



# ***GOCE Standards and Models – Challenges for the 1 cm Geoid***

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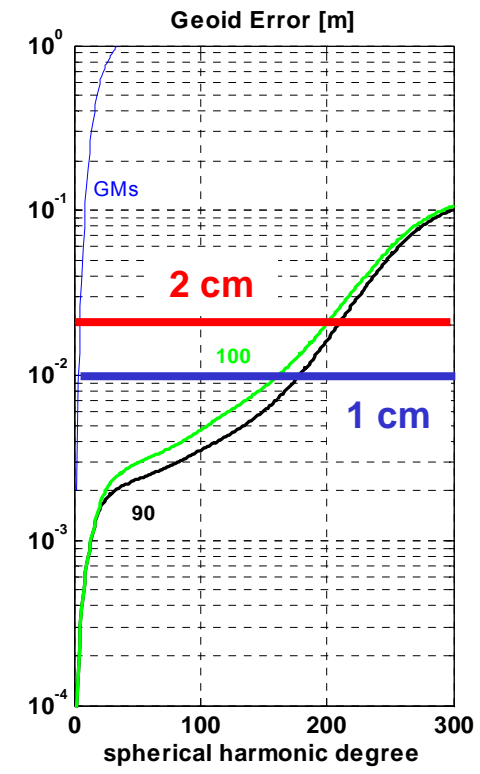
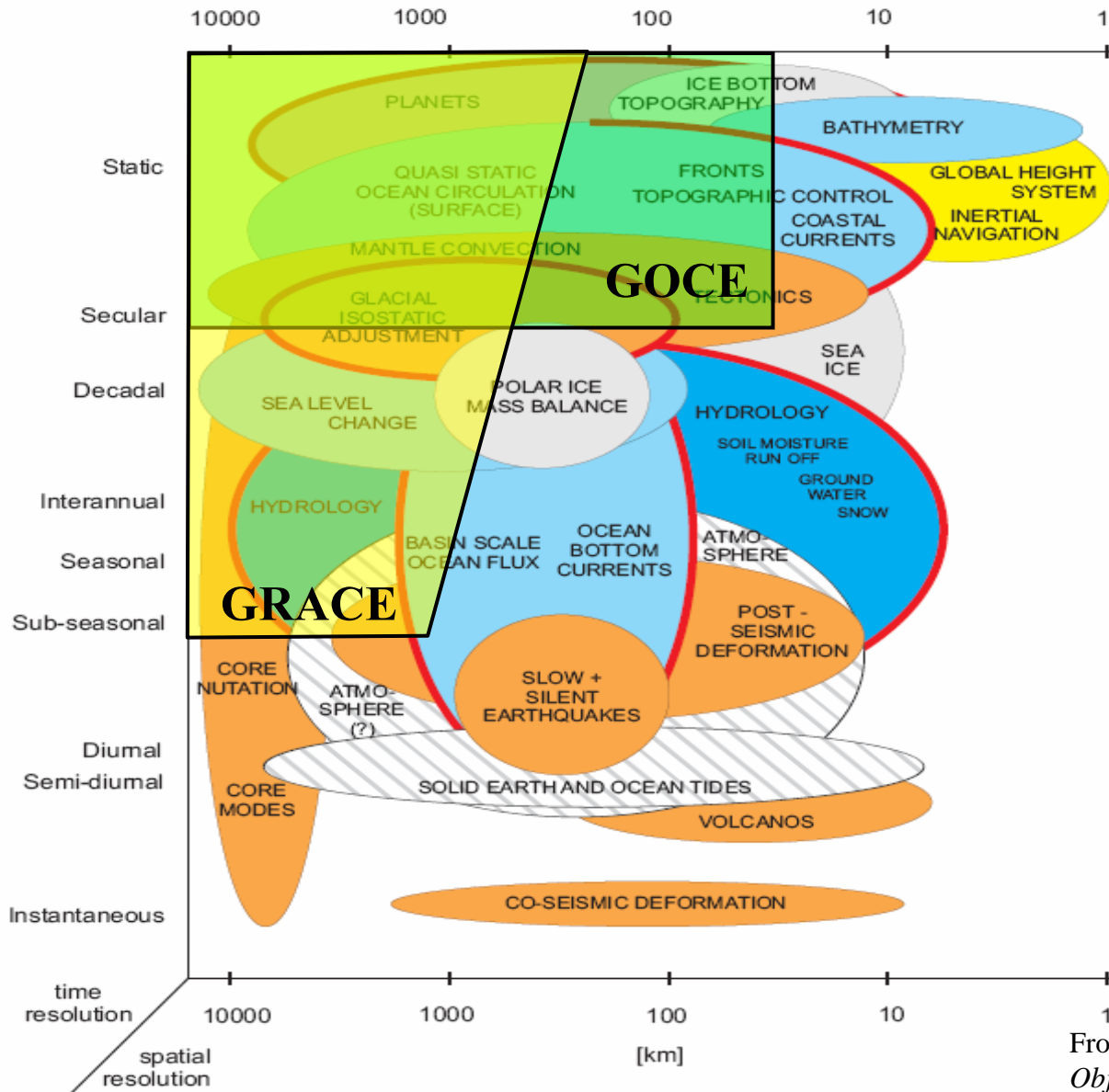
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**IAG / FIG Symposium ‘Geodetic Reference Frames’  
Munich, Germany, 9 – 14 October 2006**

# Outline

- 1. Motivation & Goals of GOCE Mission**
- 2. The GOCE High-Level Processing Facility**
- 3. Processing Standards**
  - a) Transformation between Reference Frames**
  - b) Reference Field Issues for Combination and  
Validation of Gravity Fields**
- 4. Conclusions**

# Goals of GOCE Mission



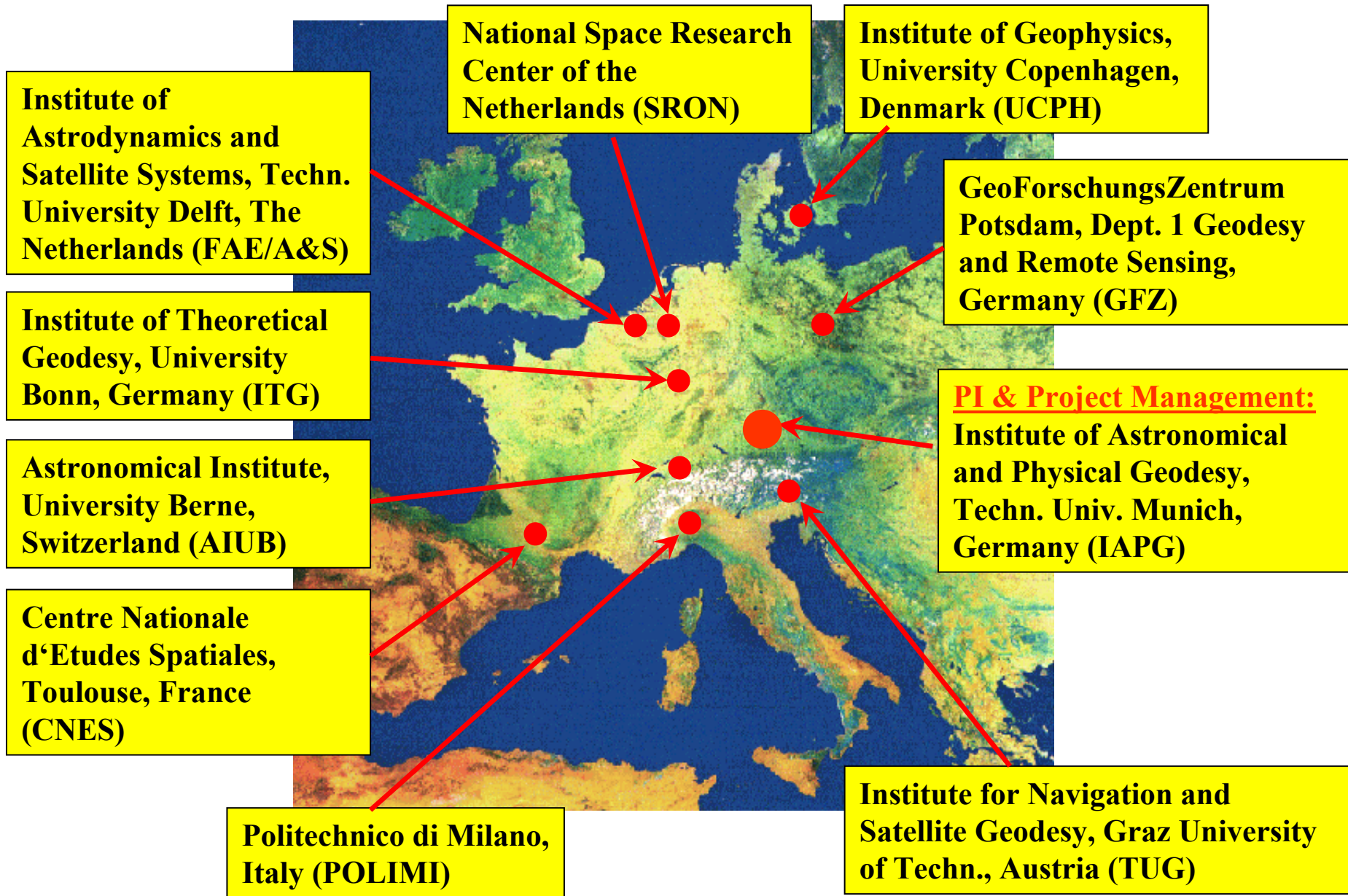
From Simulation Study

From ESA-Study: „Scientific Objectives for Future Geopotential Missions“

# GOCE Level 2 Products

| Identifier | Description   |
|------------|---|
| EGG_NOM_2  | Externally calibrated and corrected gravity gradients   |
| EGG_TRF_2  | Externally calibrated gravity gradients in Earth fixed reference frame  |
| SST_PSO_2  | GOCE precise science orbits final product   |
| EGM_GOC_2  | Final GOCE Earth gravity field model <ul style="list-style-type: none"><li>• Spherical harmonic series including error estimates.</li><li>• Variance-covariance matrix of final GOCE Earth gravity field model</li><li>• Grids of geoid heights, gravity anomalies and geoid slopes computed from GOCE model</li><li>• Quality report</li></ul> |

# The GOCE High Level Processing Facility



# GOCE Standards

|   |   |  |
|---|---|--|
|  |  | <p>GOCE Standards</p> <p>Doc. Nr: GO-TN-HPF-GS-0111</p> <p>Issue: 2.0</p> <p>Date: 22.09.2006</p> <p>Page: 1 of 72</p> |
|---|---|--|

GOCE High Level Processing Facility

## GOCE Standards

Doc. No.: GO-TN-HPF-GS-0111  
Issue: 2  
Revision: 0  
Date: 22 / 09 / 2006



Prepared by: The European GOCE Gravity Consortium  
EGG-C

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

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

# GOCE & Applications



GOCE High Level Processing Facility

GOCE Level 2 Data Handbook

Doc. No.: GO-MA-HPF-GS-0110  
Issue: 3  
Revision: 0  
Date: 22 / 09 / 2006



Prepared by: The European GOCE Gravity Consortium  
EGG-C

## GOCE Level 2 Data Handbook

- GOCE Mission Overview
- GOCE Data Processing Overview
- Reference Frames and Time Systems
- Mathematical Conventions
  - Quaternions,
  - Spherical Harmonic Series,
  - Error Propagation
- Geophysical Conventions
  - Approximations for derived quantities
  - Accurate Formulations
- Level 2 Product Definitions
  - Orbits
  - Gravity Fields & Covariance Matrix

# GOCE Data Exploitation AO

<http://eopi.esa.int/> Open since 6. Oct.; Submission of Proposal till 8. Dec.



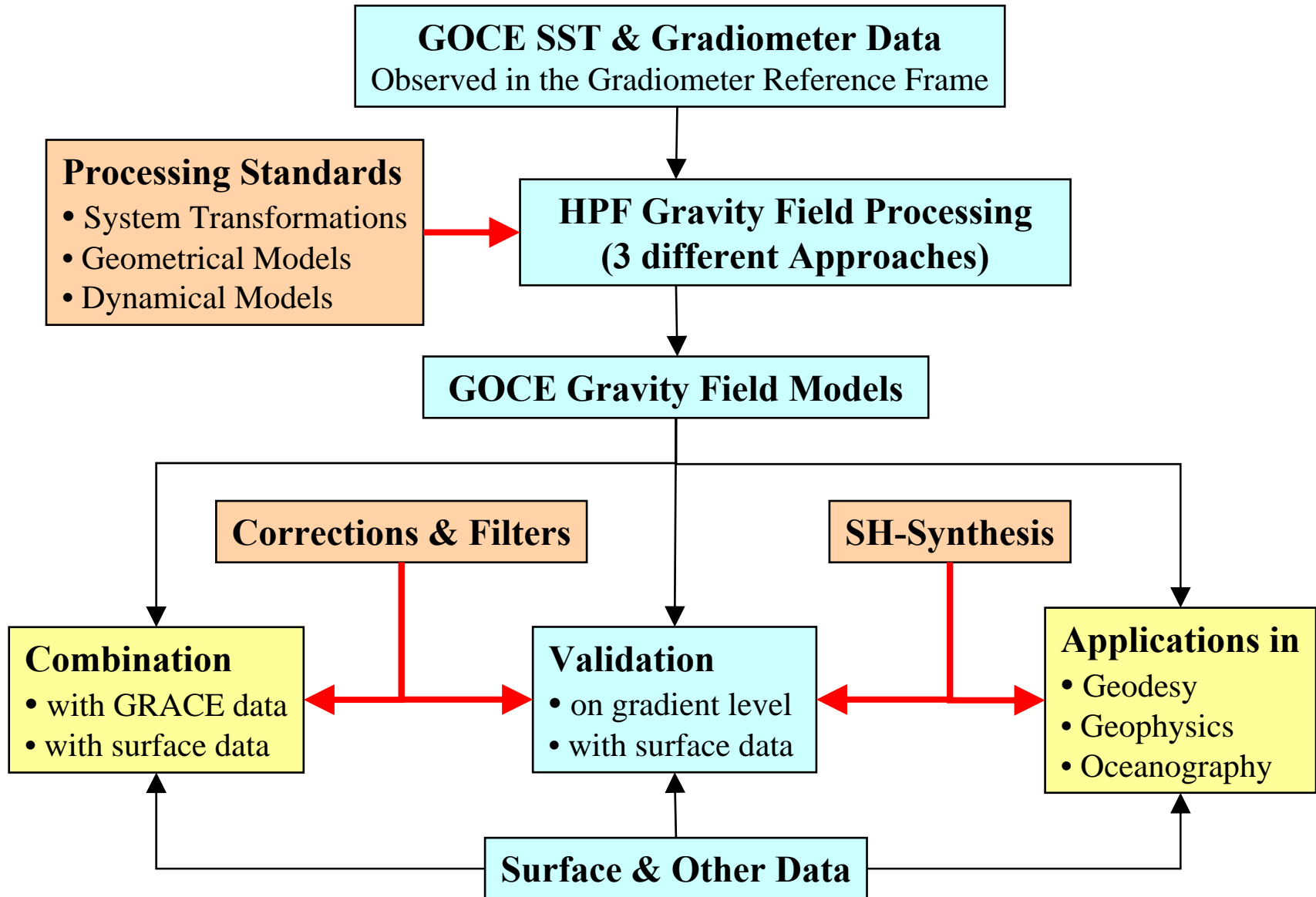
**07-Oct-2006 UT** [Contact us](#)

| Exploitation Results & News   | First GOCE Data Announcement of Opportunity  | GOCE  |
|---|--|---|
| <b>Results</b>  | <b>Data Announcement of Opportunity</b>  |  |
| <b>News</b>   |  |   |
| <b>Search</b>   | The deadline for submission of proposals is 8 December 2006  |   |
| <b>Focus on PI</b>  |  |   |
| <b>Round table</b>  | <a href="#">GOCE AO Invitation Letter</a>  |   |
| <b>AO Submission</b>  | <a href="#">Goce Data AO main Text</a>   |   |
| <b>Cat-1 &amp; Open AOs</b>   | <a href="#">Terms and Conditions for the use of ESA Data</a>   |   |
| Category-1  | <a href="#">Earth Explorers Data Policy: GOCE Update</a>   |   |
| GOCE  |  |   |
| TPM   | <a href="#">GOCE Level 1b Products User Handbook</a>   |   |
| <b>Previous AOs</b>   | <a href="#">GOCE Level 2 Product Data Handbook</a>   |   |
| <b>Update &amp; Reporting</b>   | <a href="#">GOCE Standards Document</a>  |   |
| <b>Services</b>   |  |   |
| <b>About this site</b>  | <a href="#">Guidelines for the submission of proposals</a>   |   |
| <b>ESA Data Policy</b>  | <a href="#">Submit a new Proposal</a>  |   |
| <b>FAQ</b>  |  |   |
| <b>Related Links</b>  |  |   |
| <b>How to get ESA data</b>  | The latest news and documents about GOCE are available on the <a href="#">GOCE Website</a> .           |   |
| <b>HOME</b>   | Should you need more information about the AO contact the <a href="#">ESA EO Help and Order Desk</a> . |   |
|  | Information about accepted GOCE projects will be retrievable <a href="#">here</a> .                    |   |

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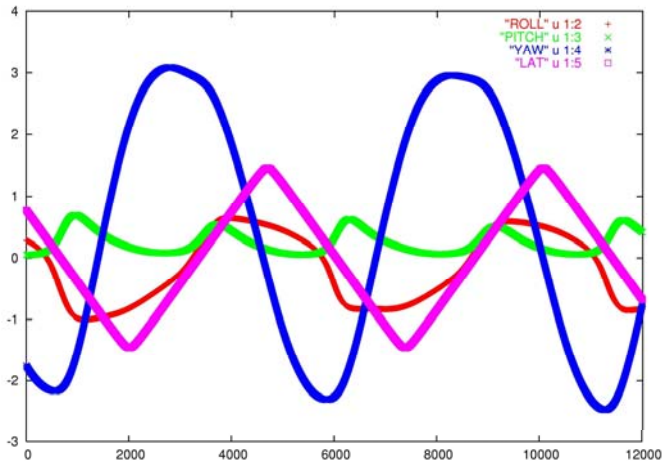


# Challenges for 1 cm Geoid



# GOCE Reference Frames

## GRF vs. LORF



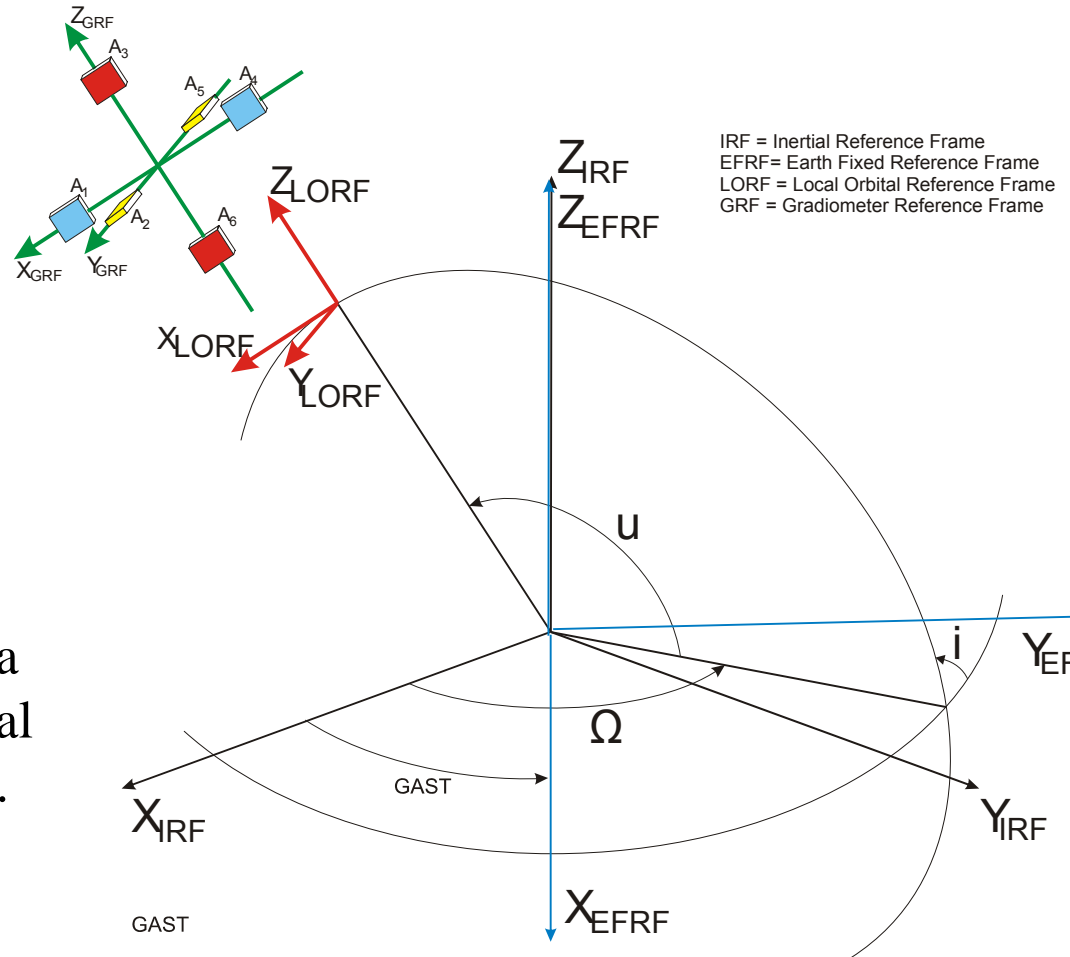
Courtesy: P. Visser / DEOS

## GRF vs. IRF

observed by 3 star cameras (with a few arcsec accuracy) and rotational information from the gradiometer.

## EFRF vs. IRF

following IERS conventions 2003

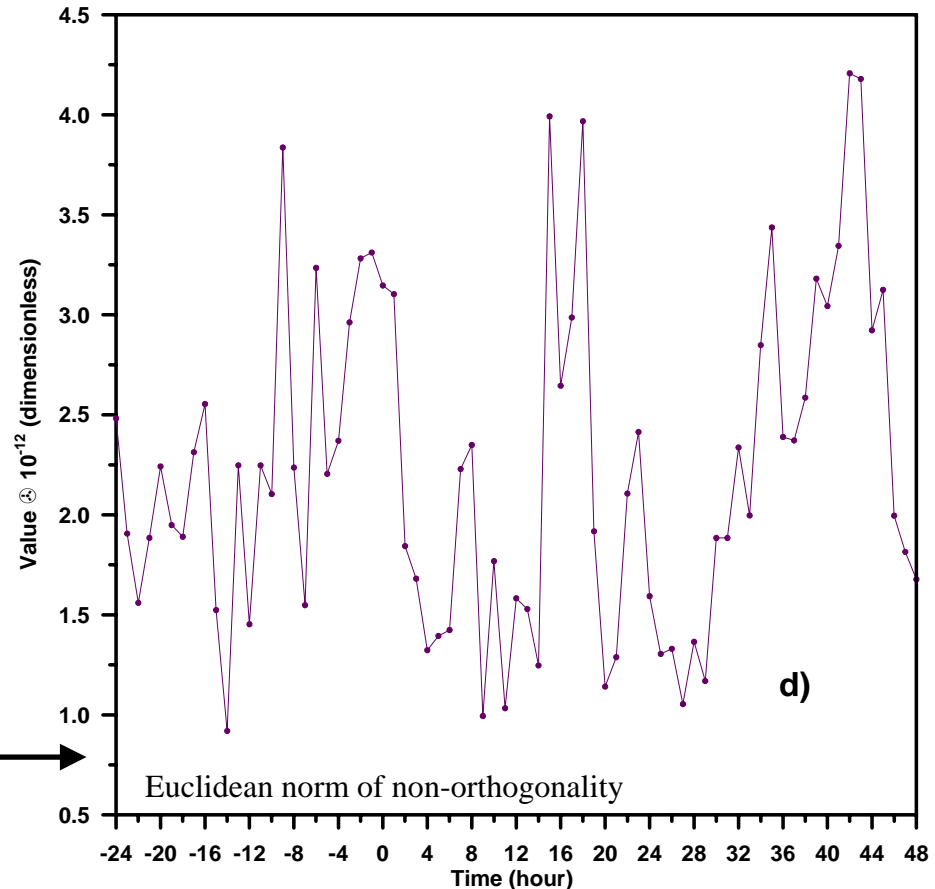


# EFRF ↔ IRF

$$\mathbf{r}^{IRF} = \mathbf{B}(t)\mathbf{P}(t)\mathbf{N}(t)\mathbf{S}(t)\mathbf{W}(t)\mathbf{r}^{EFRF}$$

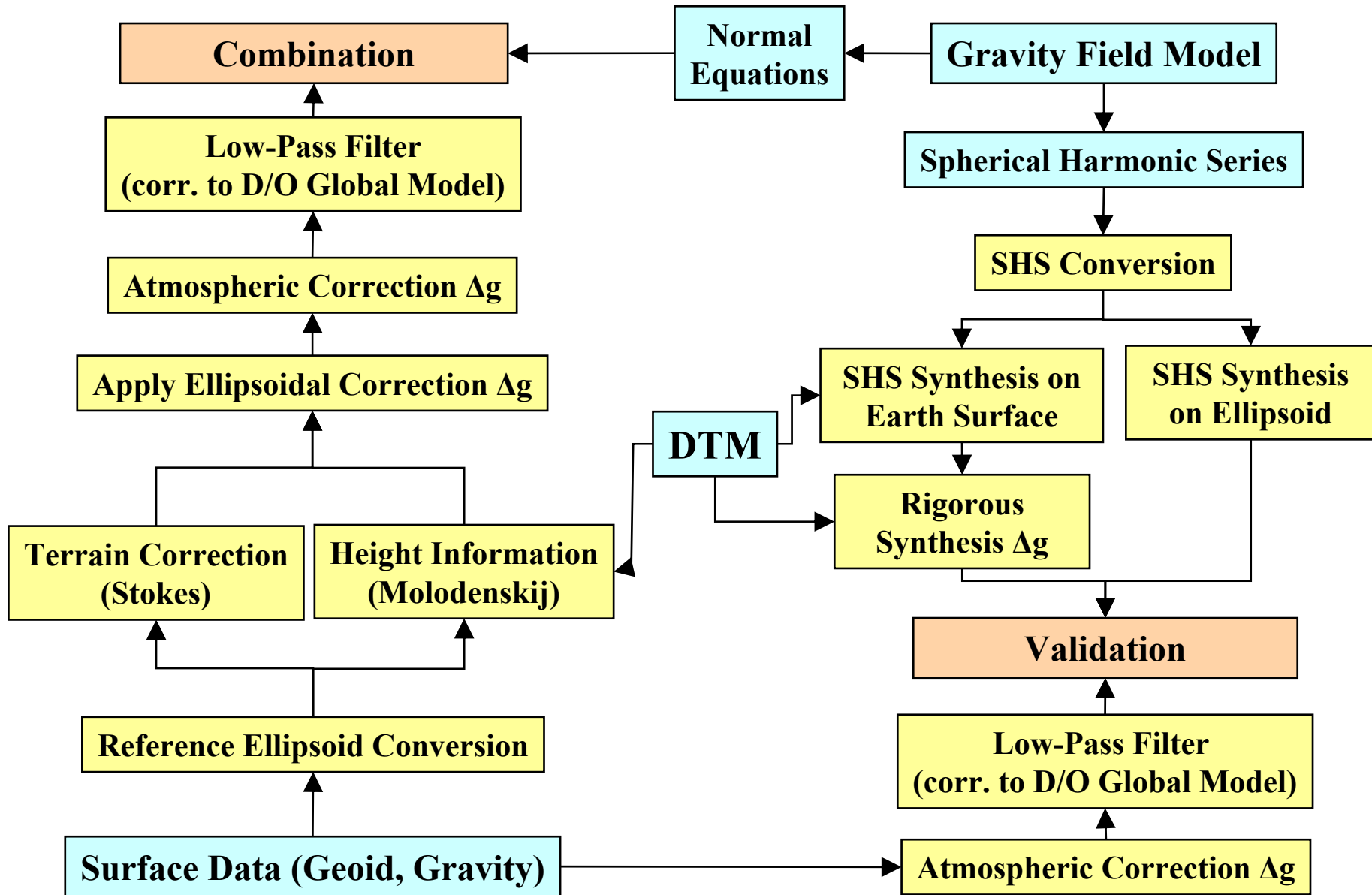
**B(t):** Frame bias matrix.  
**P(t):** Precession matrix.  
**N(t):** Nutation matrix  
**S(t):** Earth rotation matrix  
**W(t):** Polar motion matrix

Rotation matrix differences between  
IERS interactive tool and GFZ  
implementation.



Maximal deviations from the IERS results do not exceed  $4.5 \times 10^{-12}$ . This corresponds to the displacement of 0.03 mm in a point position at GOCE altitude, or to the uncertainty of 0.9 microarcseconds in the frame rotation.

# GOCE & Surface Data



# GOCE & Surface Data

## Reference Ellipsoid Conversion Geoid vs. Spherical Harmonic Series Conversion

**Given:**

$$N^{(1)}, GM^{(1)}, a^{(1)}, f^{(1)}, \omega^{(1)}, GM^{(2)}, a^{(2)}, f^{(2)}, \omega^{(2)}$$

**Given:**  $C_{nm}^{(1)}, S_{nm}^{(1)}, GM^{(1)}, a^{(1)}, GM^{(2)}, a^{(2)}$

Generalized Brun's Equation  
P: Geoid Point; Q: Ellipsoid Point

$$N = \frac{T_P}{\gamma_Q} - \frac{W_P - U_Q}{\gamma_Q}$$

**Assumption:  $W_P = U_Q$**

$$\begin{aligned} N^{(2)} &= N^{(1)} + \frac{T_P^{(2)}}{\gamma_Q^{(2)}} - \frac{T_P^{(1)}}{\gamma_Q^{(1)}} = \\ &= N^{(1)} + \frac{W_P - U_P^{(2)}}{\gamma_Q^{(2)}} - \frac{W_P - U_P^{(1)}}{\gamma_Q^{(1)}} \end{aligned}$$

**Approximations:**

$$\gamma_Q^{(1)} \approx \gamma_Q^{(2)} ; U_P^{(1)} - U_P^{(2)} \approx U_Q^{(1)} - U_Q^{(2)}$$

**Conversion:**

$$N^{(2)} = N^{(1)} + \frac{U_Q^{(1)} - U_Q^{(2)}}{\gamma_Q^{(2)}}$$

**Assumption: Constant Potential at P**

$$\begin{Bmatrix} C_{nm}^{(2)} \\ S_{nm}^{(2)} \end{Bmatrix} = \left( \frac{GM^{(1)}}{GM^{(2)}} \right) \left( \frac{a^{(1)}}{a^{(2)}} \right)^n \begin{Bmatrix} C_{nm}^{(1)} \\ S_{nm}^{(1)} \end{Bmatrix}$$

**Disturbing Potential  $T_P$**

$$\begin{Bmatrix} \Delta C_{nm}^{(2)} \\ \Delta S_{nm}^{(2)} \end{Bmatrix} = \begin{Bmatrix} C_{nm}^{(2)} \\ S_{nm}^{(2)} \end{Bmatrix} - \begin{Bmatrix} C_{nm}^{*(2)} \\ S_{nm}^{*(2)} \end{Bmatrix}$$

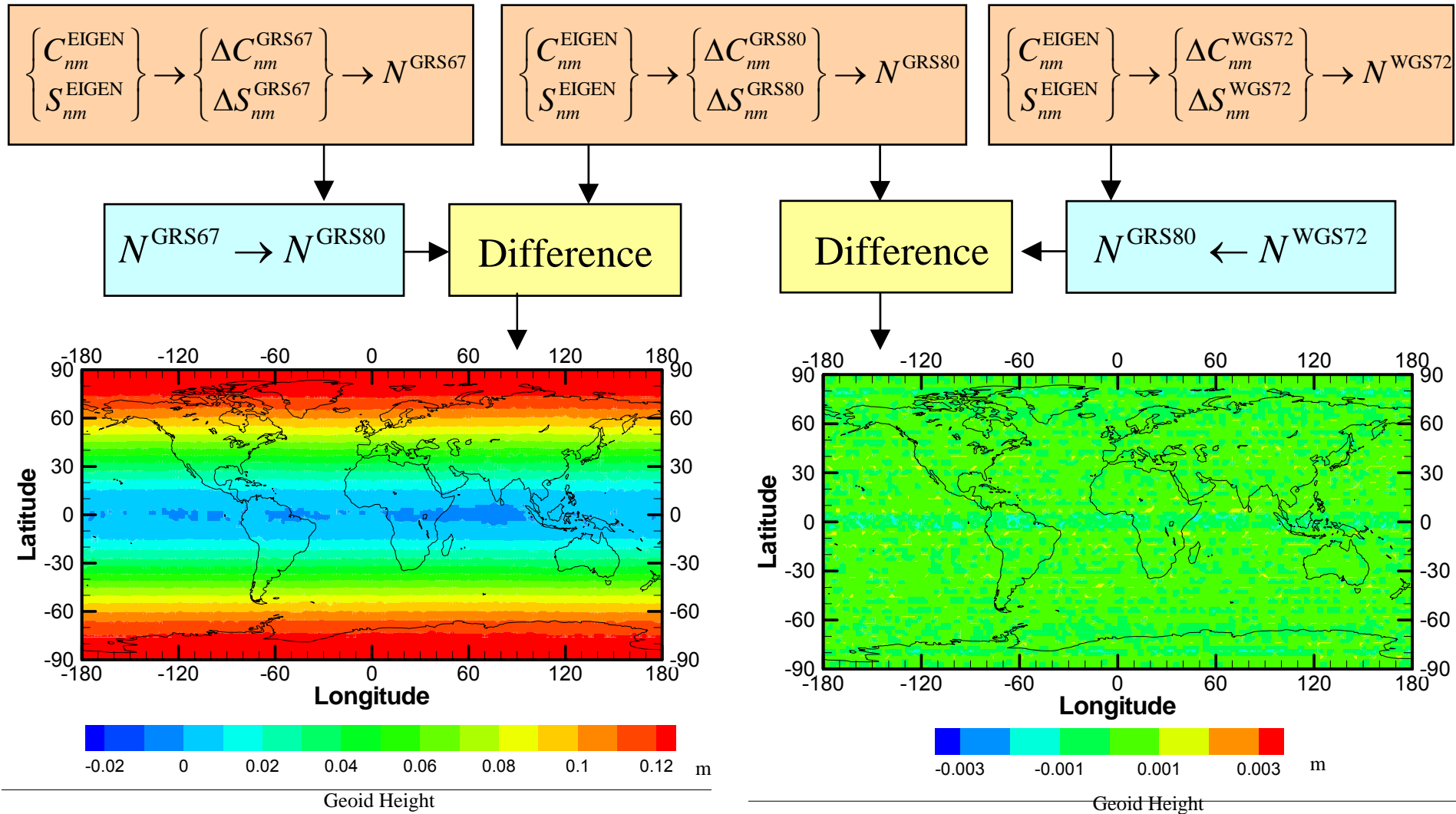
**Assumption:  $W_P = U_Q$**

$$N^{(2)} = \frac{GM^{(2)}}{r\gamma_Q^{(2)}} \sum_{n=0}^N \left( \frac{a^{(2)}}{r} \right)^n \sum_{m=0}^n (\Delta C_{nm}^{(2)} R_{nm} + \Delta S_{nm}^{(2)} T_{nm})$$

# GOCE & Surface Data

## Reference Ellipsoid Conversion Geoid vs. Spherical Harmonic Series Conversion

### Closed-Loop Test



# Conclusions

In GOCE data processing **Standards** play an important role in order to reach the prospected 1cm geoid accuracy. These include:

- System transformations and processing standards,
- Corrections and filters needed for combination and validation with surface data, and
- Geophysical conventions applied for derived gravity field quantities in view of their application.

Within the ESA High Level Processing Facility Standards have been agreed and implemented consistently at all processing centres. They are documented in the GOCE Standards and the Level 2 Product Manual (available through the GOCE Data Exploitation Announcement of Opportunity).