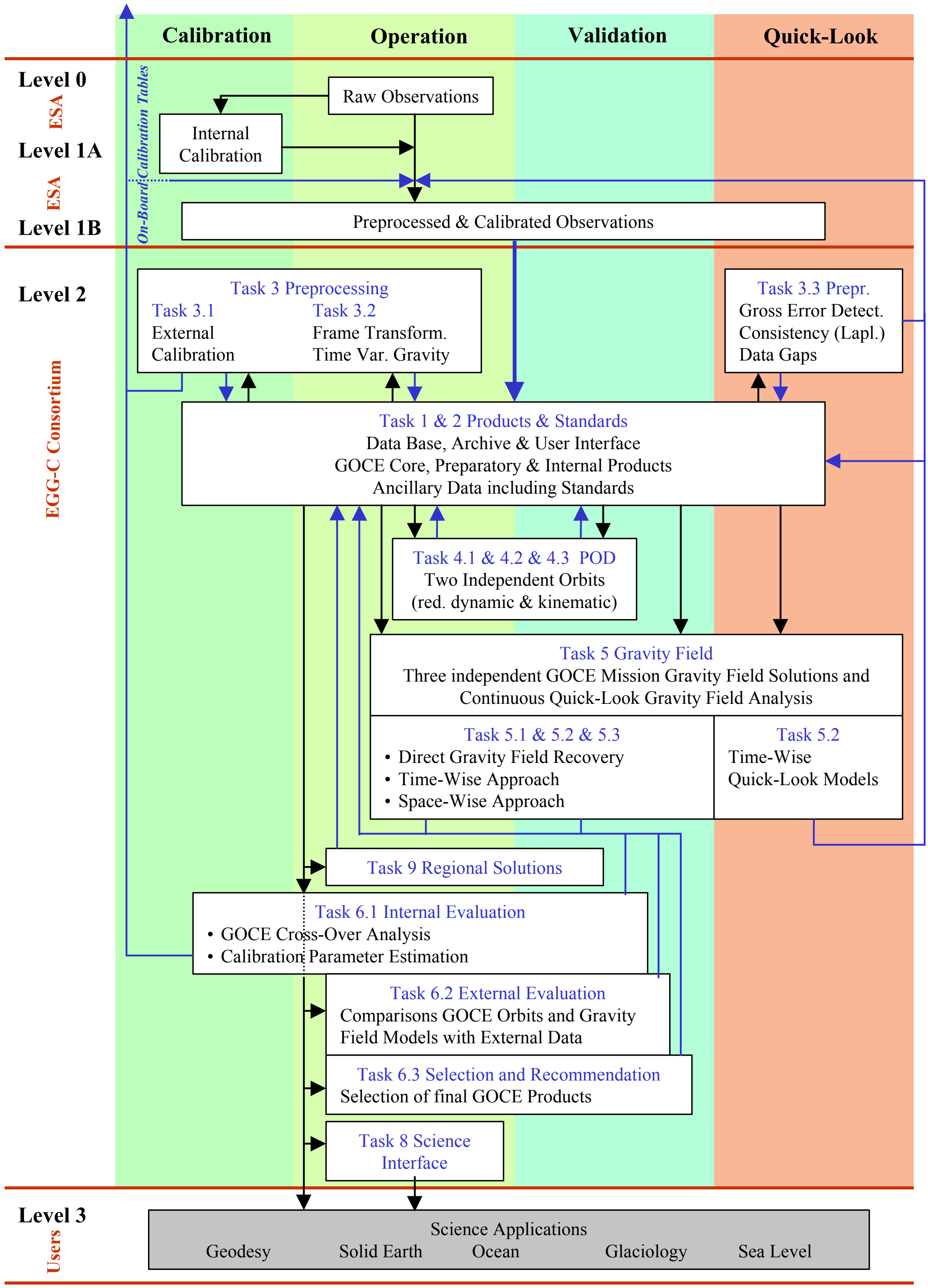
2. General Level 1 to Level 2 Processing System Architecture

Abstract

As mentioned in the introduction, the overall processing system will be built by several European groups in a common effort. Starting with level 1 GOCE data from the operational ESA processing facility, various tasks have to be performed to compute the predefined GOCE level 2 products. For these tasks also several sets of ancillary data are necessary, which have to be acquired and provided systematically by the consortium. Generally the processing system has a complex structure, which has to be divided into several groups of processing tasks and sub-tasks. This general structure is shown in the following flowchart and the tasks descriptions.

Flow-Charts

The flow-chart below shows the inter-connection between the different tasks as they are described in the next section. 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 task or sub-task 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 (more details are provided in the subsequent tasks descriptions). 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.


Calibration
Operation
Validation
Quick-Look
Level 0
ESA
Level 1A
ESA
Level 1B
Level 2
EGG-C Consortium
Level 3
Users
On-Board Calibration Tables
Raw Observations
Internal Calibration
Preprocessed & Calibrated Observations
Task 3 Preprocessing
Task 3.1
External Calibration
Task 3.2
Frame Transform.
Time Var. Gravity
Task 3.3 Prepr.
Gross Error Detect.
Consistency (Lapl.)
Data Gaps
Task 1 & 2 Products & Standards
Data Base, Archive & User Interface
GOCE Core, Preparatory & Internal Products
Ancillary Data including Standards
Task 4.1 & 4.2 & 4.3 POD
Two Independent Orbits
(red. dynamic & kinematic)
Task 5 Gravity Field
Three independent GOCE Mission Gravity Field Solutions and
Continuous Quick-Look Gravity Field Analysis
Task 5.1 & 5.2 & 5.3
• Direct Gravity Field Recovery
• Time-Wise Approach
• Space-Wise Approach
Task 5.2
Time-Wise
Quick-Look Models
Task 9 Regional Solutions
Task 6.1 Internal Evaluation
• GOCE Cross-Over Analysis
• Calibration Parameter Estimation
Task 6.2 External Evaluation
Comparisons GOCE Orbits and Gravity
Field Models with External Data
Task 6.3 Selection and Recommendation
Selection of final GOCE Products
Task 8 Science Interface
Science Applications
Geodesy
Solid Earth
Ocean
Glaciology
Sea Level

Definition

The processing blocks (= tasks) of level 2 are:
Task 1: Standards
Task 2: Data base, archive and user interface
Task 3: Pre-processing
Task 4: Precise orbit determination (POD)
Task 5: Gravity modelling
Task 6: Solution evaluation
Task 7: Public relation (not included here)
Task 8: Science interface
Task 9: Regional solutions

In its current version the numbers of these nine tasks have been kept, but the logical structure of the nine elements has been re-arranged, according to the discussion at the first progress meeting. We shall distinguish between sensor level 1 a/b, orbit and gravity processing level 2 and science & 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 shields 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 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 perform 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 feed back 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 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 (user manual) and (2) to prepare specialised data products tailored to the specific needs of assimilation models.

Input

Input to the level 1 to level 2 processing system are the pre-processed and calibrated observations from the level 0 to level 1 processing system as well as ancillary products, which are necessary to perform the processing tasks. All products are more specifically described in the GOCE products definition document [5].

Output

Output of the level 1 to level 2 processing system are the precise orbit for GOCE and the GOCE gravity field solution including their error estimates. Some derived gravity field products, which are requested by the science users will be provided together with the gravity model. Details for the level 2 products, which will be generated by the level 1 to level 2 processing system can be found in the GOCE products definition document [5].

3. Tasks Architecture

This chapter provides for each sub-task (as defined in the previous chapter) the architecture of the Software in terms of an abstract, a flow-chart, the definition of the different processing tasks, the input products and the output products. First estimates of the necessary computer resources are not included in the architectural design document, but can be found in the Software validation plan [15].

3.1. Task 1: Standards

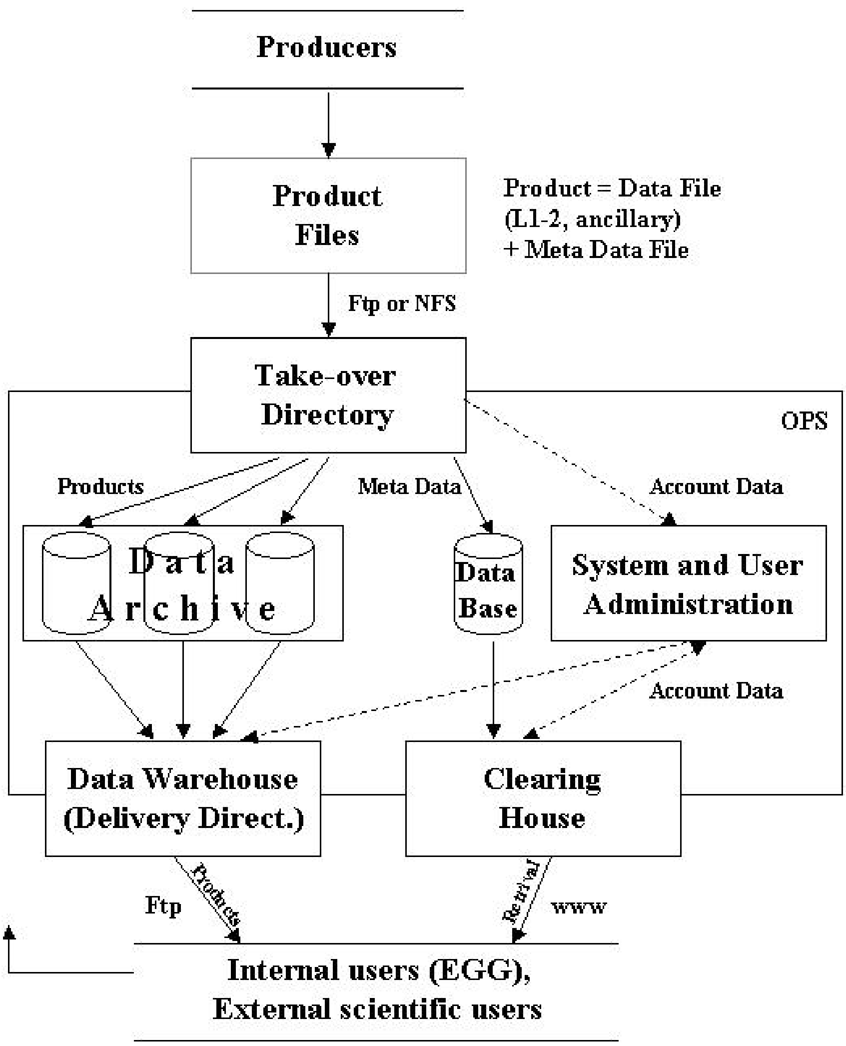
The standards are described in detail in the GOCE standards requirements document [4]. For this reason and because it is not a real processing task no further description is provided in this document.

3.2. Task 2: Data Base, Archive, User Interface

Abstract

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).

Flow Chart



Definition

The GOCE Information System and Data Center (ISDC) consists of three major functional parts, the Operational System, the Clearinghouse and the Data Warehouse.
For the ISDC, **one product** consists of a **product data file** plus a **meta data file** (containing the reference, description and the data base retrieval attributes of the product).
'Users' are GOCE product producers (internal) and external scientific users.

The **Operational System (OPS)** is responsible for

- product input (from the upload directory) via Ftp or NFS and product output (download directory)
- transfer of products into the long-term archive and vice versa
- system administration, user management and monitoring
- storage and management of product meta data in relational data base structures
- realisation of user access policy (access levels from 'public' to 'internal')
- backup strategies

The **Clearinghouse** provides

- a catalogue system for users' product retrieval in the OPS data base via graphical and non-graphical user interfaces
- access to selected meta data files
- spatial retrieval for products containing spatial attributes (regional data)

The **Datawarehouse** provides

- graphical and non-graphical product output interfaces to the users:
  a) user specific ftp-directory where the products are downloaded upon request
    - on-line, after retrieval (single event request)
    - in batch mode (following a script in the user's ftp directory) for permanent requests
    - in direct delivery mode for time-critical products directly after entering the ISDC upload directory
- visualisation of products
- spatial presentation of products containing spatial attributes (regional data)

Input

- GOCE data model (product types, rates, amounts, flow)
- GOCE data policy
- Meta data standard
- Simulated products (for development phase)
- User requirements (internal and external) concerning access modes

Constants

As defined in task 1.

Output

GOCE Information System and Data Centre (ISDC)

3.3. Task 3: Pre-processing

The pre-processing here 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 subtasks with the following functions:

Task 3.1	External calibration: *external calibration* (signal calibration and error assessment)
Task 3.2	providing corrections to the level 1B data: i. *frame transformation* (rotation of the SGG matrix) and ii. *corrections for temporal gravity*
Task 3.3	(quick-look) data screening: i. *gross error (outlier) detection* and removal/correction, quick-look validation and ii. *data gaps*.

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.

3.3.1. Task 3.1: External Calibration

Abstract

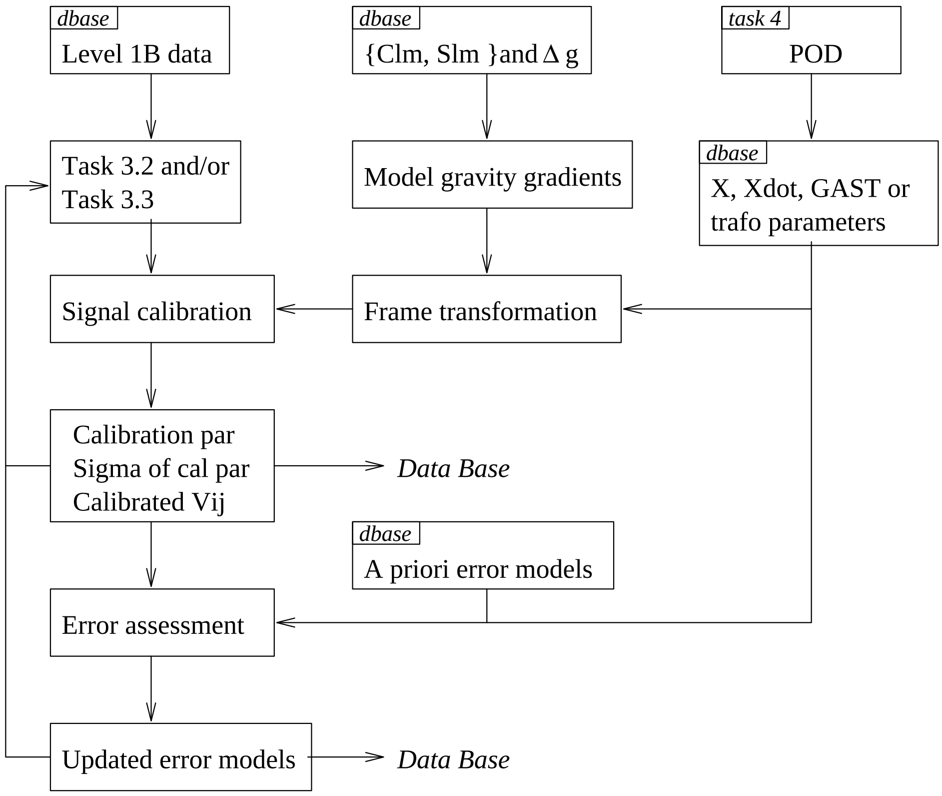
The two parts of external calibration are signal calibration and error calibration. Signal calibration is understood here in the sense that actual corrections are determined and applied to the data. Error calibration is to be understood as error assessment, where one tries to derive a proper error description of the data from the real observations themselves, supported by external data, and to compare this error to the a priori specified error model.
Here we address exclusively the external calibration of the SGG observations. Calibration of the SST observations is included in Task 4. Calibration of the common-mode observations is addressed only in as far as it relates to the accelerometer calibration parameters determined from the differential mode, but no explicit method for external calibration of the CM observations is foreseen. In Task 5 common-mode acceleration calibration parameters (bias and scale factor) are estimated. Calibration of attitude observations could include bore-sight transformation of the star sensors to the satellite reference frame, but is also not discussed here.
The aim is to estimate scale factors, biases, tilts and possibly other parameters using comparison with external data. Such calibration parameters are directly related to scale factors, biases etc. of the individual accelerometers, but more in general the external calibration performed here will also correct for any other remaining (instrumental) errors and processing errors in the level 1B data.
Two methods for external signal calibration will be considered here: calibration with global gravity field models, and calibration with ground-based gravity data, see e.g. *[Arabelos and Tscherning, 1998; Koop et al., 2001a]*. Both methods rely on an accurately determined orbit (POD, Task 4). A possible problem is the frequency dependency of the calibration parameters (TBC). Additional verification of the SGG calibration parameters provided here can be done by including the estimation of such parameters in separate runs of the level 1 to level 2 processing (see Task 5).

The error of the SGG data will be assessed using X-overs, repeat tracks and/or along track interpolation *[Albertella et al., 2000a, 2000b, Koop et al., 2001, Bouman and Koop, 2002]*. These three methods can be used for outlier detection as well (see Task 3.3).

External calibration using ground-based gravity data
At first glance it would seem impossible to calibrate GOCE data with existing (external) data, since it would imply that existing knowledge would be as good as or better than GOCE data. However, indeed in certain regions of limited size (but not globally), terrestrial data will be better than GOCE data, both in terms of resolution as accuracy. So calibration parameters like scale factors and biases will be determined from a comparison of GOCE data with terrestrial data in a certain well-surveyed region. Typically, the terrestrial data will be more accurate than GOCE data for high frequencies, maybe also for frequencies inside the GOCE measurement band-with (MBW).
A combination of high-accuracy local gravity field observations with global gravity field models is a promising way to deliver sufficiently accurate results, for example by accurately reducing the long-wavelength part in the terrestrial data, cf. *[Arabelos and Tscherning, 1998],* or by really combining the two data types into one estimation procedure, cf. *[Pail, 2001]*.

External calibration using global gravity field models
Existing global gravity field models will not be better than GOCE data in a global sense and over the whole spectral range. But, in case of SGG observations, existing models will be better than GOCE data for the lower frequencies below the MBW. So, we can determine calibration parameters from a comparison of GOCE data with global models in the lower frequency range. Here we must assume that the calibration parameters are not frequency dependent, in order to apply them to the whole frequency band containing the measured signal, see e.g. *[Koop et al., 2001a]* for a calibration simulation study for SGG observations. It is important to understand the limitations of this method due to the possible large discrepancies between the quality of such global models (e.g. aliasing!) and the expected quality of the GOCE data, both spatially and in the frequency domain. For the same reason the possibilities for the determination of an absolute scale factor for the gradiometer observations using the J_0 and J_2 terms (cf. *[ESA, 1999]*) is limited. It is expected that improved global gravity field knowledge from CHAMP and GRACE will offer better possibilities for such calibration tasks.

Flow Chart



Definition

A calibration procedure using ground data consist of the following steps:

- Selection and pre-processing of ground data, including identification of calibration areas and selection of data, subtraction of the contribution from the a-priori global model from the gravity data (depending on the specific method to be chosen), calculation and subtraction of the topographic effect from the ground data (also depending on the method).
- In case of using a collocation approach: estimation of empirical covariance function in each block or calibration area, determination of the parameters of the empirical covariance functions.
- Appropriate "reduction" of the GOCE observation data (i.e. computation of anomalous quantities being the differences between the observations and the contribution from the a-priori spherical harmonic model) to be compared to the external data.
- Upward continuation of the ground data and comparison with the GOCE observations.
- Error assessment (using the spectrum (or covariance function) of differences between the computed and the observed data).
- In case of a combined approach: apply a combined solution strategy including high-accuracy ground gravity data (mainly short wavelength information), supported by a global Earth gravity model (long wavelengths).
- Deduction of calibration parameters. The data are used to determine an approximation of the anomalous gravity field for the area using simultaneously ground and GOCE

data. As a part of this, calibration parameters (biases, tilts, scaling factors, etc.) and their error-estimates may be determined.

- Calibration factors are applied in order to correct the level 1B data.

A similar structure applies to calibration with global gravity field models, except for (of course) the steps which only apply to the ground-based gravity data.

Input

Product ID	Product
GO-1B-EGG	Gradiometer calibrated and corrected gravity gradients
GO-1B-EGG+ERM	A priori SGG error model
GO-2p-PSO+GOC_RD	GOCE precise science orbit
GO-2a-EGM	A priori global gravity field model
GO-2a-EVG	Surface and airborne gravity data with errors
GO-2a-TOP	Digital Terrain Model
GO-2p-EGM+COV	Global covariance functions for the gravity field
GO-2p-REF+LORF2RERF	Rotation matrices between LORF and RERF

Constants

All data must be given in a consistent reference system.
Gravity in calibration area must be in IGSN71 and associated heights must be in a well defined datum.

Output

Product ID	Product
GO-2p-EGG+CAL	SGG calibration parameters + errors
GO-2p-EGG+ERM	Updated gradient error model
GO-2-EGG	Calibrated gradients
GO-2i-EGG+UPC	Upward continued SGG observations from ground data

3.3.2. Task 3.2: Frame Transformation and Temporal Gravity

Abstract

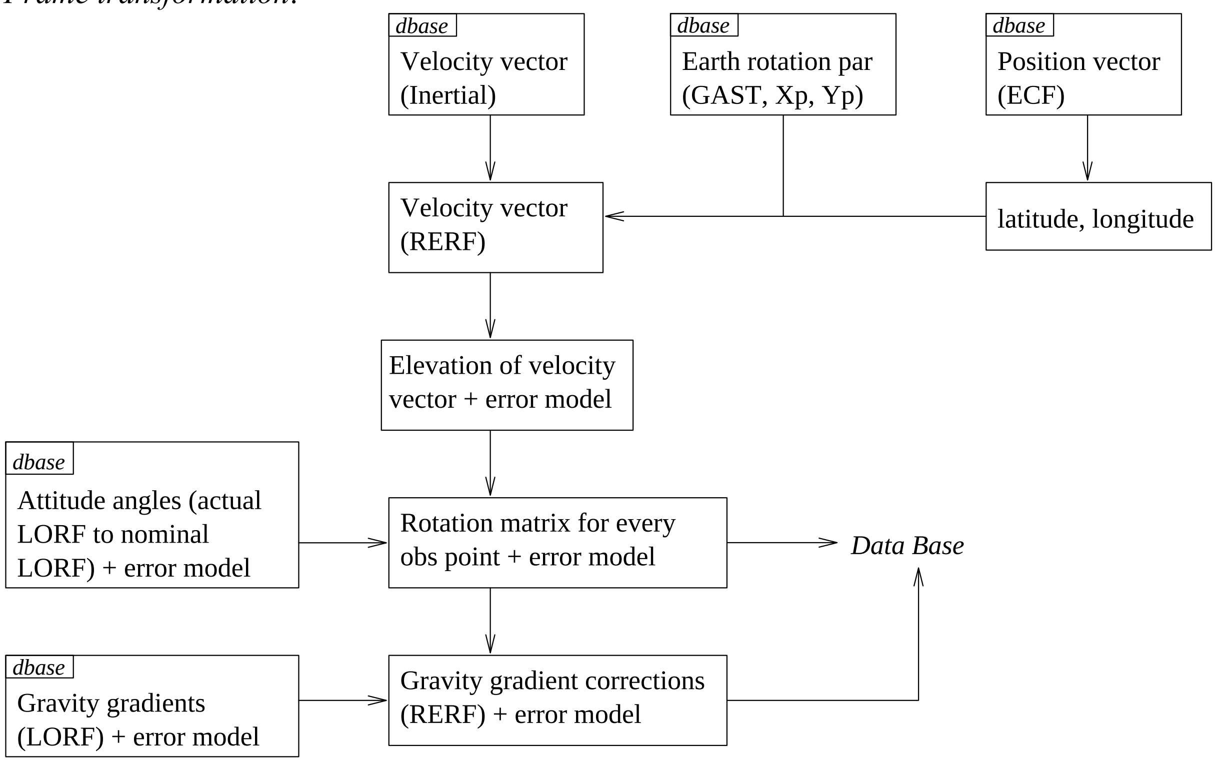
Frame transformation:
The level 1 GOCE SGG observations are given in the local orbital reference frame (LORF). The gradients (together with their error model) in the LORF will be transformed to the radial Earth-pointing reference frame (RERF). The *y*-axis of the RERF coincides with the *y*-axis of the LORF. The *z*-axis of the RERF is pointing radially outwards away from the Earth's centre. The transformation here is done for two reasons: more simple observation equations between the gradients and the harmonic coefficients are obtained (necessary for certain level 1 to level 2 processing methods, in particular task 5.3), and secondly the observed gradients themselves are an important geophysical data product which are also to be available in the RERF. The frame transformation from the actual LORF to the nominal LORF consists of a simple

rotation about the attitude angles as they are derived from the gradiometer and star tracker observations. In addition the SST observations are needed (or the satellite's state vectors) to rotate from the nominal LORF to the RERF.

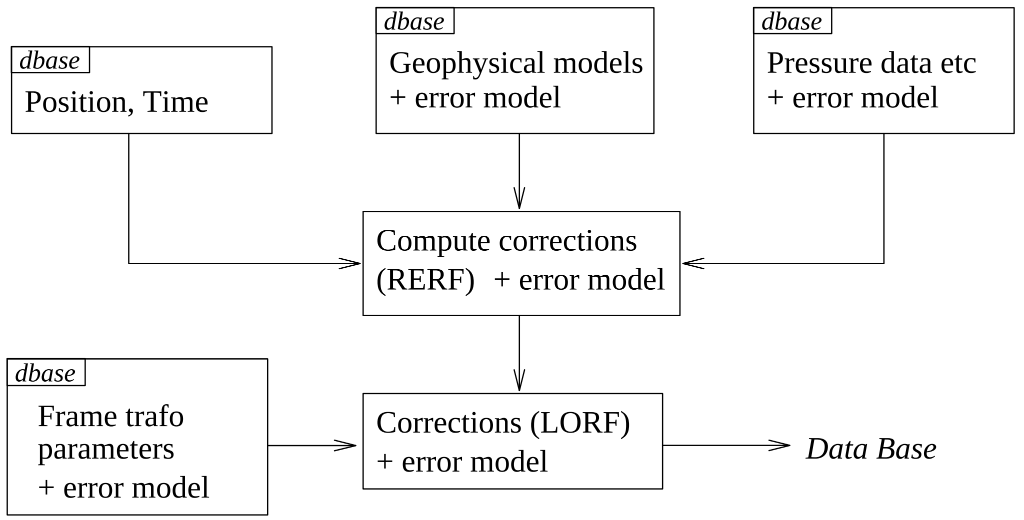
Temporal gravity:
The GOCE measurement periods consist of two (may be three?) windows of six months with a hibernation period in between. Although the aim of GOCE is the determination of the static gravity field and the measurement period of GOCE is short compared to certain temporal gravity variation signals, the GOCE observations, being extremely precise, will suffer intrinsically from both short and long period temporal gravity variations. If such temporal gravity variations during the GOCE mission would be known explicitly from models or external data one could correct the GOCE observations in the pre-processing step. At the time GOCE flies CHAMP and GRACE will have flown or still are flying, so there will be improved information available from these missions about the temporal gravity behaviour to be used for corrections to the GOCE data. An important issue here is the error assessment of the temporal gravity information and of the corrected GOCE observations. In case the estimated corrections for temporal gravity would appear to be inadequate, tests could be defined and performed where one tries to estimate corrective terms in the level 1 to level 2 processing (see Task 5).

Flow Chart

Frame transformation:



Temporal gravity:



Definition

Frame transformation:
The following steps have to be performed:

- The frame transformation of the LORF to the RERF consists of a rotation. A standard rotation matrix (rotation around the *y*-axis) is applied to the measured gradient matrix. If the measurement error of the less-accurate off-diagonal gradients (xy and yz) in the MBW would exceed the uncertainty in such gradients computed from an a priori gravity field model, the measured values should be replaced by the modelled values in order to achieve a better precision in the RERF.
- Standard error propagation of the gradients from the LORF to the RERF.

Temporal gravity:
The temporal part of the GOCE SGG observations from a priori geophysical models or directly from the GRACE data for the overlapping mission period between GOCE and GRACE (if any) will be computed and provided as corrections as part of the output data. An error assessment of the temporal gravity corrections follows.

Input

Product ID	Product
GO-2-PSO+GOC	GOCE Precise science orbit
GO-1B-ATT	Satellite attitude
GO-1B-EGG	Gradiometer calibrated and corrected gravity gradients (all 9 SGG components)
GO-1B-EGG+ERM	A priori SGG error model (for all 9 SGG components)
GO-2a-EGM	A priori global gravity field model
GO-2i-AOV	Geophysical models for temporal gravity

Constants

Data should be given in consistent reference systems.

Output

Product ID	Product
GO-2-EGG	Corrections to SGG observations for transformation from LORF to RERF
GO-2-EGG	SGG error estimates in the RERF
GO-2p-REF+LORF2RERF	Rotation matrices between LORF and RERF
GO-2-EGG	Corrections to SGG observations for temporal gravity

3.3.3. Task 3.3: Outlier Detection and Data Gaps

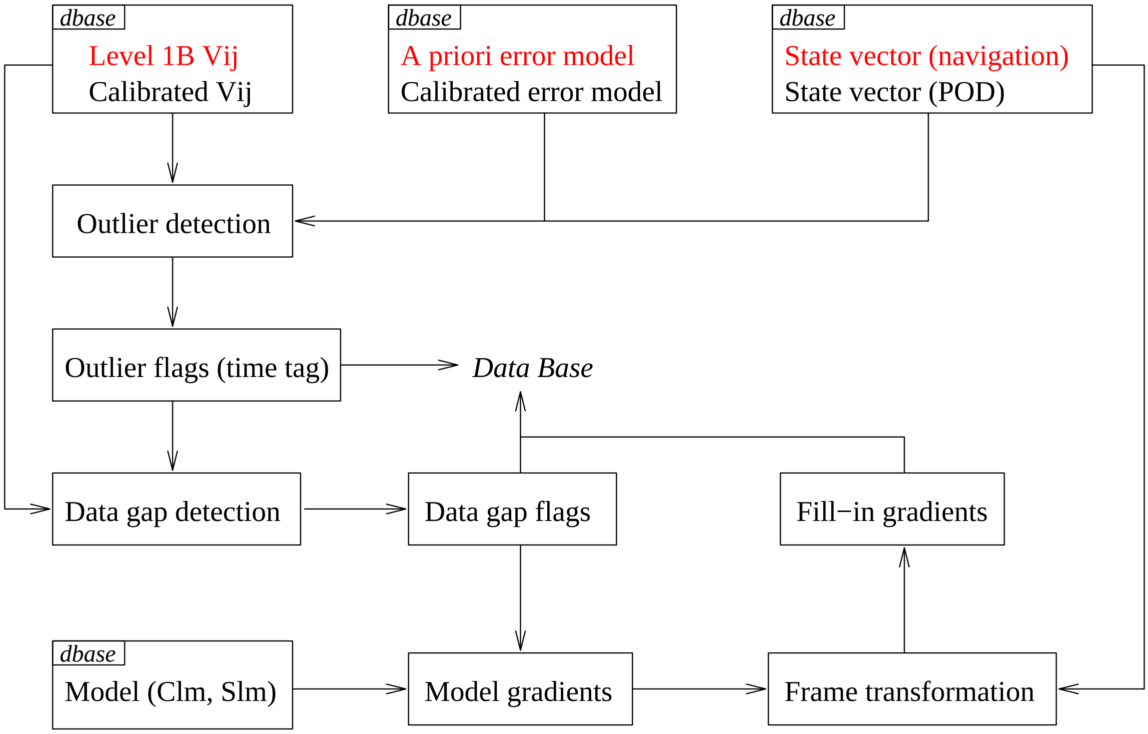
Abstract

Outlier detection
Apart from existing standard statistical tests, any method which results in computed GOCE data types from other sources or the GOCE data itself (like methods described in the section on external calibration) can be used for the detection and removal or repairing of outliers (gross errors). For a discussion and simulation studies on outlier detection methods see e.g. *[Albertella et al., 2000a, 2000b]*. The method which will be described here (see Definition) is based on the use of cross-overs. In general, the checks consist in verifying that the two estimated values lie in an interval of given significance; if one of the observed tensor components used in performing the estimates is affected by a gross error, the test will fail and the data set in use should be re-examined. Other methods based on different structures may be applied too but the application of these methods depend on the character of the data and the outliers. We here give two examples of such methods:

- loop checking procedure: The available check is $T_{ZZ}(C) = T_{ZZ}(C_0)$ with C, C_0 = loop points. As the measures are not directly performed in C, C_0, but must be interpolated starting from other points, systematic errors and noise propagation of the procedure must be assessed.
- overlapping (repeated) tracks checking procedure: For tracks with an altitude difference of less than 1 km, the available checks are: $Tii(P') = Tii(P'')$ (with *ii*=*XX, YY* or *ZZ*) where *P'* and *P''* are corresponding points (same geographic coordinates) on the upper and lower orbital arc: of course, the points along one orbital arc are observation points, while the observations along the other orbital arc must be interpolated.
  For tracks with an altitude difference of more than 1 km, the available test is on the T_{XX} component: $T_{XX}(P') \cong T_{XX}(P'') + T_{XXZ}(P'') \cdot H$ where H is the orbital height difference.

Data gaps
For small data gaps (up to only a couple of observations) fill-in values shall be provided using LSC. Such values shall be indicated (flagged) in the output data files so that subsequent users can decide to use them or not, depending on their application. This will not be done for large data gaps of considerable size (TBD) like one or more revolutions.

Flow Chart



(The inputs for quick-look control are in red, the inputs for pre-processing in subsequent Level 2 processing are in black.)

Definition

Outlier detection

Reduced GOCE data are predicted from ground data and from other (reduced) GOCE data located in an area around the data to be checked; the difference will be compared with the estimate of the error of prediction; the data will be flagged if the difference is larger than 3 times the error of prediction. For altitude differences within 1 km the available check is

$$T_{ZZ}(C) = T_{ZZ}(C_0)$$

C, C_0 = cross-over points (see also loop-checking procedure, same reasoning).
For altitude differences of 3 km, on the contrary, the noise propagation shows that the proposed checking procedure cannot be performed.
In this case, another check would be possible, namely

$$Q^+(K) = Q^-(K)$$

where Q is a suitable functional of T_{XX}, T_{XY}, T_{ZY}, computed at point K, which is the average altitude point between C and C_0, starting from the upper orbit (Q^+) and from the lower orbit (Q^-).
Description of student t test method for outlier detection:
Procedure for outliers detection and rejection consisting of a hypothesis test which uses a statistics with student t distribution. Structure of the method:

– Predict the signal $\hat{F}$ (t_k) from neighbouring data
– Compute the prediction error $e_k = F(t_k) - \hat{F}(t_k)$
– Based on e_k, construct a sample variable of known distribution, suitable to test a deviation from the zero-mean hypothesis (i.e. presence of outliers)
– The sample variable to test the hypothesis $H_0 : E\{e_k\} = 0$ (zero-mean prediction error) is:

$$\frac{e_k}{\sqrt{C\,(1-\underline{r}_0^T\;R^{-1}\underline{r}_0)}}=t_{2\Delta-1}$$

where: e_k = prediction error; Δ = width of the window of data entering the testing procedure (the distance at which the correlation function drops to zero); C = variance of the data series; $\underline{r}_0$ = correlation between the point to be tested and the other data of the series; R = correlation matrix of the data series. The concept of this test is suitable for automatic implementation.

Data gaps

Data gaps will be filled in using e.g. Least Squares Collocation (LSC). Such "filled-in" values shall be flagged in the output data file.

Input

Product ID	Product
GO-1B-RSO	GOCE Rapid science orbit
GO-2-PSO+GOC	GOCE Precise science orbit
GO-2a-EGM	A priori global gravity field model
GO-2-EGG	SGG observations in the RERF
GO-2-EGG	SGG error estimates in the RERF
GO-2i-EGG+UPC	Upward continued SGG observations from ground data

Constants

All gravity data in the same reference system.

Output

Product ID	Product
GO-2-EGG	Flags for outliers
GO-2-EGG	Flags for data gaps
GO-2-EGG	Fill-in gradients
GO-2-EGG	Statistical information

3.4. 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 well established and defined 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 (see the next sections). 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 orbit determination sub-tasks or strategies, referred to as reduced-dynamic (Task 4.2) and kinematic POD (Task 4.3). 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 needs to be 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.

Two independent types of orbits will be included in the GOCE products:

- reduced-dynamic orbit (GO-2-PSO+GOC_RD);
- kinematic orbit (GO-2-SST+POS).

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 be the best starting position in part of task 5.2 and 9, whereas the reduced-dynamic orbit solutions may be the best starting position 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 within Task 6.1 (see Section 3.6, solution evaluation) from orbits generated with different approaches, namely the reduced-dynamic orbits and the best kinematic orbit (baseline approach 'A', see task 4.3).

In addition, the dynamic orbits generated as by-product of the gravity field recovery (Section 3.5.1) will be included in the validation task 6.1 (Section 3.6). 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.

3.4.1 Task 4.1: Observation Screening

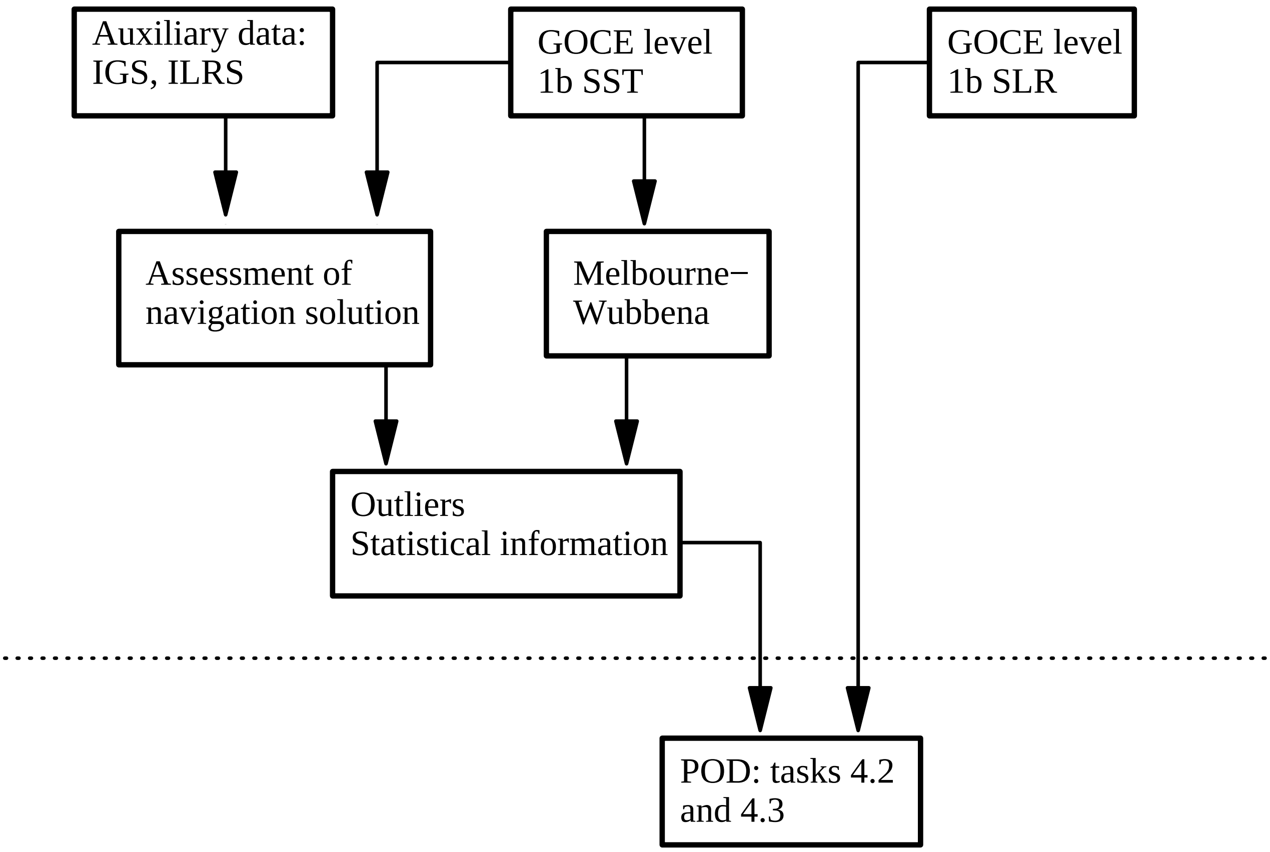
Abstract

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 results 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, for URL: see below). The issue of applying observation corrections is addressed in more detail in the chapters about the products and standards definition (Slice 1). Also for the treatment of ancillary data, e.g. GPS observations collected by ground stations, it is referred to these chapters.
In order to facilitate a fast quality check of the GPS SST data, the following methods have been identified:

1. Melbourne-Wübbena editing (e.g. *Springer, 1999*);
2. assessment of navigation solution (e.g. *Bock et al., 2001*)

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).

Flow Chart



Definition

The checking of the GOCE GPS SST observations can be divided into the following steps:

- collection of observations in RINEX format
- retrieval of IGS clock and orbit solutions of the GPS satellites
- application of observation screening methods
- flagging of outliers and statistical information such as estimated pseudo-range noise level, data gaps and percentage of suspect observations

Input

Product ID	Product
GO-1B-SST	GPS calibrated code and phase data
GO-2a-GNS+EPC	GPS ephemeris and clocks
GO-2a-SLR	Laser tracking data

It is envisaged that the tracking data will be provided in the current standard formats:

- GPS in RINEX format or related format defined by the IGS (see: http://igscb.jpl.nasa.gov)
- IGS orbit and clock solutions for the GPS satellites (also: http://igscb.jpl.nasa.gov)
- SLR (normal points and possibly full-rate observations) in formats specified by the ILRS (see: http://ilrs.gsfc.nasa.gov/ilrs_home.html)

For the first method (Melbourne-Wübbena) the RINEX files are in principle sufficient. For the second method, the clock and orbit solutions of the GPS satellites are also required.

Constants

For the GPS checking, the following constants need to be defined (see also Slice 1): velocity of light: v=299792458 m/s ; GPS: frequencies: f1=1227.6 MHz, f2=1575.42 MHz

Output

The observation screening methods will provide information of the reliability of (individual) observations and also result in statistical information, such as number of outliers and estimated noise level. Outliers are flagged and notifications about these flags are output of the algorithm. For GPS screening, one possibility is to design an enhanced RINEX format that includes flags for suspect observations.

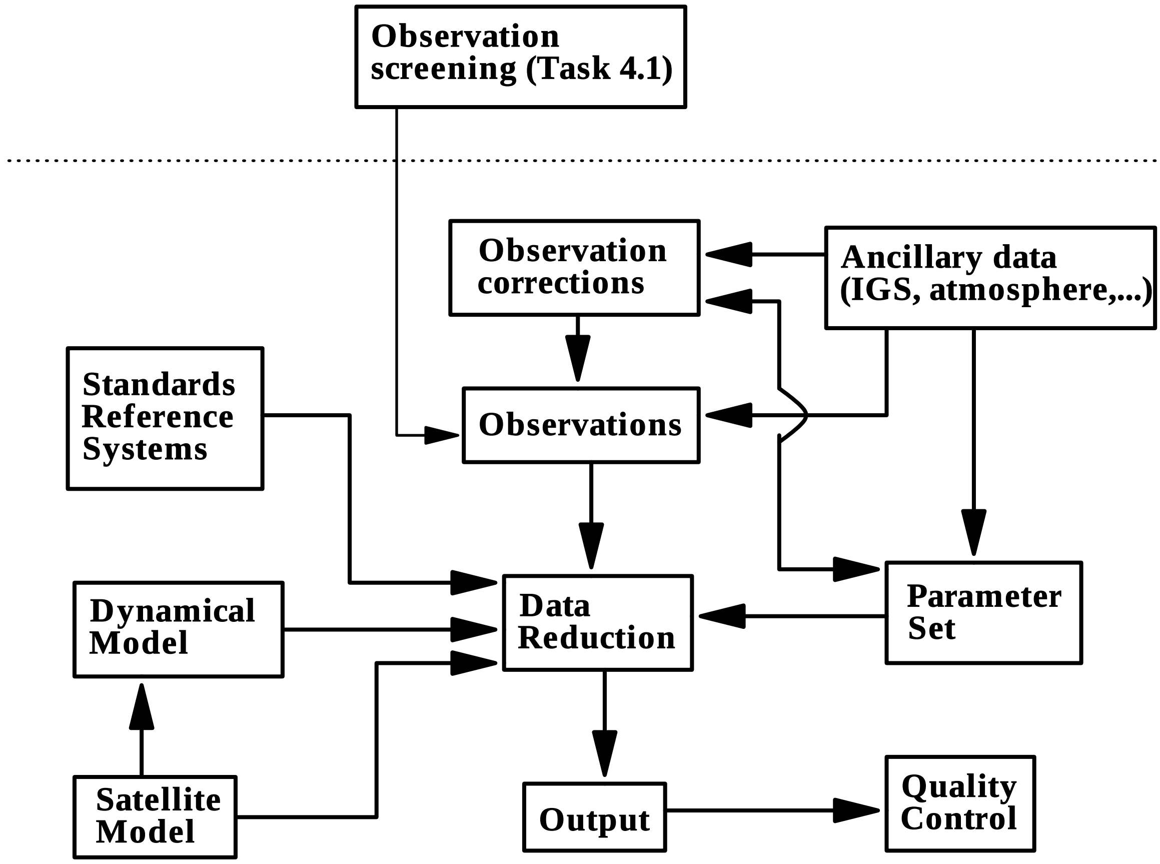
Product ID	Product
GO-2i-SST	GPS preprocessed phase and pseudo range data

3.4.2 Task 4.2: Reduced Dynamic POD

Abstract

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 (GO-2-PSO+GOC_RD). The reduced-dynamic orbit determination will be conducted with the GEODYN software (*Rowlands et al., 1995*).

Flow Chart



Definition

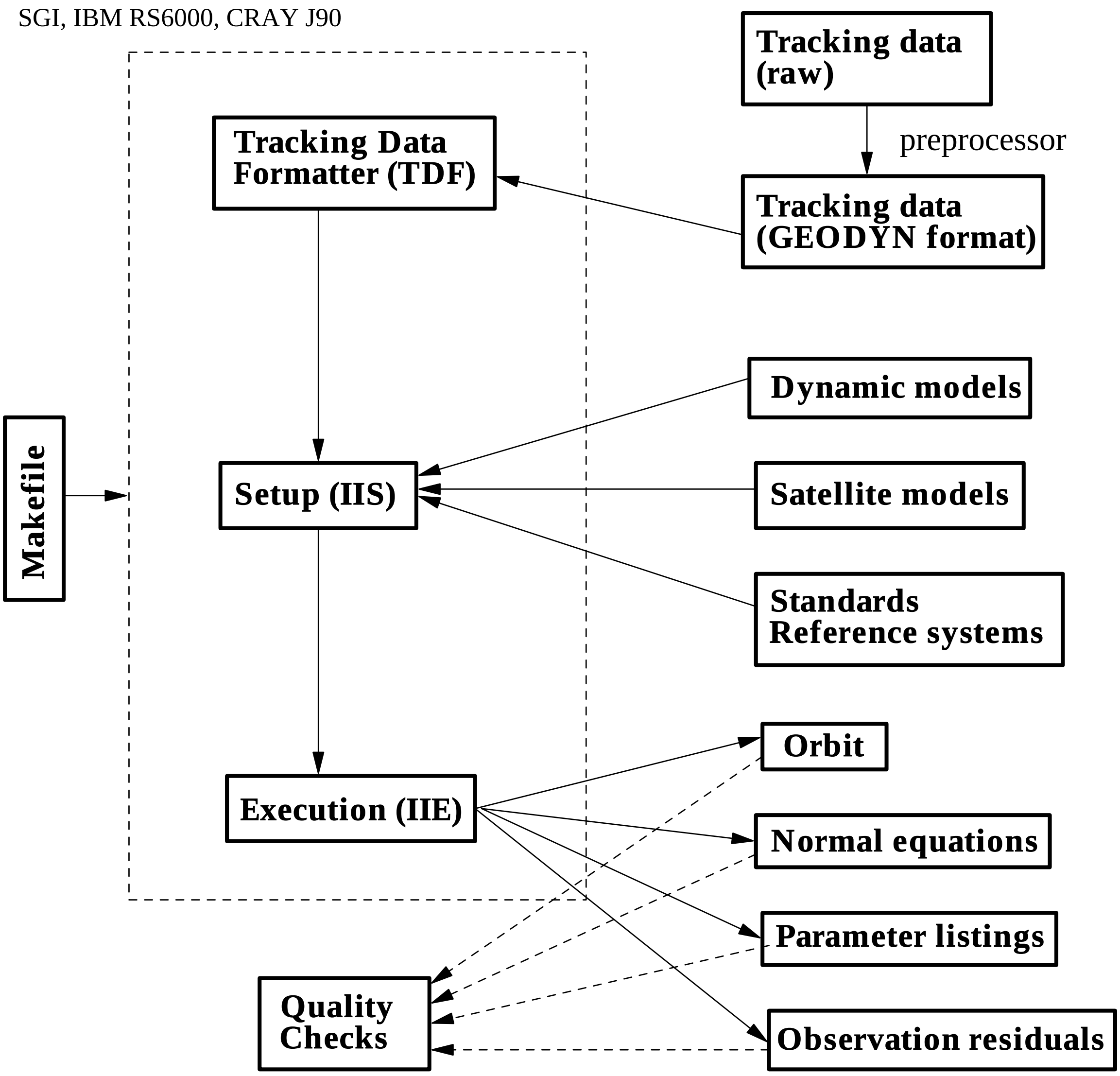
Considering the elements distinguished in the required input in conjunction with the required data reduction step, the reduced-dynamic POD task can be subdivided into the following main elements:

1. Definition of standards and reference systems: this point is addressed in slice 1. A proper definition of standards and reference systems is required for an unambiguous interpretation of GOCE c.o.m. position and velocity coordinates as a function of time.
2. Establishment of the dynamical model: this point is also addressed in slice 1. The dynamical model is intended to include models of all known relevant forces that act on the GOCE satellite and drive its orbital motion.
3. Establishment of the satellite model: again, this point is addressed in slice 1. The satellite model must contain all elements for completion of certain parts of the dynamical model, for example a macro-model to allow derivation of cross-sectional areas in combination with observed/derived/prescribed attitude motion for use in completing the non-conservative force model. In addition, a satellite model must include the information of the exact location of relevant instruments w.r.t. the c.o.m. location. Other types of necessary information include antenna phase centre calibration parameters as a function of the elevation (and azimuth – TBC) of the incoming signals, inter-frequency calibration files (in case use will be made of zero-difference techniques, i.e. deviating from the baseline) and multipath calibration files. Interfaces for these ancillary data sets need to be

established. Nominally, it is foreseen that these data will be delivered as part of Level 1B (TBD).

4. Collection of observations and application of corrections plus ancillary data: the observations can be divided in tracking observations, GOCE satellite specific observations, and auxiliary or ancillary observations. The first include GPS SST and SLR observations**,** the second common-mode accelerations, attitude time series derived from the star-tracker (and possibly gravity gradient observations) plus DFC activity parameters, and the third GPS ground data or IGS-based solutions (clocks, ambiguities, GPS orbits, ...) . The attitude information is required to accurately describe the location of the GPS instrument and location of the laser retro-reflector w.r.t. the satellite's c.o.m. Several measurement (correction) models and observation quality checks are involved in the POD, which will be used in combination with the outcome of Task 4.1 "Observation screening". Depending on the specific reduced-dynamic POD approach, GPS observation differencing schemes are to be included. Nominally, the POD will be based on GPS SST phase triple differences. Currently, a number of 50 IGS GPS ground stations is assumed to be the baseline for forming the triple differences, where the measurement time interval is nominally equal to 10 sec. Nominally, accelerometer observations and DFC parameters are used to model the surface forces. As a backup, drag and solar radiation force models can be used in conjunction with a satellite macro-model. SLR observations are primarily foreseen to serve validation purposes (Section 6.1), but might be included in the data reduction later on.
5. Definition of parameter set: before the actual orbit computations can take place, the set of unknown parameters that will be estimated needs to be defined. The type and amount of unknown parameters depend a.o. also on the quality and kind of ancillary data. They also depend on whether the IGS solutions for the GPS satellite orbits and clocks are of sufficient quality and can be kept fixed. The latter is assumed to be the case in the baseline architecture.
6. Data reduction: all information coming from the previous is input to the data reduction to a precise orbit, which is the actual (iterative) estimation of the GOCE satellite orbit, including in this case both position and velocity estimates.
7. Output generation: the outcome of the data reduction will be presented in appropriate output formats in support of all the other level 1 to level 2 tasks.
8. Accuracy quality assessment: the POD output has to contain all appropriate information for the accuracy/quality assessment, which will be addressed in more detail in the section about task 6.1**.**

Currently, it is foreseen that the reduced-dynamic POD will be conducted with the GEODYN software. The GEODYN processing stream is graphically displayed in the flowchart below.



Input

The required input for reduced-dynamic POD can be subdivided into the following parts:

1. standards and reference systems: see slice 1.
2. dynamic and satellite models: see slice 1.
3. on-board satellite observations:
   a. attitude: derived from star tracker and possibly gravity gradient observations
   b. surface forces: common mode accelerometer, DFC parameters
4. tracking observations: GPS SST. SLR will be used for validation purposes.
5. ancillary data: GPS observations from a global network of IGS ground stations is required for generating differenced observations. In addition, GPS orbit and clock solutions will be included in the POD process.
6. parameter list: depending on the quality of the entire dynamical model, i.e. including all elements described above, a set of unknown parameters has to be defined to be estimated in the reduced-dynamic POD process, or a procedure has to be established that converges to a proper set. The following list contains parameters that will nominally be included, but may be adjusted as experience grows:
   a. Dynamical model:
      i. Empirical accelerations (correlation length, type)

   ii. Drag and solar radiation scale factors when relevant, i.e. when the observed accelerations are not used in the POD
   iii. Scale factor and bias for observed accelerations from common mode
b. GPS observation model:
   i. Atmospheric parameters (fixed or estimated depending on quality of models, atmospheric observations)
   ii. GPS satellite clocks (nominally fixed)
   iii. Inter-frequency bias parameters (only in non-nominal cases when use is made of zero-difference techniques)

Product ID	Product
GO-1B-EGG	Gradiometer calibrated & corrected accelerations
GO-1B-ATT	Satellite attitude
GO-1B-THR	Thrust history of AOCS & drag-free actuators
GO-2i-SST	GPS calibrated and screened phase and range data
GO-2a-SLR	Laser tracking data
GO-2a-GNS+GST	IGS GPS ground station tracking data
GO-2a-GNS+EPC	IGS GPS ephemeris and clocks
GO-2a-GNS+GSA.MET	IGS GPS ground station tropospheric delays
GO-2a-GNS+GSA.ANT	IGS GPS antenna phase center variations, differential code biases
GO-2a-SSC	Station coordinates and velocities from ITRF
GO-2a-ERP	Earth rotation parameters form IERS
GO-2a-SCM	Spacecraft parameters
GO-2a-EGM	A priori gravity field solution
GO-2a-OTI	Tide models
GO-2a-EPH	Sun, moon & planetary ephemeris
GO-2a-RAD	Earth albedo & solar radiation
GO-2a-DTM	Atmospheric density model
GO-2a-SGA	Solar flux and geomagnetic activity indices

Constants

Several constants relating to a.o. reference frames and dynamic models need to be defined. For more details is referred to the contributions slice 1.

Output

The high-level objective of POD is to provide a high-accuracy description of the orbital motion of the GOCE satellite c.o.m. This will be in the form of time series of position and velocity coordinates in well established reference frames, including earth-centred inertial (ECI) and fixed (ECF) reference frames. In addition, information that can be used for a quality assessment (task 6.1) will be attached to the computed orbit, such as observation fits (GPS, accelerometer observations). The following output elements are foreseen:

- position and velocity: Cartesian coordinates in ITRF2000 (or update) with 10 sec time interval (SP3 or enhanced format, SP4)
- position and velocity: Cartesian coordinates in J2000 and true of date with 10 sec time interval (to be included enhanced SP3 format, possibly SP4)
- observation and residual statistics

Product ID	Product
GO-2p-PSO+GOC_RD	GOCE precise science orbit (reduced dynamic mode)

It has to be noted that for certain tasks, it may be required to have position and velocity estimates at a higher data rate. In that case, use can be made of an interpolator that has the same order as the integrator in the data reduction. This interpolator is already fully operational and forms integral part of the POD software. In other words, higher rate position and velocity coordinates can be provided at the same accuracy level in the same product format as the nominal orbits with 10 sec time step.

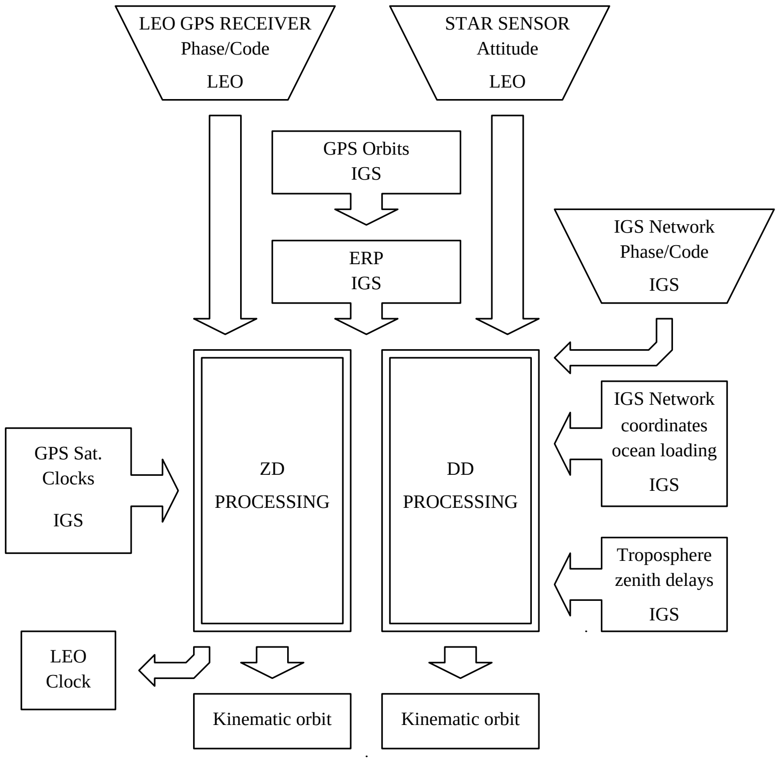
Attitude information is included in the level 1b data (derived from the star tracker and possibly gravity gradient observations). This information will be needed in order to be able to relate the exact location of the GOCE instruments to the c.o.m.

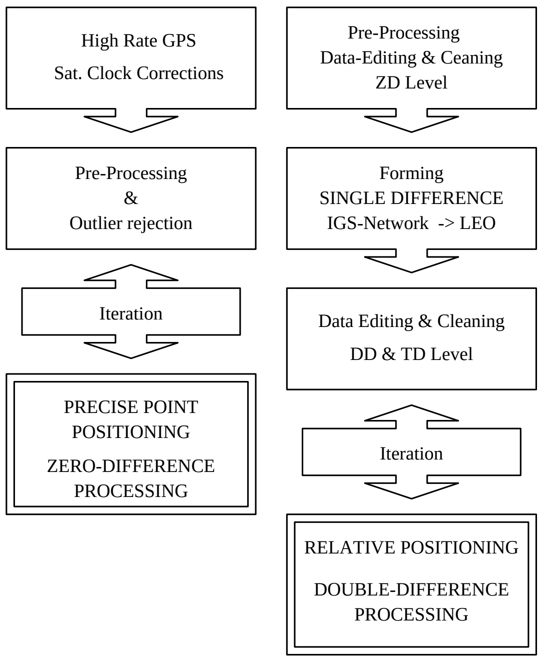
3.4.3 Task 4.3: Kinematic POD

Abstract

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 Task 6.1.
IGS products such as GPS satellite orbits and clock corrections, station coordinates and troposphere corrections are introduced as fixed where necessary. Output are kinematic positions at observation epochs, nominally reconstructed from SST phase observables only (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.

Flow Chart


LEO GPS RECEIVER
Phase/Code
LEO
STAR SENSOR
Attitude
LEO
GPS Orbits
IGS
ERP
IGS
IGS Network
Phase/Code
IGS
GPS Sat.
Clocks
IGS
ZD
PROCESSING
DD
PROCESSING
IGS Network
coordinates
ocean loading
IGS
Troposphere
zenith delays
IGS
LEO
Clock
Kinematic orbit
Kinematic orbit


High Rate GPS
Sat. Clock Corrections
Pre-Processing
&
Outlier rejection
Iteration
PRECISE POINT
POSITIONING
ZERO-DIFFERENCE
PROCESSING
Pre-Processing
Data-Editing & Ceaning
ZD Level
Forming
SINGLE DIFFERENCE
IGS-Network -> LEO
Data Editing & Cleaning
DD & TD Level
Iteration
RELATIVE POSITIONING
DOUBLE-DIFFERENCE
PROCESSING

Definition

The point positioning approach A consists of three main blocks (Figures 3 and 4):

(1) Generation of high rate GPS clock corrections (unless information from IGS can be used which is currently not available).
(2) Data editing and outlier rejection.
(3) Point positioning using code and phase together. Depending on the approach this step may further be divided into code processing, phase processing, and successive combination of the two products to compute precise point positions. As a baseline, phase only observations will be processed.

Steps (2) and (3) may be iterated.
The differential approach B consists of:

(1) Formation of baselines from ground stations to the LEO receiver
(2) Data editing and cleaning on the double or triple difference level (an initial data cleaning performed on the zero-difference level before forming baselines, task 4.1).
(3) Processing of the phase and code double difference observations of all baselines "ground station – LEO".

Input

As indicated in the abstract, a distinction can be made between analysis and kinematic POD approaches based on undifferenced ('A') or differenced ('B') GPS observations. For both approaches, the following input can be distinguished:

- GPS data: The basic input for point positioning and differential methods are GPS observations of the LEO (i.e. GOCE) in the RINEX format (adapted to space-borne receiver data, ftp://igscb.jpl.nasa.gov/igscb/data/format/rinex210.txt).
- Relative weight of code and phase observables for methods using code and phase together which may be determined from an evaluation of the noise characteristics of code and phase post-fit residuals. This input would, therefore, be a task-internal product. The baseline processing will use phase only. Code is needed for the GPS clock extraction in zero difference processing. Code will be downweighted in this case.
- GPS orbits: Both methods rely on precise orbits for the GPS satellites provided by the IGS. IGS provides GPS ephemeris in the precise ephemeris (SP3) format. For a description of the format see ftp://igscb.jpl.nasa.gov/igscb/data/format/sp3_docu.txt.
- Earth orientation: The Earth orientation information is required for all transformations between the terrestrial (ITRF) and celestial (ICRF) reference frames.
- Both proposed methods use the ionosphere-free linear combination of the frequencies L1 and L2 for the elimination of ionospheric effects thus requiring no ionosphere information.
- Centre of mass correction for the satellite (pre-flight satellite model plus corrections due to fuel consumption [if provided and model available]); attitude information (from star-tracker quaternions, possibly enhanced by using gravity gradient observations); satellite antenna position and orientation of its normal in the satellite coordinate system; phase centre offset and variation.

Required for approach A only:

- GPS satellite clock corrections: The point positioning method requires high rate GPS satellite clock corrections, e.g., in Clock RINEX format (ftp://igscb.jpl.nasa.gov/igscb/data/format/rinex_clock.txt). These may be provided by

IGS or be computed using GPS observations from an analysis of a global network of ground stations (e.g. from IGS).
- Inter-frequency bias calibration parameters: For the point positioning approach differential code biases between L1 and L2 are required. Values for GPS satellites may be obtained from IGS.

Required for approach B only:
- GPS ground station observation data: The differential method as well as the method for generating high rate GPS clock corrections require ground station GPS observations in RINEX format. The available sampling rate drives the rate at which SST data can be processed (the same is true for GPS clock extraction for approach A).
- Ground station coordinates and velocities in a well-defined coordinate frame (ITRF2000 or updated) and epoch; antenna heights and phase centre offsets and variations.
- Ground station troposphere information: Differential and clock correction methods require troposphere path delay information for the ground stations with an appropriate resolution from a global analysis, e.g., from IGS or its Analysis Centres.

Product ID	Product
GO-1B-ATT	Satellite attitude
GO-2i-SST	GPS calibrated and screened phase and range data
GO-2a-GNS+GST	IGS GPS ground station tracking data
GO-2a-GNS+EPC	IGS GPS ephemeris and clocks
GO-2a-GNS+GSA.MET	IGS GPS ground station tropospheric delays
GO-2a-GNS+GSA.ANT	IGS GPS antenna phase center variations, differential code biases
GO-2a-SSC	Station coordinates and velocities from ITRF
GO-2a-ERP	Earth rotation parameters form IERS

Constants

Speed of light; GPS carrier frequencies (see also slice 1).

Output

For both proposed methods (A and B) the output consists of a kinematic orbit for the LEO satellite, i.e. cartesian 3-D coordinates of the satellite in a specific coordinate frame for the measurement epochs and in a format still to be decided on. The SP3 format (adapted to account for LEOs) may be used. An enhancement of the SP3 format (SP4) allowing to hold e.g. covariance information and manoeuver flags is under discussion within IGS. For point positioning methods (A) the LEO clock corrections are generated in addition to the position information. No velocity information is generated by these methods.

Product ID	Product
GO-2p-SST+POS	GOCE kinematic orbit

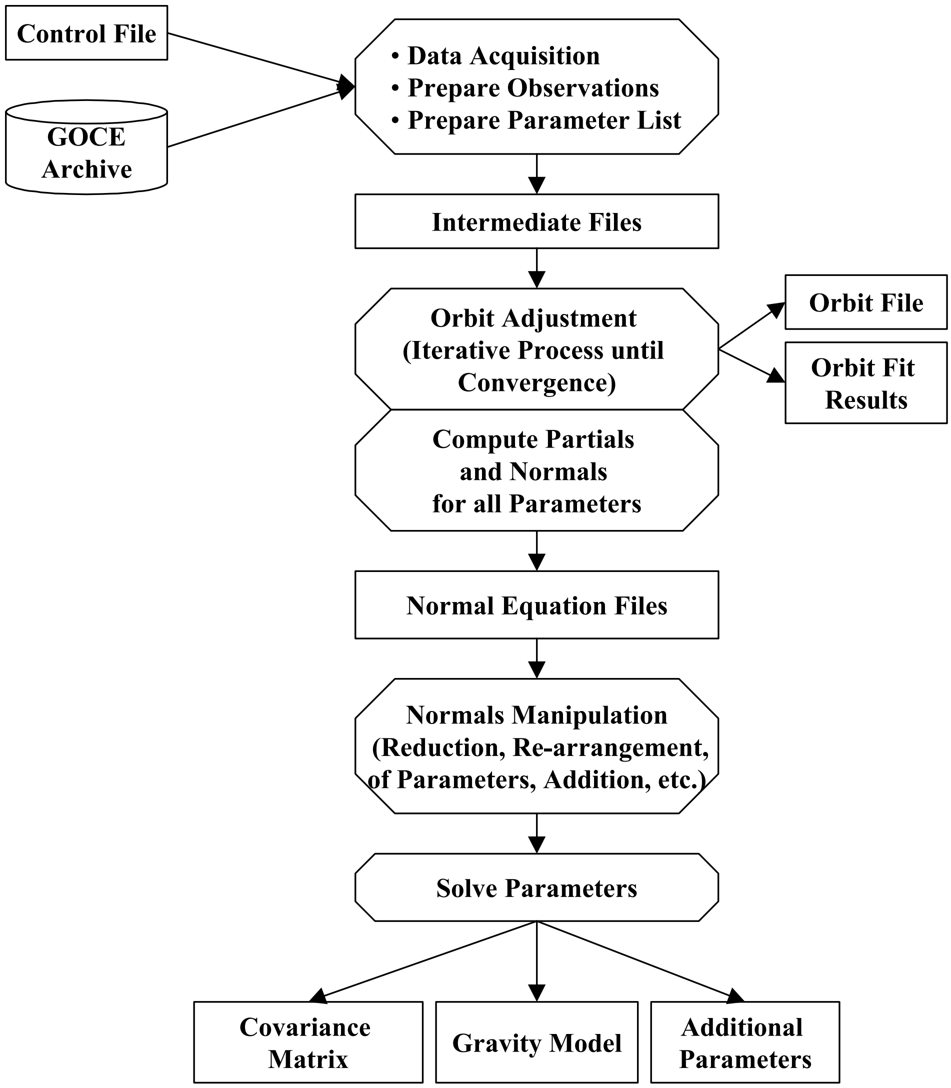
3.5. Task 5: Gravity Field Modelling

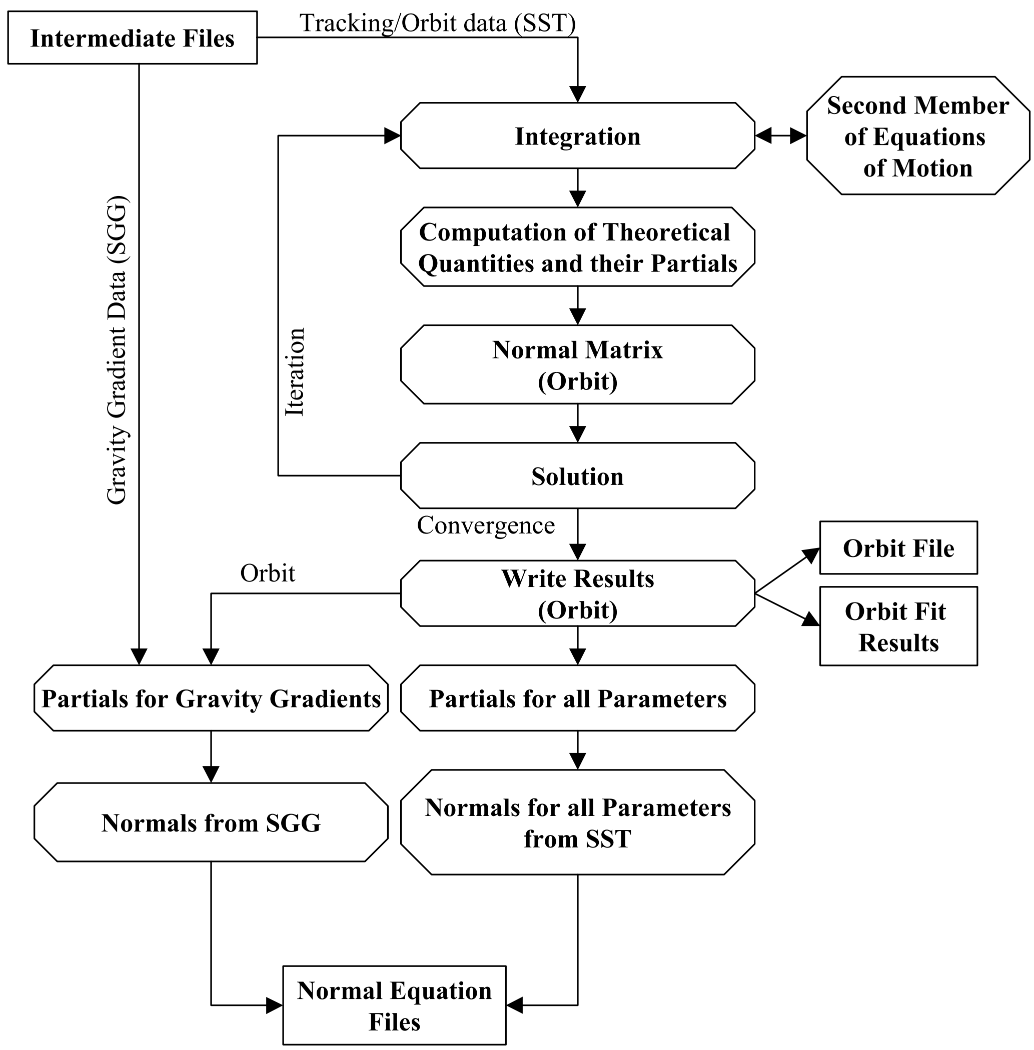
3.5.1 Task 5.1: Direct Method

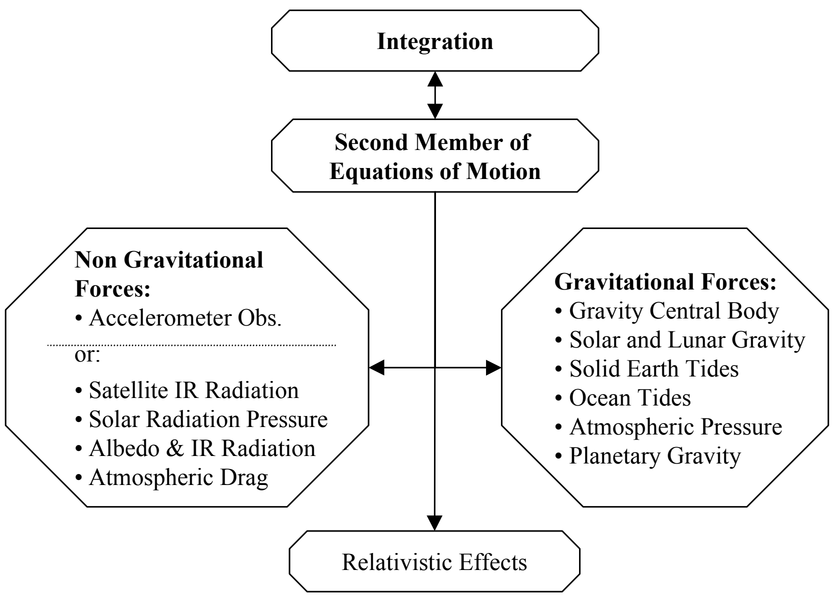
Abstract

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-observables 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.

Flow Chart


Control File
GOCE Archive
• Data Acquisition
• Prepare Observations
• Prepare Parameter List
Intermediate Files
Orbit Adjustment (Iterative Process until Convergence)
Orbit File
Orbit Fit Results
Compute Partials and Normals for all Parameters
Normal Equation Files
Normals Manipulation (Reduction, Re-arrangement, of Parameters, Addition, etc.)
Solve Parameters
Covariance Matrix
Gravity Model
Additional Parameters


Intermediate Files
Tracking/Orbit data (SST)
Integration
Second Member of Equations of Motion
Computation of Theoretical Quantities and their Partials
Normal Matrix (Orbit)
Iteration
Gravity Gradient Data (SGG)
Solution
Convergence
Orbit
Write Results (Orbit)
Orbit File
Orbit Fit Results
Partials for Gravity Gradients
Partials for all Parameters
Normals from SGG
Normals for all Parameters from SST
Normal Equation Files


Integration
Second Member of Equations of Motion
Non Gravitational Forces:
• Accelerometer Obs.
or:
• Satellite IR Radiation
• Solar Radiation Pressure
• Albedo & IR Radiation
• Atmospheric Drag
Gravitational Forces:
• Gravity Central Body
• Solar and Lunar Gravity
• Solid Earth Tides
• Ocean Tides
• Atmospheric Pressure
• Planetary Gravity
Relativistic Effects

Definition

1. {INPUT} Data retrieval (SGG, SST, SLR, IGS orbits and clocks, IERS EOP05C04, ECMWF).
2. Dynamical POD, and constitution of the single-arc normal equation system in an additional step after POD convergence.
3. Reduction and accumulation of single-arc normal equation systems into one matrix {INTERMEDIATE RESULT}.
4. Generation of normal equation systems from SGG {INTERMEDIATE RESULT}.
5. Combination with POD normal equation system {INTERMEDIATE RESULT}.
6. Estimate gravity field coefficients {OUTPUT}, and gradiometer calibration parameters (verification from time to time) {OUTPUT}.

The above listed procedure is explicitly shown in flow charts.

The gravity field model errors due to the 97º inclination of the GOCE orbit, causing a polar gap in the otherwise global coverage, are in the low-order coefficients. These errors will become negligible up to degree 120-150 by making a combined GOCE and GRACE solution, the latter satellite having an inclination of 89º.

The IERS (pole and UT1 in particular) and the ECMWF (atmospheric pressure) data are critical to the output of task 5.1, because the former parameters must otherwise be estimated by EGG-c in task 4 (POD), while the atmospheric temporal gravity effect cannot be modelled or in some way adjusted. The GPS orbits and clocks, provided by the IGS, can also be computed by a member of EGG-c, so the IGS data are not critical.

Input

Product ID	Product
GO-1B-EGG	Gradiometer calibrated&corrected gravity gradients
GO-1B-EGG	Gradiometer calibrated&corrected accelerations
GO-1B-SST	GPS calibrated&corrected phase&range data
GO-1B-ATT	Satellite attitude
GO-1B-THR	Thrust history of AOCS&drag free actuators
	Ancillary Product
GO-2a-GNS	IGS GPS Products
GO-2a-SLR	Laser Tracking Data
GO-2a-DTM	Atmospheric Density Model
GO-2a-ATM (or GO-2p-AOV)	Atmospheric Pressure Data for Time Variable Gravity Field
GO-2a-OCM (or GO-2p-AOV)	Ocean Bottom Pressure/Model Data for Time Variable Gravity Field
GO-2a-ERP	Earth Rotation Parameters from IERS
GO-2a-SSC	Station Coordinates from ITRF
GO-2a-OTI	Tide Models
GO-2a-EPH	Sun, Moon & Planetary Ephemeris
GO-2a-RAD	Earth Albedo & Solar Radiation
GO-2a-EGM	A-priori Gravity Field Solution
GO-2a-SCM	Spacecraft Parameters
GO-2a-EGT	Temporal gravity field variations (from GRACE results)
GO-2a-SGA	Solar flux and geomagnetic activity indices

Constants

GOCE standards as defined in the StRD.

Output

Product ID	Product
GO-2p-EGM+DIR	Earth gravity field model from direct method: Spherical harmonic coefficients, geoid heights, gravity anomalies including their variance-covariances and quality parameters
GO-2p-PSO+GOC_DY	GOCE precise science orbit (dynamic mode)

3.5.2 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 gradiometer 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. Both categories are described in separate sub-chapters.

A: Task 5.2: Time-wise approach

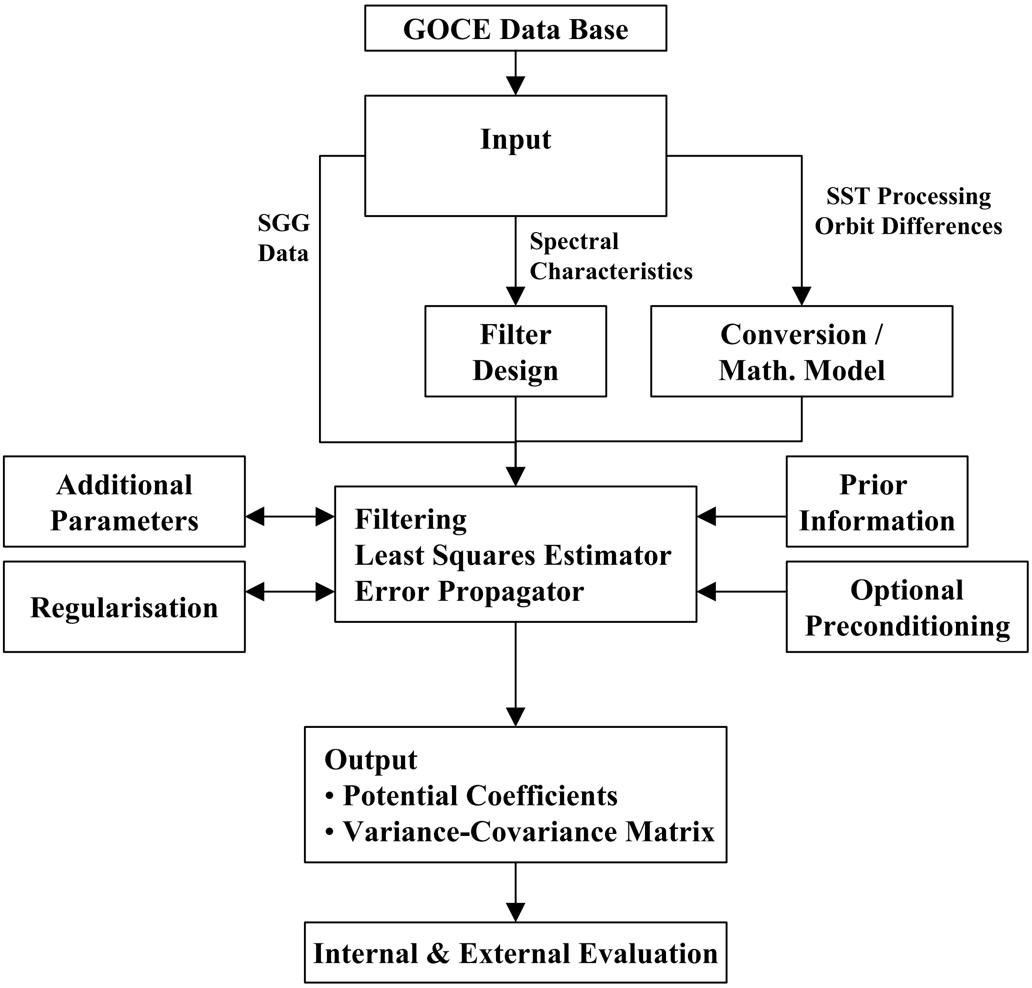
Abstract

The objective of this task is to compute a high-accuracy, high-resolution model including quality description of the Earth's static gravity field from GOCE SGG and SST 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 description 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 SGG and SST data.

The software is a tailored GOCE product and conceived in a modular manner that allows us to investigate the behaviour of partial aspects of gravity modelling such as filtering, stability, complementary of SST and SGG, 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 SGG, SST and their combination for the determination of a set of spherical harmonics including a realistic quality description.

Flow Chart



Definition

The overall data processing strategy is as follows: given the precise GOCE orbit the calibrated gravity gradients in the LORF are directly related to the unknown potential coefficients resulting in the linear observation model for all relevant tensor components. This allows us to exploit the high degree of precision and resolution of the data and to manage straightforwardly the complications arising from the polar gap and the coloured noise of the gradiometer. The information content of the SST data is exploited by making use of the precise GOCE orbit expressed in terms of position and velocity information including quality description (POD output of task 4). Differences between the precise GOCE orbit and a best-fitting a-priori dynamic orbit based on the selected non GOCE gravity field model are taken as pseudo-observations. These pseudo-observations contain the full error of the non GOCE gravity field model and are used to improve this model with GOCE data. The associated linear observation model is obtained by numerical integration of the variational equations that link the orbit differences to the disturbing potential coefficients. Error propagation provides the stochastic model of the SST pseudo-observations. The mathematical models for SGG and SST data are combined to the overall mathematical model. The potential coefficients are estimated by applying the least-squares principle. The ill-posedness of the normal equations due to the polar gaps and the downward continuation are managed by optimised regularisation techniques. The potential coefficients are converted into gravity field functionals (geoid heights and gravity anomalies) on a spherical grid. The errors due to the inaccurate estimation of the zonal and near-zonal coefficients, because of the non-observed polar areas, are restricted to these high latitude areas and do not propagate into the regions which are covered with GOCE observations. Therefore, the polar gap problem has no direct consequence for the architecture, but is implicitly related to the regularisation strategy, and the final “GOCE only” geoid does not suffer from problems in some of the estimated spherical harmonic coefficients. Information about the accuracy of the estimated potential coefficients and the gravity field functionals is obtained by error propagation. The combination with surface/airborne or other satellites mission data (e.g. GRACE) in order to improve the spherical harmonic series of the GOCE gravity field solution is regarded as a possible level 3 product and not part of the time-wise gravity field solution.

The overall data processing strategy can be comprised into 4 parts: the input, the SST processing, the least-squares estimation, and the output.

1. Input: all relevant information needed to set up the functional model and to compute the least-squares estimator (from database).
2. SST processing: dynamic orbit determination with a priori gravity field model as input and precise GOCE orbit as pseudo observations ("nominal orbit"). Computation of the differences between precise GOCE orbit and a priori orbit, reflecting gravity field model errors. Computation of the functional model with differences used as pseudo observations and design matrix entries computed by numerical integration of the variational equations along the nominal orbit. Computation of the stochastic model.
3. Least squares estimation: assembling and solution of the linear observation equations for SGG and SST data with the following main modules

   - Filter design: design of optimal filters and estimation of filter parameters from given information about the noise behaviour of the four tensor components and of the SST pseudo-observations
   - Filtering: Applying filters to properly take into account coloured observation noise of the four gravity tensor components and the SST pseudo-observations.
   - Regularisation: computation of the selected regularisation matrices by adding mathematical or physical a priori information and choice of the optimal regularisation parameter.
   - Additional parameter: computation of the linear functional and stochastic model for non-potential coefficient parameters (calibration parameters, temporal variation effects). A decision which parameters will have to be adopted is still pending and will partly depend on the actual mission performance.
   - Pre-conditioning (optional)
   - Prior information: adding prior deterministic and/or stochastic information.
   - Least squares estimator: least squares solution of the disturbing potential coefficients from SGG observations and SST pseudo-observations.
   - Error propagation: provide estimates of the variance-covariance matrix of the disturbing potential coefficients.
   - Output module: estimates of disturbing potential coefficients, other gravity field functionals, and associated variance-covariance matrices.

Input

Product ID	Product
GO-1B-EGG	Gradiometer calibrated and corrected gravity gradients
GO-1B-EGG	Gradiometer calibrated and corrected accelerations
GO-1B-EGG	Common mode and angular accelerations
GO-1B-ATT	Satellite attitude
GO-1B-THR	Thrust history of AOCS and drag free actuators
GO-1B-EGG+ERM	A priori EGG error model
GO-2-PSO+GOC	GOCE precise science orbit
GO-2a-EGM	A-priori gravity field solution
GO-2a-OTI	Tide models
GO-2a-EPH	Sun, moon and planetary ephemeris
GO-2a-EGT	Temporal gravity field variations
GO-2i-AOV	Atmospheric and oceanic mass variations gravity corrections
GO-2a-EGT	Temporal gravity field variations (from GRACE results)

Constants

Constants according to the GOCE standards.

Output

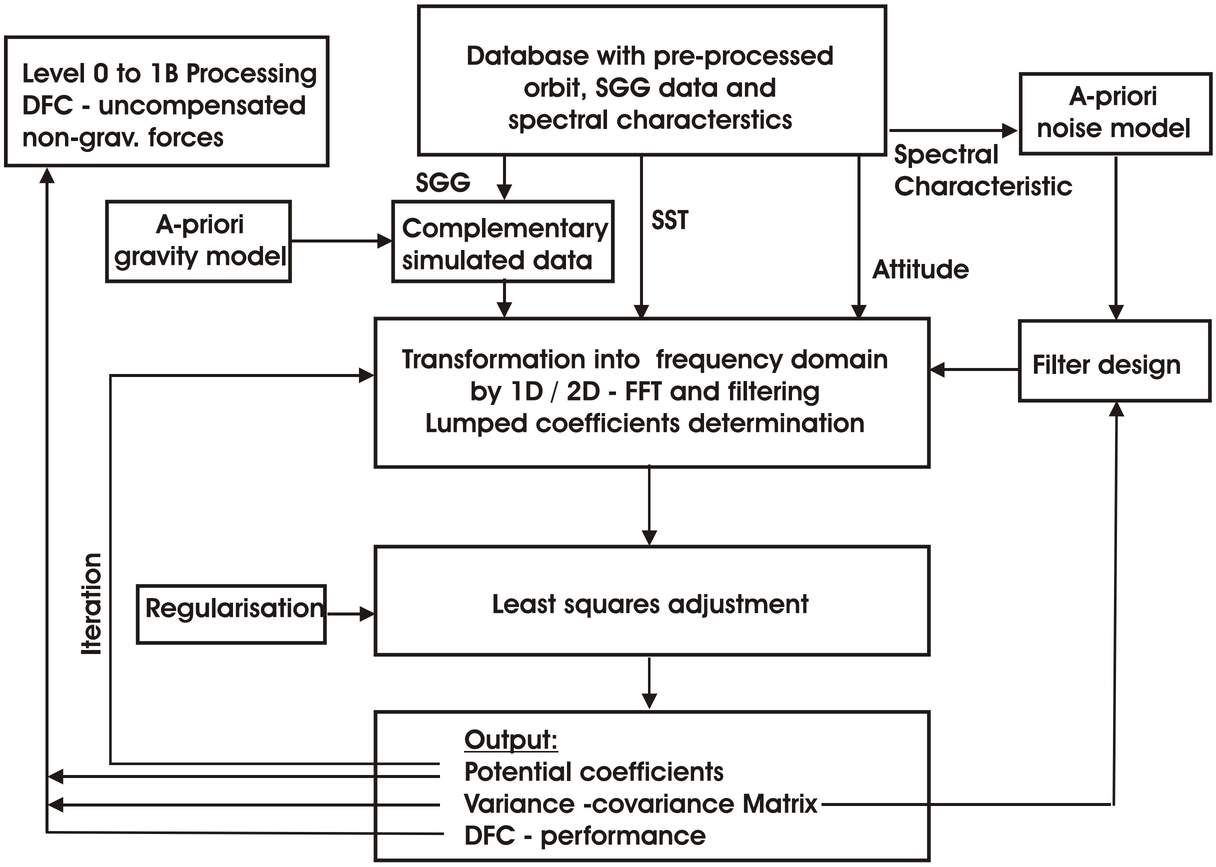
Product ID	Product
GO-2p-EGM+TIW	Earth gravity field model from time-wise approach: Spherical harmonic coefficients, geoid heights, gravity anomalies including their variance-covariances

B: SGG and SST Quick-Look Gravity Field Analysis (QL – GFA)

Abstract

The purpose of the quick-look analysis (QL-GFA) is to analyse partial sets of SGG and SST data based on rapid science orbits. The SGG data will be combined with complementary simulated data from an a priori gravity model, and to derive from this analysis a diagnosis of the system performance. 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.

Flow Chart



Definition

QL-GFA is different from the quick-look validation of Task 3 “Pre-processing”. The latter provides diagnosis of gradiometer system performance in real time (e.g. blunder detection, Laplace check), whereas here data are accumulated over some minimum time span in order to be able to analyse the field structure based on a global (but sparse) data set. QL-GFA is different from calibration, because the objective of the latter is the estimation of parameters of a calibration matrix, whereas here the global field structure is analysed.

Four complementary tests are carried out in parallel:

- SGG: Directly from the residuals of a SGG only analysis estimated noise models and other noise models are tested in comparison to the noise model provided from level 1. With this the question if the a priori noise model is realistic can be answered, and optimal filters can be designed.
- SST: The SST data analysis is based on the use of the energy conservation law. Any violation, e.g. due to non-compensated non-gravitational effects on the S/C, results in a mismatch of the conservation condition. Again such systematic effects can be identified and traced. Statistically significant deviations will be reported to the level 0 to 1b processing and may lead to a re-analysis of the DFC-performance.
- SGG, SST, SST+SGG: Spherical harmonic coefficient estimates derived separately from the partial SST and SGG data are compared. From this possible systematic distortions in particular in the SST data are identified. They can probably be traced back to deficiencies in DFC or to residual effects from uncompensated non-gravitational accelerations.

- SST+SGG: Inclusion of additional parameters for orientation errors may allow a diagnosis of the performance of the angular control or of the attitude information.

The quick-look analysis method described here is based on the semi-analytical gravity field analysis. The data is transformed into the spectral domain by 1D- or 2D-FFT. Lumped coefficients are determined and potential coefficients are estimated by a least squares adjustment with regularisation. This method has been used for covariance error propagation in the context of the GOCE pre-phase A and phase-A studies. The method is well developed and mature. Its underlying principle is that under a number of idealising assumptions this type of gravity field analysis results in a block-diagonal system of normal equations that can be solved both very easily and very fast. These assumptions are that the orbit closes into itself after a certain (integer) number of revolutions and sideral days and that the orbit is circular. Both assumptions are not met perfectly, in reality, but very closely and after iteration their effect can be considerably reduced. As partial sets of real GOCE data (minimum length two weeks) are used for quick-look analysis, it is complemented by a simulated SGG data set (e.g. six weeks) in order to attain a set that allows full gravity field modelling. One way to test the individual information content of the SGG data set is by so-called variance component estimation, i.e. a statistical check of the correctness of a priori precision estimates.

Input

Product ID	Product
GO-2p-RSO+GOC	Rapid science orbit incl. velocities
GO-2-EGG	Pre-processed gradiometer observations (output of task 3.3)
GO-1B-ATT	Satellite attitude
GO-1B-THR	Thrust history of AOCS and drag free actuators
GO-1B-EGG	Common mode and angular accelerations
GO-2a-EGM	A-priori gravity field solution
GO-2p-EGG+ERM	Gradiometer error model

Constants

Constants according to the GOCE standards.

Output

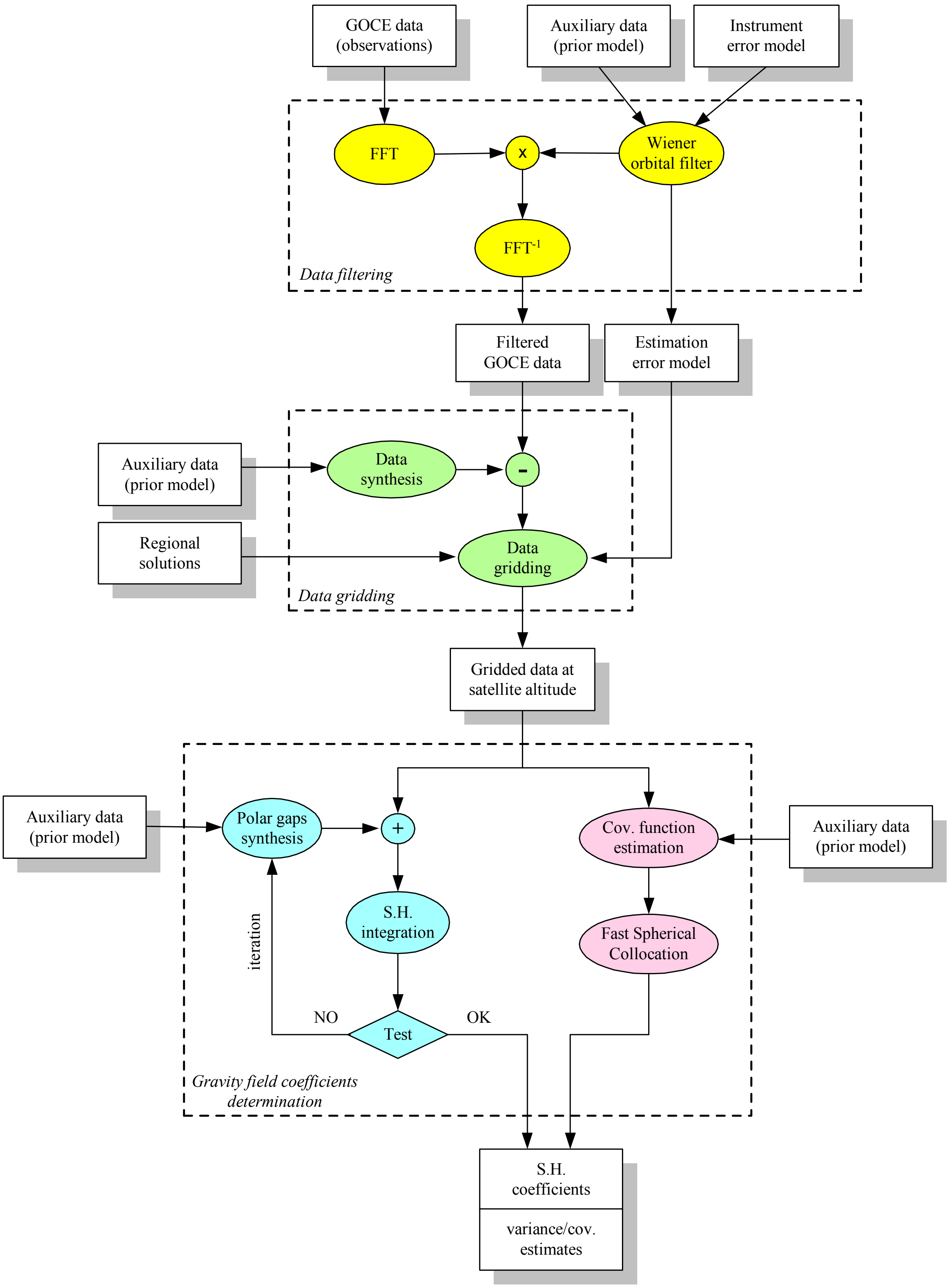
Product ID	Product
GO-2p-EGM+QLK	Quick-look Earth gravity field model: Spherical harmonic coefficients, geoid heights, gravity anomalies including their variances
GO-2p-EGM-QAR	Analysis report of GOCE quick-look gravity field solution incl. updated noise model for the gradiometer

3.5.3 Task 5.3: Space-Wise Approach

Abstract

As it is known, it is possible to retrieve the gravity field coefficients 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 (WOF).
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.

Flow Chart


GOCE data (observations)
Auxiliary data (prior model)
Instrument error model
FFT
x
Wiener orbital filter
FFT^{-1}
Data filtering
Filtered GOCE data
Estimation error model
Auxiliary data (prior model)
Data synthesis
-
Regional solutions
Data gridding
Data gridding
Gridded data at satellite altitude
Auxiliary data (prior model)
Polar gaps synthesis
+
Cov. function estimation
Auxiliary data (prior model)
S.H. integration
Fast Spherical Collocation
iteration
NO
Test
OK
Gravity field coefficients determination
S.H. coefficients
variance/cov. estimates

Definition

The space-wise approach for the recovery of the GOCE gravity field model will consist of three main blocks: this can be seen clearly from the above flow-chart.
In the following, the three blocks will be described.

(1) Data filtering (WOF)
The GOCE gradiometer data, taken in a time stream along the orbit with the gradiometer working in a specific measurement bandwidth, will be spatialized using a Wiener orbital filter (exploiting the prior knowledge of a geopotential model and the PSD of the measurement error), with covariance functions of the estimation errors (Albertella et al., 2002). For the moment WOF is applied to SGG data only. The use in a multiple-input Wiener filter of the first-order derivatives (from SST data) and of the T values derived from the energy integral method is being studied.

(2) Data gridding
For this purpose, collocation is to be considered as the baseline procedure, made up of two subsequent phases:

- *Computation of anomalous quantities corresponding to the GOCE observables.*
  Computation of the differences between the observations and the contribution from the a-priori spherical harmonic model and contingent time-varying quantities.
  The spherical harmonic model is used to calculate the values corresponding to the GOCE observables in their proper reference frame.
  The data are then used as input for gross-error detection (though this is responsibility of Task 3, it could be verified inside Task 5.3, exploiting Wiener filter estimations) and contingently flagged.
  The task will be repeated using updated spherical harmonic models.
- *Computation of gridded values on a sphere at mean satellite altitude.*
  Starting from the anomalous quantities computed at the previous phase, least-squares collocation (GEOCOL) is used to predict gridded values of T_x T_y T_z and of the two independent derivatives T_{rr} and T_{yy} or T_{xx} in an earth-fixed frame, with z-axis in the direction to the centre of the Earth. All the values at the same parallel will be associated with a fixed distance to the centre of the Earth. The grid will be constructed using for each region an individually defined covariance function.
  The procedure for the computation of gridded values is as follows:
  (a) Data (anomalous quantities) from a specific region is selected.
  (b) An approximation of the anomalous potential for the region is constructed.
  (c) Values of T_x T_y T_z and of the two independent derivatives T_{rr} and T_{yy} or T_{xx} in an earth-pointing reference frame, at a fixed radial distance (e.g. on a sphere) are computed.
  (d) Their error-estimates are computed simultaneously.

Other interpolation methods for data gridding are being studied, and they do not represent the "baseline" solution.

(3) Gravity field coefficients determination
When the data-gridding and the simultaneous formation of mean-values have been made, two methods are readily available which theoretically are equivalent. However different softwares are used, so the results can be compared both in terms of the computed spherical harmonic coefficients as in terms of the error-estimates.
The two space-wise solutions which will be implemented are the fast spherical collocation approach and the integration/iteration approach. Both methods need to work on gridded data.

The best solution shall be delivered as the output of Task 5.3. It must be remarked that at the present stage of the study, it is not advisable to define which one of the alternative space-wise methods shall give the best result, although the collocation solution software seems to be more mature. That is why the identification of the final output of Task 5.3 will be made a-posteriori.

– *Fast spherical collocation*
  Corrections to the a-priori spherical harmonic coefficients as well as their error estimates will be determined using the method of fast spherical collocation (Sansò and Tscherning, 2001) from data gridded equidistantly in longitude. The data must have assigned the same noise variance for each parallel. T_{rr} and potential difference data can be used.
  In a more detailed way, the computation procedure is as follows:
  (a) The parameters of a global covariance function are determined, using the GRAVSOFT programs EMPCOV and COVFIT.
  (b) The data computed regionally are used as input to a new program SPHGRID which implements Fast Spherical Collocation.
  (c) Corrections to spherical harmonic coefficients and the error-estimates of these coefficients are determined. Error covariances are determined.

– *Integration/iteration approach*
  Spherical harmonic coefficients will be retrieved by an integration approach. For references, see (Albertella et al., 2001b).
  A requirement of this method is that data cover the whole surface, which means that gaps left in the observation process must be amended: polar gaps due to GOCE orbit inclination are, under this respect, critical. However, it has been shown that a simple iteration filling in each step the polar gaps with the current model solves the problem (Albertella et al., 2001a). The products are spherical harmonic coefficients, error estimates and an updated global gravity field covariance function.
  In a more detailed way:
  (a) The input for the integration procedure are the block averages of T_{rr}, $T_{\lambda\lambda}$ on a sphere at mean satellite altitude. The integration is performed by means of suitable spherical harmonics to estimate the gravity field coefficients.
  (b) The iteration procedure takes as input data the coefficients set obtained at the previous step, computes suitable T-functionals in the polar caps and then uses this data as the new input to the integration program. An update of the global covariance function is performed.
  The iteration is repeated until convergence. An a-priori model shall be selected as starting point for the iterative procedure.

Input

Product ID	**Product**
GO-1B-EGG	Gradiometer calibrated & corrected gravity gradients
GO-1B-EGG	Gradiometer calibrated & corrected accelerations
GO-1B-SST	GPS calibrated & corrected phase & range data
GO-1B-NAV	On-board navigation solution
GO-1B-ATT	Satellite attitude
GO-2a-EGM	A priori global gravity field model
GO-2i-AOV	Model data for time variable gravity field
GO-2a-EGT	Temporal gravity variations (from GRACE results)

Constants

All constants related to the definition of reference frames, a priori gravity field model and models for several corrections need to be defined (Slice 1).

Output

Product ID	Product
GO-2i-SGG+WOF	Wiener orbital filtered gradiometer gradient data
GO-2i-SST+ACC	Geo-located accelerations from SST data
GO-2i-RGG	Regional grids of gradiometer data at satellite altitude
GO-2p-EGM+SPW	Earth gravity field model from space-wise method including derived geoid heights
GO-2p-EGM+COV	Global covariance function for the gravity field

3.6. Task 6: Solution Evaluation

3.6.1 Task 6.1: Internal Evaluation

Abstract

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:

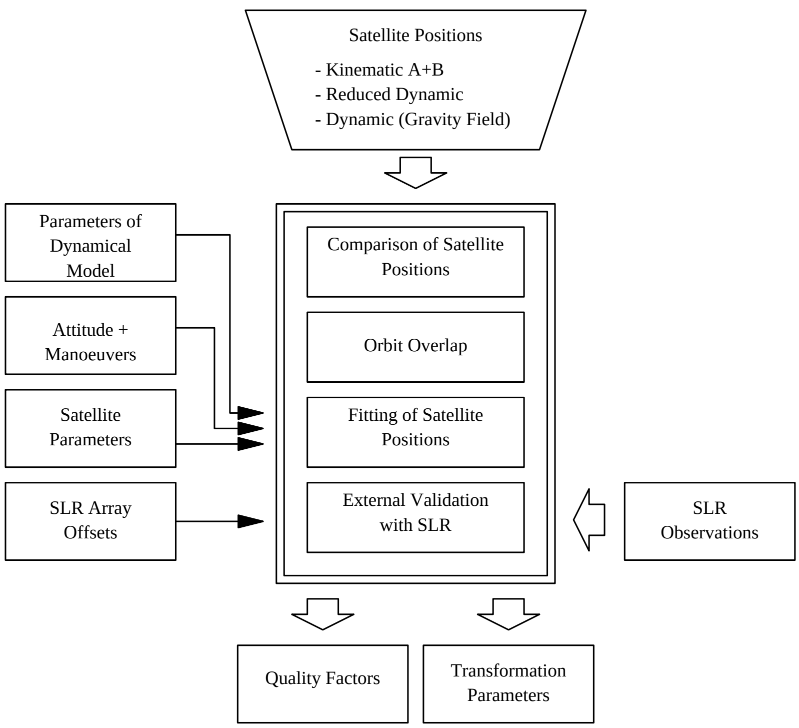
1. direct comparison of orbits computed with different techniques and/or approaches
2. orbit overlap analyses
3. fitting of satellite positions
4. external validation with SLR observations

Gravity field evaluation
The GOCE gravity field model as well as the regional solution products 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 anomalies errors.

Flow Chart

POD evaluation



Definition

POD-evaluation:
Reduced-dynamic and kinematic orbits computed with different approaches will be compared with each other in order to validate the orbits and provide a quality assessment. In addition to these orbits, dynamic orbits will be a by-product of the direct method of gravity field estimation (Task 5.1). These orbits will be included in the internal evaluation cycle. The following four evaluation methods are foreseen:

1. *Direct comparison of satellite positions:* orbits generated by different approaches are compared directly by analysing the differences between positions. RMS values of the differences may be computed. If necessary, tabular positions may be transformed to equal epochs using an appropriate interpolator to the original positions.
2. *Orbit overlaps:* different orbital arcs of the same or different methods are compared by analysing the position differences for overlapping time intervals (e.g. arc boundaries of successive arcs).
3. *Fitting of satellite positions:* one orbit solution can serve as a reference for another in an estimation process where certain unknowns are estimated, e.g. geometrical unknowns such as Helmert parameters, or resonance accelerations. This will allow the identification of reference frame problems and dynamic model deficiencies in a certain approach.
4. *External validation with SLR observations:* SLR observations are nominally not used in the POD and can thus be employed as independent data for an orbit accuracy assessment. Residuals of SLR observations are computed for each given orbit and are compared to each other. This means that the orbits are not recomputed by inclusion of SLR data, but that the given state vectors are interpolated to the SLR measurement times and that range residuals are computed. The interpolation of state vectors is a well known technique in altimetry (e.g. polynomial of degree 7) and can be applied accordingly.

Gravity field evaluation:
The GOCE gravity field solutions (direct, time-wise, space-wise, regional) will be compared with each other in order to validate and provide a quality assessment. The following evaluation techniques are foreseen:

1. *Direct comparison of spherical harmonic coefficients:* differences between the sets of spherical harmonic coefficients are evaluated using the error estimates and error covariances. Degree and error degree variances are computed and compared to each other and to degree variance models.
2. *Geoid heights comparisons:* Grids at ground level computed from the coefficients are compared to each other. Different grid resolutions are used in order to identify possible dependencies on spatial (spectral) resolutions. Additionally propagated geoid height errors are compared to each other.
3. *Gravity anomalies comparisons:* Grids at ground level computed from the coefficients are compared to each other. Different grid resolutions are used in order to identify possible dependencies on spatial (spectral) resolutions. Additionally propagated gravity anomalies errors are compared to each other.

Input

POD-evaluation:
For all comparison methods (1-4):

- Orbits generated with different approaches, 3-D tabular positions in nominally ECF frame. The following orbit types will be available:
  - two kinematic orbits from the approaches A and B,
  - reduced-dynamic orbit,
  - fully dynamic orbits generated together with the gravity field extraction using the direct method (task 5.1),
  - preliminary orbit from Level 1b (see Slice 1).

Required for comparison method (3):

- Earth gravity field models; atmospheric model; ephemeris of Sun and Moon (JPL Development Ephemeris); Earth orientation information.
- Cross-section of satellite as a function of aspect, satellite mass; attitude and manoeuvre information.

Required for comparison method (4):

- SLR observations.
- Centre of mass correction for Laser retro-reflector; attitude information.

Product ID	Product
GO-1B-ATT	Satellite attitude
GO-1B-THR	Thrust history of AOCS & rag-free actuators
GO-1B-NAV	On-board navigation solution
GO-2p-PSO+GOC_RD	GOCE precise science orbit (reduced dynamic mode)
GO-2p-PSO+GOC_DY	GOCE precise science orbit (dynamic mode)
GO-2p-SST+POS	GOCE kinematic orbit
GO-2a-SLR	Laser tracking data
GO-2a-ERP	Earth rotation parameters form IERS
GO-2a-SCM	Spacecraft parameters
GO-2a-EGM	A priori gravity field solution
GO-2a-OTI	Tide models
GO-2a-EPH	Sun, moon & planetary ephemeris
GO-2a-RAD	Earth albedo & solar radiation
GO-2a-DTM	Atmospheric density model
GO-2a-SGA	Solar flux and geomagnetic activity indices
GO-2a-SSC	ITRF station positions and velocities

Gravity field evaluation:

Product ID	Product
GO-2p-EGM+DIR	Earth gravity model from direct method
GO-2p-EGM-TIW	Earth gravity model from time-wise approach
GO-2p-EGM+SPW	Earth gravity model from space-wise approach
GO-2-RGM	Regional gravity field model

Sets of 1.degree mean gravity anomalies and mean height anomalies calculated at a surface above the highest point of the area as well as the associated error-estimates based on the 3 global solutions as well as the regional solutions will be used for the evaluation.

Constants

For all computations the constants defined in the GOCE standards have to be used in order to avoid systematic inconsistencies (see Slice 1 output).

Output

POD-evaluation:
All four comparison methods provide quality factors for the different orbit solutions such as position differences between solutions, RMS values of the position differences, and residuals.
Comparison methods (1) and (2) provide:

- (RMS values of) position differences.

Comparison method (3) provides:

- RMS and residuals of individual orbit solutions with respect to the fitted orbit in radial, along-track, and cross-track directions
- Transformation parameters between individual orbit solutions
- Parameter values (e.g. resonance accelerations).

Comparison method (4) provides:

- RMS and residuals of SLR observations for individual orbits.

Nominally, the orbits with the best overlap statistics and SLR RMS of fit are considered to be the best orbits. These values must be commensurate with the objective of computing orbits at the few cm level. High RMS values in case of nominal performance of the GOCE satellite and its instruments are indicative of the need for adjusting the POD approaches. In that case, certain steps need to be reviewed (e.g. the treatment of common mode accelerations in the POD data reduction step).

Product ID	Product
GO-2i-PSO+GOC-QUR	Quality report for orbit solutions (internal evaluation)

Gravity field evaluation:

Statistics of mean and mean square differences for each degree for the differences of the spherical harmonic coefficients for each global solution. For the mean gravity and mean height anomalies (geoid heights) the differences between the global as well as the regional solutions will be analysed in a set of 20-degree equal area blocks covering the GOCE ground tracks as well as for the total area.

The differences will be analysed using the estimated error estimates and the error-covariances. A report will describe whether the differences are statistically significant considering the errors and error correlations of the mean anomalies.

Product ID	Product
GO-2i-EGM-QUR	Quality report for gravity field solutions (internal evaluation)

3.6.2 Task 6.2: External Evaluation

Abstract

The level 2 orbit and gravity field solutions including their error estimates, which are produced by the EGG-C consortium, 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 it can be distinguished between orbital and surface/airborne test procedures and data sets.

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 respectively. 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. Laser tracking 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.

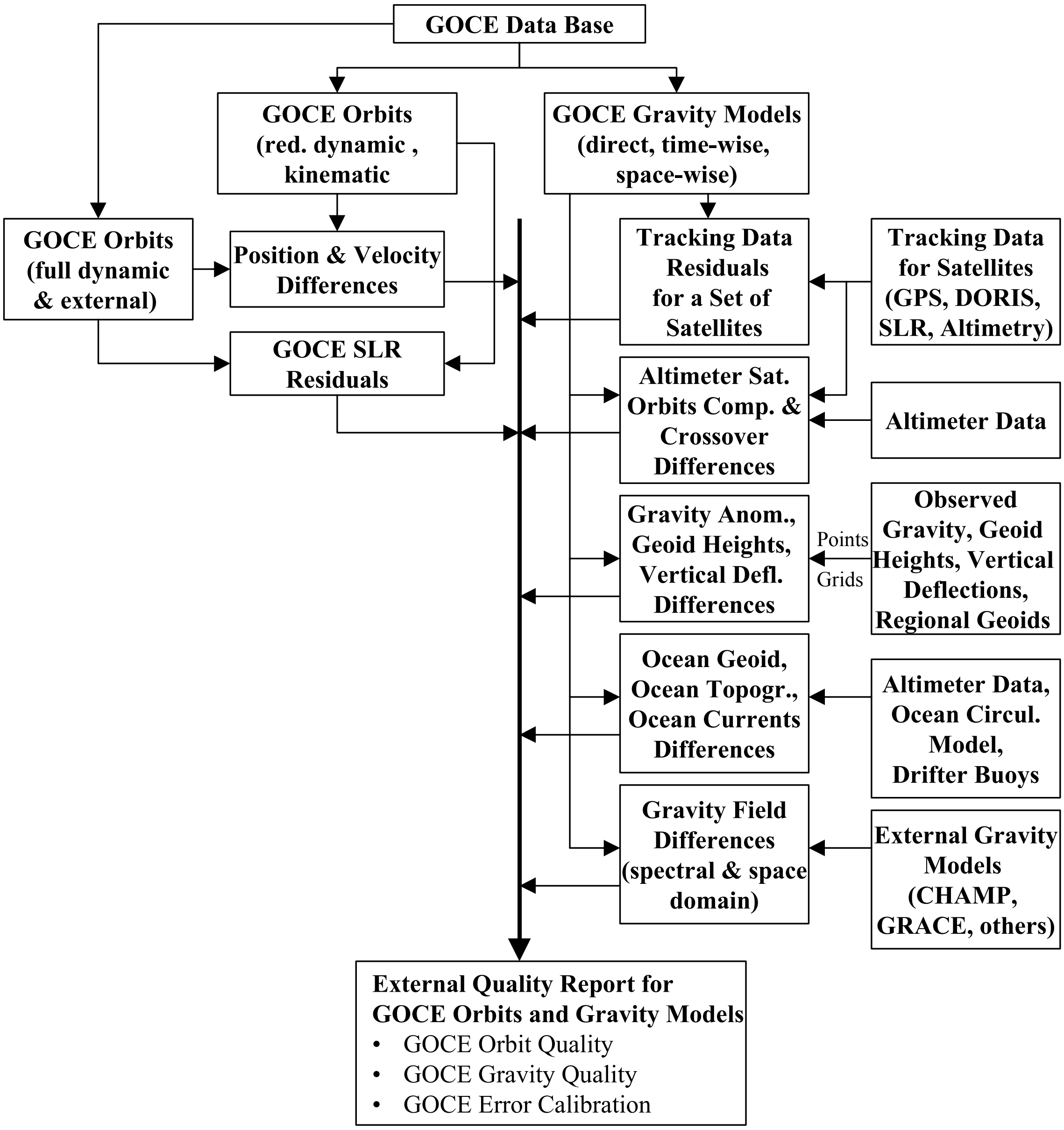
Surface/airborne test procedures are used for external evaluation of the medium to short wavelengths of the gravity field solutions and their error estimates. Adequate calibration test sites are selected taking into account coverage and quality of the available comparison data sets. This includes point-wise 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 differences 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 are going to be derived. These measures are compared with the formal error estimates (from least squares adjustment process). From the differences even calibration functions for the variance-covariance matrix are going to 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 missions 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 are provided in the external quality report.

Flow Chart



Definition

External Orbit Evaluation

As standard GOCE products a reduced dynamic and a kinematic orbit is generated. In order to evaluate these standard products with external data and products the following tasks can be performed:

- Full dynamic comparison orbits: For a predefined comparison period external evaluation orbits with the full dynamic approach are computed.
- If available external orbits from other investigators are used for comparisons (e.g. IGS LEO project)

- Position and velocity differences (if applicable) between the evaluation orbits and the GOCE standard orbits are computed and analysed.
- Satellite laser ranging residuals for all orbits are computed.
- An external quality report for the standard GOCE orbits, based on the test procedures above, is generated as part of the overall external quality report.

External Gravity Field Evaluation

As standard GOCE gravity field products gravity fields based on the direct, the time-wise and the space-wise approach are computed. In addition regional gravity solutions are computed. In order to evaluate these standard GOCE gravity field products, the following tasks can be performed:

- Computation of orbits for various satellites with different orbit characteristics and analysis of tracking data residuals for the different gravity field solutions. For this a tracking data base for all satellites to be included in the test scenario must be available.
- Orbits for altimeter satellites are recomputed based on the different gravity field models and merged into the altimeter data sets. Crossover differences (mean and RMS) are an indicator for the gravity field quality. For this purpose an altimeter data base and the necessary procedures must be available.
- Gravity anomalies, geoid heights and deflection of the vertical are computed for individual points and compared with externally observed values (on the Earth surface or by airborne campaigns). For this a data base with independent point gravity, geoid heights and deflections of the vertical is necessary. If grids of such independent observations are available (e.g. Arctic gravity project, GOCE airborne calibration campaigns, regional geoids) these should be used for comparison in order to make a quality assessment for larger representative areas.
- Mean sea surface models computed from altimeter data together with an ocean circulation model can be used to compute independently ocean geoid models, which can be compared with the GOCE solutions. In the same way ocean topography models can be computed by subtracting the GOCE geoid from the mean sea surface and by comparing it with independent ocean topography solutions from ocean models. Also observations from drifter buoys can be used to perform a point-wise comparison of ocean topography. For this oceanographic expertise has to be included to the quality analysis.
- Independent gravity field solutions from other gravity missions as CHAMP and GRACE can be used for comparison. This can be done in the spectral domain by regarding individual coefficients or degree variances or in the space domain by comparing geoid heights or gravity anomalies derived from the different models.
- An assessment of the coefficients variance-covariance matrix and the derived errors for geoid heights and gravity anomalies (all based on the least squares formal errors) is performed in order to derive an error calibration factor for each solution. The error calibration factor is derived by comparing for example model geoid heights with independent geoid heights. The difference between both can be regarded as error of the model, which should be reflected also by the model error propagation. Because the errors derived by the least squares process tend to be too optimistic usually a factor has to be applied to get the realistic errors computed by the differences.

An external quality report for the standard GOCE gravity models, based on the test procedures above, is generated as part of the overall external quality report.

Input

Product ID	Product
GO-2p-PSO+GOC_RD	GOCE precise orbit (reduced dynamic)
GO-2p-SST+POS	GOCE precise orbit (kinematic)
GO-2p-EGM+DIR	Earth gravity model from direct method
GO-2p-EGM-TIW	Earth gravity model from time-wise approach
GO-2p-EGM+SPW	Earth gravity model from space-wise approach
GO-2a-EVT	GOCE and other satellites tracking data
GO-2a-EVO	External orbits from other investigators
GO-2a-EVT	Altimeter data
GO-2a-EVG	Gravity data (surface and airborne) (points and grids)
GO-2a-EVN	Geoid data (from GPS and levelling) and regional solutions
GO-2a-EVG	Deflections of the vertical observations
GO-2a-EVH	Sea surface heights and sea surface topography models
GO-2a-EVM	Independent gravity field solutions (CHAMP, GRACE)

Constants

See Slice 1**.**

Output

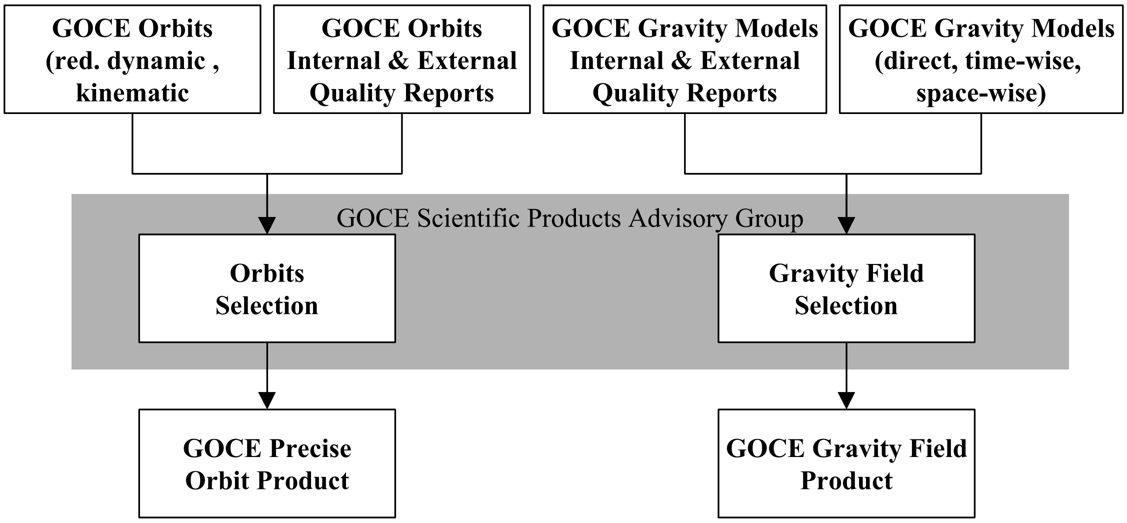
Product ID	Product
GO-2-PSO+GOC_QUR	GOCE precise orbit quality report
GO-2-EGM+QUR	GOCE Earth gravity model quality report

3.6.3 Task 6.3: Solution Selection and Recommendation

Abstract

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 is formed by ESA staff and a few gravity field experts. These experts are external reviewers and members of EGG-C consortium. The formation of the group is done by ESA on invitation only.

Flow Chart



Definition

- Select final orbit product to be adopted by ESA as a final GOCE product based on the orbit solutions and the internal and external orbit quality reports.
- Select final gravity field product to be adopted by ESA as a final GOCE product based on the internal and external gravity field quality reports.

Input

Product ID	Product
GO-2p-PSO+GOC_RD	GOCE precise orbit (reduced dynamic)
GO-2p-SST+POS	GOCE precise orbit (kinematic)
GO-2p-EGM+DIR	Earth gravity model from direct method
GO-2p-EGM-TIW	Earth gravity model from time-wise approach
GO-2p-EGM+SPW	Earth gravity model from space-wise approach
GO-2i-PSO+QUR	Quality report for orbit solutions
GO-2i-EGM+QUR	Quality report for gravity field solutions
GO-2-PSO+GOC_QUR	GOCE precise orbit quality report
GO-2-EGM+QUR	GOCE Earth gravity model quality report

Constants

As defined in task 1.

Output

Product ID	Product
GO-2-PSO+GOC	GOCE precise science orbit
GO-2-EGM	Earth gravity field model (spherical harmonics and grid values incl. Variance-covariance matrix)

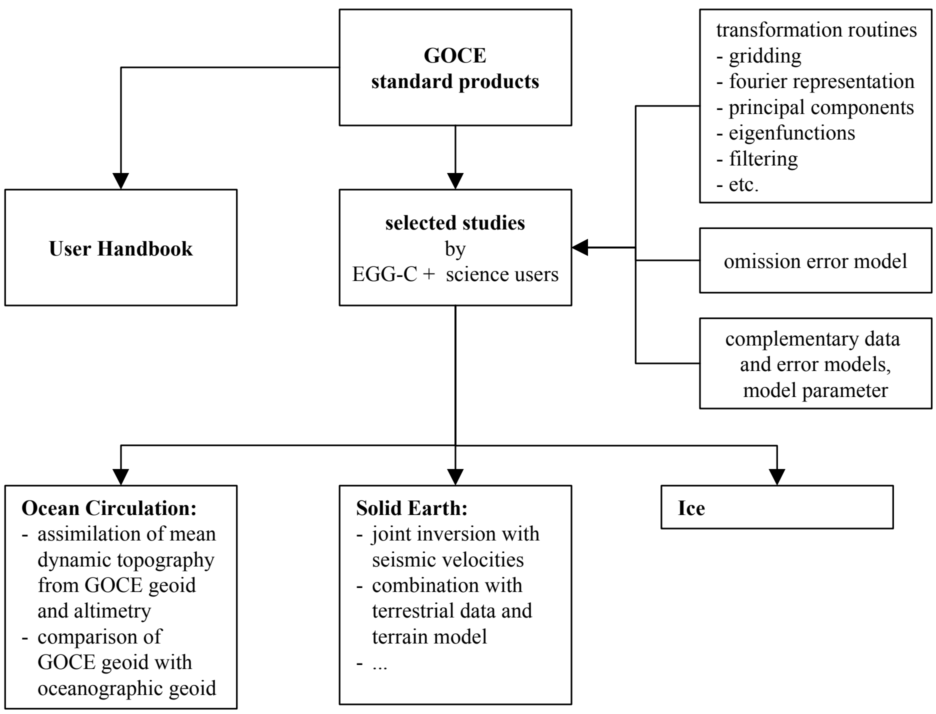
3.7. Task 8: Science Interface

Abstract

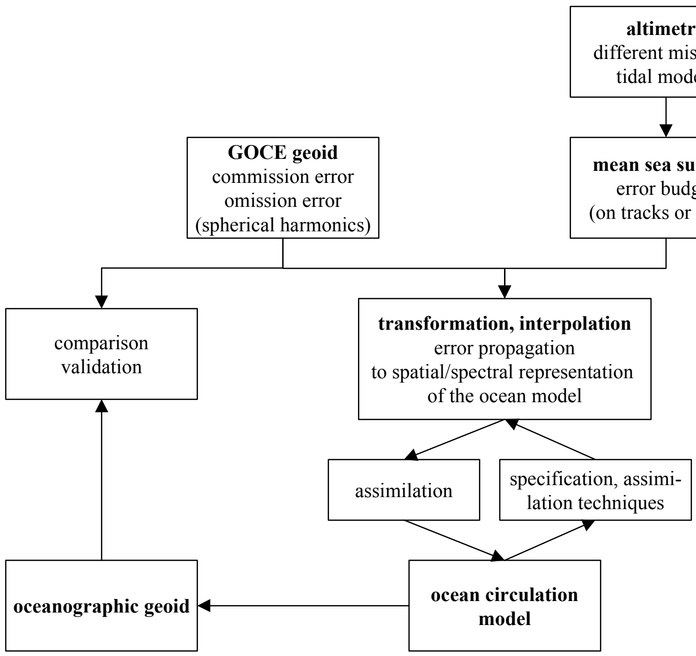
The GOCE standard products will be presented to the users in oceanography, geophysics, glaciology and geodesy together with science user oriented documentation. For some important applications, however, this is not sufficient. Ocean circulation studies showed, that the procedures to integrate (assimilate) 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.

Flow Chart

Science Interface General Flow Chart:



Ocean Circulation Flow Chart:



Definition

General Definition:
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 (finite elements) structures, along profiles (satellite tracks, ocean profiles), in Fourier representation or in other representations, error propagation for these representations, smoothing procedures, omission error model, gravity models combined with ground gravity data.

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 (e.g. LeGrand and Minster 1999, LeProvost et al. 1999).
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 (Losch et al. 2002). 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 (Zerbini et al. 1992).
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 (e.g. Cadek et

al. 1998), impact of glacial isostatic adjustment (Di Donato et al. 2000), in combination with tectonic models (Di Donato et al. 1999), rifting (Kooi et al. 1992), impact of mantle plumes.
It has to be checked, 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
- Sea ice freeboard determination from the combination of radar altimetry and the GOCE geoid (Jacobsen and Forsberg 2002)

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.

Input

GOCE-Products:

Product ID	Product
GO-2-EGM	Earth gravity field model (spherical harmonics, grid values, variance covariance matrix)
GO-2-EGG	Gradiometer geo-located gravity gradient data

Complementary Data (preliminary list, to be defined in cooperation with involved science users):

Altimetry: combination of fully processed consecutive altimetric missions, tidal models, error budgets
Ocean circulation: Ocean circulation model parameters, definition of mathematical representation and data assimilation format, grid definition
Oceanographic geoid results
Bathymetry models

Solid earth:
Seismic data (e.g. velocities)
Density and velocity models, further constraints from lithospere models
Terrestrial gravity data
Terrain models

Geolocated gravity gradients (if available)

Ice:
Ice surface from satellite or airborne altimetry
Terrestrial and airborne gravity data
Ice thickness data

Constants

- GOCE standard constants,
- Constants of application models

Output

User handbook: products description, spherical harmonic synthesis, evaluation results, description of accuracies, recommendations for filtering, omission error model etc.
Description of approved strategies (methods) for the assimilation into selected application models, together with tailored data records (non-standard products), e.g. grids with various resolution (oceanography: 1 degree, maybe 0.6 degrees)
Results and accuracies for the scientific areas of the selected studies: improved ocean circulation, heat and mass transport, lithospheric density models
Auxiliary software modules, that are needed for parts of these strategies, e.g. for the conversion between data types (spectral representations, gridding, smoothing), providing various gravity field functionals (geoid, geoid slopes, gravity etc.), for computation of omission error models.

3.8. Task 9: Regional Solutions

Global versus regional gravity field recovery

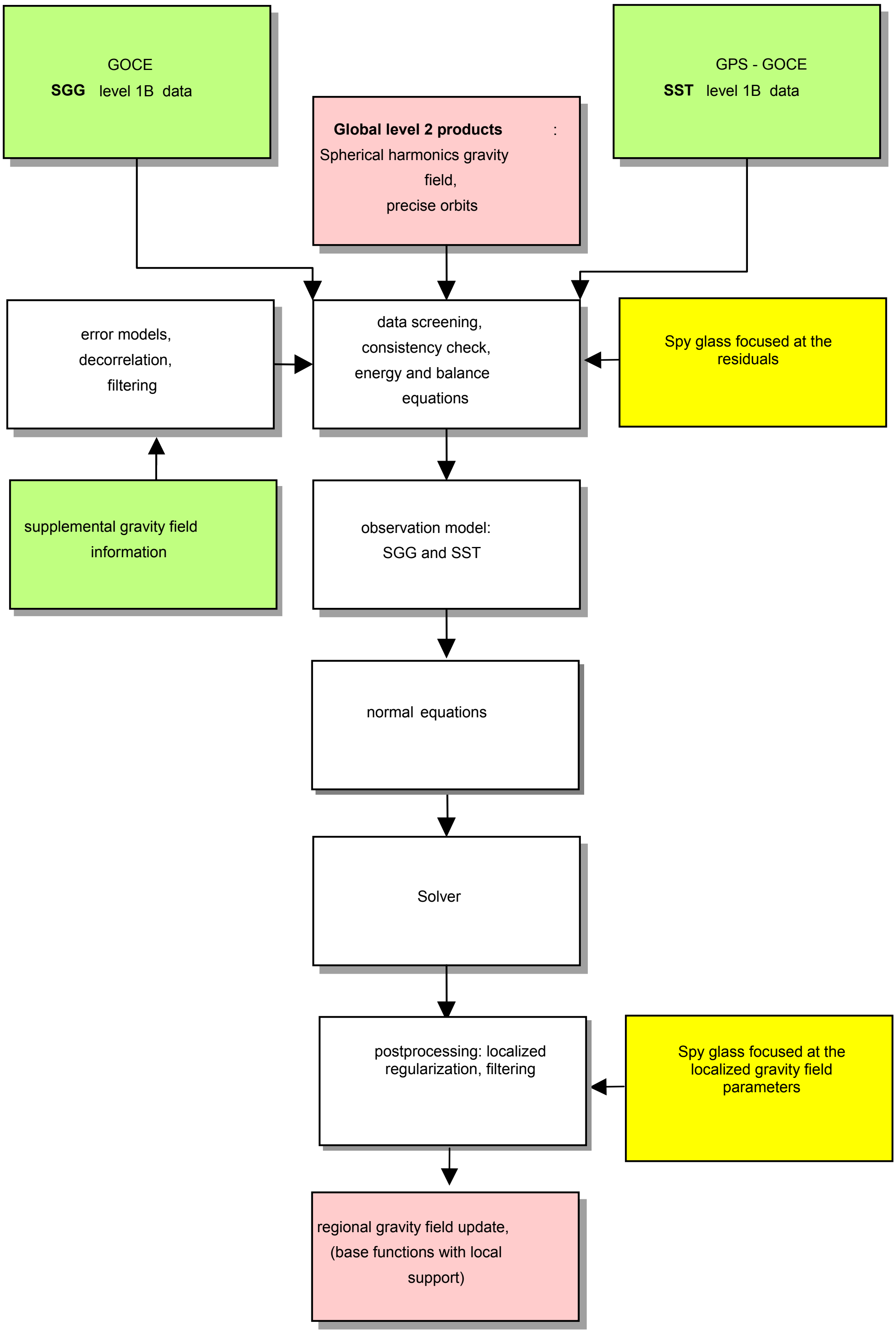
The task of GOCE is to derive a precise global static gravity field covering the complete spectral range down to a resolution of approximately 100km. A proper representation of the global gravity field is based on a linear combination of base functions with global support. At the present time there is 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 harmonics 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 the reason, that 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 will have to decide 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 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 and the multi-grid method, are 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, to our opinion there is an indispensable need for more than only one recovery procedure.

Abstract

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, least-squares collocation) 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. 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.

Flow Chart


GOCE
SGG level 1B data
GPS - GOCE
SST level 1B data
Global level 2 products :
Spherical harmonics gravity field,
precise orbits
error models,
decorrelation,
filtering
data screening,
consistency check,
energy and balance
equations
Spy glass focused at the residuals
supplemental gravity field information
observation model:
SGG and SST
normal equations
Solver
postprocessing: localized regularization, filtering
Spy glass focused at the localized gravity field parameters
regional gravity field update,
(base functions with local support)

Definition

Integral kernel approach applied in hierarchical grids:

1. Prior analysis of the data with the aim to detect regionally limited data sets with the potential to improve regional gravity field features. This is done in the box “data screening, consistency check, energy and balance equations”. It should be pointed out that this processing step is different from any sort of data preprocessing (performed in task 3). It is rather a feature useful for the focus-in procedure.
2. Hierarchical icosahedral partitioning of the sphere. The partitioning produces hierarchical grids of spherical triangles The partitioning can be efficiently combined with a multi-grid solver of the system of observation equations or normal equations in very large regions.
3. Definition of a proper kernel of the gravity field representation, e.g., Stokes' kernel, covariance functions, Abel-Poisson kernel, mass layer kernels. The software system will be designed such that between various choices can be selected, tailored to the specific task of the subsequent use of the gravity field.
4. Building of the "observed-determined" observational functionals. Consideration of topographic and isostatic models to filter and smooth the observational functionals. Further noise removal by appropriate filter techniques are to be realised. Sophisticated numerical quadrature methods combined with least squares collocation procedures are applied to derive clean pseudo-observations. It should be pointed out that these additional models are used to provide a smooth data set for the subsequent downward continuation process. They are not considered as additional gravity field information and, therefore, do not contaminate the pure satellite derived gravity field information.
5. Building of multi-grid normal equations based on iterative/direct solution strategies applying a Tichonov-Phillips-regularisation method. The regularisation factor is derived by a technique similar to the L-curve procedure.
6. A post-processing will be applied to regionally regularise the solution, tailored to the space localised signal roughness; special filtering techniques will be applied and variance component estimation techniques, again, tailored to the specific gravity field features.
7. Application of quality control procedures.

Least squares collocation:

Using the regionally modelled analytic covariance functions (see 3.3) regional solutions are constructed as linear combinations of the representers (covariance functions) of the observation functionals. These analytic representations are evaluated at the surface of the Earth or at satellite altitude in order to produce grids of varying spacing of gravity anomalies and geoid heights.

Input

GOCE GPS receiver: The code and phase measurements are used in a twofold way together with additional orbit observations of GOCE. A precise orbit determination (kinematical or reduced dynamical) provides relative orbit quantities which are used together with the high precise signal measurements to establish the observation equations for SST-observations. The original point measurements are transformed into accumulated gravity field effects (pseudo-observations) along the short orbits covering the regions to be considered (basically it represents a semi-analytical time series approach). This procedure includes a filtering and a compression step. An alternative implemented in the software is to use the precisely determined kinematic orbit of GOCE directly. In this case, the pseudo-observations are related directly to the precise orbit of GOCE and processed further as described above.

GOCE gradiometer: Calibrated GOCE level 1b data, including attitude data. The processing of the three main diagonal components of the gravity tensors are treated basically in the same way as in case of SST-observables. In addition besides the accumulated effects also point measurements along the short orbits are used directly.
Prior information: POD is used to derive additional orbit elements to process the signal measurements and to establish the observation equations for high-low SST as well as for SGG measurements. A prior spherical harmonics model is used as reference as well as a consistent regional covariance function model. Models for for topography and bathymetry are helpful to filter and smooth the observables in satellite altitude (refer to point 1, Integral kernel approach).
The use of global spherical harmonics models, derived from GOCE observables and the derivation of precise orbit computations consistent with a specific model underlines the spy-glass effect of the regional method: if there are systematic effects in the residuals then it is possible to find a consistent set of space localising parameters which improve the global solution within the specific area.
For both methods (collocation and integral kernel function approach), a-priori information about the calibrated observation error PSD is important.

Product ID	Product
GO-1B-EGG	Gradiometer Calibrated & Corrected Gravity Gradients
GO-1B-EGG	Gradiometer Calibrated & Corrected Accelerations
GO-1B-SST	GPS Calibrated & Corrected Phase & Range data
GO-1B-NAV	On-board navigation solution
GO-1B-ATT	Satellite Attitude
GO-1B-THR	Thrust History of AOCS & Drag Free Actuators
GO-2p-EGM+COV	Global covariance function for the gravity field
GO-2p-SST+POS	GOCE precise science orbit (kinematic)
GO-2i-AOV	Model data for time variable gravity field
GO-2p –PSO+GOC_RD	GOCE precise science orbit (reduced dynamic)
	Ancillary Product
GO-2a-GNS	IGS GPS Products
GO-2a-SLR	Laser Tracking Data
GO-2a-DTM	Atmospheric Density Model
GO-2a-ATM (or GO-2i-AOV)	Atmospheric Pressure Data for Time Variable Gravity Field
GO-2a-OCM (or GO-2i-AOV)	Ocean Bottom Pressure/Model Data for Time Variable Gravity Field
GO-2a-ERP	Earth Rotation Parameters from IERS
GO-2a-SSC	Station Coordinates from ITRF
GO-2a-OTI	Tide Models
GO-2a-EPH	Sun, Moon & Planetary Ephemeris
GO-2a-RAD	Earth Albedo & Solar Radiation
GO-2a-EGM	A-priori Gravity Field Solution
GO-2a-EVG	Surface and airborne gravity data with errors
GO-2a-TOP	Digital Terrain Models
GO-2a-SCM	Spacecraft Parameters
GO-2a-EGT	Temporal gravity field variations (from GRACE results)
GO-2a-SGA	Solar flux and geomagnetic activity indices

Constants

Consistent models and systems of constants as usual, following international standards

Output

Regional recovery procedures are on the one hand product-oriented. The product will be regionally focused analytic representations of the gravity field (mean gravity/height anomalies) as well as grids of gravity anomalies and geoid heights with a density depending on the regional gravity field variation. The Least Squares Collocation approach provides: Grids at ground level (not at height zero !) of gravity anomalies and geoid heights with their error estimates and error-correlations. At satellite level, grids of easy-to-use anomalous quantities (first and second derivatives) converted to an earth-pointing reference frame.
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.

Product ID	Product
GO-2-RGM	Regional gravity field model
GO-2i-RGG	Regional grids of gradiometer data at satellite altitude

4. Related Documents

[1] Gravity Field and Steady-State Ocean Circulation Mission; Reports for the four candidate Earth Explorer Core Missions; ESA SP-1233(1), July 1999
[2] Mission Objectives and Scientific Requirements Document for the GOCE Mission (MRD), Issue 2, March 2000
[3] The European GOCE Gravity Consortium, Version 10, 21. June 2001
[4] GOCE Standards Requirements Document (StRD), Draft Midterm Report
[5] GOCE Products Definition Document (PDD), Draft Midterm Report
[6] Space Engineering, Software, European Cooperation for Space Standardization, ESA-ESTEC, ECSS-E-40A, 19. April 1999.
[7] GOCE System Requirements Document for Phase B/C/D/E1, ESA, Doc. Nr. GO-RS-ESA-SY-0002, 2 Draft, 1. June 2001
[8] Gradiometer Ground Processing Algorithms Specification, Alenia Spazio, Doc. Nr. GO-SP-AI-0003, Issue 01, 14. Feb. 2002
[9] GPS Receiver Ground Processing Algorithms Specification, Alenia Spazio, Doc. Nr. GO-SP-AI-0004, Issue 01, 14. Feb. 2002
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GOCE: Preparation of GOCE Level 1 to Level 2 Data Processing

ESTEC Contract No. 14986/00/NL/DC

Slice 2

GOCE System Requirements Document (SRD)

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Contents

1. Introduction

This document 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 the European GOCE Gravity Consortium (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 preprocessed level 1B GOCE products, which are provided by ESA. Level 0 to level 1A/1B processing is not subject of this requirements document. Only possible requirements on level 1A/1B 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 [6], the system requirements are separated into 2 main categories. These are

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

General requirements are divided into specific classes which are:

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

For specific requirements for each task or sub-task, the following classes are defined:

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

Operations, maintenance and documentation as well as verification and validation requirements have to be regarded in a more general way describing the overall system architecture. Therefore they will not appear in the specific requirements section.

The requirements are sorted and numbered according to their specific category they belong to. The general numbering scheme is as follows:

R-A-BB-C-DD

with:

R:	Requirement (fixed)	
A:	Requirement category: G = General requirement S = Specific requirement	
BB:	Task number (2 digits) e.g. 52 = task 5.2; 61 = task 6.1; 10 = task 1 XX = no specific task (applicable for general requirements)	
C:	Requirement class: F,P,O,I,V (see above)	
DD:	Requirement number (2 digits) e.g. 01, 15	

For example the requirement R-G-XX-V-01, describes a general verification and validation requirement. The requirement R-S-31-I-05, specifies a specific interface requirement for task 3.1.

2. General Requirements

The following sub-sections provide a list of general requirements according to the requirement classes identified above.

2.1 Functional Requirements

R-G-XX-F-01	The EGG-C consortium shall generate GOCE level 2 science data products from level 1A/1B products. The consortium shall provide the core and supplementary level 2 products as specified in the products definition document (PDD). These are the precise orbit and the gravity field and derived quantities including an error assessment.
R-G-XX-F-02	The EGG-C consortium shall generate quick-look level 2 products in order to provide a feed-back to the satellite operations and to the level 0 to level 1A/1B processing system. This feed-back function ensures that the best as possible level 1A/1B products will be used for the final data analysis.
R-G-XX-F-03	All processing tasks shall apply the GOCE standards as they are described in the GOCE Standards Requirements Document (StRD). This ensures compatibility within the different processing levels.
R-G-XX-F-04	The EGG-C consortium shall set up a data base with all level 2 and intermediate products for long term use.
R-G-XX-F-05	The EGG-C consortium shall support the mission project calibration activities by estimating calibration parameters using external data.
R-G-XX-F-06	The EGG-C consortium shall take into consideration product requirements and wishes of the science user community in order to guarantee a maximum scientific return from the GOCE mission.

2.2 Performance Requirements

R-G-XX-P-01	The EGG-C consortium shall set up a schedule for the delivery of all level 2 products.
R-G-XX-P-02	The EGG-C consortium shall begin science data processing immediately after release of the first level 1A/1B products to the consortium.
R-G-XX-P-03	Depending on the product type, quick-look products shall be available in near real time (task 3.3: gross error detection, consistency, data gaps) or within a few days after availability of a new weekly batch of level 1 data (task 5.2: quick-look gravity model) in order to enable a feed back to the mission operation and/or the level 1 processing system.
R-G-XX-P-04	Final level 2 products shall be made available to the user community not later than 9 months after completion of level 1 processing of the planned operational phases.
R-G-XX-P-05	The EGG-C consortium shall use data of the entire planned observation period to derive the level 2 products. Data spans shall not be excluded without justification.
R-G-XX-P-06	The EGG-C data base shall be maintained for at least 5 years after completion of the mission.

2.3 Operations, Maintenance and Documentation Requirements

R-G-XX-O-01 A document with all Software components, which are necessary to generate level 2 products shall be available at the end of the development phase. This document shall contain for each processing step at least the basic description of the algorithms and the description of input and output parameters.

R-G-XX-O-02 All Software components shall be administrated by a source code administration system. Each product shall be delivered together with a release number, which enables the identification of the Software version used for processing the product.

2.4 Interface Requirements

R-G-XX-I-01 An interface between the EGG-C consortium and the ESA mission operation and level 1 processing facility shall be set up in order to make all science and housekeeping data available to the consortium.

R-G-XX-I-02 The EGG-C data base shall be the central node for GOCE products and ancillary data exchange. Each processing task shall take all information out of the data base and provide the resulting products to the data base.

R-G-XX-I-03 Interfaces to existing services as specified in the StRD (e.g. they concern IGS, IERS, and others) shall be established in order to ensure ancillary data availability for level 1 to 2 processing.

R-G-XX-I-04 Interfaces to ECMWF, because of short term atmospheric effects, and an equivalent model of ocean variability shall be implemented in order to receive the necessary data for short period gravity de-aliasing of GOCE measurements.

R-G-XX-I-05 The EGG-C consortium shall set up agreements with the external ancillary data providers to ensure that the requirements for access and latency of these products (as specified in this document) can be fulfilled.

R-G-XX-I-06 The GOCE level 1 to level 2 processing system assumes that ancillary products are provided by the external services as required by the processing tasks. If this is for a specific ancillary product not the case, the EGG-C consortium shall identify alternative data sources.

R-G-XX-I-07 Interfaces between the processing steps shall be identified and described in an Interface Control Document (ICD) together with a detailed description of the data structures.

R-G-XX-I-08 The science user interface shall be established together with the data base. Access rules and all relevant product information shall be available via the user interface.

2.5 Validation and Verification Requirements

R-G-XX-V-01 For the precise orbit and the gravity field products at least two independent solutions based on different approaches shall be generated in order to enable an independent validation and verification of these products.

R-G-XX-V-02 The gravity field solutions and the corresponding error covariances as well as the precise orbit solutions shall be evaluated based on internal and external quality estimates.

R-G-XX-V-03 The final orbit and gravity field products shall be selected by task 6.3 on the basis of the internal and external solution evaluation and taking the recommendations of designated independent reviewers on the basis of their own investigations into account.

R-G-XX-V-04 The quick-look level 2 analysis shall be used for verification and validation of the level 1A/1B products.

3. Specific Requirements

The following sub-sections provide for each identified task of the level 1 to level 2 processing system a list of requirements in the three classes, which have been identified above for the specific requirements.

3.1 Task 1: Standards

R-S-10-F-01	The GOCE standards shall be selected from the most up to date geophysical models and data. International conventions shall be taken into consideration as much as possible (e.g. IERS-2000).
R-S-10-F-02	The CHAMP and GRACE standards shall be reviewed and taken as reference where applicable.
R-S-10-F-03	The GOCE standards shall contain the reference systems, the dynamical models and the geometrical models necessary for generating the orbit and gravity field products.
R-S-10-P-01	The GOCE standards shall be fixed at the latest 3 months before launch.
R-S-10-I-01	An Interface to the CHAMP and GRACE science data processing systems shall be set up in order to make use of the most up to date static and temporal gravity field information.
R-S-10-I-02	A satellite macro-model and knowledge of the surface material and reflectivity coefficients shall be made available by the GOCE project team.

3.2 Task 2: Data Base

R-S-20-F-01	The GOCE data base shall be a central system containing all necessary information for performing the individual tasks within the level 1 to level 2 processing chain.
R-S-20-F-02	A user interface shall be established together with the data base for products access. User classes with different privileges according to their tasks within or outside of the EGG-C consortium shall be defined.
R-S-20-F-03	The data base shall contain all GOCE products of the EGG-C consortium and level 1A/1B products from the ESA GOCE processing facility, which are necessary for generation of level 2 products. This includes also ancillary data from other sources.
R-S-20-P-01	The data base and user interface shall be available 24 hours a day except for maintenance periods, which shall be announced prior to the event.
R-S-20-P-02	The data base and user interface shall be in place and tested 3 months before the GOCE launch.
R-S-20-P-03	The GOCE data base shall be used as long term archive for GOCE level 2 products.
R-S-20-I-01	All partners in the EGG-C consortium shall access their input data from the data base.
R-S-20-I-02	All science users shall access GOCE products via the user interface.

3.3 Task 3.1: External Calibration

R-S-31-F-01	The pre-flight and internal calibration activities by ESA shall be supported by external calibration of the EGG-C using external data.
R-S-31-F-02	In Task 3 the level 1B SGG products (gradiometer observations) shall be externally calibrated.

R-S-31-F-03 For external calibration of the SGG observations the following methods shall be applied:
- Comparison with ground-based or air-borne gravity data
- Comparison with existing global gravity field models

R-S-31-F-04 The EGG-C shall provide a final calibration assessment by combination of the different methods and using different calibration data.

R-S-31-F-05 The external calibration procedure shall determine values for scale factors, biases, drifts and other applicable parameters with which the level 1B data shall be corrected for any possible remaining (instrumental or operational) errors.

R-S-31-F-06 The external calibration procedure shall be capable of being performed independently so that it is possible to redo the external calibration if the outcome of Task 6 makes it necessary.

R-S-31-F-07 The external calibration described in this section is to be understood such as to include an error assessment of the level 1B SGG products using methods that take advantage of existing and external gravity data.

R-S-31-P-01 External data to be used for calibration shall be at least as accurate as the prospected GOCE observation accuracy in certain frequency bands and/or in certain geographical regions.

R-S-31-I-01 External calibration data including a proper error description shall be acquired from various sources in order to be able to apply the planned calibration methods. If necessary agreements between the EGG-C and the data provider shall be set up.

R-S-31-I-02 In case the (value of the) external calibration parameters determined in this procedure are not compatible with the expected error level of the level 1B data, the EGG-C shall feed this information back to the GOCE project to be taken into account in mission operations.

3.4 Task 3.2: Frame Transformation & Time Variable Gravity Field

R-S-32-F-01 GOCE SGG observations shall be transformed from the local orbital reference frame to a radial (Earth pointing) reference frame (z-axis radial, x-axis in the orbital plane and y cross-track). For this the full gravity gradient tensor is necessary as well as accurately enough satellite attitude (from the SGG instrument and the star trackers) and position (orbit) information.

R-S-32-F-02 Temporal variations of the gravity field due to mass variations in, on and above the Earth shall be removed during the gravity field processing in order to derive a static gravity field model.

R-S-32-F-03 Short term mass variations in the atmosphere and ocean shall be commonly analysed and taken into consideration during gravity field processing. This ensures a proper combined modelling of the oceans and the atmospheric mass variations.

R-S-32-F-04 Long term gravity field variations shall be derived from the analysis of the sequence of CHAMP & GRACE gravity field solutions, either by external parties or by the EGG-C. This information will contain the integrated signal from various sources (hydrology, ice, oceans, atmosphere, geophysics) and will represent the state of the art at the time when GOCE flies.

R-S-32-P-01 The accuracy of the gradients after frame transformation shall be compatible with the accuracy level of the original SGG measurements (only xx, yy and zz) in the local orbital reference frame.

R-S-32-P-02	An error assessment of short term gravity field variations derived from atmospheric and oceanic model information shall be performed in order to ensure accuracy compatibility with the GOCE observations.
R-S-32-P-03	The CHAMP & GRACE sequence of gravity field models shall be analysed for accuracy and homogeneity in order to ensure compatibility for usage during the GOCE data processing.
R-S-32-I-01	Star tracker and satellite tracking information shall be made available by the GOCE project (ESA) to the EGG-C.
R-S-32-I-02	For computing short term gravity field variations due to atmospheric mass re-distributions an interface to the ECMWF atmospheric model shall be implemented.
R-S-32-I-03	An interface to an ocean circulation model shall be implemented in order to estimate short term gravity field variations due to ocean mass re-distributions.
R-S-32-I-04	An interface to the CHAMP & GRACE science data processing systems shall be set up in order to get access to their gravity field products.

3.5 Task 3.3: Gross Error Detection, Consistency, Data Gaps

R-S-33-F-01	The EGG-C shall set up a tool for checking GOCE data consistency finding gross errors and identifying data gaps by using GOCE data combinations and by using external information.
R-S-33-F-02	GOCE SGG data shall be checked by analysis of repeated observations, by testing the Laplace condition, by upward continued ground or air-borne gravity data and possibly by using statistical methods (like moving point-wise interpolation).
R-S-33-F-03	Standard interpolation techniques shall be developed in order to fill small data gaps (single or few missing data points) in the GOCE SGG data stream in order to facilitate the quick-look gravity field analysis. These data shall be flagged in the data stream.
R-S-33-P-01	Gross error detection, data gap analysis and consistency checks shall be performed quickly after availability of level 1B data. Test data sets shall be prepared beforehand in order to have all information available on time.
R-S-33-I-01	Ground-based and air-borne gravity data including a proper error description shall be acquired, which can be used for SGG data checking.
R-S-33-I-02	The GOCE navigation solution shall be available to the EGG-C.
R-S-33-I-03	Results of the task, which could affect the mission operations or the data pre-processing performed by ESA, shall be delivered immediately to the GOCE project.

3.6 Task 4.1: Observation Screening for Precise Orbit Determination

R-S-41-F-01	GOCE SST observations shall be checked by the assessment of the navigation solution and by applying the Melbourne-Wübbena editing.
R-S-41-I-01	IGS clock and orbit solutions for the GPS satellites shall be available within a few days latency.
R-S-41-I-02	Formats for GOCE products related with SST observations and orbits shall be developed. Where possible existing formats such as RINEX or SP3 shall be used.

3.7 Task 4.2: Reduced Dynamic Precise Orbit Determination

R-S-42-F-01	A reduced dynamic precise orbit solution shall be computed from GPS tracking data and on-board attitude and accelerometer observations. The dynamic models and constants as specified in the Standards Requirements Document shall be used for orbit determination.
R-S-42-F-02	If the quality of existing dynamic models is not sufficient, parameters shall be estimated during the reduced dynamic precise orbit determination. The Software shall be capable to estimate various dynamic model parameters, which are relevant for GOCE.
R-S-42-F-03	The reduced dynamic POD Software shall be capable to estimate parameters for the observation model.
R-S-42-F-04	The reduced dynamic orbit product shall contain at least the position and velocity in an Earth fixed and inertial frame and observation statistics including residuals.
R-S-42-P-01	The reduced dynamic precise orbit shall be processed within 2 months after availability of the GOCE tracking data.
R-S-41-P-02	The absolute position accuracy of the reduced dynamic precise orbit shall be better than 10 cm at 10 sec interval given a nominal performance of the GPS receiver.
R-S-42-I-01	GPS ground data, clocks and GPS satellites orbit solutions from the IGS shall be used for reduced dynamic orbit restitution.
R-S-42-I-02	The satellite model (e.g. macro-model, surface characteristics, instrument locations, centre of mass) shall be provided by the GOCE project.

3.8 Task 4.3: Kinematic Precise Orbit Determination

R-S-43-F-01	A pure kinematic precise orbit solution shall be computed from GPS tracking data. The constants and geometric models as specified in the Standards Requirements Document shall be used for orbit determination.
R-S-43-F-02	Two approaches based on undifferenced and differenced GPS observations shall be investigated in order to identify the best solution strategy for the kinematic approach.
R-S-43-F-03	The kinematic orbit product shall contain the position and position differences in an Earth fixed frame and observation statistics including residuals.
R-S-43-P-01	The kinematic precise orbit shall be processed within 2 months after availability of the GOCE tracking data.
R-S-43-P-02	The absolute position accuracy of the kinematic precise orbit shall be better than 10 cm given a nominal performance of the GPS receiver.
R-S-43-I-01	GPS ground data, clocks and GPS satellites orbit solutions from the IGS shall be used for kinematic orbit restitution.

3.9 Task 5.1: Gravity Field Determination – Direct Method

R-S-51-F-01	Gravity field coefficients shall be computed using both the Satellite-to-Satellite Tracking (SST) data and the Satellite Gravity Gradient (SGG) data. The standards described in the Standards Requirement Document shall be respected.

R-S-51-F-02	The formal error estimate of the gravity field shall be delivered in the form of the full variance-covariance matrix.
R-S-51-F-03	The gradiometer common mode calibration parameters (biases and scale factors) shall be estimated simultaneously with the gravity field parameters.
R-S-51-P-01	The gravity field model, the variance-covariance matrix, and the gradiometer common mode calibration parameters shall be delivered not later than 9 months after completion of each consecutive mission phase of 6 months.
R-S-51-P-02	The gravity field model shall be computed up to at least degree and order 250, true mission profile and instrument performance permitting.
R-S-51-P-03	The SST and SGG data processing workload shall be equally distributed over GFZ and CNES.
R-S-51-I-01	GOCE reduced dynamic or kinematic orbit solutions shall be used in the dynamic orbit computation.

3.10 Task 5.2: Gravity Field Determination: Time-Wise Approach

R-S-52-F-01	A spherical harmonic model of the Earth's gravity field including an estimate of the full variance-covariance matrix shall be computed from GOCE SGG and SST data following the time-wise approach.
R-S-52-F-02	A quick-look gravity field analysis by means of the semi-analytical approach based on partial SGG and SST data sets shall be performed in order to obtain information about the level 1 data quality.
R-S-52-P-01	The gravity field model and the full variance-covariance matrix shall be delivered within 4 months after release of the necessary level 1b data sets. For each consecutive mission phase of 6 months separate gravity field solutions shall be generated as well as a final model based on all mission observation phases.
R-S-52-P-02	The gravity field model shall be computed up to at least degree and order 250, true mission profile and instrument performance permitting.
R-S-52-P-03	Preliminary quick-look gravity field solutions perform a permanent assessment of the level 1 b data quality and shall be produced every week with a latency of 2 days after release of the necessary level 1b data sets.
R-S-52-I-01	Task 5.2 shall be interfaced with Task 2 (Data Base) and Task 6 (Solutions Evaluation).
R-S-52-I-02	An interface between the quick-look gravity field modelling results and the level 0 to level 1 processing system shall be implemented in order to have feedback about the SGG data quality.

3.11 Task 5.3: Gravity Field Determination: Space-Wise Approach

R-S-53-F-01	An Earth gravity field model shall be produced by means of a space-wise approach, from GOCE gravity gradients observations.
R-S-53-F-02	The Earth gravity field model shall be represented as spherical harmonic coefficients (or corrections to an a-priori model) and error estimates and error covariances.
R-S-53-F-03	Since GOCE observations will be taken in a time stream along the orbit with the gradiometer working in a specific measurement bandwidth, “spatialized” data shall be produced using a Wiener orbital filter (WOF). The covariance function of the estimation error will be also computed.

R-S-53-F-04 The filtered data shall be processed in order to form a regular grid on a reference sphere. Approaches based on collocation or on other interpolation methods shall be made available.

R-S-53-F-05 The gravity field coefficients shall be determined by an integration approach and by fast spherical collocation. The best solution shall be identified.

R-S-53-P-01 Since the space-wise approach is intended to make use of the whole set of GOCE observations, it will not be applied in real time. A final gravity field model shall be produced at the end of the mission. Intermediate solutions shall be computed after each mission phase.

R-S-53-I-01 The local analysis of the signal "second derivatives of the potential" shall be shared with Task 9 (Regional Solutions) and the assessed error grids of second derivatives shall be produced for further local analysis.

R-S-53-I-02 Task 5.3 shall be naturally interfaced with Task 6 (Solutions Evaluation) and all the output of Task 5.3 will have to be used in the assessment phase.

3.12 Task 6.1: Internal Evaluation

R-S-61-F-01 Precise orbit solutions from the reduced dynamic and the kinematic approaches shall be compared by direct position comparisons and orbit overlaps.

R-S-61-F-02 Precise orbit solutions shall be evaluated by fitting satellite positions with a dynamical orbit model and analysis of the position residuals.

R-S-61-F-03 The internal gravity field quality measures shall be derived from the differences of the gravity field solutions and the corresponding error covariances.

R-S-61-P-01 The internal evaluation procedure shall provide the internal quality report not later than 1 week after completion of the precise orbit product.

R-S-61-P-02 The internal evaluation procedure shall provide the internal quality report not later than 1 week after completion of the gravity field product.

R-S-61-I-01 For precise orbits and gravity field solutions an internal quality report shall be generated according to pre-defined standards. This report shall include at least:
For precise orbit: Transformation parameters between orbits, position differences and RMS of state vectors and overlaps, residuals to fitted orbits in radial, along and cross track direction.
For gravity field: Comparison of different gravity field solutions in terms of spherical harmonic coefficients differences and degree variance differences and grids of geoid height and gravity anomaly differences.

3.13 Task 6.2: External Evaluation

R-S-62-F-01 Reduced dynamic and kinematic orbit solutions shall be evaluated by comparisons with dynamic GOCE orbits and externally provided orbits and independent GOCE laser tracking data.

R-S-62-F-02 The GOCE gravity field solutions shall be evaluated by computing orbits for various geodetic satellites and analysing the tracking data residuals (including altimeter crossover residuals).

R-S-62-F-03 The GOCE gravity field solutions shall be evaluated by comparison with independently observed gravity field information.

R-S-62-F-04 Altimeter data shall be used extensively for evaluation of the GOCE gravity field.

R-S-62-F-05 Comparison data shall be consistently prepared. They shall be transformed to a defined common reference system and they shall be filtered if necessary in order to remove information, which is not relevant for GOCE.

R-S-62-F-06 The internal error estimates of the gravity field solutions (variance-covariance matrix) shall be evaluated with respect to external comparison results. If necessary a calibration function shall be determined and applied to the variance-covariance matrix.

R-S-62-F-07 An external quality report summarising all results of the external quality evaluation shall be prepared.

R-S-62-P-01 Calibration test sites and orbit test arcs shall be selected such that they are representative for GOCE solution evaluation (data quality and resolution).

R-S-62-P-02 The external evaluation procedure shall provide the external quality report for the GOCE orbit products not later than 1 month after completion of the precise orbit product for the defined test period.

R-S-62-P-03 The external evaluation procedure shall provide the external quality for the GOCE gravity field solutions not later than 2 months after completion of the gravity field products.

R-S-62-I-01 The external quality report shall be delivered to ESA and task 6.3 for solution selection and recommendation.

R-S-62-I-02 For the external evaluation comparison data sets, which are necessary to perform the planned tests, shall be acquired continuously. Interfaces to other facilities (e.g. IGS LEO group) shall be established if necessary.

R-S-62-I-03 An interface to task 3.1 (external calibration) shall be established in order to harmonize calibration and evaluation site selections and data sets.

3.14 Task 6.3: Model Selection and Recommendation

R-S-62-F-01 An external reviewer, selected by the GOCE project and the EGG-C consortium shall select the final orbit and gravity field products to be released as the reference solution. The selection shall be based on the internal and external quality reports and on additional investigations by the reviewer.

R-S-62-F-02 The final decision for selection of the reference solution shall be done by the GOCE project, the EGG-C consortium and the external reviewer during a common meeting.

R-S-62-P-01 The selection of the final models by the external reviewer shall not be later than 4 weeks after release of the models and the internal and external quality reports to the external reviewer.

R-S-62-P-02 The final decision for the reference solution shall not be later than 4 weeks after the selection of the product by the external reviewer.

3.15 Task 8 : Science Interface

R-S-80-F-01 A detailed GOCE user handbook shall be compiled. It shall contain a presentation of the GOCE products, information about the spatial and spectral resolution and accuracy of the GOCE gravity model, the usage of the spherical harmonic coefficients as well as the corresponding error measures and the combination with other data types.

R-S-80-F-02 An inventory of applications in geosciences, which demand high resolution gravity information, shall be collected. It shall be based on the GOCE Granada report [1] and new literature. In addition, science users from all main fields of applications (solid earth, oceans, ice, geodesy, sea level) shall be contacted in order to complete the inventory.

R-S-80-F-03 The models of the applications listed in the inventory, such as ocean circulation models, lithospheric models or ice flux models, shall be checked, whether they need non-standard gravity field products or procedures, taking into account the feedback from science users. Examples for non-standard products and procedures which are already identified are: Gravity/geoid data in gridded (finite elements) structures, along profiles (satellite tracks, ocean profiles), in Fourier representation or in principal component representation, error propagation for all these representations, smoothing procedures, omission error model.

R-S-80-F-04 Studies in cooperation with science users for the integration of both, standard and non-standard products, into application models shall be stimulated.

R-S-80-F-05 Specifications shall be formulated, how non-standard gravity field products shall be derived to ensure that the GOCE gravity information is applied in an optimal way.

R-S-80-F-06 For selected applications auxiliary software shall be developed to produce derived (non-standard) gravity field products. Especially the necessary tools for conversion between different representations of the gravity field (e.g. spectral representations, gridding. smoothing) shall be developed.

3.16 Task 9: Regional Solutions

R-S-90-F-01 The EGG-C consortium shall provide a tool for analysing systematic deviations of the observables (SGG and SST) from global solutions in selected regions.

R-S-90-F-02 Preprocessing tools for discrete SGG and SST observations shall be provided (filtering, decorrelation, etc.).

R-S-90-F-03 The Regional Gravity Field Software shall be provided in a modular form to be able to adapt the local gravity field representation to the special features of the region of interest (grid definition, kernel choice, regularization procedure).

R-S-90-F-04 The Regional Gravity Field Software shall be structured in such a way that it represents a tool box for regional gravity field recovery in view of additional gravity field information.

R-S-90-F-05 The Regional Gravity Field Software shall represent a tool with especially close connections to the science interface and shall be tailored to this tasks to be specified.

R-S-90-P-01 The Regional Gravity Field Software shall be able to generate mean gravity and mean geoid heights (height anomalies) for 1° and0.5° blocks above terrain level within 5 weeks after GOCE data availability, including error estimates; error correlations on demand.

R-S-90-P-02 Grids of gradient data at mean satellite altitude in a radial frame as well as their error estimates; mean values of gradients at satellite altitude.

R-S-90-I-01 The Regional Gravity Field Software shall be able to support the validation and calibration tasks.

4. Related Documents

[1] Gravity Field and Steady-State Ocean Circulation Mission; Reports for the four candidate Earth Explorer Core Missions; ESA SP-1233(1), July 1999
[2] Mission Objectives and Scientific Requirements Document for the GOCE Mission (MRD), Issue 2, March 2000
[3] The European GOCE Gravity Consortium, Version 10, 21. June 2001
[4] GOCE Standards Requirements Document (StRD), Draft Midterm Report
[5] GOCE Products Definition Document (PDD), Draft Midterm Report
[6] Space Engineering, Software, European Cooperation for Space Standardization, ESA-ESTEC, ECSS-E-40A, 19. April 1999.

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

ESTEC Contract No. 14986/00/NL/DC

EGG-C

Development Plan

Slice 3

Development Plan Document

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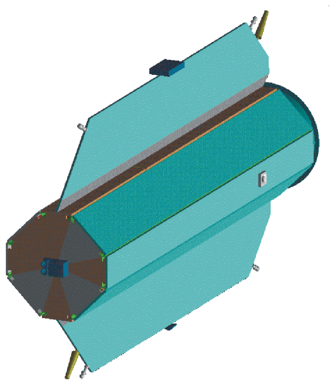

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GOCE

Development Plan Document

Contents

0. Summary

The development plan assumes that the whole level 2 activity is broken down into nine tasks (of which eight have been considered in the present preparatory study). Its main goal is to identify those 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 gravitational potential and associated functionals (geoid heights and slopes, gravity anomaly field) 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 the 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 development plan addresses all questions: 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.

1. Introduction

The foreseen activity presupposes that the whole level 2 work is broken down into 9 different tasks, as per the EGG-C document (version 10, June 21, 2001), i.e. in summary:

- T1. Standards (constants, models, reference systems,…)
- T2. Data bases
- T3. Aid to pre-processing
- T4. Precise orbit determination
- T5. Global gravity field model determination
- T6. Solution evaluation and product selection
- T7. Communication (web), documentation, publication, public relations
- T8. Interface to science
- T9. Regional solutions

Task 7 is outside the scope of this preparatory study, and Task 3 is the subject of a separate report (of *Slice 5*). Task 1 is concluded by the GOCE Standards Requirements Document (**StRD**; [RD3]). The GOCE Products Definition Document [RD2] defines all GOCE products at different levels and especially those resulting from the different tasks listed above.

The development plan is based on *Slice 2* and is taking into account the selection of the "official" product which is a global model of the gravitational 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.

2. Development sequence

For clarity and consistency (within each task) we present the different components separately for each task (or sub-tasks), as follows:

(a) Inventory
(b) Outstanding items
(c) Prototypes
(d) Implementation in operational chain

2.1. Task 1: Standards

(a) Inventory

See **StRD** [RD3].

(b) Outstanding items

- Presently the IERS-1996 conventions and/or GRIM5 standards are implemented and used daily in all software producing precise orbits from various types of tracking data, and in global gravity field recovery software. Once the GOCE standards are agreed upon, the software will be updated accordingly.
- Macro-model of the GOCE spacecraft.

(c) Prototypes

All existing POD and global gravity recovery software.

(d) Implementation in operational chain

The standards are handled in computer form (parts included in software modules, parts in data base), and the implementation should pose no other problems than making the interfaces for some of them (e.g. the time-varying parts coming from geophysical fields - such as the atmospheric pressure, or models, or GRACE results).

2.2. Task 2: Data base, archiving, formats, distribution

(a) Inventory

- Various data base management systems.
- ORACLE, STAF at CNES.
- CHAMP databases: mission database at GFZ.
- CHAMP-STAR database at CNES.
- GRACE databases: at GFZ (CHAMP heritage), under completion.
- at CNES: under development (from CHAMP).
- GPS multi-mission database at AIUB and CNES.
- General satellite database at CNES and at GFZ.
- Satellite database at DEOS.

(b) Outstanding items

- Definition of meta data standard.
- Definition of retrieval attributes.
- Development of Datawarehouse functions (graphical).
- Representation of products, transformations (e.g. spherical harmonics to grid values), data extraction.
- Definition of data policy.
- Combination of WWW and database server (user interfaces, access scenarios).
- Archive management (storage media, backup strategies).
- Management of all GOCE products of Level 1B and 2 (including internal, ancillary products) and intermediate processing results (e.g. normal equations).
- Data flow among the GOCE distributed processing centres.
- Handling of very huge files (normal, correlation and var.-cov. matrices).

(c) Prototypes

c.f. CHAMP, GRACE under (a)

(d) Implementation in operational chain

Requirements Phase (Data Model), Definition Phase, Prototyping Phase (simulated products), Acceptance

2.3. Task 3: Pre-processing

2.3.1 External calibration

A. Calibration with existing global gravity field models

(a) Inventory

Estimation of scale factor, bias, tilt and higher order effects at 1 to 4 cpr for SGG observations is implemented in Matlab. First, gradients from a global geopotential model are computed in the orbit points using standard synthesis s/w. Then the Matlab module compares the simulated gradients with the observations given at the orbit points which come from the POD. From the differences the calibration parameters are estimated in a least squares sense (signal calibration). Among the options to be chosen are: length of observation series (arc) for which the calibration parameters are computed, type of calibration parameters to be estimated, gradient to be calibrated (xx, yy or zz component). PSD's of observations, calibration gradients (from the model), calibrated gradients, and of the effect of the calibration are provided to check the calibration. Among the output are: calibration parameters, calibration corrections to the gradients in the frequency and in the time domain, calibrated gradients. Test results indicate that the lower part of the spectrum (below the MBW), where large errors from the measurement process remain (see the results from the SGG end-to-end simulations), can be very well calibrated with this method. The calibration removes the large error peaks at 1-4 cpr. The results are "clean" gradients to be directly used as output product or to be input to the gravity field estimation. Since the method does not improve the data quality inside the MBW it is strictly not really needed as input for the gravity field estimation process, but it may relief the tight requirements on the filtering process of the gradient observations.

(b) Outstanding items

- The choice for the length of the calibration period is done in a rather empirical manner. More robust criteria have to be devised to choose the optimal arc length for this calibration. Such criterion will depend a.o. on the height variations along the arc and the number of points.
- Proper choice of parameter model to avoid spectral leakage phenomena.
- Frequency dependency of calibration parameters.

(c) Prototypes

A Matlab user interface is ready to perform the calibration.

(d) Implementation in operational chain

Currently input and output is by means of Matlab files or ASCII files. Interfaces or data conversion routines have to be included to be able to use the module in the operational chain.

B. Calibration with terrestrial data

(a) Inventory

- SELECT: program to extract data in a region or conversion to GRAVSOFT format.

- GEOCOL: subtraction of the contribution from an a-priori model. Data may be given in the specified satellite oriented frame. Program may be used for upward continuation of the ground data.
- Calibration parameters (bias+tilt) and their errors may be estimated.
- TC: calculation and subtraction of topographic effects from ground and satellite data.
- EMPCOV: estimation of empirical covariance function (from ground or satellite data).
- COVFIT: analytic modelling of empirical covariance function.
- Prototype software for the combination of local and global gravity field information by joint adjustment procedure.

All programs have simple ASCII-based interfaces using the GRAVSOFT standards.

(b) Outstanding items

- GEOCOL: from spherical approximation to no-approximation. Atmospheric corrections needed as well as correction for pole-tides.
- TC: upgrade to be used on gravity gradient data in satellite frame.
- COVFIT: upgrade so that Bjerhammar sphere totally included in the Earth is used, and so that covariance functions, which do not use spherical approximation, may be modelled. Since COVFIT will have to be used after each new gravity model has become available, it would be worthwhile to find a method for automatic determination of the parameters which define an analytic model.
- Proper choice of the test area (or test areas), particularly concerning location, spatial extension, amplitude and spectral characteristics of its gravity field and availability of validated data. For a collocation approach, some areas may lack ground data to be used in the covariance estimation (satellite data can be used for this purpose after launch).
- Depending on the spectral calibration characteristics and on the method of choice the reduction of data for topographic effects needs to be addressed.
- Quality of external data (of any kind) compared to the GOCE data quality, especially in the frequency domain.

The upgrades will be tested using simulated data.

A document describing the upgrade of GEOCOL will be updated.
All the GRAVSOFT modules contain detailed descriptions imbedded in the software. Algorithms are documented by direct reference to the scientific literature. Changes are documented in an update log for GEOCOL.

[See http://www.gfy.ku.dk/~cct/geocol15.log]

(c) Prototypes

All the above mentioned programs are in daily use for gravity field modelling of regional data where spherical approximation may be used. The used algorithms are documented in the scientific literature.

(d) Implementation in operational chain

The prototypes have already been tested in earlier ESA studies. It may not be necessary to upgrade TC. It depends on the use of the program.

2.3.2 Frame transformation and temporal gravity

A. Frame transformation

(a) Inventory

This function is an option in the processing s/w. Some level 2 methods need gradients in a radial Earth-pointing frame (RERF) and also some level 3 users might want to have gradients be given in such a frame. This frame transformation encompasses the transformation (rotation) of the gradient tensor from the Local Orbital Reference Frame (LORF) to the RERF. This rotation is a straightforward computation for which simple subroutines are available or readily made. Prerequisite is the availability of accurate angles (rotation parameters) between the LORF and the RERF which should come from the attitude measurements (star trackers), gradiometer and POD. Another unsolved issue is the error propagation, since not the whole tensor in the LORF is measured with good accuracy. A method for this error propagation still has to be agreed upon and implemented.

b) Outstanding items

- Determination of rotation parameters.
- Method to deal with non-measured gradients in the tensor.
- In order to obtain the gradients in the RERF with comparable accuracy as in the LORF, the attitude of the satellite should be adequately controlled. Limits on the allowable angles should be derived and may lead to performance requirements for GOCE.

(c) Prototypes

For the rotation itself, prototypes are available (Fortran or C++ code). For the error propagation not available yet.

(d) Implementation in operational chain

See (c).

B. Temporal gravity

(a) Inventory

Given a set of harmonic coefficients which describe the temporal effects, corrections to the gradients are readily computed (synthesis). Unsolved issue so far is how to obtain such set of coefficients which is accurate enough for GOCE.

(b) Outstanding items

- Developments are currently going on in the field of finding out the best way to obtain proper geophysical models describing temporal gravity effects.
- Accuracy of most of the existing temporal gravity models compared to the required accuracy for GOCE.
- Seasonal effects which may image as a kind of systematic error in the static gravity field solution.

(c) Prototypes

- Software for derivation of harmonic coefficients from geophysical models
- Software for frequency-wavenumber analysis to derive the temporal and spectral characteristics of several phenomena
- Software for simulation of SGG / SST contributions due to temporal gravity effects

(d) Implementation in operational chain

see (c).

2.3.3 Outlier detection and data gaps

A. Outlier detection

(a) Inventory

- GEOGRIDX: Program for outlier detection by prediction from surrounding data of the same data type, and at the same altitude. It processes the data one by one, using the data within a given pre-defined radius. (Spatially defined covariance functions are not used). This program may be sufficient for quick-look validation and data screening.
- GEOGRIDXX: same as GEOGRIDX, but spatially defined covariance functions are used. Only usable for one data type. Uses fixed covariance function parameters for a region.
- GEOCOL: Uses all datatypes, but is not well suited to handle large datasets. Useful for gross-error detection. Uses fixed covariance function parameters for a region.

(b) Outstanding items

- GEOGRIDXX must be updated to handle several data-types (gravity gradients) simultaneously.
- Implementation in the program GEOGRIDX of the possibility of using simultaneously different quantities.
- Further tests needed of software. The program uses isotropic covariance functions. This has as a consequence that data which vary strongly (e.g. in mountains) may be flagged erroneously.
- A point of attention may be the development of an enhanced RINEX format for GOCE that includes flagging and statistical information coming from the screening process.

(c) Prototypes

GEOGRIDX, GEOGRIDXX and GEOCOL are all well-tested prototypes.

(d) Implementation in operational chain

The interface is using the GRAVSOFT standard interface.

B. Data gaps

(a) Inventory

GEOCOL: the program may be used to fill a data gap by prediction using least-squares collocation.

(b) Outstanding items

- Upgrade so that spherical approximation is not used/needed for large data gaps, see above in section 3.1 on external calibration.
- The effect of (not filled-in) data gaps on L1-L2 data processing methods needs further attention.
- The question whether data gaps needs to be filled in or not needs to be addressed. Data gap fill-in using external data may hamper from quality differences between the external data and the GOCE data.

(c) Prototypes

GEOCOL is a working prototype.

(d) Implementation in operational chain

It is fully implemented, but may need upgrade.

2.4. Task 4: Precise Orbit Determination (POD)

Two methods (and several different software) will be used for deriving precise orbits, prior to the gravity field determination (independently of the approach):
- the reduced dynamic method,
- the kinematic method.

One will verify the other so as to make the final optimal choice of the orbit product. Validations will also include comparisons with fully dynamical orbits at different stages and naturally after the derivation of the final global gravity solution.

2.4.1 Observation screening

(a) Inventory

Two methods are proposed, Melbourne-Wübbena editing and a screening method based on a navigation solution. The methods have already been coded and implemented on the AIUB and DEOS computers.

(b) Outstanding items

Nominally no upgrades are foreseen, but new developments due to experience with CHAMP and future GRACE data might result in enhancements.

(c) Prototypes

As indicated above, prototypes are already running at AIUB and DEOS.

(d) Implementation in operational chain

The prototypes form already optionally part of the AIUB and DEOS POD processing schemes.

2.4.2 Reduced dynamic POD

(a) Inventory

For reduced-dynamic POD, operational softwares are available for computing LEO satellite orbits from GPS and SLR tracking observations, with the possibility to include accelerometer observations. Examples are GINS at GRGS, EPOS at GFZ, and the NASA GSFC GEODYN and JPL GIPSY/OASIS softwares both running on DEOS computers. These four softwares also - and usually, perform fully dynamic POD. For GOCE, reduced-dynamic orbits will likely be computed with GEODYN or GIPSY/OASIS.

(b) Outstanding items

Future developments to enhance reduced-dynamic POD can be divided into general, continuously ongoing and GOCE-specific activities. The first include:

- updating/improving implementations of standards and reference systems;
- improving pre-processing and correcting tracking observations;
- tuning POD parameterisation (number and type of unknown parameters);
- including accelerometer observations.

As indicated in the Task 4 contribution to Slice 2, a focal point of these activities is the investigation of ambiguity resolution techniques.

The second part of activities relies on information that can be provided in advance to the industrial phases of the GOCE mission (see also the Task 4 contribution to Slice 2):

- possibly including a GOCE macro model in the POD process and developing the macro model itself,
- fine tuning of the inclusion of accelerometer observations in accordance with the GOCE accelerometer configuration,
- possibly including drag free control (DFC), center of mass and attitude information.

(c) Prototypes

The software which are here considered are fully developed tools which have been in use by several groups. Before the GOCE processing necessary updates are implemented, the software can be considered as very good prototypes.

(d) Implementation in operational chain

The GEODYN and GIPSY/OASIS were developed by American groups. The DEOS team especially has a deep knowledge of GEODYN and is capable of bringing the modifications necessary for GOCE - and it has the liberty to do so.

2.4.3 Kinematic POD

This will be performed by means of the Bernese GPS Software (BSW) - which also has dynamic OD capability.

(a) Inventory

[i] General

The BSW is a commercially available software package for geodetic applications demanding for highest accuracy. It has been developed at the Astronomical Institute of the University of Berne since the late eighties and is currently available in version 4.2. A new version 5.0 is being prepared. An extended (500 pages) documentation of the software package is available [ref.1].

The purpose of BSW is the processing of GPS observations from local, regional, and global tracking networks in order to compute station coordinates and velocities, Earth orientation parameters, GPS satellite orbit parameters, satellite and station clock offsets, and tropospheric and ionospheric parameters. The software is in daily use at CODE (Center for Orbit determination in Europe, located at AIUB) to compute, among other products, high precision orbits for the GPS satellites in the framework of the International GPS Service (IGS). Internal consistency of the orbits, compared to other IGS analysis centers, proves to be of the order of 3–5 cm. External validation using SLR observations to the two GPS satellites equipped with retro-reflectors show an accuracy of 5 cm.

Table 1 gives a list, short description, and status of the main BSW programs to be used for POD in the framework of EGG-C. In the last few months modules were added or updated in order to allow the processing of spaceborne geodetic receivers (‘adapted to LEO’ in Table 1). Orbit and data formats (SP3 resp. RINEX) were adapted in the framework of the IGS LEO Pilot Project in order to hold tabular positions for LEOs resp. GPS observation data from spaceborne receivers. The modules were tested using simulated and real data.

Table 1: Inventory of Bernese GPS Software programs to be used for POD in the framework of EGG-C.

Program	Description	Status
RXOBV3	Reformatting of observations.	In operational use, adapted to LEO.
RNXSMT	Data cleaning by code smoothing.	In operational use, adapted to LEO, may be replaced by CLKEST.
SNGDIFF	Formation of baselines for double difference method.	In operational use, adapted to LEO.
MAUPRP	Detection of cycle slips in differenced observations.	In operational use, adapted to LEO, may be replaced by CLKEST/LEOKIN.
GPSEST	Main parameter estimation program in BSW, part of large software package.	Updated to cope with spaceborne receivers, capable to generate kinematic and reduced dynamic orbits of LEOs in zero and double difference mode.
ORBGEN	Preparation of GPS orbits, interpolation of tabular orbits.	In operational use.
CLKEST	Generation of high rate clocks for GPS satellites	In operational use.
LEOKIN	Kinematic POD in zero difference mode, cleaning of LEO observations.	In development and testing phase.
SORBDT	Dynamic POD with flexible orbit modelling capabilities based on kinematic positions as pseudo-observations.	In development and testing phase. Orbit models need further refinement.

[ii] Kinematic POD with BSW

Because BSW was built to process data of stationary or moving stations on the ground, the new modules allowing to include spaceborne receivers immediately extended the capability of the software to compute *kinematic orbits of LEOs* in both zero difference and double difference modes. Tests at AIUB of the zero difference method and at IAPG of the double difference method using simulated and real data show that kinematic POD is possible with BSW (program GPSEST). With the double difference method it was even shown that the resolution of phase ambiguities is possible, although not all technical problems are solved (large number of ambiguities).

N.B. The program GPSEST may also be used to generate *reduced dynamic orbits* based on zero- and double-difference observations.

All zero difference methods require clock corrections for the GPS satellites at the measurement rate. The program CLKEST was developed allowing the generation of high rate and high precision clock corrections for GPS satellites and stations. The program may furthermore be updated to perform an efficient data screening for ground-station data (necessary for the double difference approach).

[iii] Additional pre-processing

A new program LEOKIN allows the kinematic orbit determination of a LEO using the zero difference method and eliminating the ambiguities by forming differences of the phase observations from one epoch to the next. In addition, the program contains efficient data screening capabilities. Algorithms and options are currently tested using simulated data as well as real observations from TOPEX/POSEIDON, CHAMP, and SAC-C.

Data screening proves to be an essential component of POD with GPS. The program LEOKIN contains efficient data screening algorithms which may eventually replace the programs RNXSMT (code smoothing and cycle slip repair) and MAUPRP (cycle slip detection at double difference level) as preprocessing steps for GPSEST (zero and double difference method). In addition, the program CLKEST may be used to efficiently screen the observations provided by the global tracking network.

N.B. Dynamic POD: The orbit model implemented into BSW is tuned to the high altitude GPS satellites. The program SORBDT was developed to allow a very flexible selection of different dynamic models. The program contains models for air drag, solar radiation, albedo, allows to set-up a large number of stochastic pulses, empirical forces, as well as the utilization of external attitude information, maneuver information, and accelerometer data. Dynamic models as well as the orbit interface require refinement. The program is being applied to real data from TOPEX/POSEIDON, CHAMP, and SAC-C.

[iv] Validation with the Bernese GPS Software

Several tools exist in the BSW for the comparison of satellite orbits. This involves the program STDDIF for comparing dynamic orbits in inertial space, computing residuals, rms difference values, and Helmert transformation parameters between two sets of orbits (individual or entire constellation) as well as the program ORBCMP to perform similar comparisons based on tabular orbits in precise orbit format (SP3). The program STDELE allows to analyze orbit overlaps based on dynamic orbits.

BSW is also capable of processing SLR observations. A program (QLRINEX) exists to convert SLR observations into RINEX. The GPSEST program can use SLR observations and generate residuals with respect to a dynamic orbit and, in principle, can combine SLR observations with GPS observations. Tools for computing SLR residuals for kinematic orbits do not exist currently.

(b) Outstanding items

Software upgrades and new developments in the framework of EGG-C concern the following programs:

- GPSEST: May need adaptations to overcome technical limitations for the fixing of ambiguity parameters to integer numbers. Updated and agreed on standards will have to be implemented.
- CLKEST: Upgrade necessary in order to use the program for data screening and cycle slip detection for GPS stations in permanent networks. This will improve data screening and preprocessing for double-differencing approach.
- LEOKIN: Algorithms and options for data screening and kinematic orbit determination need further tuning to real data from spaceborne receivers.

- SORBDT: Dynamic orbit modelling requires refining and testing. Orbit output and possibly the internal orbit format have to be upgraded. Updated and agreed on standards will have to be implemented.
- A new program allowing a direct comparison of tabular orbit positions with SLR observations has to be developed. Modules from GPSEST and STDDIF may be used.

(c) Prototypes

Existing prototypes are the programs CLKEST, LEOKIN, SORBDT which are not yet part of the official version of the BSW. CLKEST has a level of maturity that allows transferring the program into the official version soon while the two other programs require upgrades and modifications. They do fulfill their tasks; however, they are not yet at the expected sophistication level.

The other programs listed in Table 1 are mature programs that can be used for EGG-C without modifications (maybe with some modifications in GPSEST).

As a conclusion it can be stated that a prototype for kinematic (and also reduced dynamic) POD based on BSW exists. Its performance will be improved with time. The orbit validation task contains a prototype program which is built from existing Bernese routines.

(d) Implementation in operational chain

Interfaces between programs of the BSW are well defined and documented in [ref.1]. The interfaces to the ‘outside world’ are internationally used file formats, e.g. precise orbit format (SP3) for tabular orbits in Earth-fixed frame, RINEX files for GPS observations. The formats and interfaces to other processing blocks in the EGG-C processing chain have to be agreed on (tba), see slice 1.

Reference:

[1] Hugentobler, U., S. Schaer, P. Fridez (Eds.): “Bernese GPS Software Version 4.2”, Astronomical Institute, University of Bern, Feb. 2001.

2.5. Task 5: Gravity field modelling

The direct method - sometimes also called "brute force" method, a semi-analytical time-wise method and a space-wise approach will be used for deriving the parameters (spherical harmonic coefficients) of the global gravity field model. They are described in the following three sections.

2.5.1. Direct method

(a) Inventory

The POD software packages GINS and EPOS from CNES/GRGS and GFZ, resp., are used in the framework of the GRIM and EIGEN gravity field projects, which cooperation dates back to 1971. These software have the capability of deriving, from any kind of satellite geodetic measurements (except for gradiometer measurements at present), so-called observation and normal equations for almost any type of parameters of the force model underlying the dynamical reconstruction of the orbit (of one or several spacecraft at a time). The labelling and organization of the unknowns are identical. The programs are frequently cross-validated at the force model and data reduction level to verify the equivalence of the computations. The GRIM5 standards are presently employed, which are for the largest part according to the IERS-1996 conventions, so these must be updated once the GOCE standards are agreed upon. The complete processing chain for the CHAMP mission, GPS-SST data reduction in combination with the measured linear accelerations provided by the STAR accelerometer, is presently operational. It has been used to compute the EIGEN gravity field (up to degree 120) and STAR accelerometer calibration parameters (bias, scale factor, temperature dependence, CoM offset). The general architecture and environment of the POD software, and its high-level architecture are provided in the **ADD** [RD1].

(b) Outstanding items

The following areas need new efforts and/or developments:

- New pieces of software have been written (separately from the main programs) to process SGG data, also to account for sophisticated time variations in the gravity field model. They need to be merged and tested in the operational chain.
- The software cannot easily handle data with coloured noise, e.g. they cannot to-day take fully into account the limited bandwidth of the GOCE gradiometer. Algorithms (very likely based on those developed by the Graz group in the recent years) will have to be programmed and implemented. Another way out could be the a priori filtering of the data so as to keep information only in the measurement bandwidth.
- The solution of the inverse problem is formulated and computed in the least-squares context and uses the normal equations. The present capabilities of the software (which use the BLAS 3 linear algebra package with automatic parallelization - but on a small number of processors) do not presently allow the full solution of the GOCE inverse problem. Besides, numerical accuracy when forming and solving such large normal systems has not been analyzed, although it is known that one looses accuracy by forming normal equations. On the other hand, resolution via the preconditioned conjugate gradient technique has been implemented (following the work of the Graz team), but it does not exactly provide the inverse (covariance) matrix of the system. Further studies and software developments will be necessary in order to compute the full covariance matrix.
- Storage requirements.

- Communication links between robot, mainframe, data centres (GOCE data base, IGS, ECMWF).
- Computational resources (number of processors, memory per processor and disk space).
- Numerical accuracy of the normal equation solution strategy.
- Possibility of computing the covariance matrix.

(c) Prototypes

Based on the above inventory and description of capabilities, one can say that the GINS and EPOS software are already good prototypes which will be able to run simulated cases when the SGG data handling is implemented.

An alternative approach, of which the prototype is not available, is presently under consideration. In short this approach consists in choosing either GINS or EPOS, stripping it of all subroutines that are superfluous in the framework of GOCE data processing, and developing a dedicated GOCE software package starting from that skeleton. This approach has the following advantages:

- Unique software package.
- Less documentation required.
- Prototype (validated) can be ready by mid 2003.
- Management and labelling of the unknowns (orbit+gravity+accelerometer) operational.

The choice of the skeleton program must be made based upon the following criteria:

- State of advancement w.r.t. GOCE data processing.
- Computational speed.
- Portability of the code.
- Modularity of the code.
- State of the code (headers complete, clear structure).
- Existing documentation.

The resulting software package will be GOCE-dedicated and thus not subject to other development, as GINS and EPOS basically are. However, provisions should be made for accommodating necessary upgrades in case of unforeseen events in the course of the mission. It will run on both CNES and GFZ computers.

(d) Implementation in operational chain

- SGG data handling: interface with database, formation of observation equations, proper weighting (or filtering).
- Development of a strategy different from the normal equation approach: QR factorization, SRIF formulation,… This would require in-depth changes in the software, and needs to be evaluated in the context of rapid computer power increase (e.g. the availability at GFZ and/or GRGS, in 2005+ , of mainframes with a large number of processors could avoid going to another least-squares formulation - final precision permitting).

2.5.2. Time-wise method and semi-analytical quick-look approach

(a) Inventory

Time-wise approach:

Prototypes for the least-squares inversion of the four relevant tensor components (xx, yy, zz, xz) into gravity field parameters have been developed and tested. Simulations up to maximum degree and order varying between 180 and 300 using 1-s and 5-s data corrupted by coloured noise over periods varying between 2 months and 6 months have been performed successfully. Both direct and iterative solutions of the normal equations have been tested. In addition, the variance-covariance matrix of the potential coefficients has been computed exactly and approximately. The implementations have been done on parallel systems (SGI Origin 3800, Beowulf clusters). Earlier versions have also been tested on single processor workstations.

Pre-conditioning: Two block-diagonal pre-conditioners have been developed. One uses the conventional block-diagonal approximation of the normal matrix, which is based on the assumption that the satellite orbit is perfectly circular. The other takes deviations from the circular orbit assumption into account without destroying the block-diagonal structure. Both pre-conditioners have been used in many realistic simulations and both may be used in SGG data inversion.

Filtering: Different approaches of filtering have been developed, implemented, and tested. Detailed numerical simulations have shown that they perform excellent in ideal situations, i.e. in the absence of spikes. All are based on a priori information about the gradiometer noise PSD. First simulations of the influence of data gaps and spikes have been performed. Data gaps and spikes in the measurement time series are a serious problem, because they introduce edge effects into the solution. This is a general problem for all inversion strategies and a definite solution is still missing. Investigations into strategies for suppressing edge effects are going on. Techniques based on filling the gaps with a priori information and successive iterative improvement have been successfully implemented.

Regularization: Various parameter choice rules have been developed and tested. Stand-alone modules are available for (a) Morozov's discrepancy principle, (b) L-curve, (c) Generalized Cross Validation. Different modules for Tikhonov regularization are ready for use.

Covariance matrix: First implementations have been applied successfully to the computation of the covariance matrix of the geopotential coefficients. The efficiency has to be improved to compute the full covariance matrix up to the maximum degree and order.

Covariance matrices of gravity field functionals: Modules for error propagation are available as prototype.

SST tracking data for gravity field determination is taken into account as orbit perturbations relative to a dynamically computed reference orbit based on the adopted a priori gravity field model. The associated design matrix is obtained by numerical integration of the variational equations (see ADD). The joint inversion of these pseudo-observations with SGG observations has been tested successfully for a maximum degree and order 80.

SGG and SST Quick-look gravity field analysis:

As the semi-analytical approach is by far the fastest, it is used as the quick-look tool. It considers the measurements along the orbit as a periodic time series. In a first step 'lumped coefficients' are computed by FFT methods, and in a second step the gravity field parameters are estimated by a least squares adjustment, using the dominant block-diagonal structure of the normal equations. The deviations from this property are incorporated by means of an iterative procedure. Since this approach partially works in the frequency domain, it provides a direct access to the spectral instrument characteristics, which can be treated in the processing in a very easy and fast way.

(b) Outstanding items

Time-wise approach:

Upgrades or new developments are needed for

- Filter strategy for time series with gaps and spikes (upgrade for regular cases, new development in case of re-initialisation of the instrument)
- Automatic selection of the "optimal" regularisation parameter (upgrade/new development)
- Optimised strategies for an efficient computation of the normal matrix and the variance-covariance matrix (upgrade)
- Incorporation of non-geopotential parameters (upgrade/new development)
- Interface between SST pre-processor and SGG/SST processor (upgrade).
- Development of a pre-conditioner for SST pseudo observations if normal equations are solved iteratively (new development).
- Optimal relative weighting of SGG and SST data (new development).

SGG and SST Quick-look gravity field analysis:

Upgrades or new developments are needed for:

- Filter strategy for time series with gaps and spikes (upgrade)
- Selection of regularisation parameters (upgrade/new development)
- Combination of real and simulated data (new development)
- Combination of SGG and SST observations (new development)
- Optimised strategies for coefficient recovery in the case of partial data sets and non-repeating orbits (upgrade)
- Incorporation of non-geopotential parameters (upgrade/new development)
- Filter estimation algorithm from residuals of the adjustment (upgrade)
- Evaluation of confidence tests for checking the significance of identified potential distortions in the mission performance (upgrade/new development)
- Drag free control analysis (new development)

(c) Prototypes

Prototypes for the least-squares inversion of SGG and the joint inversion of SGG and SST data according to the time-wise approach and for the semi-analytical quick-look tool, as they are described in the ADD, have been developed. Many simulations have been done successfully with realistic mission scenarios. They have demonstrated that the software is capable of processing GOCE data and estimating gravity field parameters. Primary platforms are parallel systems (SGI Origin 3800 and Beowulf clusters). Some modules have to be upgraded or have to be developed newly as discussed under item (b). See also Slice 4: Development and test of critical modules.

(d) Implementation in operational chain

Definition of interfaces with Task 2 (Data bases) and with Task 6 (Solution evaluation); definition of interfaces between modules for SGG and combined SGG + SST solution using fully calibrated data.

The quick-look gravity field analysis tool will run regularly with partial data sets, with a minimum time delay after the data is recorded, to derive from this analysis a diagnosis of the system performance.

2.5.3. Space-wise approach

Three stages are distinguished in the space-wise method, according to the Flow chart and Definition reported in Slice 2. For each stage the development sequence will be presented, according to the DP document format.

(1) Data filtering (WOF)

(a) Inventory

The PoliMi program WOF for data filtering along the orbit will be used.

(b) Outstanding items

The software needs to be upgraded in order to deal with all the second derivatives provided by the GOCE gradiometer. The first derivatives are also to be filtered.
The method needs an a-priori gravity model to estimate the signal spectrum; a measurement noise PSD for each gravitational gradient (or a global noise PSD) is also required.
How to use the filtered first derivatives to improve the estimation of the gravitational gradients at low degrees has to be studied.

(c) Prototypes

The WOF program exists in prototype version, working with the second radial derivatives only.

(d) Implementation in operational chain

The current version of the software is in MATLAB and C code, largely using the Fast Fourier Transform (FFT) algorithm.

(2) Data gridding

– *Computation of anomalous quantities corresponding to the GOCE observables.*

(a) Inventory

The GRAVSOFT program GEOCOL will be used to handle this task.

(b) Outstanding items

Software modules, available elsewhere, must be integrated in GEOCOL, for the computation of atmospheric effects and pole tides.
The prototype treats SGG data as if they contained all gravity field harmonics. How this problem should be solved is still an open question.
SST data may be treated as potential differences using the state-vector. But information is lost when converting from single velocity vector components to the absolute velocity.
Furthermore there is the problem of how non-eliminated non-inertial forces should be treated. Will the function of thrusters eliminate these forces?
(c) Prototypes

GEOCOL.

(d) Implementation in operational chain

It should not pose any problem (minor effort needed). But it is assumed that fully calibrated data are available.

– *Computation of gridded values on a sphere at mean satellite altitude.*

(a) Inventory

The GRAVSOFT program GEOCOL is used.

(b) Outstanding items

GEOCOL must be upgraded from spherical approximation to no approximation. See the description in Task 3.
Test of combination of SGG and SST data.

(c) Prototypes

GEOCOL is a working prototype.

(d) Implementation in operational chain

The method is presently implemented in spherical approximation. The upgrades referred to above, should pose no problems.

(3) Gravity field coefficients determination
Two space-wise solutions will be implemented, namely the fast spherical collocation approach and the integration/iteration approach. The best solution shall be identified a-posteriori, and delivered as the output of Task 5.3 (see Slice 2).

– *Fast spherical collocation*

(a) Inventory

EMPCOV and COVFIT will be used to determine a global analytic representation of the covariance function.

The program SPHGRID is available. It has been tested on EGM96 data and using simulated data.

(b) Outstanding itens

The real data will be correlated. A method to take this into account is not available at present.

(c) Prototypes

COVFIT need to be tuned to global covariance functions and to not using spherical approximation.
SPHGRID is fully implemented.

(d) Implementation in operational chain

See above.

– *Integration/iteration approach*

(a) Inventory

The basic software for the estimation of the spherical harmonic coefficients at POLIMI is composed of two modules:

INTEGRATION module: the input is block averages of T_{rr}, $T_{\lambda\lambda}$ on a sphere at mean satellite altitude (let us remember that T_{xx}, T_{yy} can provide two independent information which we assume to be: $T_{xx} + T_{yy} = - T_{rr}$ and $T_{\lambda\lambda}$). The package then computes the integration of block averaged data with suitable spherical harmonics to estimate coefficients. The same package includes the possibility of working with first derivative block averaged functionals, namely T_r , $\nabla_\sigma T$. It takes the value zero on the polar caps when no data are given there.

ITERATION module: it is a sub-routine which takes a given coefficients set, computes suitable T-functionals in the polar caps and then gives this data as input to the INTEGRATION module.

Both modules are state-of-the-art for T_{rr} and $T_{\lambda\lambda}$.

(b) Outstanding items

The software needs to be upgraded in order to include the possibility of working with first derivatives block averaged functionals.

The software needs also to be upgraded to provide a coarse estimation of the variance, covariance of the coefficients.
Assessment of the error of the block averaged observations.
Construction of a full combined solution from several data sets.
Development of error-propagation software.
investigation whether the rotation from satellite frame to nominal orbit frame (needed for the observations T_{zz} , T_{xx} , T_{yy} , which are oriented according to a triad attached to a nominal orbit) can be performed with a-priori gravity models and with negligible errors.

(c) Prototypes

The PoliMi INTEGRATION and ITERATION modules are prototypes.
A fast simulator for GOCE data also exists (see paper by POLIMI at IAG 2001).

(d) Implementation in operational chain

State-of-the-art modules are in MATLAB and C code, in spherical approximation.

2.6. Task 6: Solution evaluation

Both the orbits produced by Task 4 and the gravity solutions (produced by Task 5 - also by Task 9) will be evaluated.

2.6.1.Internal evaluation

POD evaluation

The GOCE orbit products quality has to be investigated and continuously monitored for precision, accuracy and possible systematic offsets/effects.

(a) Inventory

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 (and by different groups/institutes)
2. orbit overlap analyses
3. fitting of satellite positions
4. external validation with SLR observations

(b) Outstanding items

Nominally no upgrades are foreseen, but new developments due to experience with CHAMP and future GRACE data might result in enhancements.

(c) Prototypes

All 4 methods are fully operational at either or both AIUB and DEOS.

(d) Implementation in operational chain

The prototypes form already optionally part of the AIUB and DEOS POD processing schemes.

Gravity field evaluation

Besides comparing different spherical harmonic models, we plan to compare those to a global set of regional solutions.

(a) Inventory

The solution(s) in terms of spherical harmonics and the regional solutions will be used to compute mean geoid heights and mean gravity anomalies. The anomalies will be computed at mean altitudes above the surface of the Earth.

The mean values will cover the same area as the one covered by GOCE.

(b) Outstanding items.

None

(c) Prototypes.

GEOCOL for the evaluation of spherical harmonic series and for the evaluation of regional solutions determined using LSC.

Regional solutions determined by U-Bonn give solutions in terms of mean gravity anomalies or mean geoid heights.

(d) Implementation in operational chain

Software is fully developed for this purpose.

2.6.2 External evaluation

External orbit evaluation

The GOCE orbit products quality has to be investigated and continuously monitored for precision, accuracy and systematic effects. Task 4 orbits will be compared with fully dynamic orbits from task 5.1 and possibly orbits computed outside the EGG consortium.

(a) Inventory

Use will be made of the same methods selected for the internal comparison (section 2.6.1)

(b) Outstanding items

See section 2.6.1

(c) Prototypes

- see section 2.6.1

- task 5.1: GINS, EPOS software modules

(d) Implementation in operational chain

The prototypes form already optionally part of the AIUB, DEOS, GFZ and CNES POD processing schemes

External Gravity Field Evaluation.

(a) Inventory.

Ground data will be used to estimate mean geoid and gravity anomalies and their errors over equal area blocks of size 2, 1 and 0.5 degree. The height associated with the mean value will be the maximal height in the block area. The heights and the gravity anomalies must be computed over surfaces above the highest point of the surface, and not at sea-level.
The block values will be used for comparison with the same kind of data evaluated from the spherical harmonic series and from the regional solutions.

(b) Outstanding items.

- Acquisition of independent test data sets with sufficient accuracy for EGG-C consortium.
- “un-biased” comparisons (are the results free of systematic effects because of e.g. reference system differences ?).
- Interpretation of results in terms of quality estimates for an individual gravity model.
- A method to evaluate the error-covariances is lacking and has to be developed.
- Correct estimates of the errors of the ground data are missing. Mean height anomalies do not exist at present. Mean values of oceanographic geoid heights do not exist.

(c) Prototypes.

GEOCOL will be used to estimate ground mean values and their associated errors. The same program will be used to evaluate the mean values from spherical harmonic coefficients and from LSC regional solutions. The U-Bonn functionals are given in terms of such quantities (to be checked)

The propagation of the errors on the spherical harmonic coefficients to mean values of geoid heights and gravity anomalies will be done with current software (e.g. COVHSM at GRGS).

(d) Implementation in operational chain.

Fully implemented, except the error propagation from coefficients, which will require some reworking on the interfaces.

2.6.3. Solution selection and recommendation

The selection of the GOCE products will be based on the above described internal and external evaluations. Moreover, an analysis center outside EGG-C will make recommendations. The final product will be agreed upon taking this recommendations into account.

2.7. Task 7: Communication, Documentation, Publications, Public relations

This is not included in the present study. We simply recall it here for it is an important issue and it should be addressed properly in the next study.

2.8. Task 8: Interface to science (level 3)

The most important output of this task will not be software, but a systematic description of procedures to convert the GOCE standard level 2 products into the representations needed by various application models (see ADD [RD1]). Nevertheless, software modules for the interface to some applications will be delivered, as well as auxiliary software modules. Some of them are already agreed upon, others will be agreed upon during the development of the procedures.

(a) Inventory (procedures and software)

- Oceanography
Assimilation of mean dynamic topography implemented into ocean models, with varying input requirements.
Error propagation implemented, but results not yet satisfying.

- Solid Earth
Simulation models for the joint inversion of GOCE gravity data and seismic velocities have been developed.
Concepts for the determination of other parameters and effects exist: mantle viscosity determination by convection model runs, impact of mantle plumes, impact of glacial isostatic adjustment, crustal structure.

- Ice
No procedures established yet.

- Geodesy
Many operational applications: combined high resolution geoid/gravity model computation with terrestrial anomalies, GPS levelling, datum connection, inertial navigation, satellite orbit computation.

- Auxiliary Software
Global and regional spherical harmonic synthesis.
Collocation (GEOCOL, SPHGRID).
Omission error model.
Full variance-covariance propagation.

(b) Outstanding items

- Oceanography
Continuation and testing of assimilation of mean dynamic topography and error modelling.
Comparison of oceanographic geoid with GOCE geoid.

- Solid Earth

More concepts have to be collected. The implementation of (simulated) GOCE data assimilation has to be defined.
Joint inversion: the combination of simulated GOCE data and real seismic velocities has to be tested.
The combination of GOCE data with terrestrial gravity data, e.g. point values, has to be implemented, including error propagation and combination.

- Ice
Concepts to be collected. The implementation of (simulated) GOCE data assimilation has to be defined.

In all of these application areas joint studies (under participation of EGG-C scientists) should be stimulated. Funding has to be organised.

- Auxiliary Software
Existing modules to be updated according to the needs of science users.
Definition and development of additional modules as far as required for the developed strategies - e.g. transformation to other spectral representations.

(c) Prototypes

A prototype of the science interface procedures will consist of routines (modules) for transformations and the assimilation, tailored for a selected application model, as well as for the associated error propagation. For geoid assimilation into Ocean Circulation Models a prototype is under development. For solid earth and ice applications advances in the assimilation methods have to be made first. For combination with terrestrial gravity data prototypes exist (GEOCOL).

(d) Implementation in operational chain

The science interface routines (modules) will use GOCE standard products in standard format as input. For the required complementary data (altimetry, seismic data, etc.) formats and parameters depend on the type of application and the properties of the individual models. They have to be discussed and defined. The same holds for the output data which will be assimilated into the application models. Therefore the development and implementation has to be compatible with the corresponding application models.

2.9. Task 9: Regional solutions

(a) Inventory

- Software for multi-grid-solution implemented at “simulation status” for SST and SGG data.
- Simplified deterministic/stochastic models; numerical procedures not optimized, regularization procedure only applied in a uniform way for the selected region – no space localizing features included.
- LSC software ready as a prototype (EMPCOV: estimation of regional covariance functions from ground gravity or from space data, COVFIT: determines parameters of analytic covariance functions representing the empirically determined GEOCOL – see

slice2/global solutions). Conversion to avoid using spherical approximation in progress.

(b) Outstanding items

- Upgrading of pre-processing procedures for SST-pseudo observables (eventually also for SGG).
- Upgrading of hierarchical grid structures and developments of alternative kernel definitions.
- Upgrading of solvers for normal equations and/or observations.
- Development of space-localizing regularization procedures (stability might be more critical in space localizing regional solutions than in global ones if downward continuation procedures are applied – on the other hand more flexible regularization procedures can be applied).
- LSC: critical item is whether the simultaneous use of 3 gravity vector components and 4 gravity gradient components lead to instabilities due to the high physical correlation between the measurements. A simple solution is to use normal points/values.

(c) Prototypes

Prototypes are available for various modules and test modules, as e.g., geographic and icosahedral grid hierarchies, gravity field representations by gravity anomalies, downward continuation procedures and regularization parameter estimation strategies as well as various alternatives for solvers of large normal equations.

(d) Implementation in operational chain

LSC is interrelated with Task 5.3. The multi-grid procedure is a focus-in procedure based on a global spherical harmonic solution and, therefore, is interrelated also with the outcome of a consistent global solution.

3. 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 study. The manpower matrices are also given per task in Appendix A, in which the personnel provided by EGG-C is indicated also. 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)

The time schedule of the software developments is presented per task. 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. A version of the final processor, or a subset of modules of it, tested with test data/simulated data under controled 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).
b. The volume of data handled by this version may be reduced compared to the final, operational version; e.g. 2 months i.s.o. 20 months of observations, lesser maximum degree and order of the gravity model.
c. Simplified assumptions may be taken.
d. Processing may be less automated, simpler MMI (Man-Machine Interface).

Some additional explanation:

ad a. output should still be representative of the required output of the final, operational processor

ad b. for some modules there may/will be an effect of the numerical computations (round-off errors, significant digits) on the (accuracy of) the results. The size of this effect may depend on the maximum degree and order of the gravity model or on the number of data processed. We can think of e.g. the size of the normal matrix, the sparseness of it, the size of the design matrix, etc. All these matrices have to be handled (inverted, decomposed, stored into memory, etc.) leading to the possibility (for large matrices) of numerical effects.

ad c. as long as the output is representative of the required output of the final processor, there may still be some assumptions taken in a prototype version (simpler mathematics or algorithms) for which more sophisticated modules can be plugged in at a later development stage

ad d. less use of user interfaces (or GUI's), more operator control

The specific tests for each prototype are described in the EGG-C Software Validation Plan (**SWVP**; [RD4]). 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.

Note: the software development and methodology activities during the operational phase of the mission are required only in case of unforeseen events or malfunctioning of an instrument/system. The validated software, after the SRR, should not be radically modified unless such an unforeseen event occurs.

3.1 Task 1

(proto=prototype S/W; SRR=S/W Readiness Review; OP=operational)

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Data processing							
Software development							

3.2 Task 2

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Software development							
Data base management							

3.3 Task 3

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
management							
S/W development							
Mathematical algorithms							
Data processing procedure							
Simulation and testing							
Technical writer							
Data processing							
Scientific evaluation							
Methodology							

3.4 Task 4

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
management							
S/W development							
Mathematical algorithms							
Data processing procedure							
Simulation and testing							
Technical writer							
Data processing							
Scientific evaluation							
Methodology							

3.5.1 Task 5.1

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
management							
S/W development							
Mathematical algorithms							
Data processing procedure							
Simulation and testing							
Technical writer							
Data processing							
Scientific evaluation							
Methodology							

3.5.2 Task 5.2

task	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Management							
Algorithm & S/W Development & Upgrade							
Software Validation							
Data Processing							
Quality Assessment							
Documentation							

3.5.3 Task 5.3

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Management							
S/W development							
Mathematical algorithms							
Simulation and testing							
Technical writer							
Data processing							
Scientific evaluation							

3.6. Task 6

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Software development							
Automatization of procedures							
Development & Acquisition							
GOCE Testing & Reporting							

3.7. Task 8

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
Management, Contacts							
User Manual Compilation							
Algorithms and Software Development							
Software, Model and Manual Adaption							

3.8. Task 9

activity	2002	2003	2004	2005	2006	2007	2008
event		proto1	proto2	SRR	OP	OP	OP
management							
S/W development							
Mathematical algorithms							
Data processing procedure							
Simulation and testing							
Technical writer							
Data processing							
Scientific evaluation							
Methodology							

4. Software validation plan

The **SWVP** [RD4] is 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.

5. Reference documents

[RD1] EGG-C **Architectural Design Document**

[RD2] EGG-C **Products Definition Document**

[RD3] EGG-C **Standards Requirements Document**

[RD4] EGG-C **Software Validation Plan**

Appendix A

Manpower matrices per task, given in man-year (m-y)

Task 1

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Data processing procedure Software development	2002.5 - 2005 2002.5 - 2005	0.5 0.5
		total: 3.5 m-y
Operational phase (O):		
Data processing*	2006 - 2007	0.5
		total: 1 m-y
* present staff		**Total: 4.5 m-y (incl. 1 m-y*)**

Task 2

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Software development	2002.5 - 2005	0.5
		total: 1.75 m-y
Operational phase (O):		
Data base management	2006 - 2007	0.5
		total: 1 m-y
* present staff		**Total: 2.75 m-y (incl. 0 m-y*)**

Task 3

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Management* Software development Mathematical algorithms* Data processing procedure Simulation and testing* Documentation	2002.5 - 2005 2002.5 - 2005 2002.5 - 2005 2002.5 - 2005 2002.5 - 2005 2002.5 - 2005	0.5 1 1 1.5 1 0.5
		total: 19.25 m-y
Operational phase (O):		
Management* Data processing Scientific evaluation* Methodology* Software development Documentation	2006 - 2008 2006 - 2008 2006 - 2008 2006 - 2007 2006 - 2007 2006 - 2007	0.5 1 1 0.5 0.5 0.5
		total: 10.5 m-y
* present staff		**Total: 29.75 m-y (incl. 14.25 m-y*)**

Task 4

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Management*	2002.5 - 2005	0.5
Software development*	2002.5 - 2005	2
Mathematical algorithms*	2002.5 - 2005	0.5
Data processing procedure*	2002.5 - 2005	0.5
Simulation and testing	2002.5 - 2005	2
Documentation	2002.5 - 2005	2
		total: 26.25 m-y
Operational phase (O):		
Management*	2006 - 2008	0.5
Data processing	2006 - 2008	2
Scientific evaluation*	2006 - 2008	1
Methodology *	2006 - 2007	1
Software development*	2006 - 2007	1
Documentation	2006 - 2007	1
		total: 16.5 m-y
* present staff		**Total: 42.75 m-y (incl. 20.75 m-y*)**

Task 5.1

Activity	**Year**	**# of personnel/yr**
Development phase (D):		
Management*	2002.5 - 2005	0.5
Software development *	2002.5 - 2005	2
Mathematical algorithms	2002.5 - 2005	1
Data processing procedure	2002.5 - 2005	2
Simulation and testing *	2002.5 - 2005	2
Documentation	2002.5 - 2005	1
		total: 29.75 m-y
Operational phase (O):		
Management*	2006 - 2008	0.5
Data processing	2006 - 2008	2
Scientific evaluation *	2006 - 2008	2
Methodology *	2006 - 2007	0.5
Software development *	2006 - 2007	0.5
Documentation	2006 - 2007	0.5
		total: 16.5 m-y
* present staff		**Total: 46.25 m-y (incl. 25.25 m-y*)**

Task 5.2

Activity	**Year**	**SST+SGG Gravity Field**	**Quick-Look Gravity Field**
Development Phase (D):		***# of personnel***	
Management	2002.5 - 2005	0,5*	
Documentation	2002.5 - 2005	0,5*	
Algorithm & Software Development	2002.5 - 2005	2*+2	2*
Software Validation	2002.5 - 2005	1	1
		17,5* + 14,0	
Operational Phase (O):		***# of personnel***	
Management	2006 - 2008	0,5*	
Documentation	2006 - 2007	0,5*	
Data Processing	2006 - 2008	1,5	1
Quality Assessment	2006 - 2008	0,5*	
Software Upgrade	2006 - 2007	0,5	0,5
Total Operational Phase	***man-years***	4,0* + 9,5	
Total Man-Years	man-years	21,5* + 23,5	
		Total: 45 m-y (Incl. 21.5 m-y*)	

*) Note: Third party funded personnel (e.g. national or other sources) from approved or submitted proposals will be dedicated as far as possible to the development and operational tasks specified above. Additionally to a certain extent also permanent staff will be allocated to this work (e.g. management)

Task 5.3

Activity	**Year**	**# of personnel/yr**
Development Phase (D):		
Management*	2002.5 - 2005	0.5
Software development	2002.5 - 2005	2
Mathematical algorithms *	2002.5 - 2005	2
Data processing procedure	2002.5 - 2005	0
Simulation and testing *	2002.5 - 2005	2
Documentation	2002.5 - 2005	0.5
		total: 24.5 m-y
Operational Phase (O):		
Management*	2006 – 2008	0.5
Data processing	2006 – 2008	2
Scientific evaluation *	2006 – 2008	2
Methodology *	2006 – 2007	0
Software development *	2006 – 2007	0.5
Documentation	2006 – 2007	0.5
		total: 15.5 m-y
* present staff		**Total: 40 m-y (incl. 24.25 m-y*)**

Task 6.1

Activity	**Year**	**# of personnel/yr**
Development Phase (D):		
Software development* Automatization of procedures	2002.5 – 2005 2002.5 - 2005	0.5 0.33
		total: 2.9 m-y
Operational Phase (O):		
Scientific evaluation	2006 - 2008	0.25
		total:0.75 m-y
* present staff		**Total: 3.65 m-y (incl. 1.75 m-y*)**

Task 6.2

Activity	**Year**	**# of personnel/yr**
Development Phase (D):		
Development of test procedures (orbits, altimetry, surface data), acquisition of test data and documentation	2002.5 - 2005	2.0
		total: 7.0 m-y
Operational Phase (O):		
Test of GOCE orbit and gravity field models and generation of external quality reports	2006 - 2008	1.0
		total: 3.0 m-y
* present staff		**Total: 10 m-y (incl. 0 m-y*)**

Task 8

Activity	**Year**	**# of personnel/yr**
Development Phase (D):		
Management, contacts User manual compilation Algorithms and software development for assimilation	2002.5 - 2005 2002.5 - 2005 2002.5 - 2005	0.5* 0.5 1
		total: 7 m-y
Operational Phase (O):		
Consultation, management Software, model and manual adaption	2006 - 2008 2006 - 2008	0.5 0.5
		total: 3 m-y
* present staff		**Total: 10 m-y (incl. 1.75 m-y*)**

Task 9

Activity	**Year**	**# of personnel**
Development Phase (D):		
Management*	2002.5 - 2005	0.25
Software development *	2002.5 - 2005	2
Mathematical algorithms	2002.5 - 2005	2
Data processing procedure*	2002.5 - 2005	2
Simulation and testing *	2002.5 - 2005	1
Documentation*	2002.5 - 2005	0.25
		total: 26.25
Operational Phase (O):		
Management*	2006 - 2008	0.25
Data processing	2006 - 2008	1
Scientific evaluation *	2006 - 2008	1
Methodology *	2006 - 2007	0.5
Software development *	2006 - 2007	0.5
Documentation	2006 - 2007	0.5
		total: 9.75
* present staff		**Total: 36 m-y (incl. 25 m-y*)**

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

ESTEC Contract No. 14986/00/NL/DC

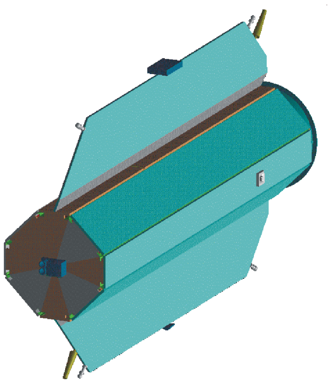
Slice 3

Documentation Requirement Document (DRD)

EGG-C

Prepared by:

Sean Bruinsma
CNES/GRGS



Revision 1.0

1 February 2002

Document Change Record

Issue	Rev.	Date	Change
0		29.01.02	Draft of document
1		01.02.02	Revision 1

Abbreviations

ADD	Architectural Design Document
CRR	Computation Resources Requirements Document
DP	Development Plan
DPM	Detailed Processing Model Document
DPPR	Data Processing Performance Requirements
HiPS	High Priority Studies
I/O DD	Input / Output Data Definition
PDD	Products Definition Document
PDL	Parameter Data List
PDS	Payload Data Segment
SGG	Satellite Gravity Gradiometry
SST	Satellite-to-Satellite Tracking
StRD	Standards Requirement Document
SWRD	Software Requirements Document
SWVP	Software Validation Plan
TDD	Test Definition Document
TDS	Test Data Set
TPD	Test Procedure Document

1.0 Purpose of Document

The main activities during the different development steps, which are described in the **DP [RD1]**, are outlined and the documentation to be delivered at different stages is specified.

2.0 Introduction

This document 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.

3.0 Reference Documents

[RD1] EGG-C **Development Plan**

[RD2] **Software Engineering Standard (ECSS-E-40B)**

[RD3] EGG-C **Standards Requirements Document**

[RD4] EGG-C **Products Definition Document**

[RD5] EGG-C **Software Requirements Document**

[RD6] EGG-C **Architectural Design Document**

4.0 Development Phases

A two phases approach is considered for the processing software development: a definition and a design phase, respectively.

Phase 1 serves to perform a critical review and, if necessary, a detailed re-formulation 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** [RD3] and **PDD** [RD4].

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 purpose and contents of these documents is described in the **sections 4.1.1** through **4.1.5**.

4.1.1 Development Plan

This document shall define the activities to be performed during the second phase of the project, based on the information collected in the documents under sections **4.1.2 - 4.1.5**. With reference to the list of required **High Priority Studies (HiPS)**, possible industrial or scientific teams shall be identified and the budgets to be allocated for the studies shall be estimated. A realistic
schedule for the delivery of the prototype codes, test / reference data bases (see below) and the complete set of final documentation shall be given. The basic milestones and the list of deliverable items are discussed below.

4.1.2 Data Processing Performance Requirements

The **DPPR** shall provide an updated list of requirements on the SST and SGG data processors employed in the preprocessing, orbit determination, and gravity field recovery steps. It shall reflect the actual requirements per processing task imposed by data products definition, product availability scenarios and requirements on external data sources (laser tracking data, Earth rotation parameters, etc.). The actual instrument development status, including recent and expected late design changes, shall be considered.

4.1.3 Detailed Processing Model

The **DPM** shall describe the basic logical processing model based on current knowledge. The model shall take into account all results from scientific and industrial studies performed in earlier phases. A top-down decomposition of the processor model into the basic descriptions of the algorithms and physical models shall be given.

This document also provides a complete list of input / output data as required or generated by the processors (**I/O DD**). In particular detailed formats for the ancillary input data, given in the Ancillary Data Fact Sheets of the PDD [RD4], shall be given.

The **Parameter Data List** consists of a complete set of physical constants (defined in the **StRD**), parameters and variables used in the model. The **PDL** forms an appendix to the **DPM**.

4.1.4 Computation Resources Requirements

Based on the information compiled in the **DPM** first estimates on computing resources requirements shall be given. The estimate shall be based on a detailed inspection of the basic mathematical equations, the information given in the **PDL** and on the logical model indicating the approximate number of execution of a certain function per time interval. Only the basic operations such as integer / floating point addition/multiplication shall be analyzed. No operations such as I / O transfers or possible parallel execution of steps shall be considered at this stage.

4.1.5 List of High Priority Studies

Following a critical analysis of the information compiled in the above documents, a list of critical elements or unsolved problems shall be generated. From this list a plan for dedicated high priority studies (**HiPS**) shall be established. For each study the type (engineering / basic scientific problem), the estimated effort and the time sequence in which the tasks should be performed shall be identified.

The impact of each study on the above identified documents shall be precisely identified:
- module(s) affected,
- impacts of the possible change (complexity, run time, etc.),

4.2 Prototype Design Phase

The second phase aims at the generation of the final set of documentation that will be forwarded to the consortium to form the basic input for the coding of the operational Processing software (preprocessing, orbit determination, gravity field recovery). In parallel with the prototype coding a set of technical notes shall be generated to document the software development in sufficient detail, allowing to trace the changes in the processing model and in the architecture introduced during the **Prototype Design Phase**. The naming of these technical notes follows partly the conventions introduced in [RD2] to indicate certain similarities to elements in the **Software Life Cycle Model** of the **ESA Software Engineering Standards**.

The basis for the prototyping phase is the set of documents produced in the **Detailed Definition Phase**. The information included in these documents is used, in a first step, to establish the **SWRD** [RD5] which shall provide a complete set of requirements for the software prototype covering functional (arising from the results of **Phase 1**) and additional, implementation-specific requirements imposed by the hardware and software environment in which the prototype will have to be operated.

In parallel a detailed plan for performing the **HiPS** identified in the proposal (**section 4.1.5**) shall be established. The schedule for the availability of the study results shall be taken into account when establishing the software prototype development plan. In particular, it will permit to identify the impact of these study results to the phasing of software prototype releases and the documents related to the prototype (see below) and to the processing model (**I/O DD**, **DPM/PDL** and **Computation Resources Requirements)** to be updated accordingly.

The steps to be performed during the **Prototype Design Phase** are as follows:

1. In an initial step, a Software Requirements Document (**SWRD)** shall be generated to compile a full set of requirements for the prototype, describing the needs of functionality, performance, selected hardware and software environment, interfaces to input / output data and operational conditions (user interaction, access to processing results, ...) under which the prototype will have to be used. A proposed list of contents for the **SWRD** is given in **Appendix 1**.

2. Based on the output of **Phase 1** and on the **SWRD** an **Architectural Design Document** (**ADD**) for the software prototype shall be generated [RD6]. This document shall reflect a suitable implementation of the Logical Model of the processor for a specific hardware and software environment (see **section 6.0**). The breakdown of the main functional elements into different hierarchy levels and the control and data flow between the individual components shall be described. The **ADD** shall describe a complete physical model of the processor for the elected environment and describe the relations between the functions in the **DPM** and the corresponding modules/subroutines in the physical model in a transparent way such that any modifications in the **DPM** can be immediately reflected in the **ADD**.

3. Once the architectural design has been established, the processing model can be implemented in a prototype code.

4.3 Final Documentation on Algorithms Specifications

4.4 The Test Data Sets

Once the iterative software development process is finalized the prototype code will be renamed into **Reference Code** and used to process reference **Test Data Sets (TDS)**. The **TDS** shall contain sets of input data and expected processor output data for typical measurement scenarios. These data will be used as a reference for verification of the final operational software. The test data shall be based on actual instrument characterization data taking into account late changes in instrument design and performance.

4.5 The Test Definition / Procedures Document

The **Test Definition / Procedures Document (TDD / TPD)** shall describe the detailed test program to be followed to verify the proper implementation of the Detailed Processing Model of 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 **TDD / TPD** and the **TDS** will constitute the **Software Validation Plan (SWVP)**.

4.6 Documents on Computation Resources Requirements and Detailed Processing Model Document

The documents on **Computation Resources Requirements** and **Detailed Processing Model Document** (including **I/O DD** and **PDL**) are produced on the basis of the latest issues of the documents described in **sections 4.1.3 - 4.1.4**. These documents will undergo a final, critical revision and the general structure and list of contents will be modified accordingly.

5.0 Deliverable Items

In the final stage of the **Prototype Design Phase** the following documents shall be produced:

- A Detailed Processing Model Document (DPM)

- A Computation Resources Requirements Document (CRR)

- **A Software Validation Plan (SWVP)**

- **A Data Processing Performance Requirements Document (DPPR)**

6.0 Operational Environment for Prototype Software

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	(Does not apply)[1]			
9	2GHz PC/3/2GB 2GHz PC/4/2GB	LINUX LINUX	2TB 2TB	C & F77 C++ & F77/90

[1] Task 8 is platform independent.

Appendix

SWRD table of contents:

Appendix

ADD table of contents:

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

ESTEC Contract No. 14986/00/NL/DC

Slice 3

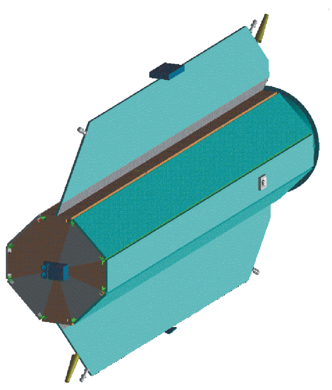
Software Validation Plan

EGG-C

Prepared by:

Sean Bruinsma

CNES/GRGS



13 May, 2002
revision 1

Table of contents 2

Abbreviations

ADD	Architectural Design Document
DRD	Documentation Requirement Document
MMI	Man-Machine Interface
POD	Precise Orbit Determination
SGG	Satellite Gravity Gradiometry
SST	Satellite-to-Satellite Tracking
SWVP	Software Validation Plan
TDD	Test Definition Document
TDS	Test Data Sets
TPD	Test Procedures Document

1. Introduction

1.1 Purpose of document

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 the **TDD, TPD** and the **TDS**, as was stated in the **DP** [RD1].
The verifications by simulations, which will cover the ideal (no noise) to the most realistic cases, will be performed for each separate software package described in the **ADD** [RD2] so 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. A prototype is a version of the software defined as follows [RD1]:

a. a version of the final processor, or a subset of modules of it, tested with test data/simulated data under controled 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);
b. the volume of data handled by this version may be reduced compared to the final, operational version; e.g. 2 months i.s.o. 20 months of observations, lesser maximum degree and order of the gravity model;
c. simplified assumptions may be taken;
d. processing may be less automated, simpler **MMI**.

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**)

1.2 Reference documents

[RD1] EGG-C **Development Plan**
[RD2] EGG-C **Architectural Design Document**
[RD3] EGG-C **Documentation Requirement Document**
[RD4] Lemoine et al., 1998, The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96, NASA/TP-1998-206861, Goddard Space Flight Center, Greenbelt, Maryland, The United States.
[RD5] Biancale et al., 2000, A new global Earth's gravity field model from satellite orbit perturbations: GRIM5-S1, *Geophys. Res. Lett.*, **27**, 3611-3614.
[RD6] Gravity Field and Steady-State Ocean Circulation Mission; Reports for the four candidate Earth Explorer Core Missions, 1999, ESA SP-1233(1).
[RD7] Rapp, R., Y. Wang and N. Pavlis (1991) The Ohio State 1991 geopotential and sea surface topography harmonic coefficient models, Report No. 410, Department of Geodetic Science and Surveying, Ohio State University.

2. Hardware / software environment

The environment in which the tests will be performed is given in chapter 6 of the **DRD** [RD3]. For the sake of completeness, the task/environment matrix is repeated here.

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	(Does not apply)[1]			
9	2GHz PC/3/2GB 2GHz PC/4/2GB	LINUX LINUX	2TB 2TB	C & F77 C++ & F77/90

[1] **Task 8 is platform independent.**

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

ESTEC Contract No. 14986/00/NL/DC

Slice 3

Software Validation Plan: Test Definition Document

EGG-C
Prepared by:
Sean Bruinsma
CNES/GRGS

13 May, 2002
revision 1

1.1 Task 3 Pre-processing

1.1.1 Task 3.1: External calibration

The tests for the 1st prototype of the external calibration software shall start with “closed-loop” tests in which the goal is not to estimate realistic calibration parameters but rather a verification of the functionality and proper operation of the software implementation and the method (“null-tests”). These tests will be based on very simple synthetic signals without the addition of noise or other disturbing effects. The tests shall study the effects of model simplifications and assumptions, upward continuation, method parameter choices like test area size, calibration length, reduction of external (terrestrial) data.

Secondly, the tests shall verify the correct implementation of the software with more realistic though simplified simulated data, in particular concerning the inclusion of disturbing effects (noise, systematic effects) and the choice of the calibration (external) data. The aim is to verify the software implementation to work with realistic data and to test the physical significance of the estimated calibration parameters.
The number of tests for different values of parameters defining the calibration (mission length, size and location of calibration area with terrestrial data, different error levels, etc.) will be limited to cover only the most typical cases.

The tests for the 2nd prototype shall verify the software with more realistic data and noise characteristics. The SRR version shall be tested with the most realistic (and independent) data coming from the industrial end-to-end simulator.

1.1.2 Task 3.2: Frame transformation and temporal gravity

Frame transformation:
The tests for the 1st prototype shall include direct and inverse transformations of a simple matrix between two reference frames to verify the correct implementation of the software. This test shall include the error propagation rules.

Secondly, tests shall be conducted with realistic gravity gradient matrices to study the effect of differences in signal amplitudes and spectral error characteristics.

Tests for the 2nd prototype shall focus on the effect of error propagation from the use of erroneous attitude angles as derived from star-tracker quaternions and other observational data. For the SRR version these tests shall be repeated.

Temporal gravity:
Based on the availability of temporal gravity models (ancillary data), the tests for the 1st prototype shall include the computation of temporal gravity contributions to the GOCE observations and a comparison of these contributions with simulated measurements both spectrally and in the spatial domain. An assessment of these results shall be done, in order to reveal to what extent temporal gravity effects play a role for GOCE. For the 2nd prototype and the SRR version, the same tests are repeated with updated (state-of-the-art) geophysical models.

1.1.3 Task 3.3: Outlier detection and data gaps

Outlier detection:
The software exists as well-tested prototype. Tests of the software in the context of this architecture can be directly focused on tests with realistically simulated data, where outlier (gross-errors) have been include systematically and randomly.
Tests of subsequent prototypes shall include implementation of simultaneous screening of different quantities and more sophisticated covariance functions.

Data gaps:
The software is a working prototype, and tests of the software can directly be focused on case studies to fill in data gaps in different scenarios. The tests should be followed by gravity field estimation tests (Task 5) to study the effect of data gap fill-in on the final gravity field solution. Tests for subsequent prototypes may include testing of upgrades of the software if required.

1.2 Task 4 Precise Orbit Determination (POD)

In general, a few days of tracking data is sufficient to test all POD procedures and software. In all cases, a period of at least 5 consecutive days of GPS and SLR tracking data will be analysed, where orbital arcs have a length of 30 hours enabling 6-hour orbit overlap comparisons. It has to be noted that the POD software is capable of providing simulated data sets of longer duration when this is needed for testing purposes in the framework of other tasks.

1.2.1 Task 4.1 Observation screening
Prototypes have already been implemented and tested with real GPS observations from CHAMP and TOPEX/POSEIDON. Tests of subsequent prototypes will be conducted based on a few representative days (at least 5) of CHAMP and GRACE data (when made available).

1.2.2 Task 4.2 Reduced dynamic POD
The prototype of choice, GEODYN, has been tested with real GPS observations from CHAMP and TOPEX/POSEIDON and by comparisons with orbits computed by external software packages. The current prototype and foreseen updates (e.g. the possible inclusion of accelerometer observations) will be tested with a few representative days (at least 5) of CHAMP and GRACE data (when made available).

1.2.3 Task 4.3 Kinematic POD
Prototypes for kinematic POD using Bernese GPS Programs are being tested using simulated data and real GPS observations from CHAMP, SAC-C, and TOPEX/POSEIDON and compared with dynamic and reduced-dynamic orbits. The prototypes will be tested with a few representative days (at least 5) of CHAMP and GRACE data (when made available).

1.3 Task 5 Gravity field modelling

1.3.1 Task 5.1 Direct method

The tests for the prototype software 'proto 1', given in chapter 3 of the **DP** [RD1], shall verify the software on the following points:

- The correct implementation of the **SGG** observation equations.
- The recovery of the reference gravity field coefficients from **SST**+**SGG** test data in the ideal (test 1), white noise (test 2), and white+coloured noise (test 3) cases.
- The accuracy of the normal equation algorithm.
- The **SGG** data filtering procedure.
- Identification and possible solving of bottlenecks (using pixies).

These first simulations shall employ a simplified processing model, namely Earth's static gravity field only, in order to isolate this module for testing. Temporal gravity effects shall be ignored. The drag free control of the spacecraft is assumed to counter the non-gravitational forces exactly. Moreover, for practical reasons (CPU time and disk space), the maximum degree of the gravity field recovery shall be limited to 200 for which a 60-day simulation is sufficient.

The second prototype, 'proto 2', shall verify the software on all of the above-listed points but to a higher degree and order of the gravity field (depending on the available resources). In addition, the following points shall be verified:

- The recovery of the reference gravity field coefficients from **SST**+**SGG** test data (white+coloured noise) in the presence of residual drag, measured by the accelerometers.
- Employment of the complete gravitational processing model.

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

A: Time-wise approach

The test for the prototype software described in chapter 3.5.2 of the **DP**, shall verify the software concerning the following aspects:

- Validation of the correct implementation of the functional model for SGG observations observations (all tensor components), including the corresponding covariance description.
- Validation of the correct implementation of the functional model for SST observations using linear orbit perturbations, including the stochastic error model.
- Test of the correct set-up of normal equations for SGG and SST, applying parallel computing techniques.
- Validation of regularisation and weighting techniques.
- Test of coefficient recovery for SGG only, SST only and the combined SGG+SST solution, based on the ideal case (no noise) and applying a realistic coloured noise model.
- Test of digital filters for the whitening of SGG observations.

The goal of the testing procedure is two-fold: (1) to validate the conception of the–gravity field solution and to prove that there are no significant bugs in the software, and (2) to assess whether the current functional and stochastic model is adequate to meet the mission objectives. The latter may lead to the extension of the functional or stochastic model to take additional, non-gravitational parameters into account. In order to reach these goals the tests should be run with both noise-free and noisy data. The test procedure shall be based on two scenarios:

- The test data sets contain only the effects of a purely static gravity field, i.e. the absence of temporal gravity as well as (uncompensated) non-conservative forces shall be assumed (cf. TDS, (a) to (d)).
- Also DFC deficiencies and residual temporal gravity shall be included in the SST and SGG observations (cf. TDS, (e) and (f)).

B: SGG and SST Quick-look gravity field analysis

The tests for the prototype software described in chapter 3.5.2 of the **DP**, shall verify the software concerning the following aspects:

- Validation of the correct implementation of the functional model for SGG observations observations (all tensor components) in terms of a semi-analytic functional model.
- Validation of the correct implementation of the functional model for SST observations using the energy balance approach.
- Test of coefficient recovery for SGG only, SST only and combined SGG+SST solution, based on the ideal case (no noise) and applying a realistic coloured noise model.
- Validation of the generation of complementary simulated data based on a-priori gravity field models.
- Test of coefficient recovery in the case of partial data sets, data gaps, non-repeating orbits and a realistic coloured noise model.
- Test of filters applied in the frequency domain for the whitening of SGG observations.
- Test of optimal filter estimation from residuals of the adjustment.
- Validation of confidence tests for checking the significance of identified potential distortions in the mission performance.

The goal of the testing procedure is two-fold: (1) to validate the conception of the–gravity field solution and to prove that there are no significant bugs in the software, and (2) to assess whether the current functional and stochastic model is adequate to meet the mission objectives. The latter may lead to the extension of the functional or stochastic model to take additional, non-gravitational parameters into account. In order to reach these goals the tests should be run with both noise-free and noisy data. The test procedure shall be based on two scenarios:

- The test data sets contain only the effects of a purely static gravity field, i.e. the absence of temporal gravity as well as (uncompensated) non-conservative forces shall be assumed (cf. TDS, (a) to (d)).
- Also DFC deficiencies and residual temporal gravity shall be included in the SST and SGG observations (cf. TDS, (e) and (f)).

1.3.3 Task 5.3 Space-wise approach

The tests for the prototype software ('proto 1') of Task 5.3 shall verify the software on the following points:

- the SGG data filtering procedure by means of the Wiener Orbital Filter (WOF);
- the performance of the interpolation algorithms for the gridding of the SGG data on a reference surface;
- the recovery of the gravity field coefficients and the computation of error estimates from SGG gridded test data both with and without noise, using:
  - fast spherical collocation algorithm (which implies also testing the estimation of the covariance function),
  - integration/iteration approach.

These simulations shall employ a simplified processing model. Temporal gravity effects shall be ignored, and the drag free control of the spacecraft shall be assumed to counter-act the non-gravitational forces exactly.

Other hypotheses shall be: recovery of the gravity field up to degree 180, corresponding to a $1° \times 1°$ gridding (or $0.5° \times 0.5°$), for which a 60-days (or 120-days) simulation will be performed, with observations taken at a 1 second rate.

1.4 Task 6 Solution evaluation

1.4.1 Task 6.1 Internal evaluation

The prototypes have all been fully tested with real GPS observations from CHAMP and TOPEX/POSEIDON. Subsequent prototypes will be tested with a few representative days (at least 5) of CHAMP and GRACE data (when made available).

1.4.2 Task 6.2 External evaluation

The external evaluation Software is to a large extend independent from the specific GOCE requirements. Therefore the evaluation procedures can be tested independently by using other LEO orbits and other gravity field solutions (e.g. from the GRACE project). The tests shall verify the following functions of the external evaluation Software, which is separated in two categories (orbit and gravity field evaluation).

External orbit evaluation:

- Full dynamic orbit restitution
- Interfaces to external orbits
- Position and velocity differences between orbits
- Computation of laser residuals for given orbits

External gravity field evaluation:

- Tracking data residuals for various satellites for a given gravity field model
- Re-computation of altimeter satellite orbits for a given gravity field model and analysis of altimeter crossover residuals.
- Computation of geoid heights, gravity anomalies and vertical deflections for individual points or grids for a given gravity field model and comparison with independent observations.

- Computation of sea surface topography solutions from a given gravity field model by subtraction from a mean sea surface and oceanographic analysis.
- Direct comparison of gravity field models in the spectral and space domains.
- Determination of an error calibration function for a given gravity field variance-covariance matrix.

The prototype Software shall be able to generate an external quality report for a state of the art gravity field model prior to the GOCE mission. Due to the quality requirements on the test data sets, which are closely connected to the prospected GOCE gravity field accuracy, the Software has to be tested with the state of the art gravity field model, which is available prior to the GOCE mission (e.g. GRACE gravity model).

1.5 Task 8 Interface to science

For validation and testing, the science interface procedures will be used to assimilate existing earth gravity models (e.g. EGM96 [RD4]) and gravity data from the CHAMP and GRACE missions into selected application models from oceanography, solid earth geophysics and other areas. The required transformation steps will be tested as well as the associated error propagation routines, using various input error models. Different filtering techniques will be tested.
Test runs of the application models using the filtered data and the propagated errors will be performed (this last step may exceed the EGG-C frame at least for some parts/applications).
The test results will be examined and discussed by associated science users. The questions to be addressed are

- how big is the contribution of the gravity field data to the model results,
- what is the impact of changes in the error models and in the weighting,
- are the base functions of the model and the filtering techniques adequate to preserve the full gravity information content,
- identification of weak points in the assimilation procedures.

Where possible, the transformation and filtering routines should work on various platforms to enable their use in different application models.

1.6 Task 9 Regional solutions

Multi-grid approach:
The test procedure is divided in three steps: two prototypes and a final SRR to arrive the specifications of 3.9 DPD:
Prototype 1: Test of the (available) implemented gravity field representation (gravity anomalies, disturbing potentials) in icosahedral grid partitionings with hierarchical spherical triangle densifications based on error free SST and SGG observations. Only the Earth's static gravity field is considered. No additional forces are to be taken into account. Tests are performed by comparison with simplified simulation scenarios.
Prototype 2: Test of SST observation equations implementations (analysis of GOCE orbit from POD, analysis of high-low SST links) as well as SGG observation equations. Coloured noise of the observations are taken into account. Preprocessing, filtering and compression of observables based on stochastic models. Combination of SGG and SST contributions, regularization (prior information, weighting, smoothing, etc.). Postprocessing of space localizing gravity field parameters. Tests are performed by comparison with more sophisticated simulation scenarios.

SRR: State-of-the-art models are included and tested. Additional elements of force function (third-body effects, etc.) will be taken into account; realistic reference frames (space fixed, earth fixed) and transformations will be included. Tests are performed by comparison with sophisticated simulation scenarios. As long as SST is concerned, use of CHAMP and GRACE data.

LSC approach:

The method of collocation will be used to produce gridded data at satellite altitude in a radially oriented frame (see 5.3) as well as 1-degree or 0.5 degree mean gravity anomalies and mean height anomalies at terrain height in two 20 degree blocks of size 20 degree x 20 degree. One block will contain an area of moderately varying topography and the other one will include a mountainous area. Error estimates will also be calculated.

A first test will use noise-free SST (state-vector) and SGG data generated from a spherical harmonic model. Temporal gravity effects will be ignored and the drag-free system will be regarded as perfect. In a second validation test random noise as well as bias/tilt errors will be added to the data.

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

ESTEC Contract No. 14986/00/NL/DC

Slice 3

Software Validation Plan:
Test Data Sets

EGG-C
Prepared by:
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13 May, 2002
revision 1

1.1 Task 3 Pre-processing

1.1.1 Task 3.1 External calibration

The test data sets that will be used shall have a progressing level of realism with respect to the following characteristics:

- temporal gravity effects in the data
- smoothness of the simulated measurement data set (concerning e.g. orbital height variations, data gaps, homogeneous coverage)
- measurement noise spectrum (systematic errors included, frequency dependence of the calibration parameters)
- choice of calibration data (reductions of the terrestrial data, choice of a priori global model)

The final and most realistic test data set should come from the ESA/industrial end-to-end simulator. Global gravity models are readily available, terrestrial calibration data are to be acquired as ancillary data.

1.1.2 Task 3.2 Frame transformation and temporal gravity

Frame transformation:
The test data set that will be used shall consist of:

- a limited time series of simulated SGG observations (6 elements of the gravity gradient matrix), including realistic errors in the time domain (from the E2E simulator).
- modelled off-diagonal elements of the gravity gradient matrix (from an existing global gravity model)
- simulated attitude angles between the LORF and the RERF including realistic errors in the time-domain.

Temporal gravity:
Test data consists of global temporal gravity field models for oceans, hydrology, atmosphere and solid earth. Test data should be available in the form of sets of spherical harmonic coefficients, or, in case they are available in gridded or other form, spherical harmonic coefficients should be computed from them first. Most probably the test data shall be derived from the GRACE data.

1.1.3 Task 3.3 Outlier detection and data gaps

Outlier detection:
Test data sets should include simulated SGG observations with systematic and randomly added outliers of different amplitudes. Test data sets should be well distributed over the globe as to cover regions of both smooth as well as rough gravity signals.

Data gaps:
Test data sets include simulated GOCE observations with both systematically and randomly distributed data gaps.

1.2 Task 4 Precise Orbit Determination (POD)

The test data sets will include a few representative days (at least 5) of both real GPS SST, SLR and accelerometer observations from CHAMP and possibly GRACE (when made available) and simulated GOCE observations (possibly from the End-to-End simulator). The exact contents need to be defined in the next phases of the project. Simulated data sets of tracking observations of longer duration can be provided in support of other tasks when this is required (see also TDD).

1.3 Task 5 Gravity field modelling

1.3.1 Task 5.1 Direct method

The test data sets that are necessary to evaluate the prototype software 'proto 1' on the points stated in section 1.3.1 of the **TDD** are described first.

The **TDS** are generated with the **POD** and gravity field recovery software, described in the **ADD** [RD2], employing the reference gravity field EGM-96 [RD4] up to degree and order 250. Starting from a realistic initial state-vector, the reference ('true') orbital positions and velocities over the entire 60-day period are extrapolated and archived every 5s. For each position, the corresponding gravity gradients are calculated and archived separately. Data gaps shall not be considered, but can easily be simulated by corrupting the reference **SGG** test data sets.

The reference **SGG** data shall equally be calculated with a white noise of 1-2 mEötvös, and a coloured noise that respects the instrument specifications. Noise shall not be added to the reference **SST** data (positions) because the same effect can be obtained by employing a different a priori gravity field and weighting in the recovery procedure as described in section 1.3.1 of the **TPD**.

The test data sets that are necessary to evaluate the prototype software 'proto 2' on the points stated in section 1.3.1 of the **TDD** are described next.

The reference **SST** and **SGG** data as well as common mode acceleration data shall be provided by the GOCE End-to-End simulator.

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

A: Time-wise approach

Realistic GOCE orbits (positions and velocities) are generated by an orbit integration software, using the Earth model EGM-96 as true model. They should be sun-synchronous near-repeat orbits with a repeat period in the order of 2 months and a mean altitude between 250 and 260 km. The corresponding SST error model shall be derived by means of error propagation from the POD. The SGG observations are generated by spherical harmonic synthesis along the realistic GOCE orbits. The SGG observations shall be generated with a different synthesis program than used in the gravity field solution in order to make the two steps independent from each other. Data sets with and without applying a realistic noise model shall be generated.

For the first test scenario, the SGG observables shall be based only on the pure static gravity field, neglecting the effect of uncompensated non-conservative forces and temporal gravity phenomena. The data sets shall be generated for the ideal case (no noise) and with a realistic coloured noise according to the Alenia specifications. For the second test scenario, the SGG observables shall contain also the effects of uncompensated DFC deficiencies and optionally temporal gravity effects.

In detail the following test data sets are used:

a. Noise-free set of SGG data:
   - "True" gravity field model: EGM-96 complete up to degree and order Lmax=250
   - Duration: 2 months at least
   - Sampling rate: between 1 and 5 seconds
   - Tensor components: xx, yy, zz, and xz (in the LORF)

b. Noise-free set of SST data:
   - "True" gravity field model: EGM-96 complete up to degree and order Lmax=80
   - Duration: 2 months at least
   - Sampling rate: at least 10 sec
   - Pseudo-observations: co-ordinate differences with respect to a "reference" orbit

c. Set of SGG data with random coloured noise:
   - "True" gravity field model: EGM-96 complete up to degree and order Lmax=250
   - Duration: at least 2 months, with 5% gaps.
   - Sampling rate: 1 sec
   - Tensor components: xx, yy, zz, and xz (in the LORF)
   - Noise: coloured random noise according to the latest end-to-end close-loop simulations

d. Set of SST data with random coloured noise:
   - "True" gravity field model: same as in the case of noisy SGG data up to degree and order Lmax=80
   - Duration: same as in the case of noisy SGG data
   - Sampling rate: between 5 and 10 sec
   - Noise: coloured random noise according the latest end-to-end close-loop simulations

e. Set of SGG data with random and systematic noise
   - Same as (c) but with realistic systematic errors (e.g. temporal effects) added.

f. Set of SST data with random and systematic noise
   - Same as (d) but with realistic systematic errors added.

B: SGG and SST Quick-look gravity field analysis

The same data sets as described in A shall be used.

1.3.3 Task 5.3 Space-wise approach

The Test Data Sets shall be generated starting from an orbit simulation employing the reference gravity field EGM 96 [RD4] up to degree and order 300. Positions shall be given with a 1 second rate. Orbit simulation shall be performed at two levels of complexity: polar orbit and orbit with inclination equal to 96.5°.

In general, it would be useful to have a common test data set for all the sub-tasks of Task 5.

For each position, the corresponding gravity gradients shall be computed and archived. Data gaps shall not be considered, but can be easily simulated by corrupting the reference SGG test data sets.

The reference SGG data shall be computed both without noise and with a coloured noise which respects the instrument specifications.

Noise shall not be added to the reference SST data (positions).

The auxiliary data which will be needed to perform the test shall be represented by an a-priori gravity model which we will assume to be EGM 96.

1.4 Task 6 Solution evaluation

1.4.1 Task 6.1 Internal evaluation

The test data sets are defined by the output of Tasks 4.2, 4.3 and 5.1.

1.4.2 Task 6.2 External evaluation

The following data sets are necessary for testing the external evaluation Software:

External orbit evaluation:

- GPS tracking data for LEO satellite (e.g. CHAMP, GRACE)
- Laser tracking data for LEO satellites (e.g. CHAMP, GRACE)
- External orbits for LEO satellites (e.g. from IGS LEO project)

External gravity field evaluation:

- Gravity field models with variance-covariance matrix.
- Tracking data of different types (optical, microwave, laser) for various satellites in different orbit configurations (e.g. from EDC/CDDIS, old data bases).
- Tracking data for altimeter missions (e.g. ERS-1/2, Envisat, Topex-Poseidon, Jason-1).
- Altimeter data (e.g. for ERS-1/2, Envisat, Topex-Posiedon, Jason-1).
- Point and grid values of geoid heights (height anomalies), gravity anomalies, deflections of the vertical from independent sources for different regions in the world.
- Mean sea surface models, sea surface topography models, drifter buoy observations.

1.5 Task 8 Interface to science

The following test data sets will be used:

Gravity test data:

- Global gravity model (e.g. EGM96 [Rd4], GRIM5 [RD5]) with accuracy model (variances/covariances),
- CHAMP and GRACE gravity models
- gravity field omission error model,
- terrestrial gravity data, if neccessary

Complementary data:

- altimetric mean sea surface, with accuracy information, for selected test areas,
- tidal models
- oceanographic data, oceanographic geoid,

- seismic velocity data for selected test areas,
- digital terrain and bathymetry models
- to be completed

Application model parameters:
- grid or point resolution
- model base functions

1.6 Task 9 Regional solutions

Multi-grid approach:
As test data sets for ***prototype 1*** those as provided by IAG SC7 Simulated Mission scenarios can be used, that means:

- Pseudo real field: EGM96 (n=360)
- Reference field: OSU91 (n=36)
- Test region: $\varphi \in [-20°,+40°], \quad \lambda \in [+60°,+130°]$

  To avoid geographical truncation: 10° to 30° strip of dummy parameters around the recovery region
- Discretization: varying: icoshedral triangel densification, block compartments
- Kernel function: Stokes, Poison, etc.
- Smoothing: varying: splines, block windows, a-priori signal variances
- Observable generation: GOCE orbit integration (30 days mission, 5 sec. Step size),

  Computation of full gravitational tensor at every 5 sec.;
  Integration of GPS satellites, derivation of intersatellite
  Observations (ranges and range-rates)

The test data sets for ***prototype 2*** will be extended such that white and coloured noise of the observations can be taken into account. SGG error models will be taken from data sets provided by IAG SC7 Simulated Mission scenarios. White and coloured noise for the GOCE orbit and the intersatellite observables will be generated. Feature as described in prototype 1 SWVP/TDD (1.6 Task 9 regional solutions) have to be included.
The test data sets for ***SRR*** will be extended such that the feature as described in prototype 2 SWVP/TDD (1.6 Task 9 regional solutions) can be tested. The test data sets have to be generated such that the results can be recovered in a sort of end-to-end simulation procedure. In this final step, the software has to be modified for the processing of real observation data.

LSC approach:
The **TDS** for 2 areas (tbd) are generated with the **POD** and gravity field recovery software, described in the **ADD** [RD2], employing the reference gravity field EGM-96 [RD4] up to degree and order 250. The reference **SGG** data shall be calculated with a white noise of 1-2 mEötvös, and a coloured noise that respects the instrument specifications. Noise shall not be added to the reference **SST** data (positions) because the same effect can be obtained by employing a different a priori gravity field and weighting in the recovery procedure.

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

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Slice 3

Software Validation Plan:
Test Procedures Document

EGG-C
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1. Detailed Test Procedures

1.1 Task 3 Pre-processing

1.1.1 Task 3.1 External calibration

Scale factors, biases, tilts and possibly other calibration parameters will be estimated from a comparison of the simulated "measurement" data with the "calibration data" according to the methods described in the ADD. The simulated data should be computed independently from the software to be verified. The calibration parameters are on the level of the SGG data. It is assumed that the internal calibration procedure has been fully implemented to the level of accuracy specified in the system requirements. Interpretation of the calibration results may reveal information on the (physical) imperfections of the measurement instruments and ground data processing procedures which have been modeled. With the calibration parameters the measurements are calibrated (corrected) and the calibrated data are compared with the ideal measurements to reveal the effect of the calibration.

1.1.2 Task 3.2 Frame transformation and temporal gravity

Frame transformation:
Case studies shall be defined for typical values of the error PSD's of the SGG observations and the rotation angles. For all defined cases, the error in the gradients, transformed from the LORF to the RERF, shall be compared to the mission requirements. These sensitivity studies reveal the appropriateness of the LORF to RERF transformation. Special care has to be taken w.r.t. the coupling of the least-accurate observed gradients into the diagonal gradients and into the off-diagonal element Vxz.

Temporal gravity:
Computation of temporal gravity contributions from series of harmonic coefficients, both in the spatial as well as spectral domain, and comparison of these contributions to the amplitudes of the observations themselves and their errors (again both in the spatial as well as the spectral domain).

1.1.3 Task 3.3 Outlier detection and data gaps

Outlier detection:
The outliers, detected by the software, can directly be compared to the outliers which have deliberately been added to the data.

Data gaps:
Data gaps are flagged and filled-in. The appropriateness of the data gaps fill-in procedure can only be tested by computing its effect on the final gravity field solution (Task 5).

1.2 Task 4 Precise Orbit Determination (POD)

The computation procedure is described in sections 3.4.1-3.4.3 of the **ADD** and displayed in Figures 3.1-3.4. The procedures will be applied to the relevant test data sets **(TDS)**. Case studies will be defined based on a few typical days (at least 5) of CHAMP and GRACE data (when made available).

1.3 Task 5 Gravity field modelling

1.3.1 Task 5.1 Direct method

The computation procedure for all test cases is described in section 3.5.1 of the **ADD** [RD2] and displayed in Figure 3-6.
The procedure for the three tests described in section 3.3.1 is nearly the same and will be described next. GOCE arcs, of a length of 1-2 days, are computed employing the a priori gravity field GRIM5-S1 [RD5] instead of the reference field EGM-96 [RD4]. This will cause the orbit to deviate from the reference one. The XYZ positions of the reference orbits are used as **SST** observations and this allows for the initial state-vector to be adjusted and partial derivatives of the gravity field coefficients with respect to the orbit perturbation to be calculated up to degree and order 140 (tbd.). The **SGG** partials with respect to the a priori gravity field are equally computed but for the full gravity field (200x200). In case of test 3 (coloured noise), the **SGG** observations are filtered first employing a FIR bandpass filter of the MATLAB signals toolbox.
Each arc thus generates two normal equations: one for **SST** data and one for **SGG** data. These normal equations are subsequently accumulated, possibly with different weights on the **SST** and **SGG** parts. The spherical harmonic coefficients are solved for using the entire observational period.

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

A: Time-wise approach
Phase 1: testing individual software modules:

- Testing stand-alone inversion of SGG data using data set (a). Pass criterion: the error is significant smaller than the propagated noise (except of polar areas).
- Testing stand-alone inversion of SST data using data set (b). Pass criterion: the error is significant smaller than the propagated noise (except of polar areas).
- Testing the whitening filters. The input: realisations of coloured noise. Pass criterion: noise PSD becomes (almost) frequency-independent.

Phase 2: testing the software for joint SST+SGG inversion as a whole in the absence of noise using data sets (a) and (b). Pass criterion: the error is significant smaller than the propagated noise (except of polar areas).

Phase 3: testing the software for joint SST+SGG inversion in the presence of random coloured noise using data sets (c) and (d).

- Testing the module for optimal weighting of different data sets. Pass criterion: the identified weights match the a-priori known stochastic properties of the data.

- Testing the module for finding the optimal regularisation parameter. Pass criterion: the regularisation parameter found leads to a better model (or at least to a model of comparable quality) than any other regularisation parameter.
- Testing the joint SST+SGG inversion. Pass criteria: the accuracy of the model obtained matches the mission objectives; the misfits are reasonably distributed in the spatial and spectral domains.

Phase 4: testing the software for joint SST+SGG inversion in the presence of random and systematic errors using data sets (e) and (f). Pass criteria: the accuracy of the model obtained matches the mission objectives. If the accuracy of the model obtained is insufficient, the systematic errors responsible for them should be identified and a decision has to be made about incorporation of additional parameters into the inversion scheme to minimise the influence of systematic errors.

Phase 5: Testing the software for computing the model covariance matrix for joint SST+SGG inversion using data sets (a) and (b). Pass criteria: the matrix obtained is symmetric positive-definite; various computational techniques do not show significant differences.

Phase 6: Testing the software for computing the gravity field functionals and their errors. Pass criteria: the gravity field functionals and associated error covariance matrices for various computational techniques do not show significant differences.

B: SGG and SST Quick-look gravity field analysis

The computation procedure for the software validation for all test simulations is described in section 3.5.2 A of the **ADD** and summarised in the respective flow chart.

Since the SST shall be based on the energy balance principle, the SST (pseudo-)observations are velocities derived from the positions of the kinematic or reduced dynamic POD. Both the SST and the SGG components are represented in terms of a semi-analytic functional model. In the case of coloured noise, a corresponding filter will be applied in frequency domain.

Partial data sets are simulated by eliminating observations from the test data sets as defined in **TDS**, section 1.3.2, and the resulting gaps will be filled by complementary simulated data based on an a-priori gravity field model.

1.3.3 Task 5.3 Space-wise approach

The computation procedures for the tests are as described in Section 3.5.3 of the **ADD** and displayed in the flow chart.

The SGG data will be computed at positions along the orbit with a 1 second rate for a time length of 60 days. The a-priori gravity field EGM 96 will be used. Data will be spatialized by means of a Wiener Orbital Filter. Subsequently, for the data gridding the collocation procedure will be tested:

- computation of the differences between the observations and the contribution from the a-priori spherical harmonic model and contingent time-varying quantities;
- least-squares collocation (GEOCOL) is then used to predict gridded values of T_x, T_y, T_z and of the two independent derivatives T_{zz} and T_{yy} or T_{xx} in an earth-fixed frame, with z-axis in the direction to the centre of the Earth.

Starting from the gridded SGG data, the recovery of the gravity field will be tested by two alternative methods.

- Fast spherical collocation algorithms:
  - the parameters of a global covariance function are determined;
  - Fast Spherical Collocation is applied to the data computed regionally;
  - corrections to spherical harmonic coefficients and the error-estimates of these coefficients are determined.
- Integration/iteration approach:
  - integration is performed on gridded data by means of suitable spherical harmonics;
  - the iteration procedure takes as input data the coefficients set obtained at the previous step, computes suitable T-functionals in the polar caps and then uses this data as the new input to the integration program: an update of the global covariance function is performed. An a-priori model shall be selected as starting point for the iterative procedure.

1.4 Task 6 Solution evaluation

1.4.1 Task 6.1 Internal evaluation

The computation procedure is described in sections 3.6.1 of the **ADD** and displayed in Figures 3.9. The procedures will be applied to the relevant test data sets **(TDS)**.

1.4.2 Task 6.2 External evaluation

The detailed test procedures for the external evaluation Software are described in the **ADD** (see sections 3.5.1 for the dynamic orbit determination and section 3.6.2 for the test procedures themselves). All test procedures provide results for the specific tests, which are compiled in the external quality report. The test procedures described in the **ADD** fulfil the defined tests in the test definition document.

1.5 Task 8 Interface to science

Assimilation into Ocean Circulation Model (OCM):

The geoid from EGM96 gravity model (up to degree 250) or geoid models from CHAMP and GRACE (up to maximum available resolution) will be used for the assimilation test. The geoid heights will be transformed into the representation of the altimetric mean sea surface (grids or points along tracks) for selected test areas defined by the chosen OCM. The difference between geoid an mean sea surface gives the mean dynamic ocean topography, which will then be transformed into the base functions of the OCM, using various filter procedures.

Error propagation for these steps will be performed using various models for the geoid commission error (e.g. EGM96 error variances/covariances) as well as for the geoid omission error. These errors will be combined with altimetric error models.

OCM test runs will be performed for the various filters and error models. The results will be compared The effects of the various error models and the resulting model improvements will be discussed together with the involved oceanographers.

Where possible, the results will be checked using independent control data.

Other application areas:
While the procedure for OCM assimilation is already quite clearly defined, other assimilation procedures (combination with seismic velocities, other solid earth applications, ice) are still under definition. When advances in this process will be achieved, also for these applications test procedures will be defined, based on the general test definition (see corresponding section of the Test Definition Document).

1.6 Task 9 Regional solutions

Multi-grid approach:
The computation procedure of the regional approach is described in section 9 of the **ADD** [RD2] and displayed in the flow chart.
As a preprocessing step the pseudo-real observations are analysed based on the reference orbits and reference gravitational tensor components whether they show systematic deviations. If white or coloured noise will be included filter or decorrelation procedures are applied to smooth the observatios (prototype 2). Residual force function effects effects are considered as well (SRR)
SGG–observables: For the pseudo-real GOCE orbit of a simulated mission length of 30 days those short orbits crossing the test area specified in **SWVP/TDS** including the “dummy”-strip around the test region are selected. The simulated gravitational tensor components (only diagonal elements) are used as pseudo-real observations. From these simulated observations the reference gravitational tensor components (using OSU91) are subtracted. The differences are related to the unknown space-localizing field parameters to result in the system of observation equations. Then the normal equations are established. In case of white or coloured noise the weight matrices are included to build the normal equations (prototype 2).
SST-observables: The SST-observationals can be treated in two different ways, depending on which observations are available. If precise intersatellite functionals are available, the contact arcs of GOCE with the GPS satellites crossing the test region including the “dummy”-strip are selected. Then the point-observations are used to derive pseudo-observations by a transformation in the spectral domain. This step allows an additional smoothing and compression of the observations. If the precise orbits of GOCE are derived by (kinematical) POD from an orbit determination procedure based on GPS measurements, then the xyz-components are used and transformed again in the spectral domain. The subsequent processing steps are identiacl in both alternatives. The normal equations are established, in case of white and coloured noise by applying the respective weight matrices.
The two normal matrices (from SGG and SST observations) are accumulated and by applying a properly selected regularization matrix solved for the unknown parameters. It is not clear yet whether the regularization procedure should be applied to the accumulated normal equations, or separately for each normal equation. In the latter case the combination of the results, again considering properly selected weight matrices, has to be performed.
In a post processing step the residual oscillations in the solution caused by not completely removed unstability effects will be smoothed out.

LSC approach:
The program GEOCOL will be used to carry out the tests described in the TDD. Based on SST (state-vector data) and SGG data LSC solutions will be created in two 20 deg. x 20 deg. blocks. These solutions are linear combinations of covariance functions, and the coefficients are determined by solving a system of normal equations with as many unknowns as the number of observations.

From the solutions are derived grids of Tzz at mean satellite altitude, 1 deg. mean gravity and mean geoid heights (height anomalies) at blocks with altitude above terrain level. The error-estimates will also be computed. The computed values will be compared with values derived directly from the spherical harmonic model used to generate the SST and SGG data.

The computations will be repeated using data with coloured noise and with bias and tilt added to the data. The biases and tilts will be estimated (and removed) and their error estimates will be computed.

2. Pass / fail criteria

2.1 Task 3 Pre-processing

2.1.1 Task 3.1 External calibration

The outcome of the "null-tests" should be either 1 (e.g. in the case of a scaling factor) or 0 (e.g. bias, drift, ...). Deviations from these values can mean one of the following: error in the software implementation, numerical round-off effects or effects (which should be acceptable according to pre-defined criteria) coming from assumptions or approximations in the method.
The outcome of the tests with realistic data should be compatible with the systematic errors which have been modeled in the simulated data.

2.1.2 Task 3.2 Frame transformation and temporal gravity

Frame transformation:

The identity test should reveal the effect of: numerical round-off errors or errors in the software implementation.
Assessment of results from tests with realistic SGG observations shows the effect on the error due to rotation of the matrix. According to the system requirements the error in the MBW for the three diagonal elements in the RERF should be compatible with the error in the LORF, so no large degradation should occur.

Temporal gravity:

We distinguish between two cases: 1. the temporal gravity corrections remain below the level of the observation noise, and 2. the temporal gravity corrections rise above the level of the observation noise, either in the MBW or in the lower part of the spectrum. In the first case, the corrections could be applied to the data without additional care. In the second case, corrections can also be applied but gravity field recovery simulation studies should follow (Task 5) to study the effect of the corrections on the static gravity field solution.

2.1.3 Task 3.3 Outlier detection and data gaps

Outlier detection:

Statistical information is output from the software and should be analyzed to show the correctness of the (implementation of the) method and algorithm.

Data gaps:

By means of sensitivity studies the effects of data gap fill-in can be assessed.

2.2 Task 4 Precise Orbit Determination (POD)

Precise orbits will be computed based on a few representative days (at least 5) of CHAMP data and, when available, GRACE GPS SST data. The objective for GOCE is to compute orbits with an accuracy at the few cm level. For CHAMP, the requirements are less strict, and the pass criteria are therefore based on a 3-dimensional orbit accuracy of 10 cm:

- 3-dimensional 6-hour overlap RMS of differences smaller than 10 cm (consistency)
- RMS of fit of SLR observations at the 5-cm level or better (assuming that the SLR observations give orbit information in one direction and that the 3-dimensional orbit accuracy is approximately equal to the square root of 3 times the SLR RMS).

When GRACE GPS SST data become available, also at least a 5-day period of these data will be analysed. The requirements for GRACE are more strict and use can be made of very high accuracy low-low SST observations in the POD. However, using the low-low SST observations is beyond the scope of the GOCE level 1→ 2 data processing. In addition, the requirements for the GOCE GPS receiver are much more demanding. Therefore, the pass criteria will be the same as those for CHAMP POD.

2.3 Task 5 Gravity field modelling

Geoid heights will be computed with the gravity field coefficients that are estimated for each of the tests described in section 1.3.1-1.3.3 of the **TDD**. These will then be compared to the reference geoid heights computed with EGM96. The pass criteria, based on Table 8.4 and Figure 8.6 of the ESA report SP-1233(1) [RD6], are the following:

- RMS of the accumulated geoid error no larger than 2.5 mm at degree 200
- RMS of the accumulated gravity anomaly error no larger than 0.08 mgal at degree 200

The tests are passed if the EGM96 gravity field model is recovered within the expected accuracy level (in terms of geoid heights and gravity anomalies on a geographical grid between a latitude band of ±80 degrees). This level is different for the time-wise and the quick-look solutions (task 5.2), because the later one applies various simplifications. Also the introduced data noise has to be taken into account for the analysis of the test results. An exact recovery of the gravity field is only possible in the noise-free case. If noisy data are used, the recovery of EGM96 shall be within the prospected GOCE accuracy stated above.

2.4 Task 6 Solution evaluation

2.4.1 Task 6.1 Internal evaluation

The software to be used for the internal evaluation will be used to compare the orbits computed by the different methods, the coefficients produced by the gravity field modeling tasks (5.1, 5.2, 5.3) as well as their associated error-estimates. Mean gravity and mean geoid heights derived from these methods as well as from the two regional methods will be compared. The error-estimates will be used to verify that the differences between the results are within acceptable statistical limits. Error-correlations will not be used. The pass/fail criteria will be that these comparisons can be made.

2.4.2 Task 6.2 External evaluation

The external evaluation Software is tested with state of the art gravity field models for which usually quality estimates are available from the originator. The external evaluation Software provides additional results for the gravity field quality, which are compared to the available results. The external evaluation Software test is passed if the results are within the same level of accuracy as provided by the originator. In case of larger differences the Software has to be checked intensively for possible error sources. The external available error estimates, which are used for comparisons, have to be checked for reliability.

2.5 Task 8 Interface to science

The test results will be compared with previous accuracy estimates (e.g. from Granada report) and with independent measurements where available. No exact pass/fail criteria are defined.

2.6 Task 9 Regional solutions

Multi-grid approach:

Gravity functionals as used for the gravity field representation in the recovery procedure are estimated according to the test scenarios described in **TDD.** The pass criteria of the results (rsolution/rms) are not clear in the present moment. They should correspond at least to those for the global recovery procedures transformed to the space localizing gravity field parameters. The recovered space localizing gravity field features in rough gravity field regions shall give more significant gravity field information than those derived from global solutions.

LSC approach:

The computed quantities (gridded Tzz values at satellite altitude, mean gravity and mean geoid heights (height anomalies) at above terrain level) must agree with the "truth" to within 3 times the estimation error. The same criteria will be used for estimated bias/tilt parameters.