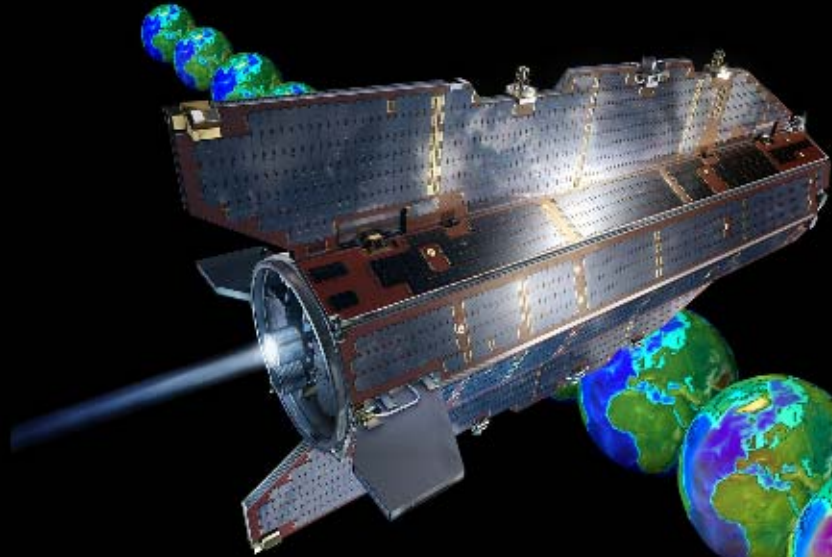


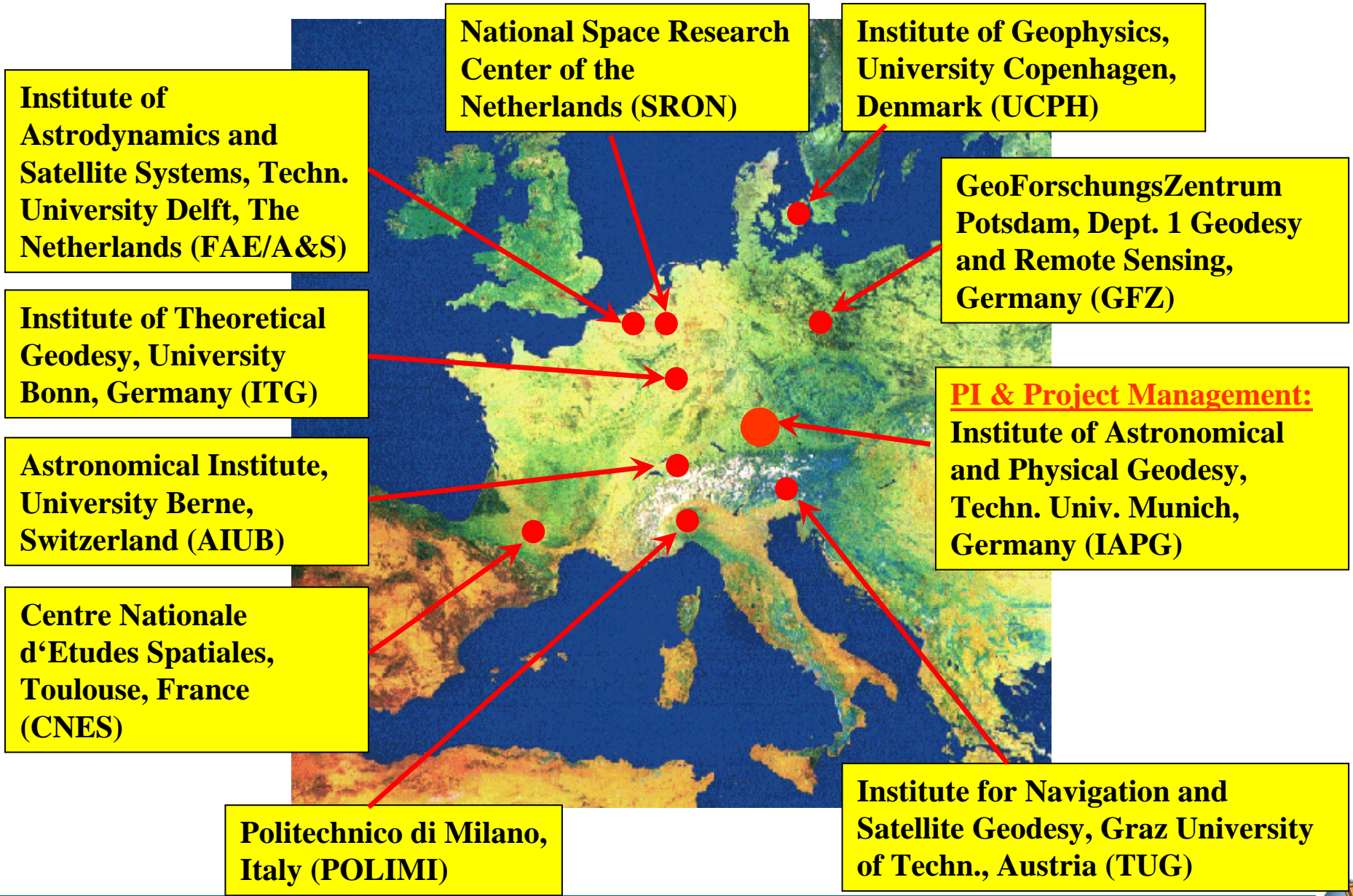
GOCE Level-2 Products - A Guide for Users





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Institut für Astronomische und Physikalische Geodäsie

The EGG-C Consortium Operating the HPF



GOCE Data Handbook

		<i>GOCE Level 2 Product Data Handbook</i> Doc. Nr: GO-MA-HPF-GS-0110 Issue: 4.0 Date: 30.04.2008 Page: 1 of 75
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GOCE High Level Processing Facility

GOCE Level 2 Product Data Handbook

Doc. No.: GO-MA-HPF-GS-0110
Issue: 4
Revision: 0
Date: **July 2008**



Prepared by: The European GOCE Gravity Consortium
EGG-C

Content

Issue 4.0 in July 2008

- GOCE Mission Overview
- GOCE Data Processing Overview
- Reference Frames and Time Systems
- Mathematical Conventions
 - Quaternions and Interpolation,
 - Spherical Harmonic Series,
 - Error Propagation
- Gravity Field Conventions
 - Approximations for derived quantities
 - Accurate Formulations
- Level 2 Product Definitions
 - Gradients & Orbits
 - Gravity Fields & Covariance Matrix
 - Format Descriptions (XML, other)

GOCE Standards

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GOCE High Level Processing Facility

GOCE Standards

Doc. No.: GO-TN-HPF-GS-0111
Issue: 3
Revision: 0
Date: 15 / 07 / 2008



Prepared by: The European GOCE Gravity Consortium
EGG-C

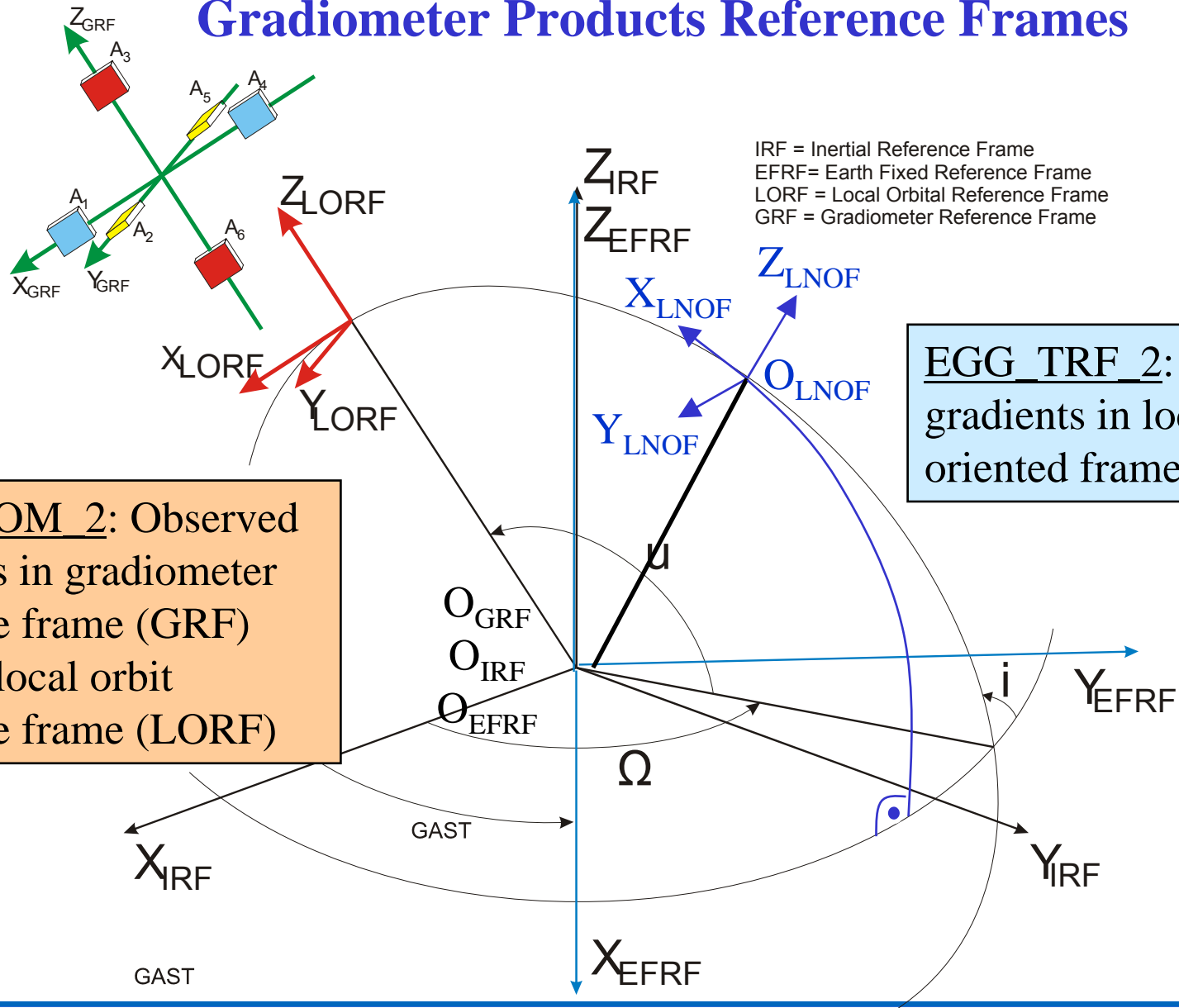
GOCE Standards implemented for ESA's High level Processing Facility:

Issue 3.0 in July 2008

- Numerical Standards
- Time Systems
- Reference Systems Definitions
- Transformation between Reference Systems
- Geometrical Models
- Dynamical Models
- Height, Gravity & Tide Systems
- GOCE Reference & Time Systems

Gravity Gradients

Gradiometer Products Reference Frames

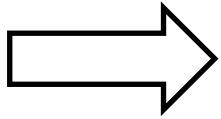


EGG NOM 2: Observed gradients in gradiometer reference frame (GRF) close to local orbit reference frame (LORF)

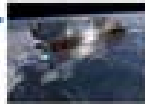
EGG TRF 2: Rotated gradients in local North oriented frame (LNOF)

Gravity Gradients

Gradiometer Data Processing



For more details on how to get gravity gradients in the GRF see poster presented by Claudia Stummer et al.



GOCE Gradiometry - A Guide for Users

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²Deutscher Geodätischer Forschungsausschuss, München, Germany; ³Aeronautilus Institut for Space Research (IRON)



Abstract

The GOCE High-Level Processing Facility (HLPF) is in charge of the production of the final GOCE level 2 products. The calibrated and corrected gravity gradients form one of these products. Several aspects have to be considered when using these gradients. First it is important that the same gradient components can not be measured with equal accuracy. The reason is that the GOCE gradiometer consists of six accelerometers, which only have two high sensitive axes and one less sensitive axis, each. However, the axial aspects of the gradients show that an accuracy of a few microgals (microgals; 10⁻⁶Gal) can only be reached within the measurement bandwidth of the gradiometer from 0 to 100 mHz. It is also important to keep in mind that for GOCE several reference frames play a role. The gradients are measured in the Instrument Reference Frame (IRF). This reference frame is instrument-fixed and differs by a few degrees from the Local Orbital Reference Frame (LORF), which is defined by the instantaneous direction of the velocity vector. Because the gravity gradients themselves the product contains also additional information, the corrections to the gradients due to temporal gravity variations. This information can be used to gain the rough-sphere static gravity field information from GOCE. This poster summarizes the important aspects of gradiometry with GOCE.

Fig. 1. GOCE gradiometer

One of the two key systems of the GOCE mission is the gravity gradiometer. (The second key system is the space GPS). The gradiometer consists of three pairs of identical accelerometers, which are mounted on three mutually orthogonal arms. The arms are made of carbon fiber and are connected to the instrument body by a central hub. The accelerometers are mounted on the arms at a distance of 100 cm from the instrument body.

From acceleration measurement to Gravity Gradients

Measured accelerations, not taking into account accelerometer bias and scale factors, mountings, location of mass displacements, etc.)

$$a = -\ddot{r} + \dot{\omega} \times r + \omega \times (\omega \times r)$$

Differential accelerations, example accelerometer pair 1-4:

$$\begin{aligned} a_{1-4} &= \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} = \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} \\ &= \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} = \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} \end{aligned}$$

Example to determine pair 1 and 4:

$$\begin{aligned} a_{1-4} &= \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} = \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} \\ &= \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} = \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} - \begin{pmatrix} -\ddot{r}_x \\ -\ddot{r}_y \\ -\ddot{r}_z \end{pmatrix} \end{aligned}$$

to get the signal after Gravity Gradients it is necessary to separate the rotational part from the measurements

Gradients angular accelerations

Contribution of attitude information from gradiometer and from other sensors:

Optimal and algorithm which finally takes the attitude information from the star sensor into a certain substitution frequency and feeds the gradiometer about this frequency

Fig. 3, 4, 5: Important GOCE Reference Frames

The axes of the IRF shown in dashed arrows are aligned with the two sensitive accelerometer axes (Fig. 1). The axes of the IRF shown in solid arrows are aligned with the ultra-stable accelerometer axis. The IRF is the reference frame in which the gradients are measured and which represents the orientation of the whole instrument with respect to external reference frames (Fig. 2). Because the satellite attitude is controlled by magnetometers the instrument-fixed IRF differs by a few degrees from the Local Orbital Reference Frame (LORF), which is defined by the instantaneous direction of the satellite's trajectory.

Fig. 2: Gravity Gradient Tensor (GTT) components in the Earth-fixed frame

at a height of approximately 300 km and after subtraction of a Normal Field. Note that the tensor is symmetric, which implies that $GTT_{12} = GTT_{21}$, and $GTT_{13} = GTT_{31}$, and $GTT_{23} = GTT_{32}$, respectively and that the sum along the diagonal is zero. All GTT components in figure 2 are smaller than $\pm 1 \cdot 10^{-6}$ E. GTT_{11} contains a strong pattern in east-west direction, whereas GTT_{22} structures in north-south direction (vertical stripes). GTT_{33} contains both patterns and makes them visible in both planes. Since the Gravity Field information decreases rapidly with growing height above the Earth, GOCE will be put in a very low orbit of about 270 km.

Fig. 6: Note that the extremely high accuracy of a few mGal can only be achieved with the components GTT_{11} , GTT_{22} , GTT_{33} and GTT_{12} and only within the 4000 Hz-500 mHz!

Gravity Gradients

Content of EGG_NOM_2

Gravity Gradients in the Gradiometer Reference Frame (GRF) corrected for temporal gravity field variations, outliers, data gaps and externally calibrated

GPS Time	Gradient observation time in [sec]
Gravity Gradients	Externally calibrated & corrected gravity gradients T_{xx} , T_{yy} , T_{zz} , T_{xy} , T_{xz} , T_{yz} in [1/sec ²]
Errors of Gravity Gradients	Sigmas of all 6 gravity gradients derived from a-priori or HPF estimated gradiometer error model in [1/sec ²]
Gradient Flags	Flags for each gravity gradient as 1 byte integer. Meaning of bits: Bit 0: Original gradient (from L1B product) Bit 1: Original gradient with temporal corrections added Bit 2: Original gradient with temporal and ext. calibration added Bit 3: Outlier suspected, fill-in provided (from spline interpolation) Bit 4: Outlier suspected, no fill-in, as for bit 2 Bit 5: Data gap, fill-in provided (from spline interpolation) Bit 6: Data gap, no fill-in provided.

Gravity Gradients

Content of EGG_NOM_2

Gravity Gradients in the Gradiometer Reference Frame (GRF) corrected for temporal gravity field variations, outliers, data gaps and externally calibrated

Direct Tides	Correction applied for direct tides for all 6 gradients in [1/sec ²]
Solid Earth Tides	Correction applied for solid Earth tides for all 6 gradients in [1/sec ²]
Ocean Tides	Correction applied for ocean tides for all 6 gradients in [1/sec ²]
Pole Tides	Correction applied for pole tides for all 6 gradients in [1/sec ²]
Non-Tidal Mass Variations	Correction applied for combined atmospheric & oceanic mass variations for all 6 gradients in [1/sec ²]
External Calibration	Correction applied due to external calibration using global models for all 6 gradients in [1/sec ²]
Inertial Attitude Quaternions	Quaternions defining frame rotations between the GRF and the Inertial Reference Frame (IRF)

Gravity Gradients

Content of EGG_TRF_2

Gravity Gradients in Local North-Oriented reference Frame (LNOF) corrected for temporal gravity field variations, outliers, data gaps and externally calibrated

GPS Time	Gradient observation time in [sec]
Position	Geocentric latitude in [deg], longitude in [deg], height in [m]
Gravity Gradients	Externally calibrated & corrected gravity gradients T_{xx} , T_{yy} , T_{zz} , T_{xy} , T_{xz} , T_{yz} in [1/sec ²]
Errors of Gravity Gradients	Sigmas of all 6 gravity gradients derived from a-priori or HPF estimated gradiometer error model in [1/sec ²]
Gradient Flags	Flags for each gravity gradient as 1 byte integer. Meaning of bits as for EGG_NOM_2.

Gravity Gradients

Remarks on Gradient Products

EGG_NOM_2

- Gravity gradients are **un-filtered** (original observations plus corrections applied).
- Errors are estimated **from error model**
- All corrections are **individually removable**
- Interpolated records are marked by flags
- GRF to IRF **rotation quaternions are provided** in (L1B MDS - IAQ)

EGG_TRF_2

- In order to minimize errors due to gradient transformation (badly observed gradients map to high quality gradients) a **global model is used as reference**.
- Gravity **gradients are filtered**, i.e. GOCE observations only in MBW, long wavelength part from a model.
- Product **not applicable for gravity field determination**, but for **geophysical/oceanographic applications**.

Orbit Products

Content of SST_PSO_2

Precise science orbits from reduced dynamic approach (positions and velocities) and kinematic approach (positions), both in EFRF. Additionally included is variance-covariance information for the kinematic orbits (over 9 epochs) and the rotation matrix for each epoch from the EFRF to the IRF in terms of quaternions.

Kinematic Orbit	GPS time in [sec] X,Y,Z position in [m] in Earth fixed frame Clock correction Standard deviation of position and clock Variance-covariance matrix for positions (over 9 Epochs)
Reduced Dynamic Orbit	GPS time in [sec] X,Y,Z position in [m] in Earth fixed frame X,Y,Z velocity in [m/sec] in Earth fixed frame Standard deviation of position and clock
Rotation Matrix from EFRF to IRF	GPS time in [sec] Quaternions (4) describing rotation angles

Orbit Products

Content of SST_AUX_2

Non-tidal time variable gravity field potential with respect to a mean value in terms of a spherical harmonic series determined from atmospheric and oceanic mass variations as well as from a GRACE monthly gravity field time series.

Spherical Harmonic Series (SHS)

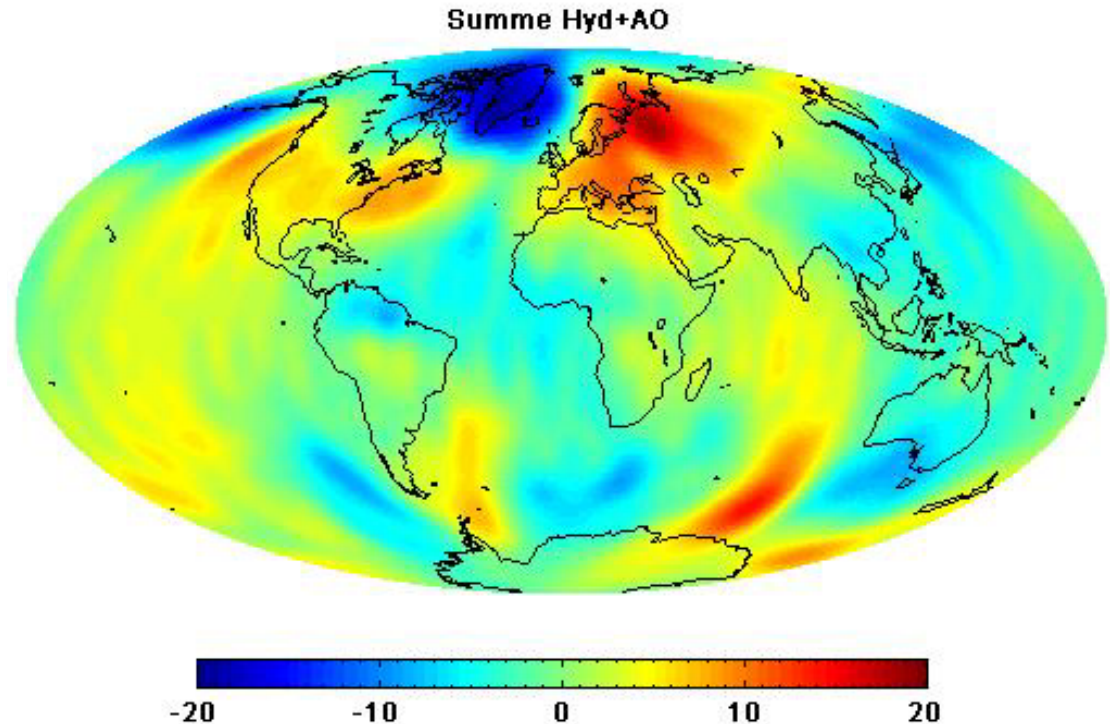
Degree; order; C/S-coefficients of gravity potential

Minimum and Maximum Geoid Variations in [mm] for Nmax=30

only Hydrology (GRACE):
[-6.74 to 5.06]

Atmosphere + Ocean:
[-18.88 to 16.59]

Atmosphere + Ocean +
Hydrology (GRACE):
[-19.13 to 18.57]



Orbit Products

Remarks on Orbit Products

SST_PSO_2:

- Positions, velocities and variance-covariance matrix information are given in **EFRF** (1 sec time resolution).
- The **Rotation Matrix** is defined in terms of **Quaternions**. Earth Orientation Quaternions are provided for every integer second of GPS time and are computed according to **IERS Conventions 2003**.
- Rotation Matrix Quaternions have to be interpolated to time of positions applying the **Kinematic Equation** (see L2 Data Handbook).

SST_AUX_2:

- Non-tidal gravity **variations of gradients** are computed from this product as well (see EGG_NOM_2).

GOCE Gravity Field Model

Content of EGM_GOC_2

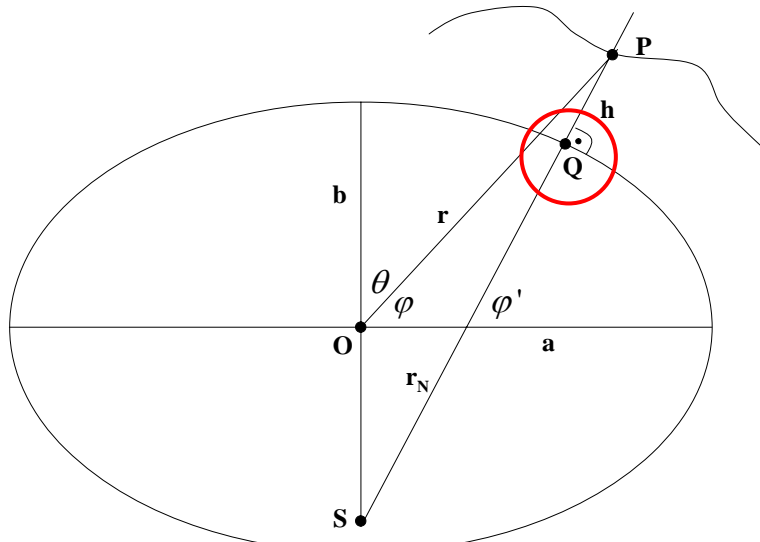
GOCE gravity field model in different representations including geoid error:

Spherical Harmonic Series (SHS)	Degree; order; C/S- coefficients ; Sigmas of coefficients (dimensionless)
Geoid Heights	30'x30' global grid with geoid heights computed from SHS in [m] using wgs84 as reference ellipsoid.
Gravity Anomalies	30'x30' global grid with gravity anomalies computed from SHS in [m/s ²] using wgs84 as reference ellipsoid.
North-South Deflection of the Vertical	30'x30' global grid with North-South deflections of the vertical computed from SHS in [arc-sec] using wgs84 as reference ellipsoid.
East-West Deflection of the Vertical	30'x30' global grid with East-West deflections of the vertical computed from SHS in [arc-sec] using wgs84 as reference ellipsoid.
Geoid Height Error	30'x30' global grid with geoid height standard deviation computed from error propagation of full variance-covariance matrix in [m].

GOCE Gravity Field Model

Remarks on Gravity Field Products

- Spherical harmonic series represents the main result of GOCE.
- For computation of derived quantities approximations are applied.
 - **Computation point on reference ellipsoid**
 - **Spherical approximation** of fundamental equation of physical geodesy (approximating real plumb line by geocentric vector)



$$\Delta g = g_P - \gamma_0 = -\frac{\partial T}{\partial h} + \frac{1}{\gamma_0} \frac{\partial \gamma}{\partial h} T$$

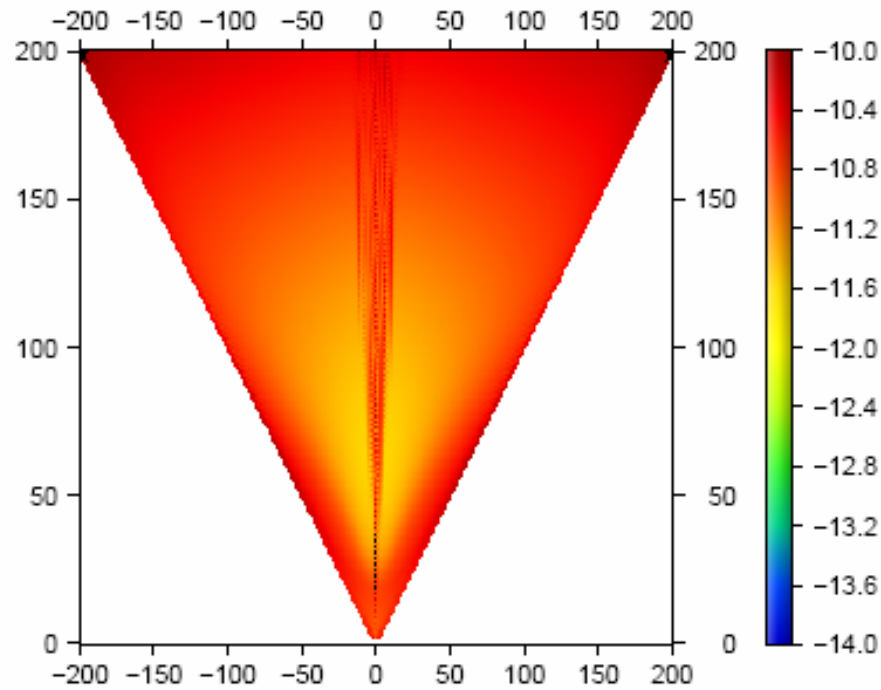
$$\Delta g \approx -\frac{\partial T}{\partial r} - \frac{2}{a^{REF}} T$$

$$\xi \approx -\frac{1}{a^{REF}} \frac{\partial N}{\partial \varphi} \quad ; \quad \eta \approx -\frac{1}{a^{REF} \cos \varphi} \frac{\partial N}{\partial \lambda}$$

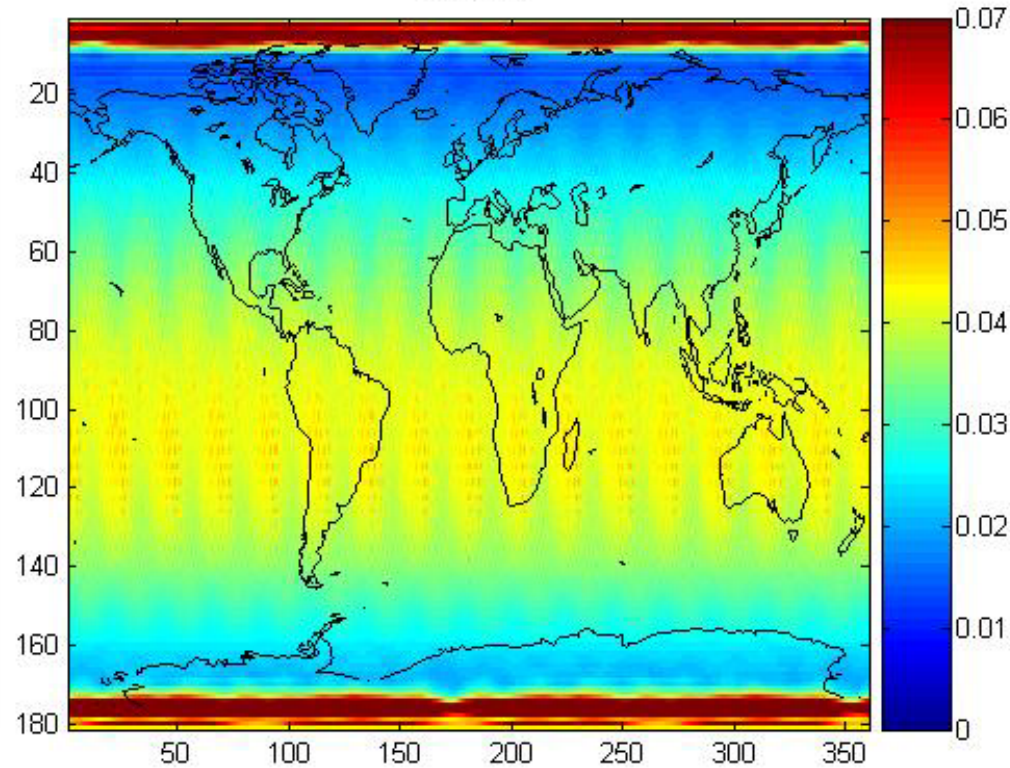
GOCE Gravity Field Model

Examples

Coefficient Errors



Geoid Height Errors



GOCE Gravity Field Variance-Covariance Matrix

Content of EGM_GVC_2

Complete variance-covariance matrix for the coefficients of the spherical harmonic series of the GOCE gravity field model EGM_GOC_2

Header File

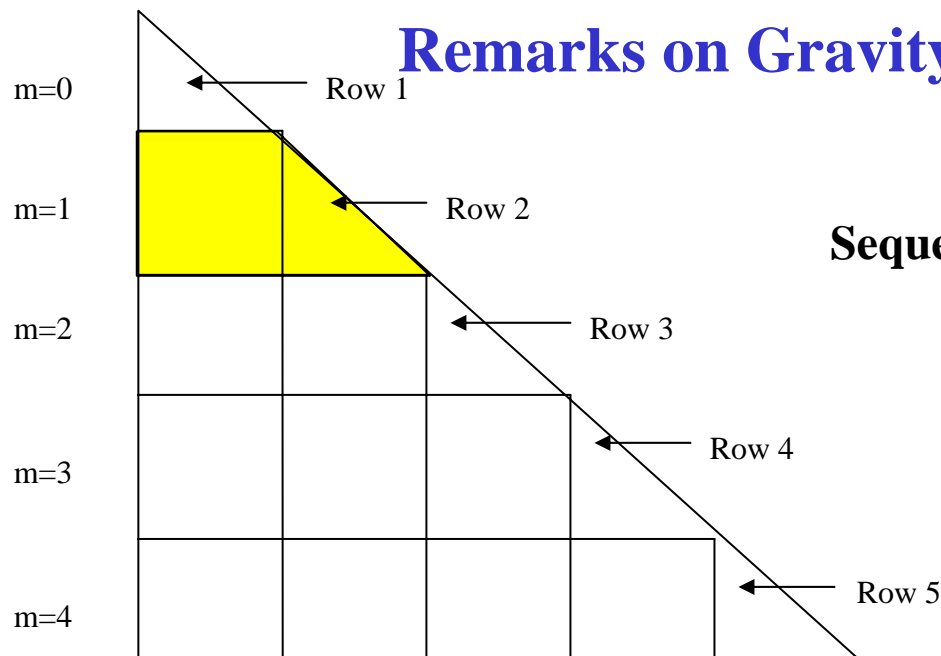
GM (Earth mass times gravity constant)
a (Radius)
Maximum degree
Sequence of coefficients
Sequence of files

Data File(s)

Harmonic order of the file
Number of data values
Data entries for this order

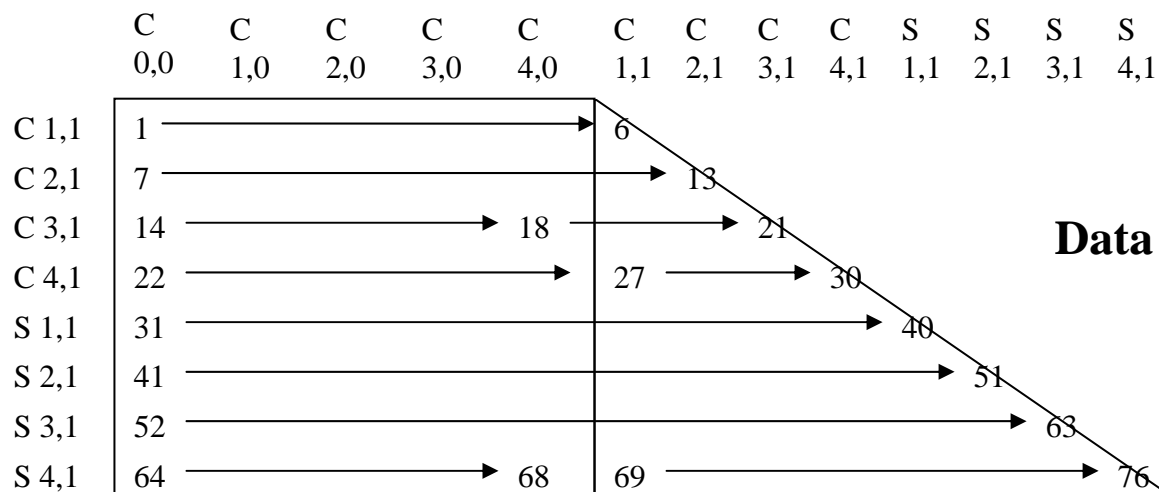
GOCE Gravity Field Variance-Covariance Matrix

Remarks on Gravity Field Products



Sequence of Files

File Size < 250 MB
Total Product Size: several GB



Data Sequence in File

GOCE Gravity Field Variance-Covariance Matrix

Examples

```
product_type          variance-covariance matrix
modelname             EXAMPLE-MODEL-1
earth_gravity_constant 0.3986004415E+15
radius                0.6378136460E+07
max_degree            4
errors                formal
covariance_matrix_type full
sequence_number_entries 25
    C_000_000
    C_001_000
    C_002_000
    C_003_000
    C_004_000
    C_001_001
    C_002_001
    .
    .
    .
    C_004_003
    S_003_003
    S_004_003
    C_004_004
    S_004_004
sequence_number_files 5
    data_file_1_000
    data_file_1_001
    data_file_1_002
    data_file_1_003
    data_file_1_004
```

Meta Data File

Data File

```
meta_data_file_name  meta_data_file_1.IIH
order                 1
number_entries        76
begin_data            -0.7657887654320E-09
...
...
(all together 76 numbers in ASCII format)
...
...
+1.0567758766890E-14
end_data
```

Summary & Conclusions

Complete description of products and formats is provided in the **GOCE Level 2 Product Data Handbook**.

Standards and Models applied in Level 2 processing are defined in the **GOCE Standards Document**.

Gradients are provided in two products:

- **Observed gradients** external calibrated and corrected
- **Transformed gradients** for applications in geophysics & oceanography

Gravity field is provided as spherical harmonic series and derived quantities on grids.

Variance-covariance matrix first time will be available to all users.

EGG-C is Ready for Launch

