GOCE Level-2 Products -
A Guide for Users

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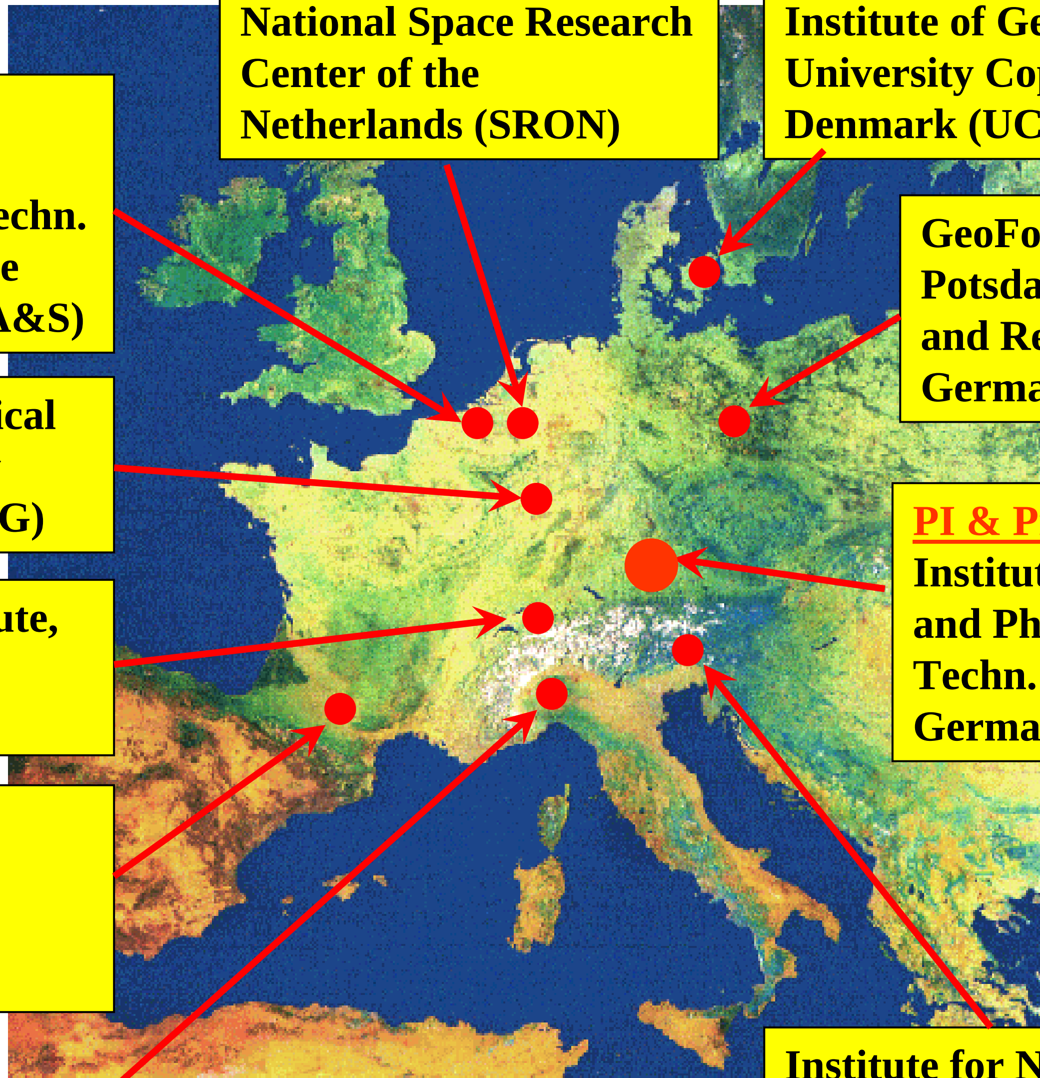
The EGG-C Consortium Operating the HPF



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GOCE Data Handbook

GOCE Level 2 Product Data Handbook
Doc. Nr: GO-MA-HPF-GS-0110
Issue: 4.0
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Page: 1 of 75

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

GOCE High Level Processing Facility

GOCE Standards

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Prepared by: The European GOCE Gravity Consortium
EGG-C

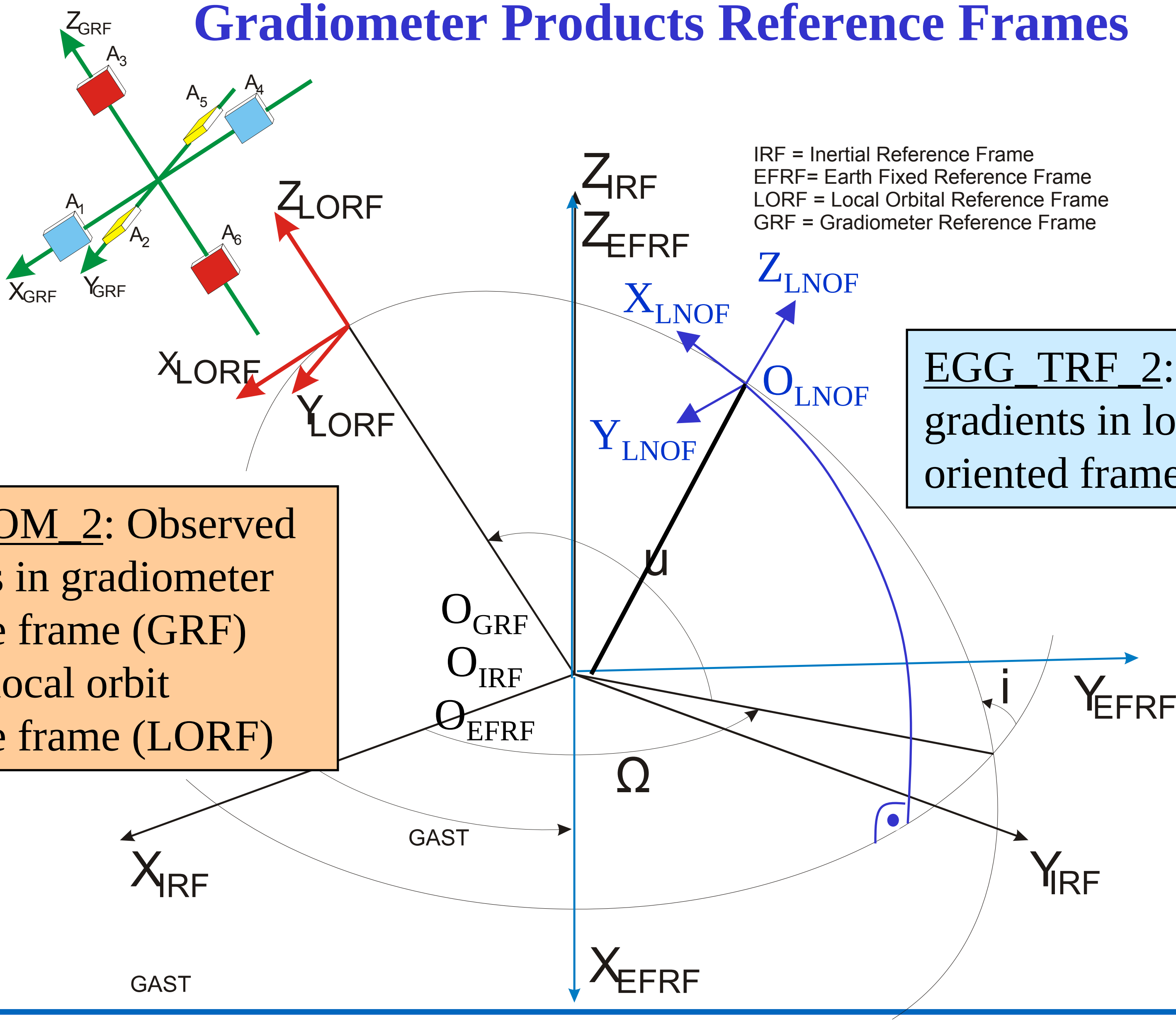
GOCE Standards implemented for ESA‘s High level Processing Facility:

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

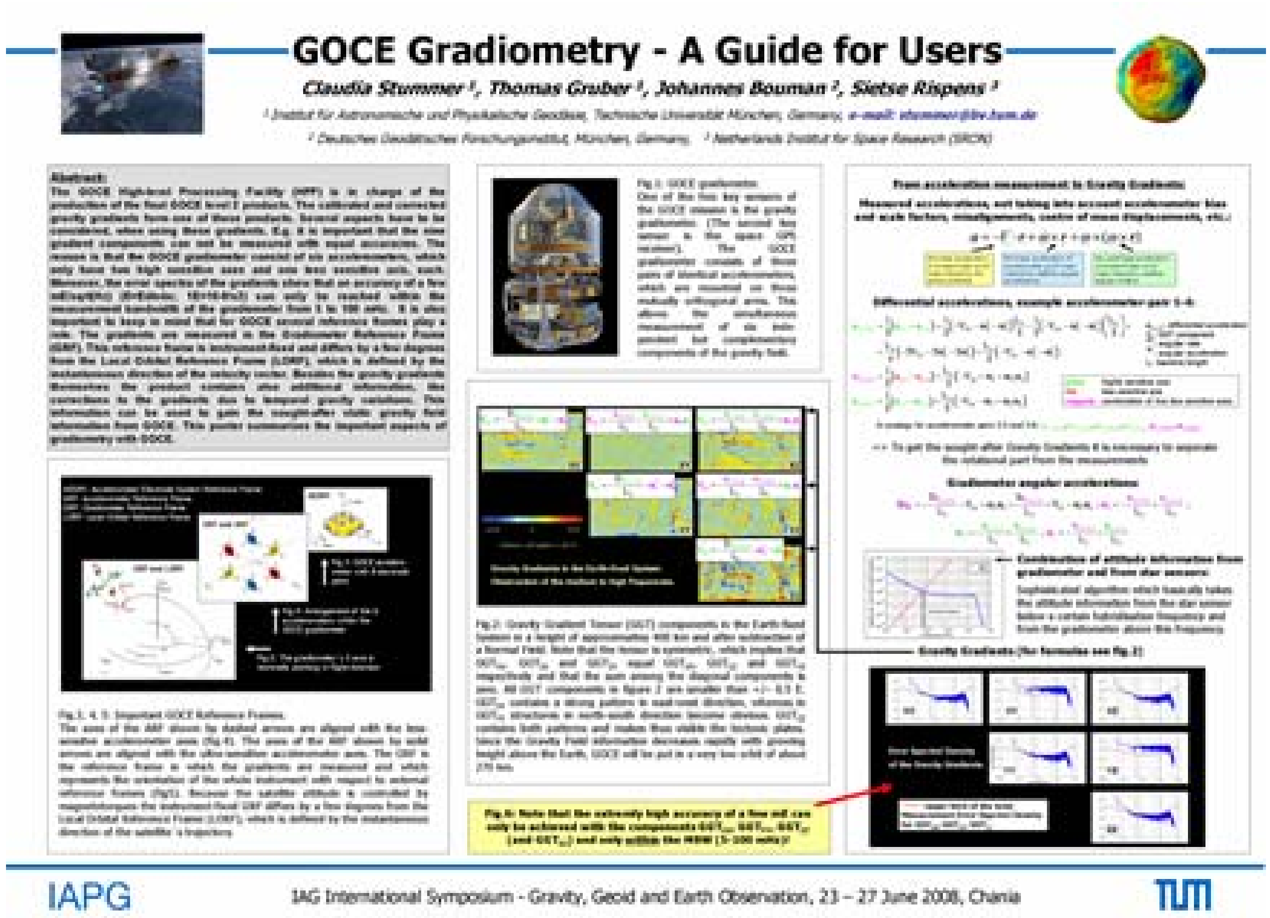


EGG_TRF_2: Rotated gradients in local North oriented frame (LNOF)

EGG_NOM_2: Observed gradients in gradiometer reference frame (GRF) close to local orbit reference frame (LORF)

Gradiometer Data Processing

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



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.

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

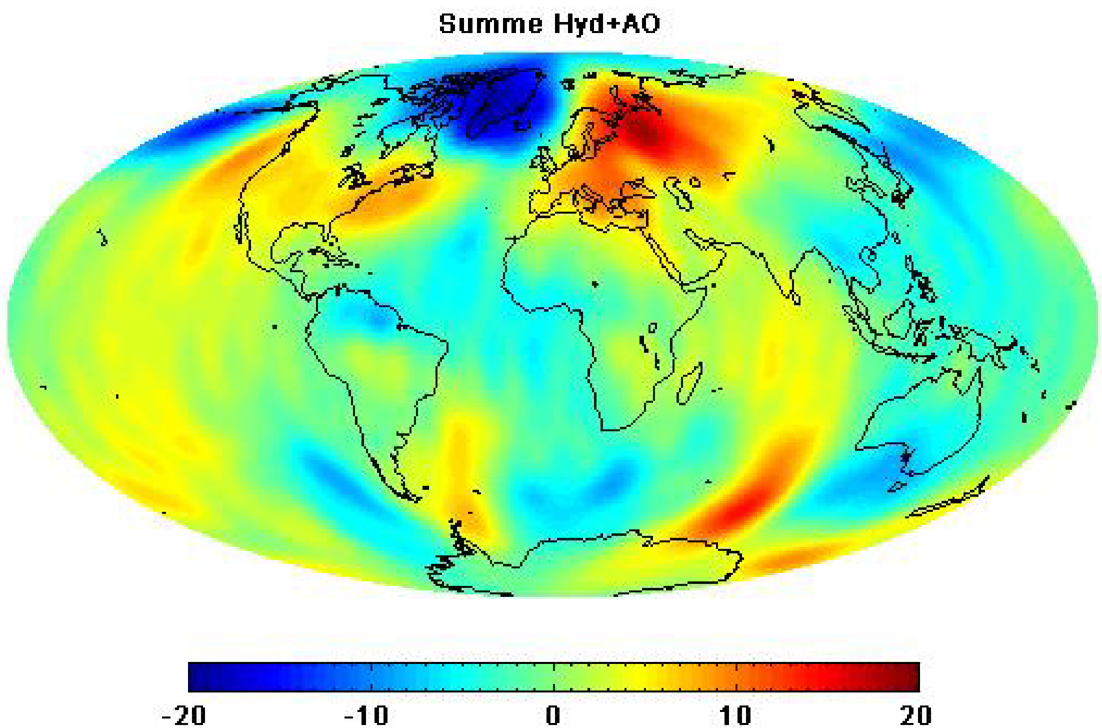
Non-tidal time variable gravity field potential with respect to a mean value in terms of a spherical harmonic series determined from atmospheric and oceanic mass variations as well as from a GRACE monthly gravity field time series.	
Spherical Harmonic Series (SHS)	Degree; order; C/S-coefficients of gravity 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]



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

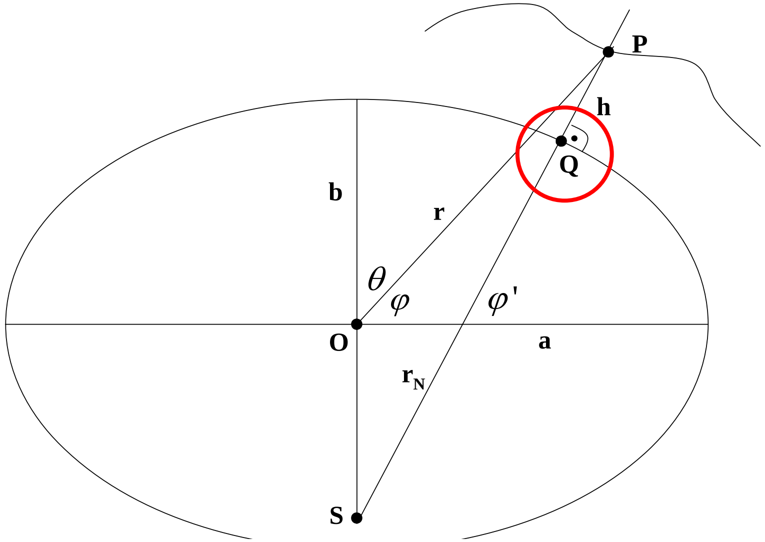
Content of EGM_GOC_2

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)



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

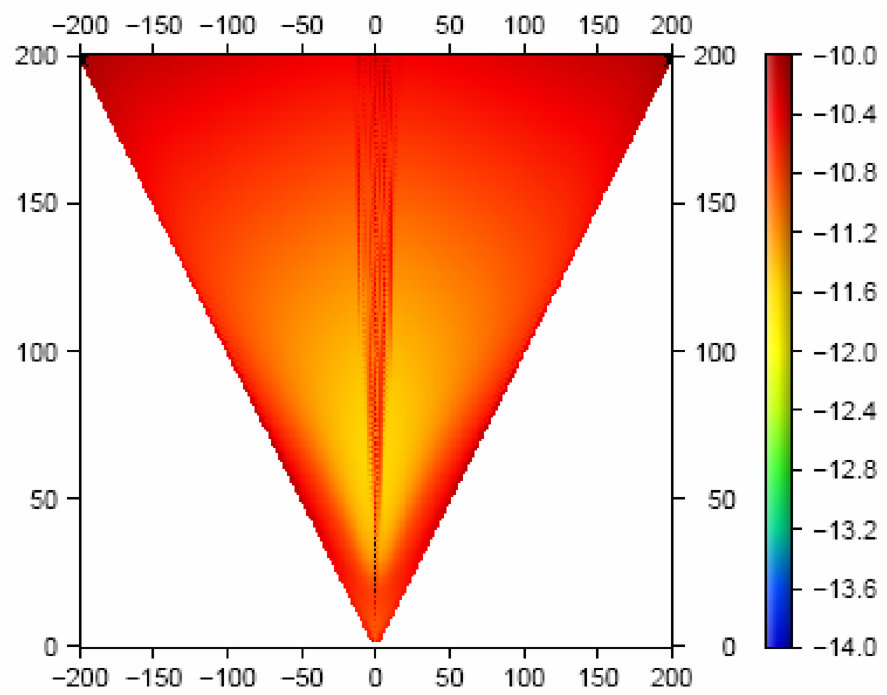
$$\Delta g \approx -\frac{\partial T}{\partial r} - \frac{2}{a^{REF}} T$$

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

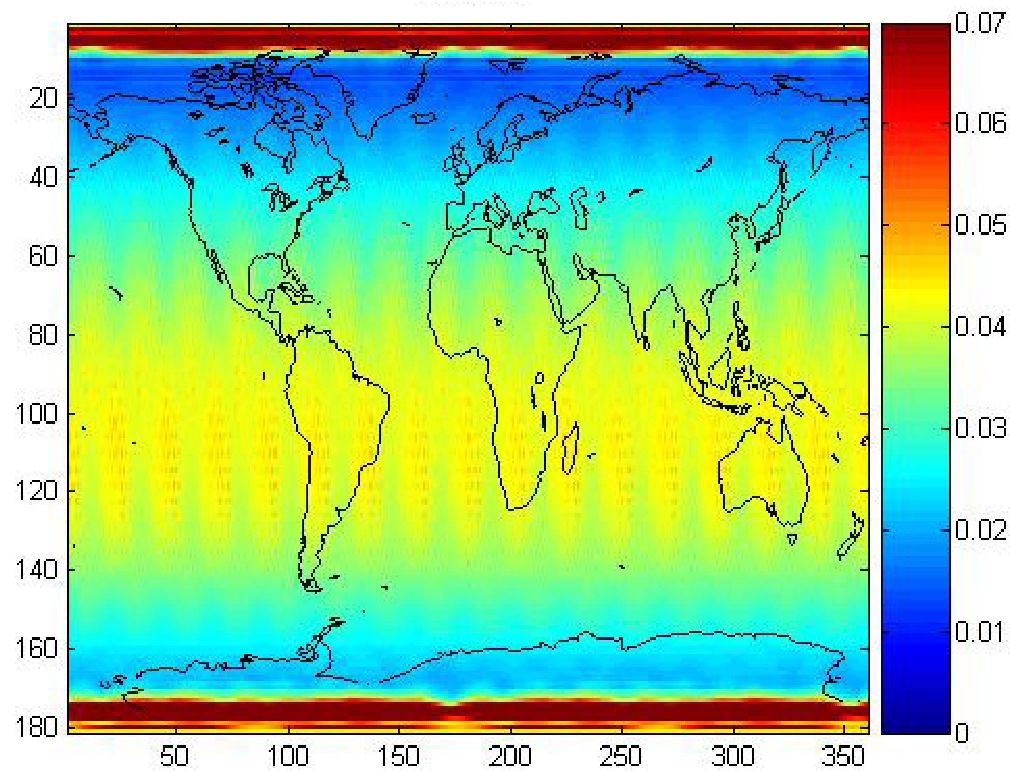
GOCE Gravity Field Model

Examples

Coefficient Errors



Geoid Height Errors



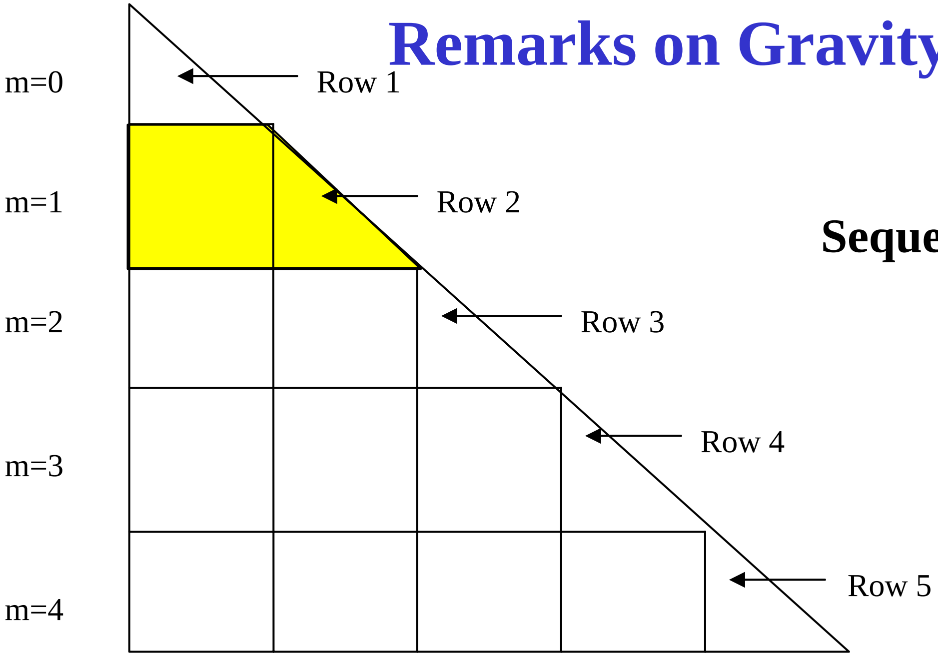
GOCE Gravity Field Variance-Covariance Matrix

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

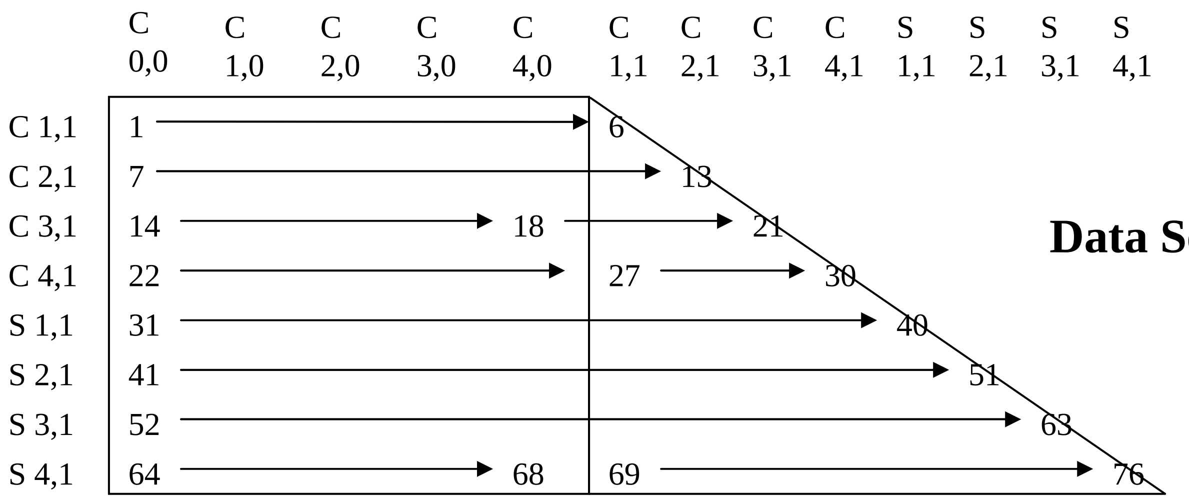
GOCE Gravity Field Variance-Covariance Matrix

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

Meta Data File

```
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
```

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.

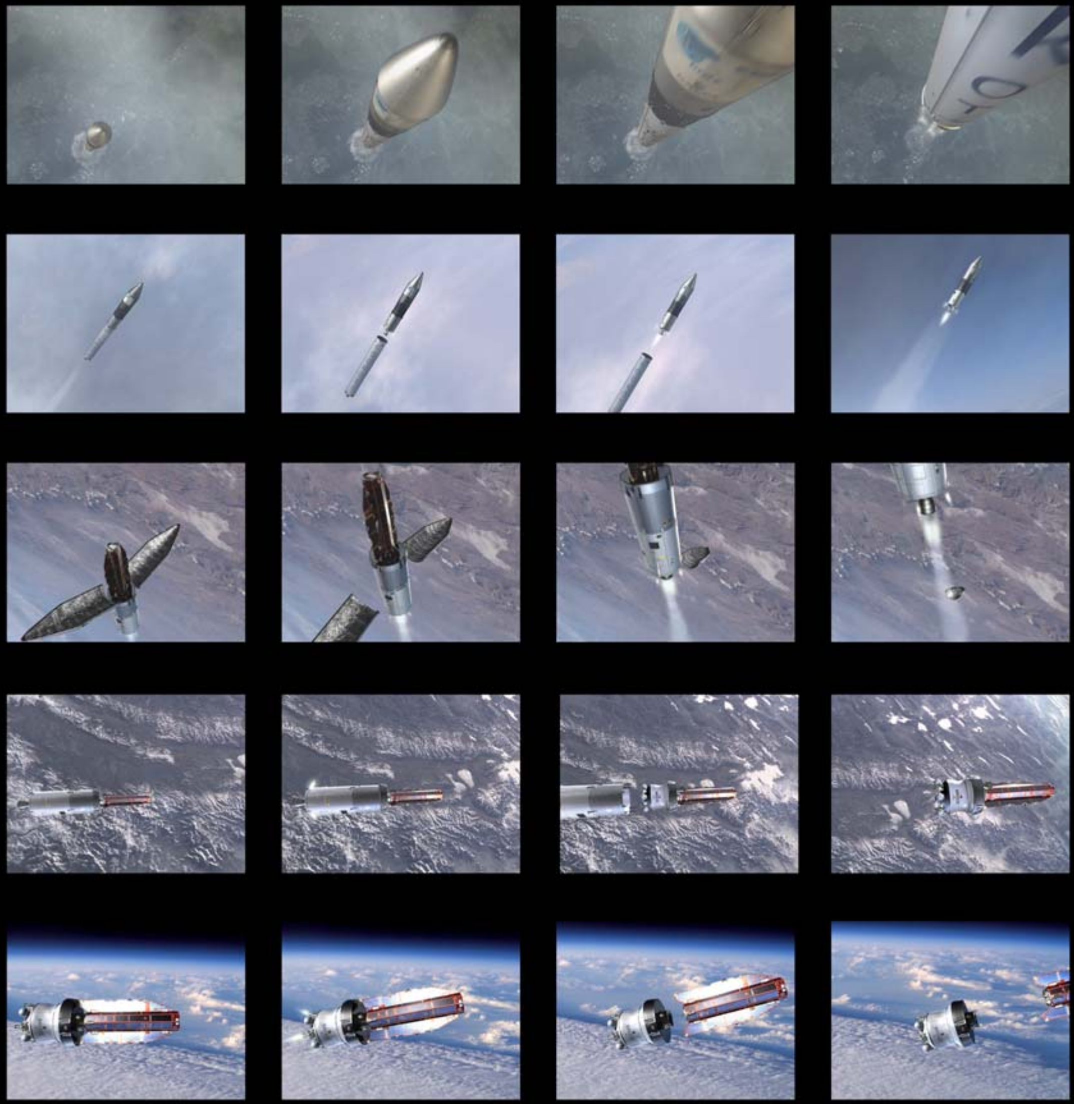
Standards and Models applied in Level 2 processing are defined in the GOCE Standards Document.

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



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