GOCE Sensor System & Data Processing

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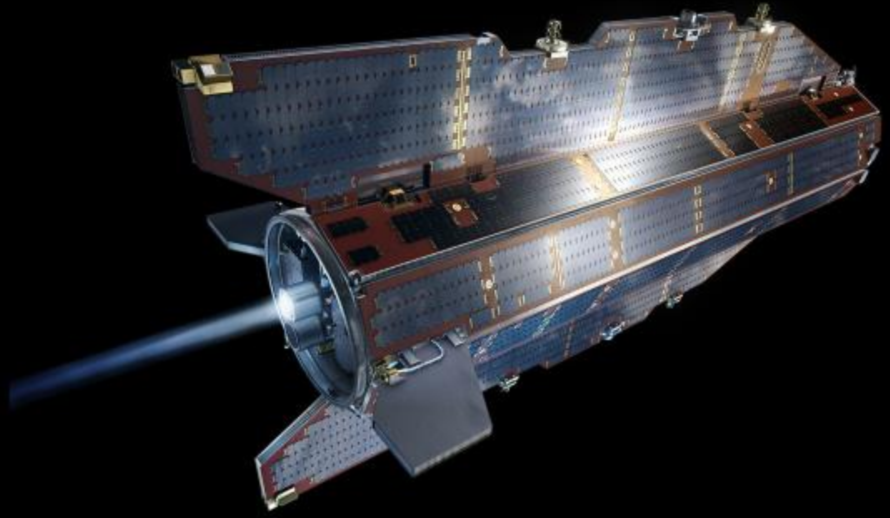
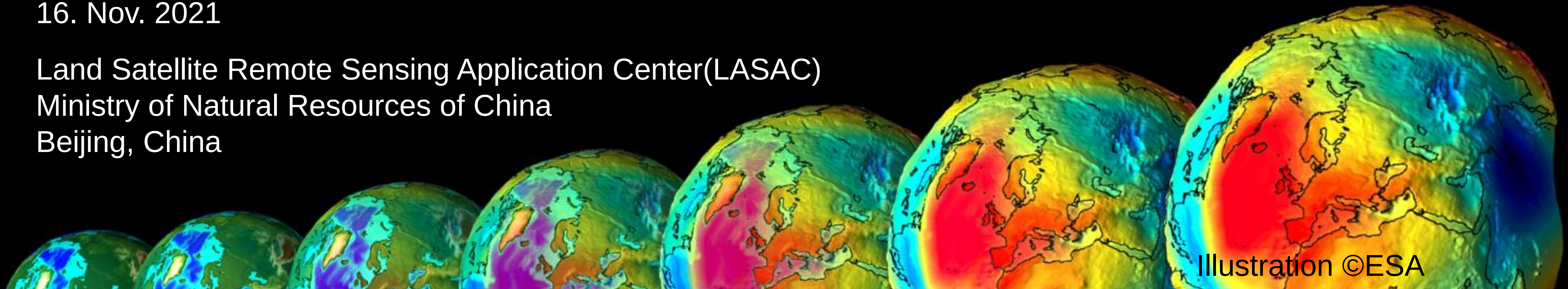


International Forum on Satellite Gravity Cooperation
16. Nov. 2021

Land Satellite Remote Sensing Application Center(LASAC)
Ministry of Natural Resources of China
Beijing, China

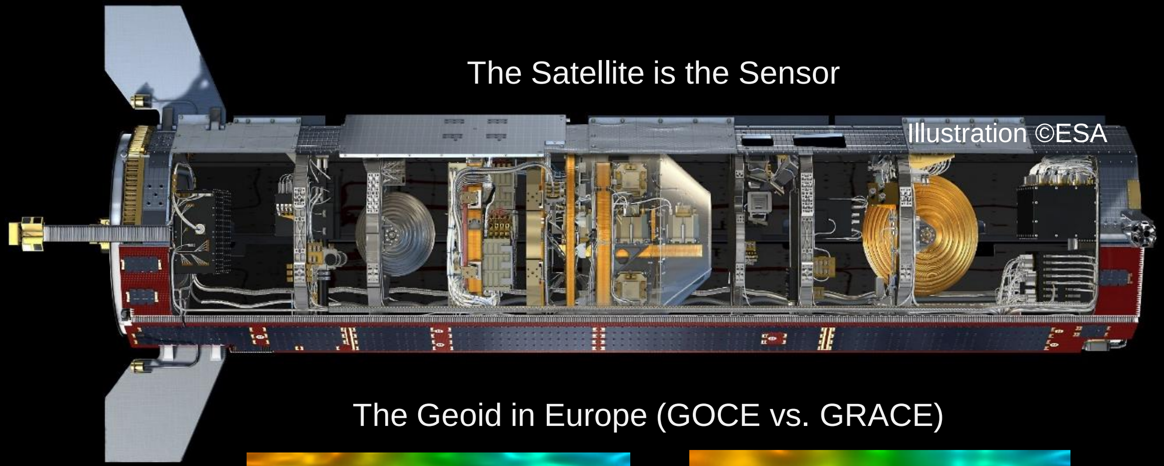


Outline

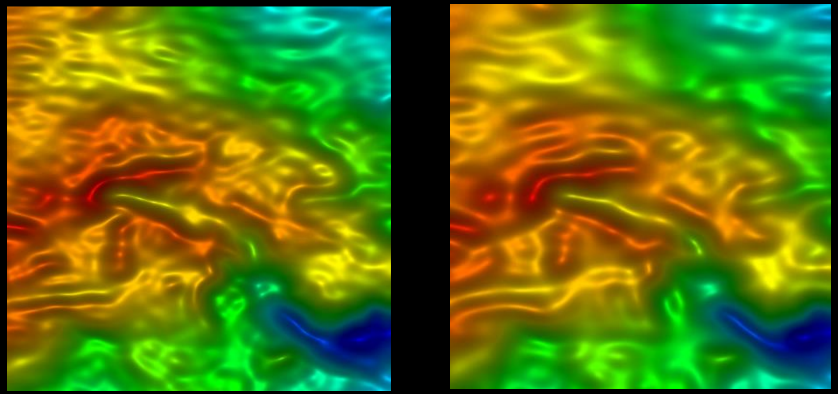
- Mission Goal
- GOCE Sensor System
- GOCE Data Processing
- GOCE Gravity Field Models

1 mGal = 10^{-5} m/s^2

The Satellite is the Sensor



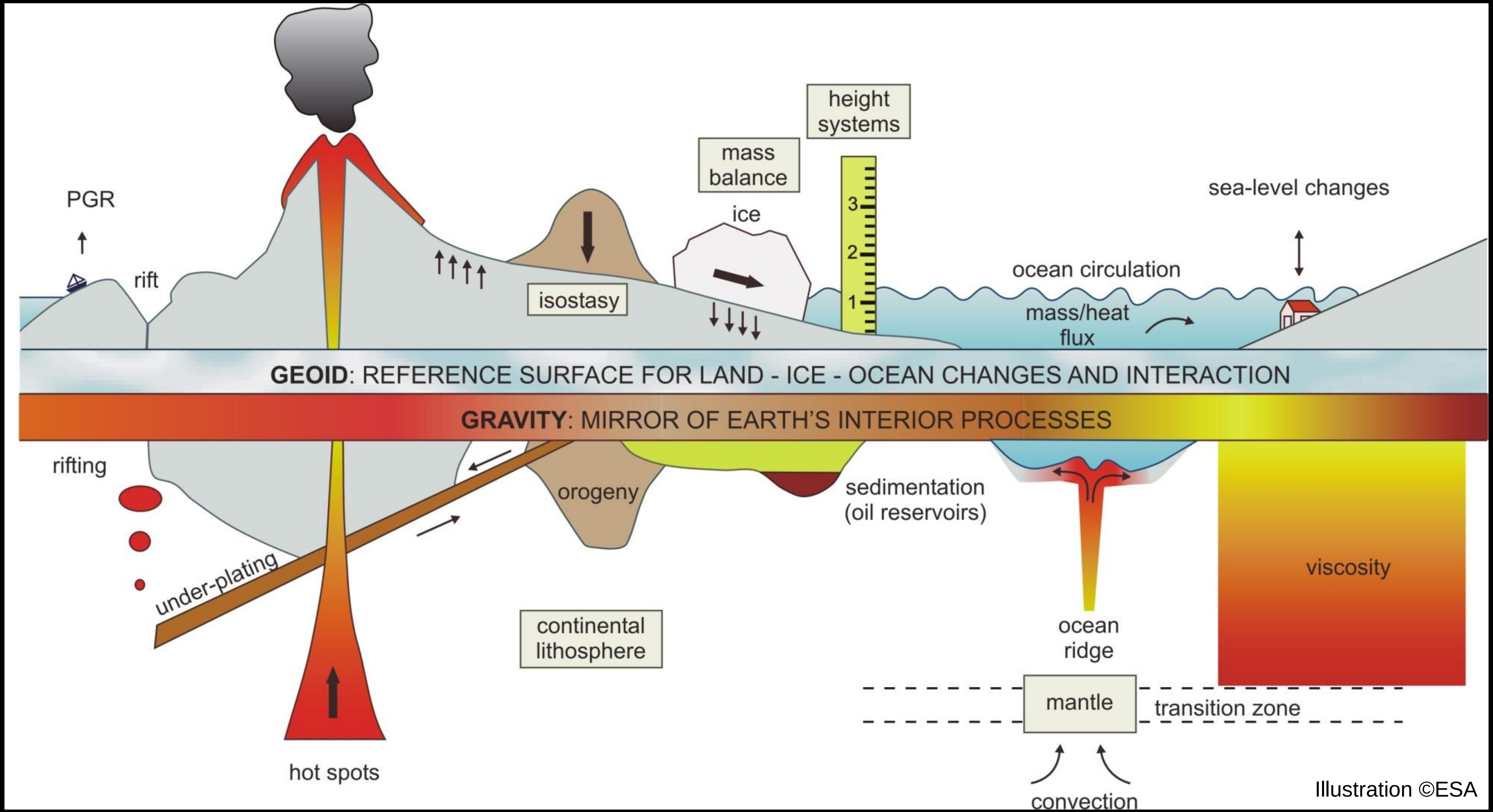
The Geoid in Europe (GOCE vs. GRACE)



Mission Goal

Static Gravity Field

1-2 cm in Geoid corresponding to 1 mGal in Gravity with 100 km spatial Resolution

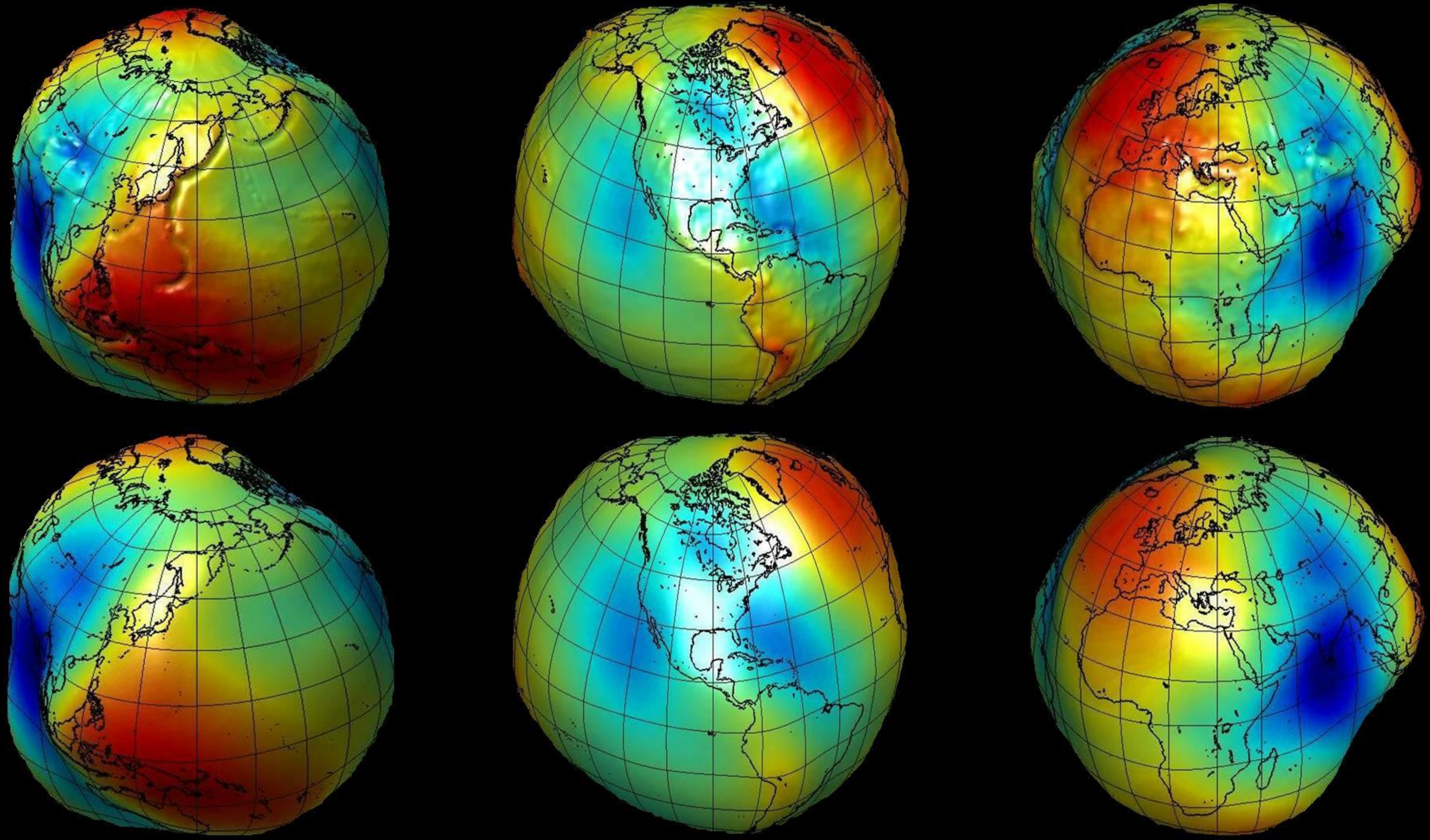


GOCE Sensor System

Earth Gravity Field

On Ground

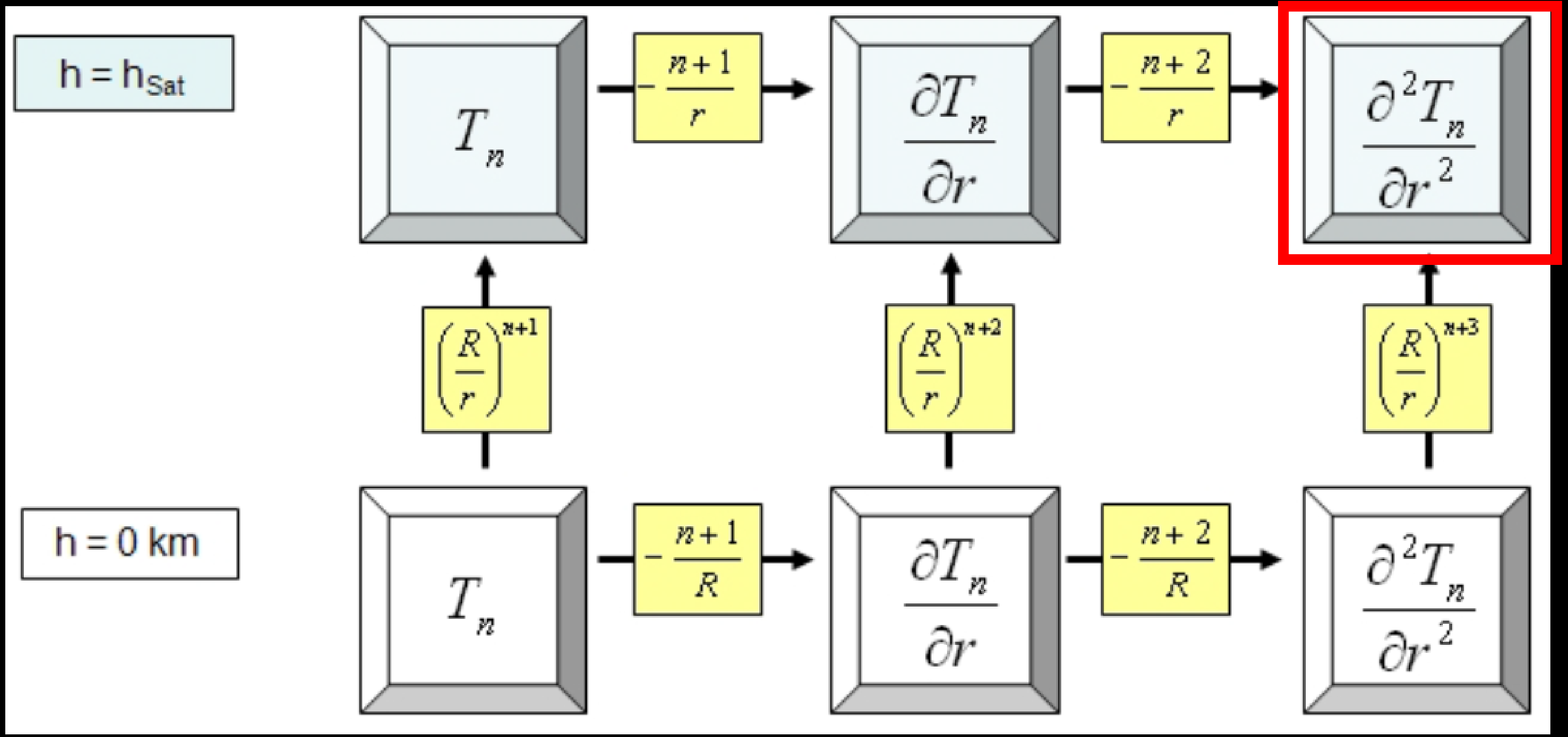
At Satellite Altitude



GOCE Sensor System

Meissl Scheme [1]

Satellite-to-Satellite Tracking



Satellite Gradiometry

Gravity Disturbance

(1) from R. Rummel

GOCE Sensor System

Non-Gravitational Forces

Non-Gravitational (Surface) Forces:

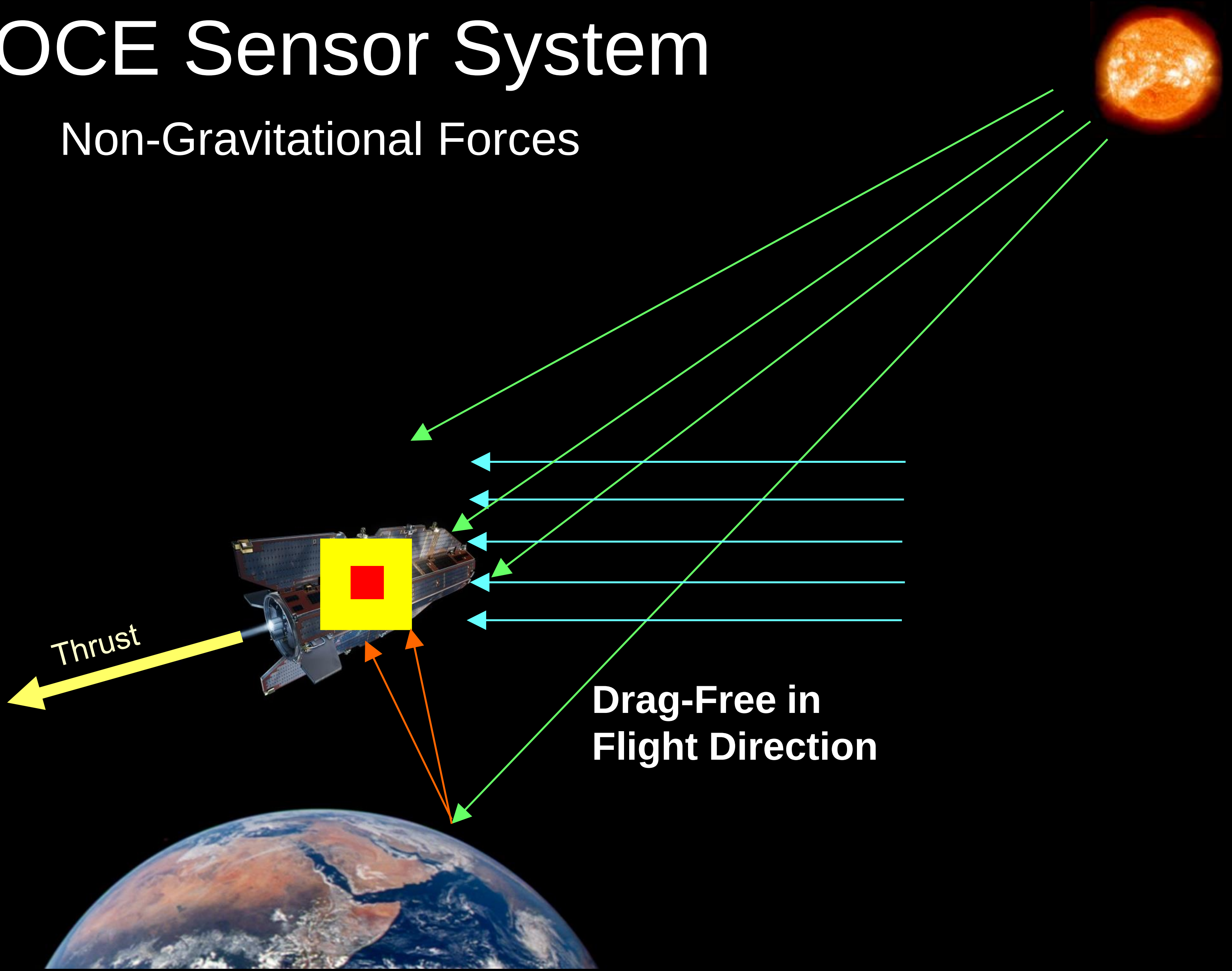
Atmospheric Drag

Solar Radiation Pressure

Earth Albedo

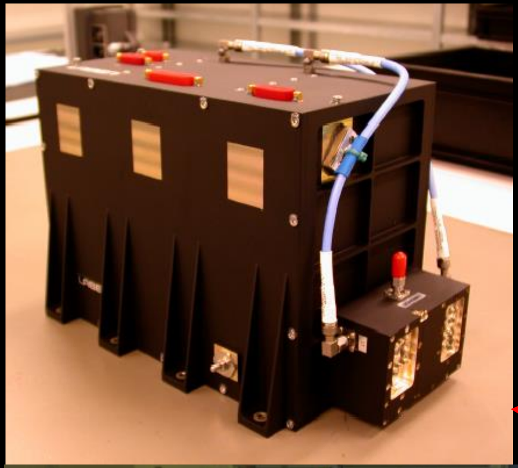
Accelerometer in Center of Mass (virtual)

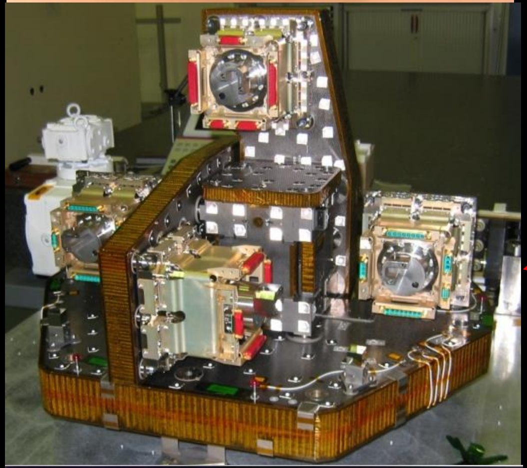
Test Mass in free Fall (virtual)

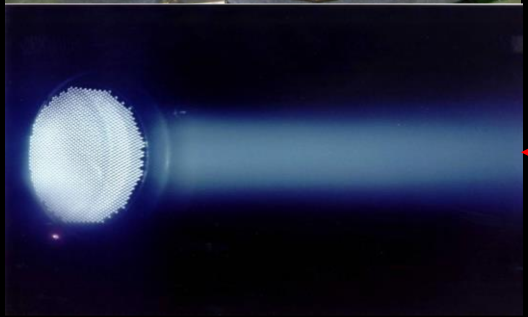


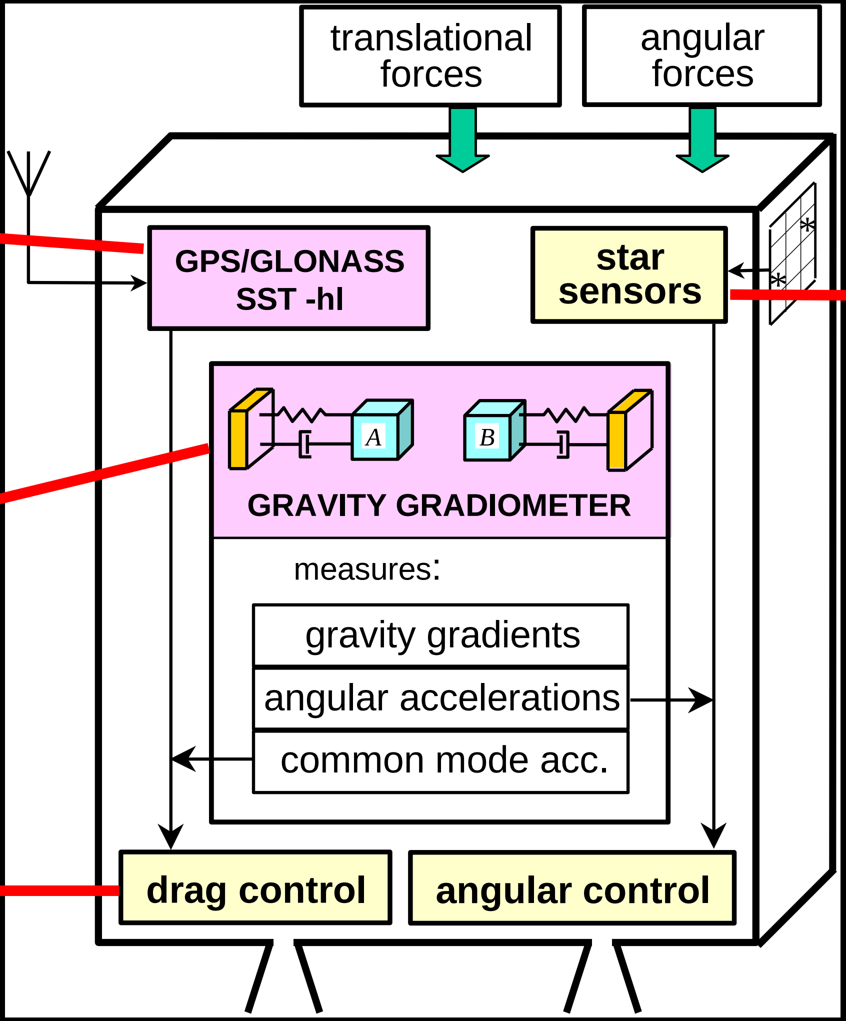
GOCE Sensor System

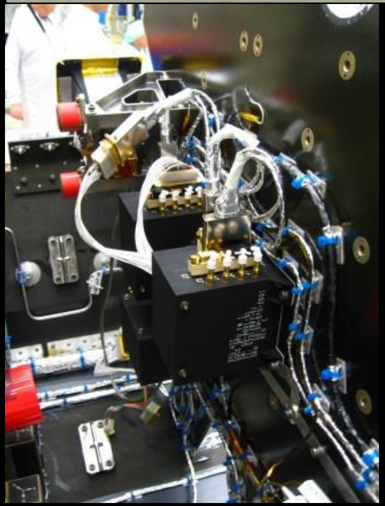
Overview









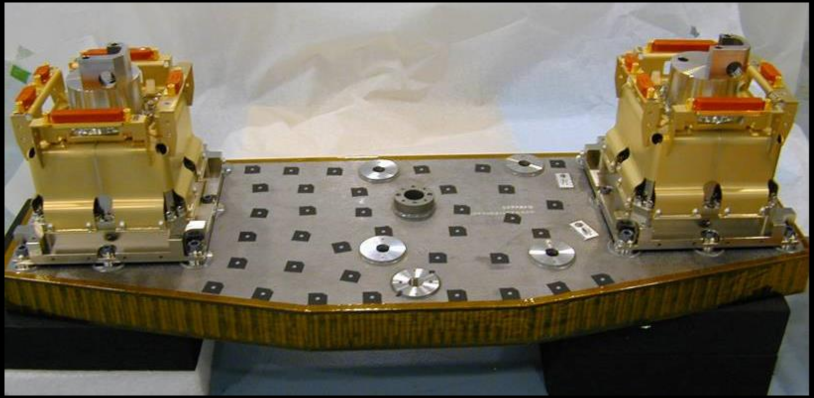


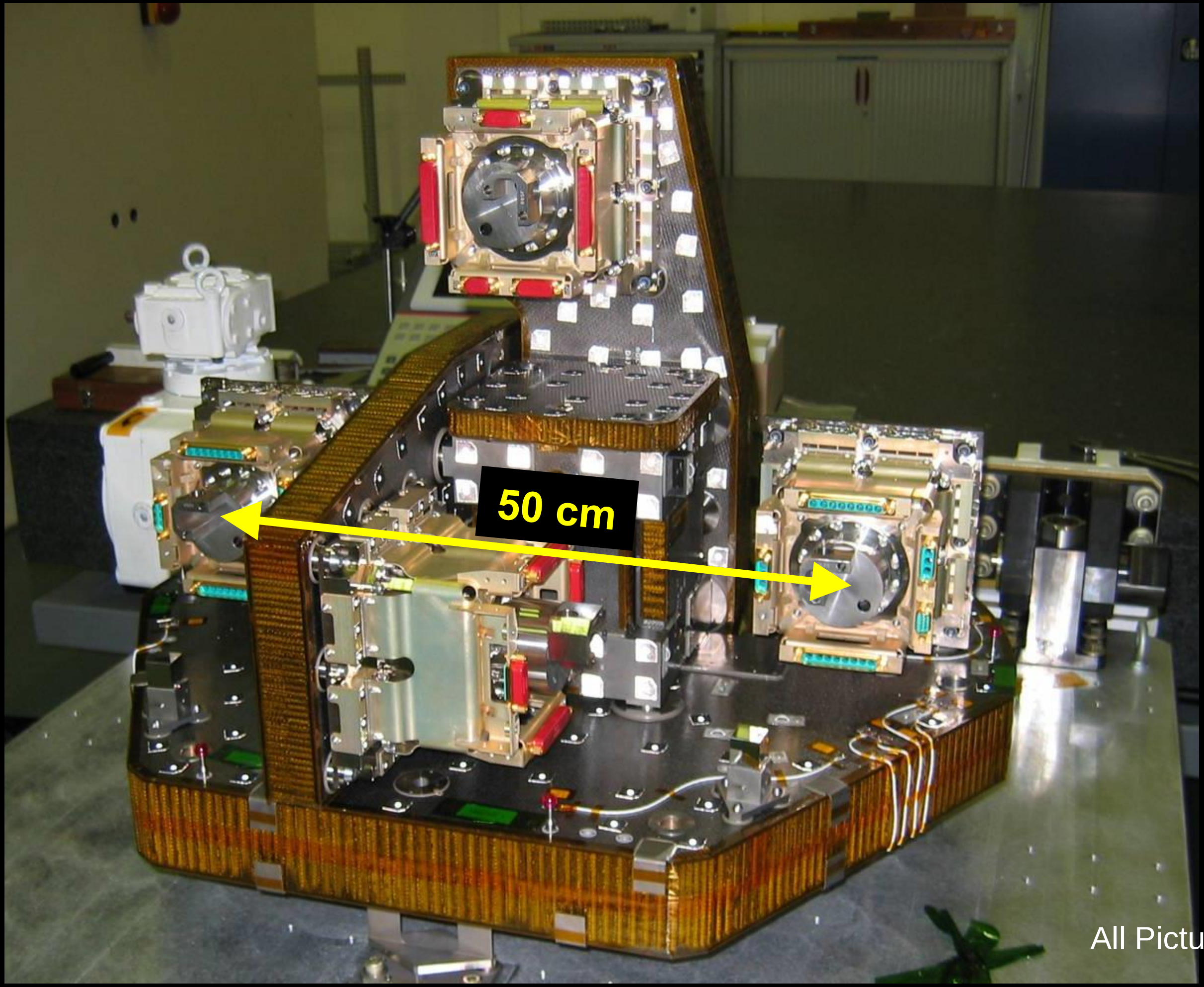
All Pictures ©ESA

GOCE Sensor System

Key Features

1. The first Gravity Gradiometer in Space with High Precision Thermal Control

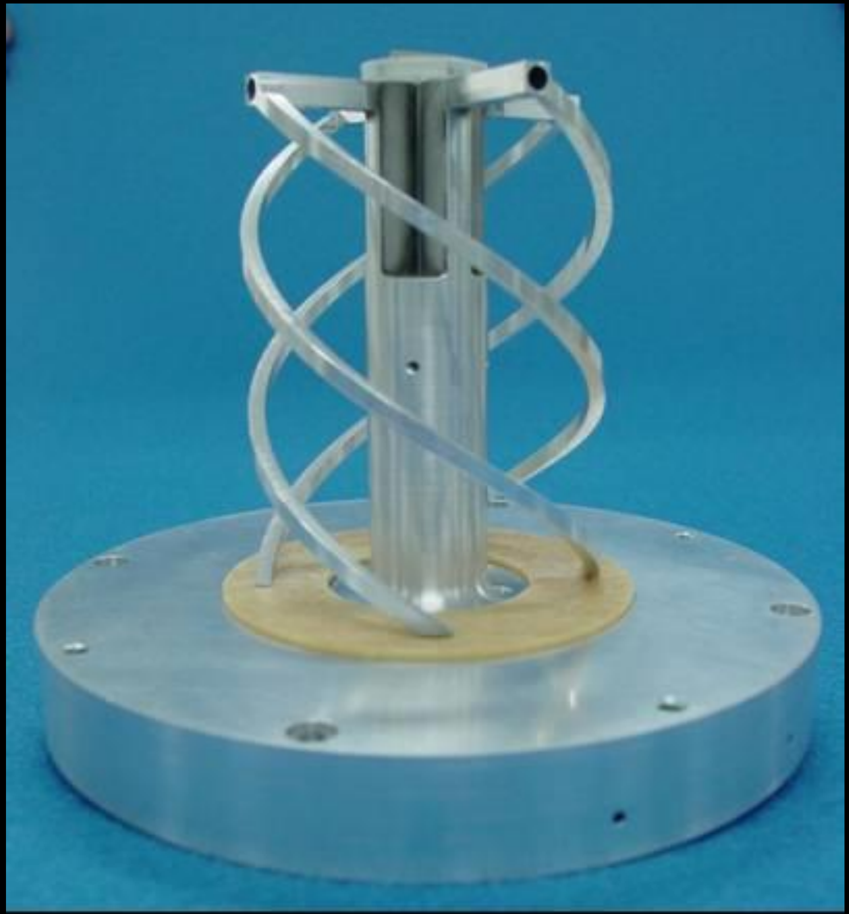


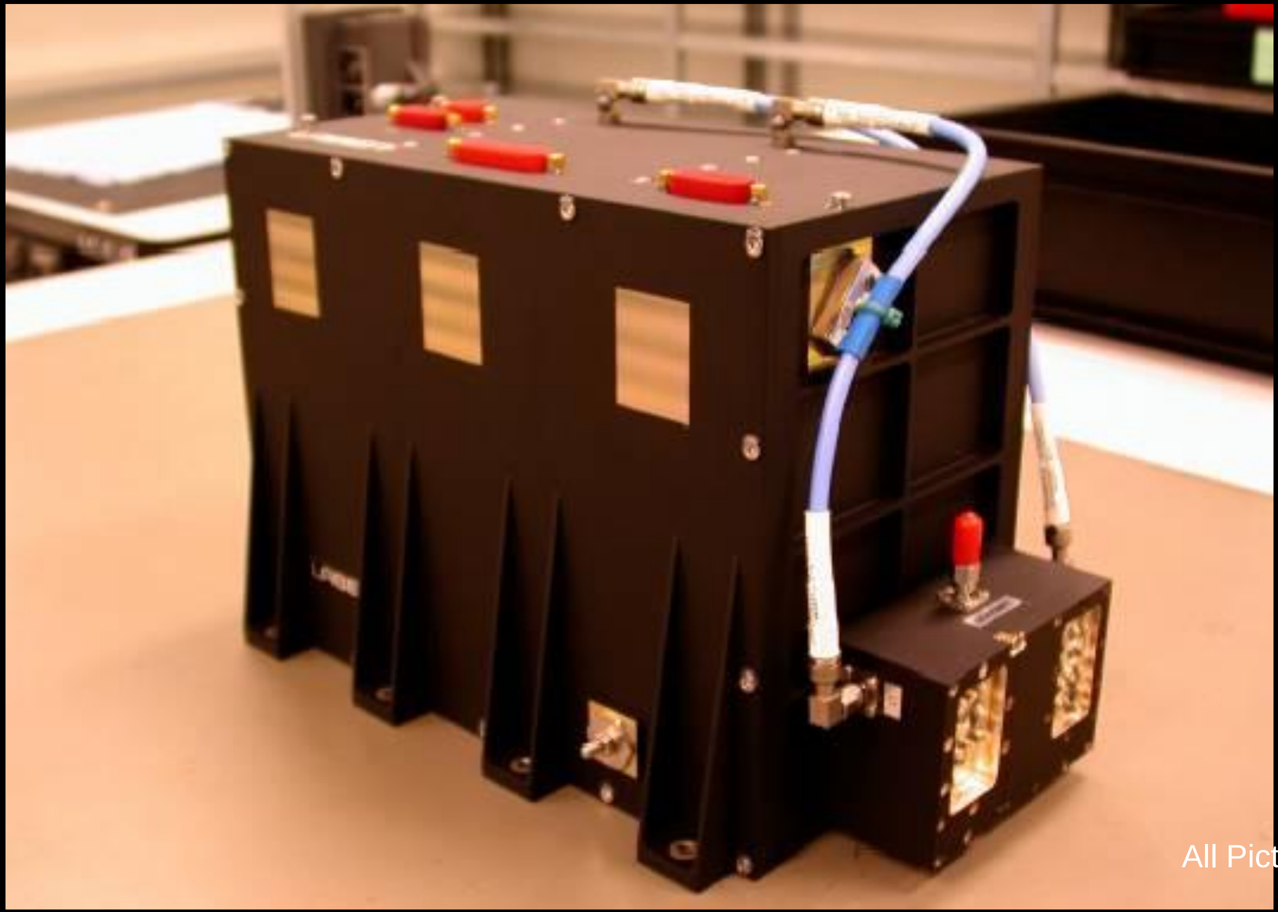


GOCE Sensor System

Key Features

1. The first Gravity Gradiometer in Space with High Precision Thermal Control
2. Newly developed European Space GPS-Receiver with Geodetic Precision





GOCE Sensor System

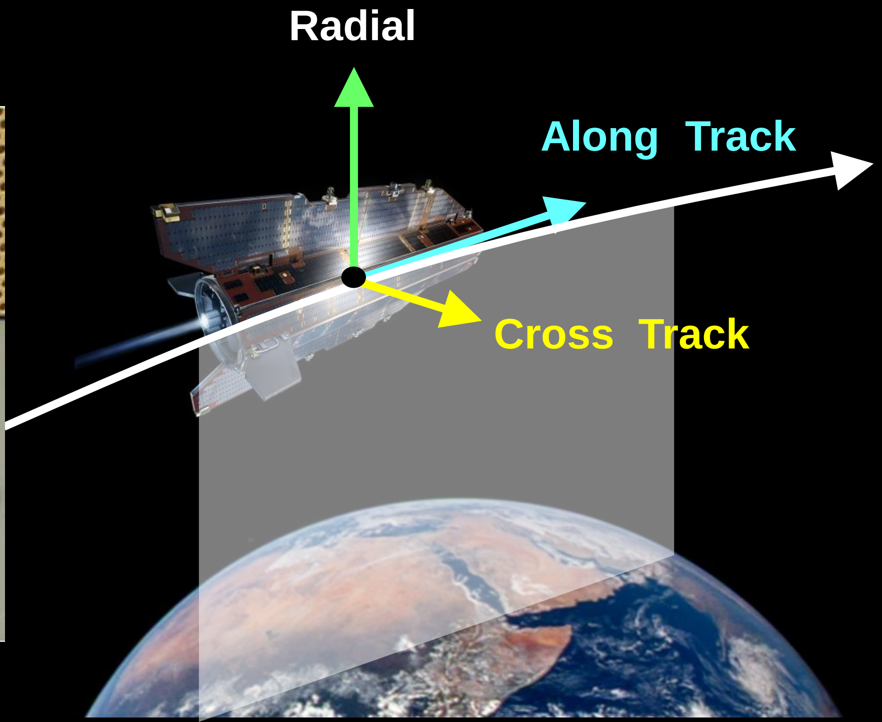
Key Features

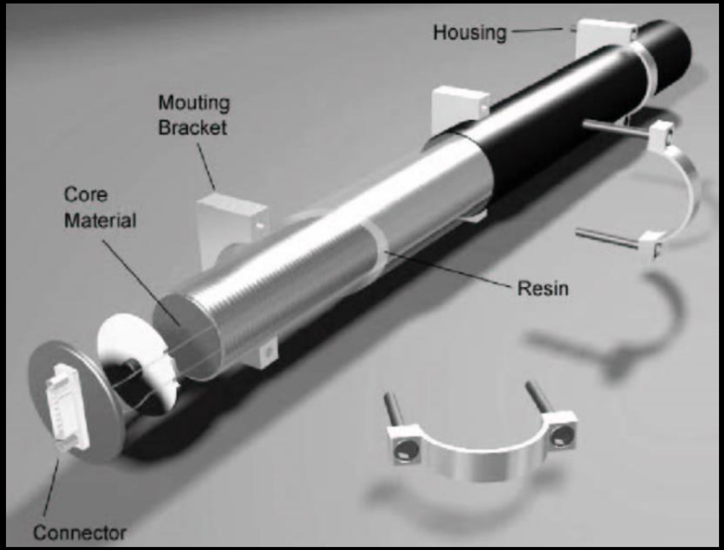
1. The first Gravity Gradiometer in Space with High Precision Thermal Control
2. Newly developed European Space GPS-Receiver with Geodetic Precision
3. Very Low Orbit in 250 km Height with Drag Compensation using ion engine

GOCE Sensor System

Key Features

1. The first Gravity Gradiometer in Space with High Precision Thermal Control
2. Newly developed European Space GPS-Receiver with Geodetic Precision
3. Very Low Orbit in 250 km Height with Drag Compensation using ion engine
4. High Precision Attitude Determination with Star Cameras and smooth Spacecraft Attitude Control System

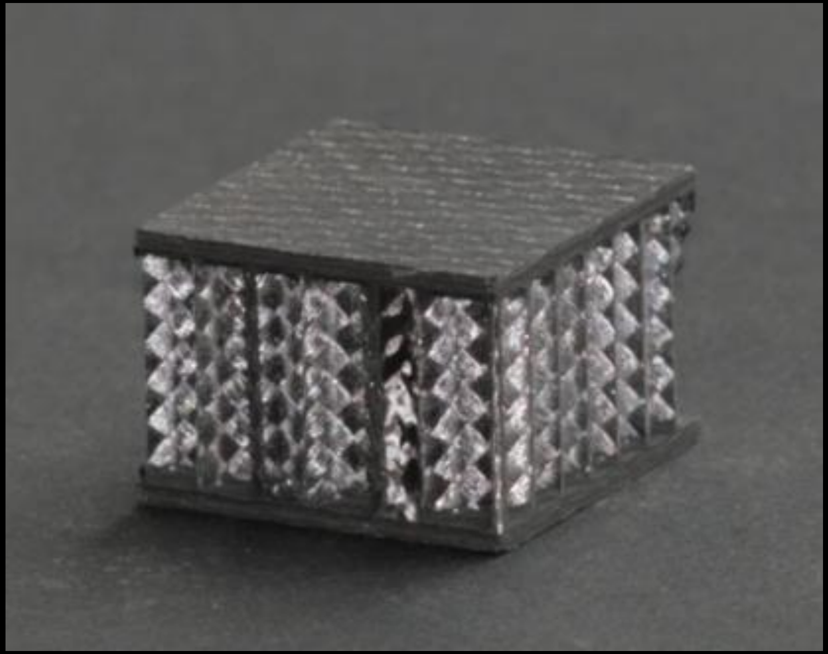


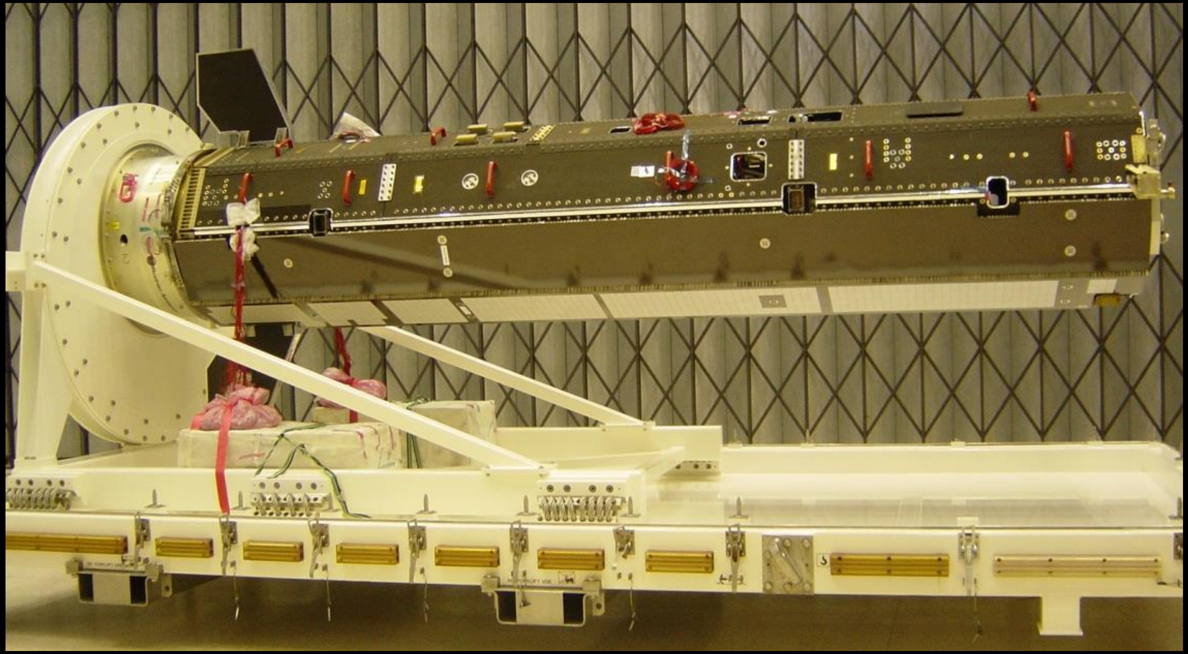


GOCE Sensor System

Key Features

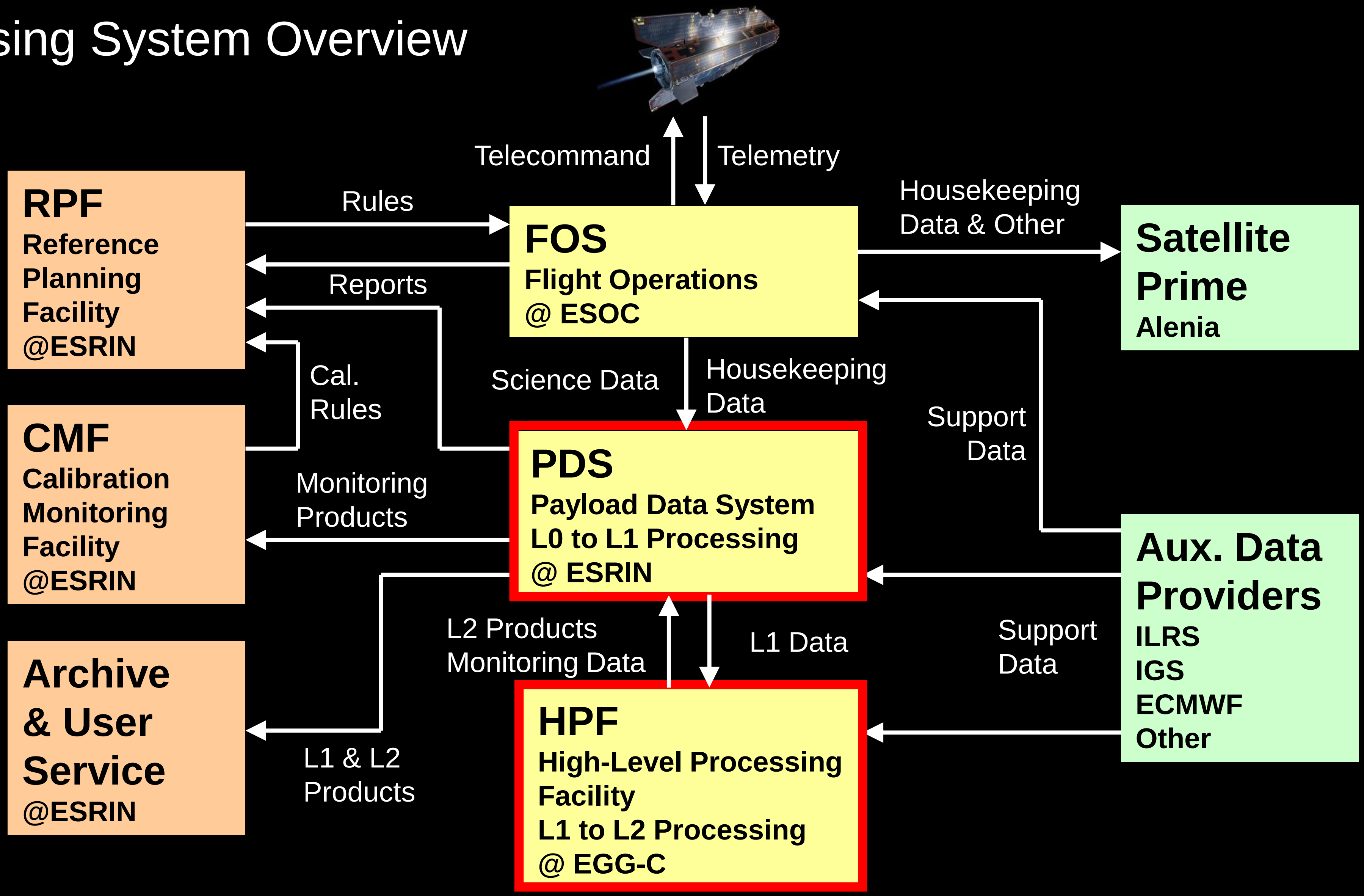
1. The first Gravity Gradiometer in Space with High Precision Thermal Control
2. Newly developed European Space GPS-Receiver with Geodetic Precision
3. Very Low Orbit in 250 km Height with Drag Compensation using ion engine
4. High Precision Attitude Determination with Star Cameras and smooth Spacecraft Attitude Control System
5. Largest Carbon Construction of a Satellite for Stiffness and Thermal Stability





GOCE Data Processing

Processing System Overview

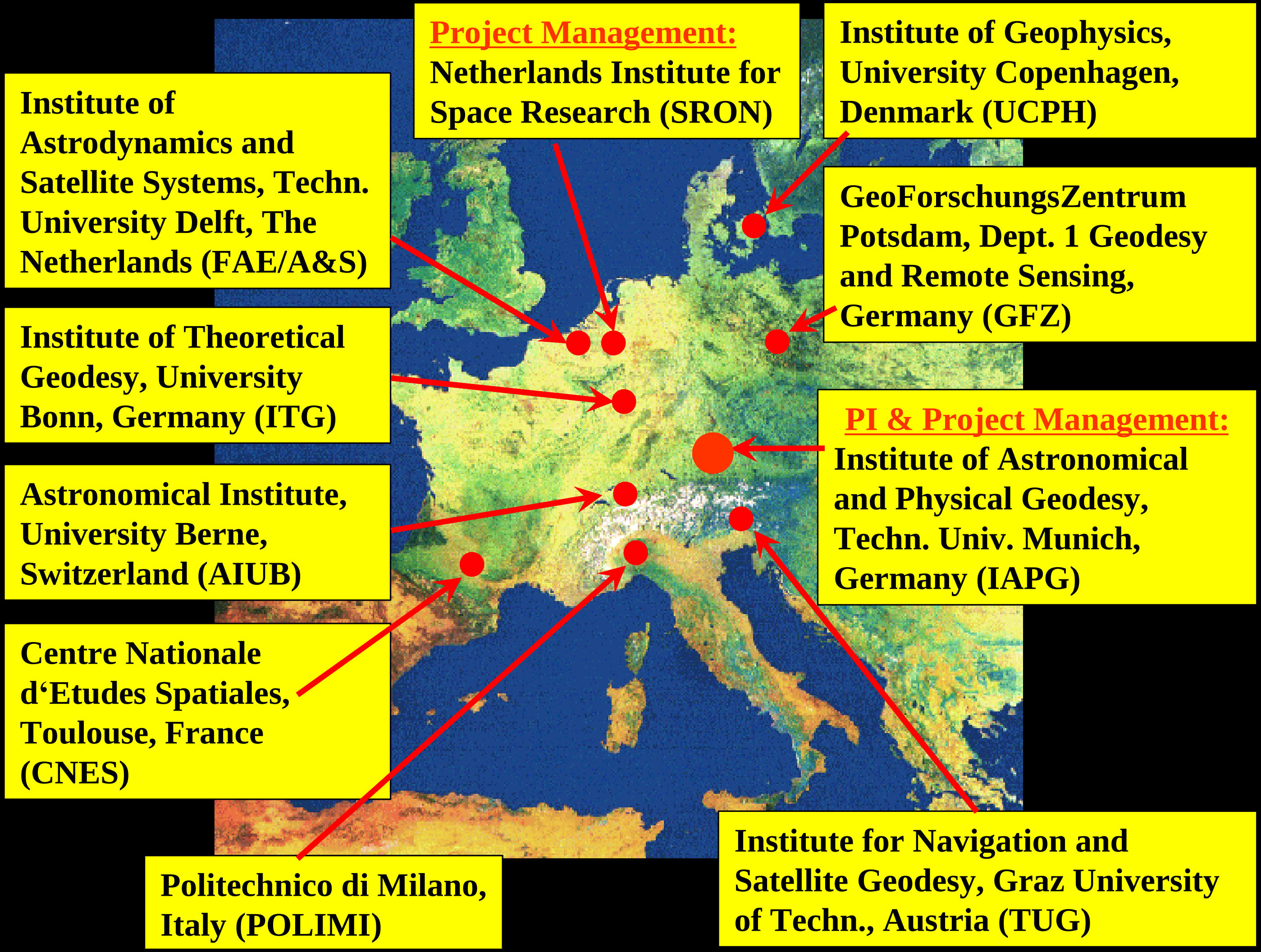


GOCE Data Processing

High Level Processing Facility – EGG-C Consortium

Key Features

- Developped & Operated by European GOCE Gravity Consortium (EGG-C)
- EGG-C is a Group of European Universities & Institutes with complementary Experience in Gravity Field Research
- Significant National & Institutional Support
- Distributed System
- Independent Validation by Overlap of Expertise



GOCE Data Processing

High Level Processing Facility – Processing Tasks

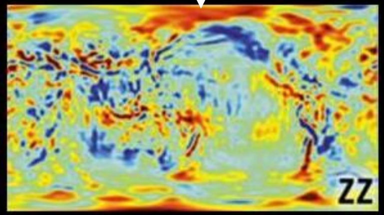
GOCE Ground Segment I/F

Central Processing Facility
De- Encoding, Archive, Data Distribution

External Interfaces

Gravity Modeling: Space-wise Approach

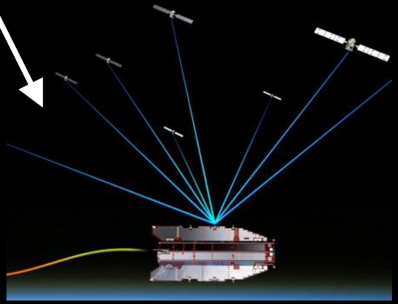
Scientific Pre-Processing and External Calibration



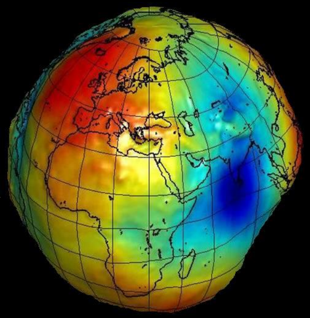
Gravity Modeling: Direct Approach

Orbit Determination (2 Methods)

Gravity Modeling: Time-wise Approach

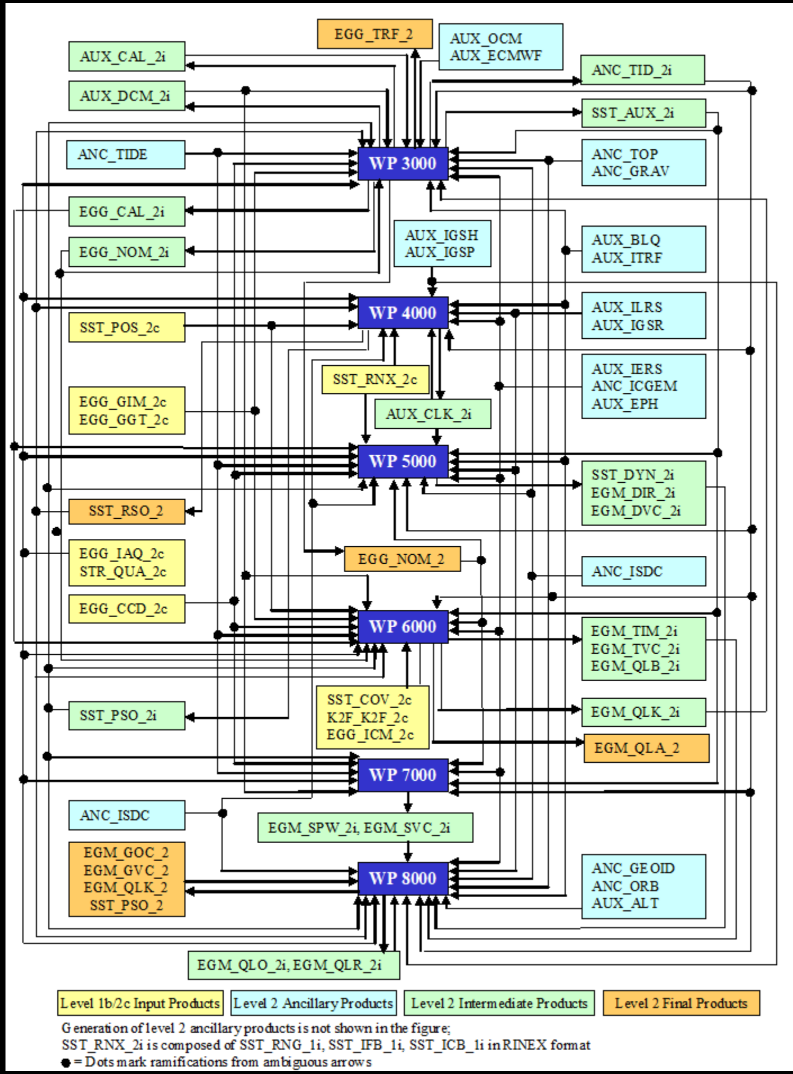


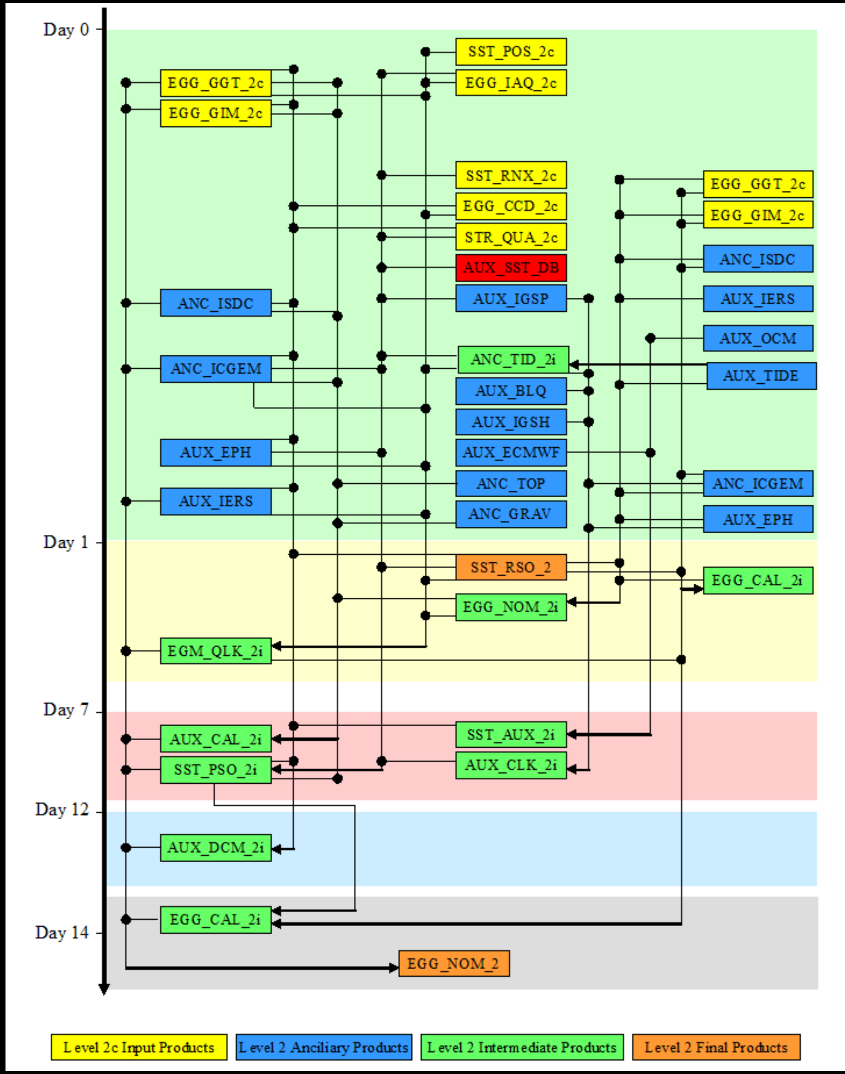
Product Validation and Selection of Final Products



GOCE Data Processing

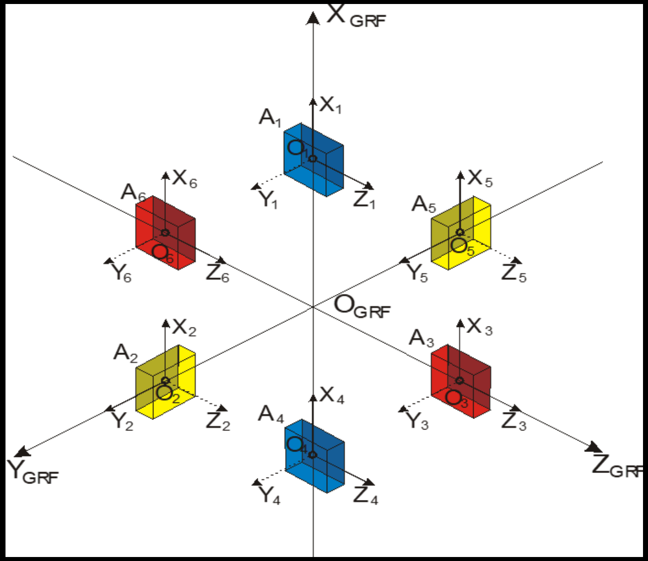
High Level Processing Facility – Static and Dynamic Design

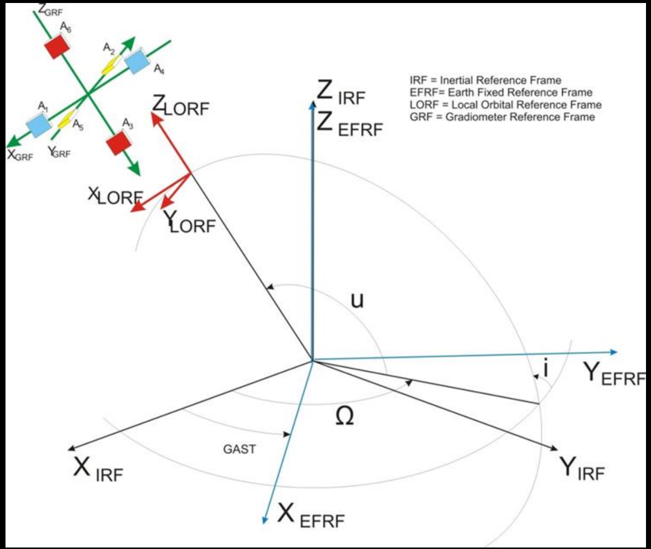




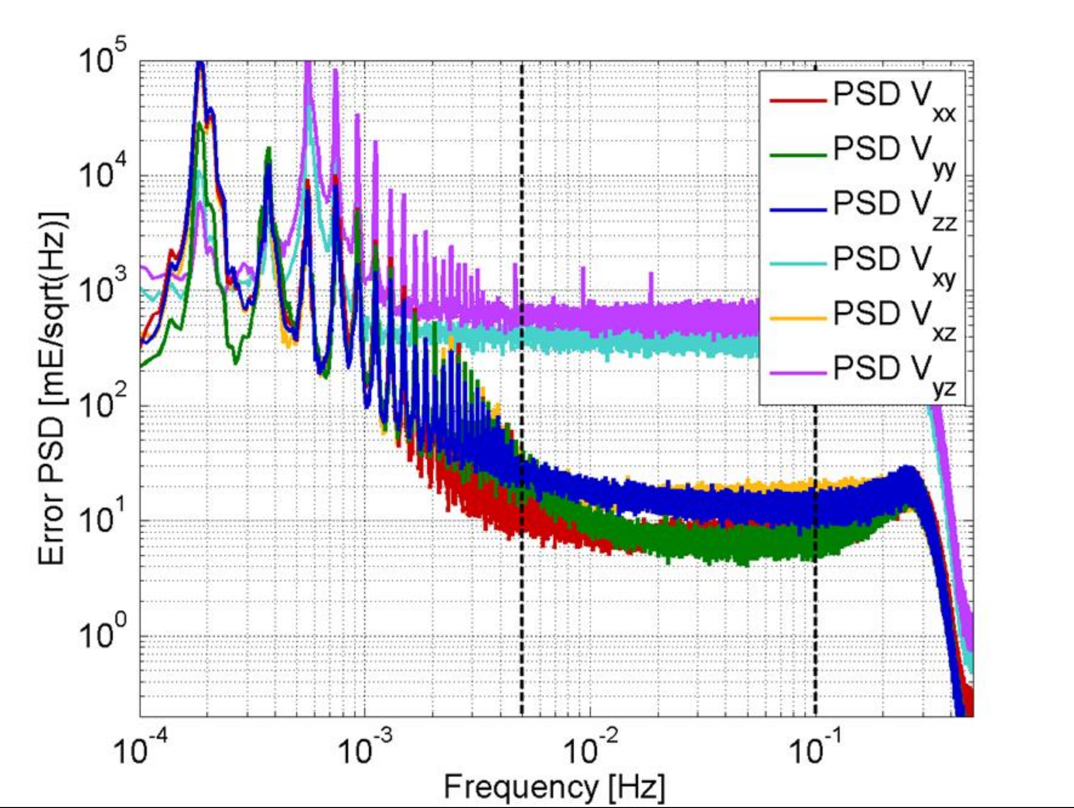
GOCE Data Processing

High Level Processing Facility – Gradiometer Data Processing



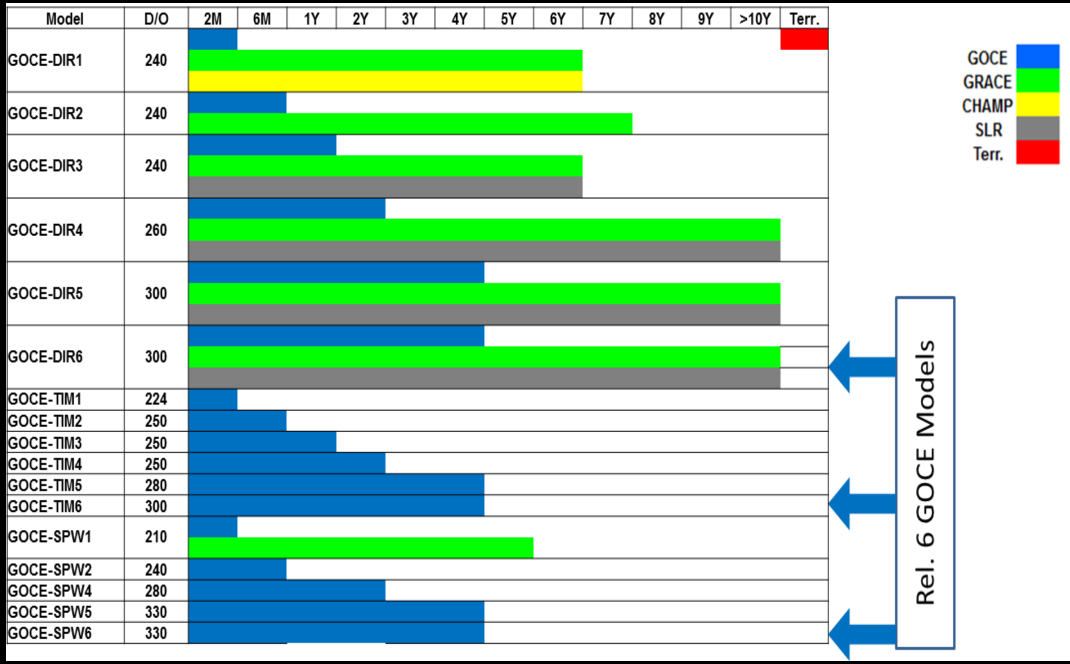


$$\underline{a} = \underbrace{-\underline{V}_{ii} \cdot \underline{r}}_{\text{gravity gradient}} + \underbrace{\dot{\underline{\omega}} \times \underline{r}}_{\text{angular acc.}} + \underbrace{\underline{\omega} \times (\underline{\omega} \times \underline{r})}_{\text{centrifugal acceleration}}$$



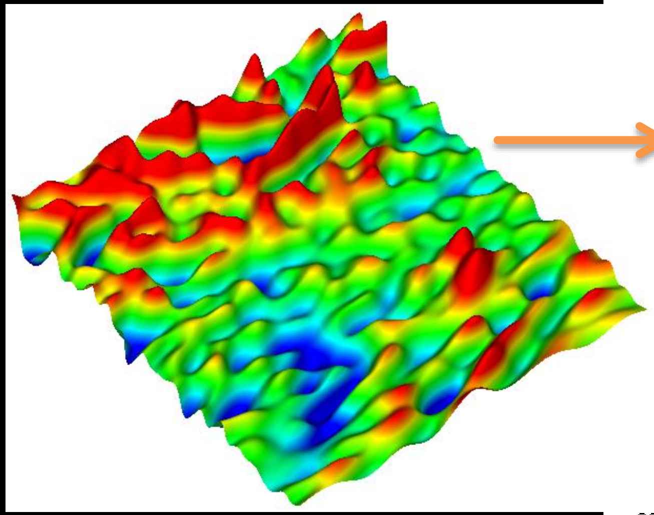
GOCE Gravity Field Models

Overview



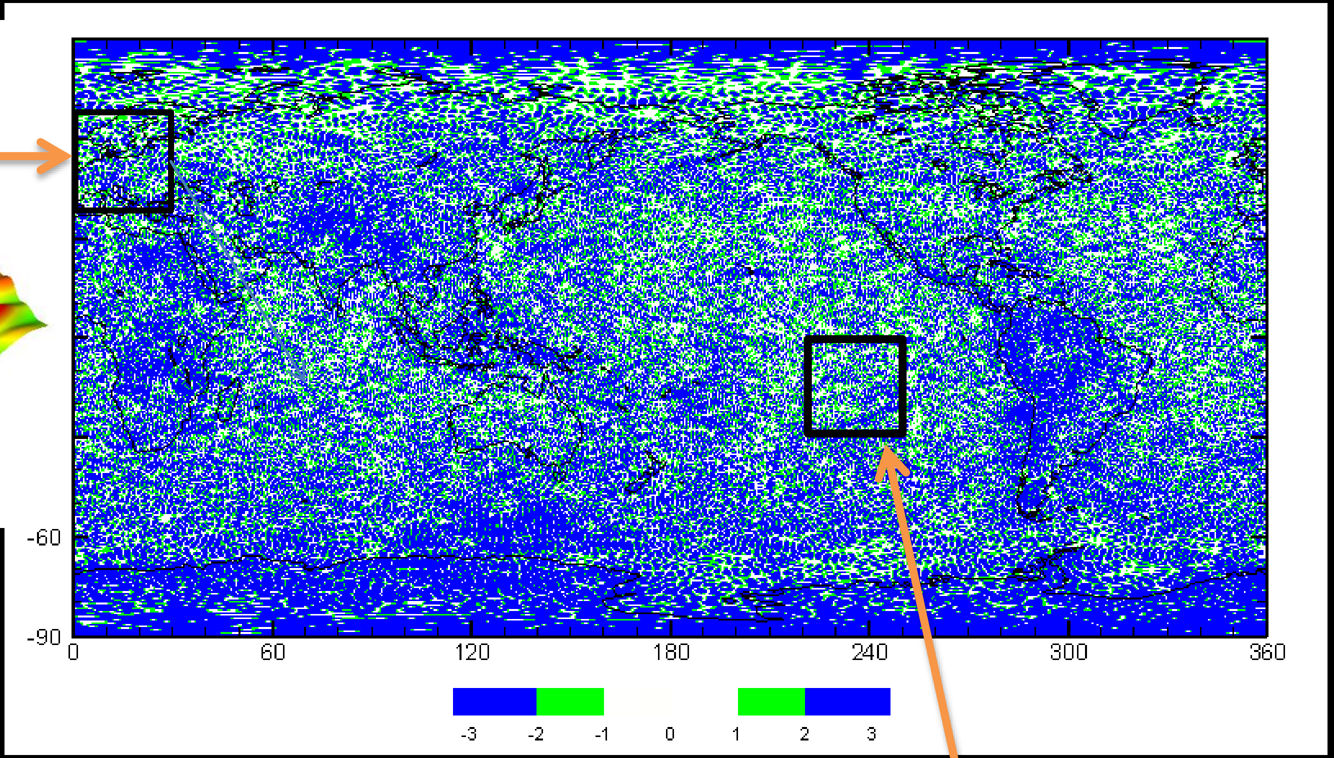
	DIR6	TIM6
Maximum D/O	300	300
GOCE Data Volume	09.10.09-20.10.13; ~3.5 yrs (net)	01.11.09-20.10.13; ~3.5yrs (net)
Gravity Gradients	V_{xx}, V_{yy}, V_{zz}, V_{xz} ≈440 Mio. Obs.	V_{xx}, V_{yy}, V_{zz}, V_{xz} ≈442 Mio. Obs.
Gradient Filter	Low-pass filter, 46 segments	ARMA filter for 49 segments
GOCE SST (GPS)	-	Short arc approach (d/o 150)
GRACE SST (K-Band)	2007-2014 GFZ RL06 (d/o 130)	-
LAGEOS et al (SLR)	2002-2018 /d/o 60)	-
Regularization	spherical cap based on GRACE; Kaula zero constraint (d/o > 180)	Kaula zero constraint (d/o > 200) Zero observations polar regions (d/o 11-300)

GOCE Gravity Field Models



Gravity Anomalies Signal in Europe (TIM1 d/o 224)

GOCE TIM1 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)

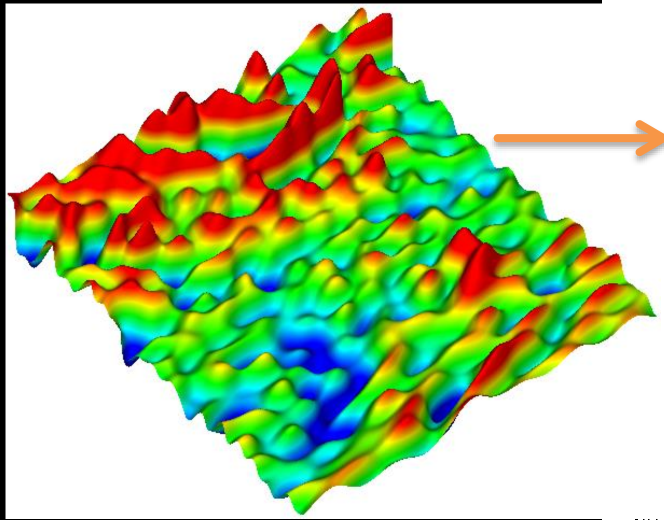


RMS of Differences in Test Area [mgal]

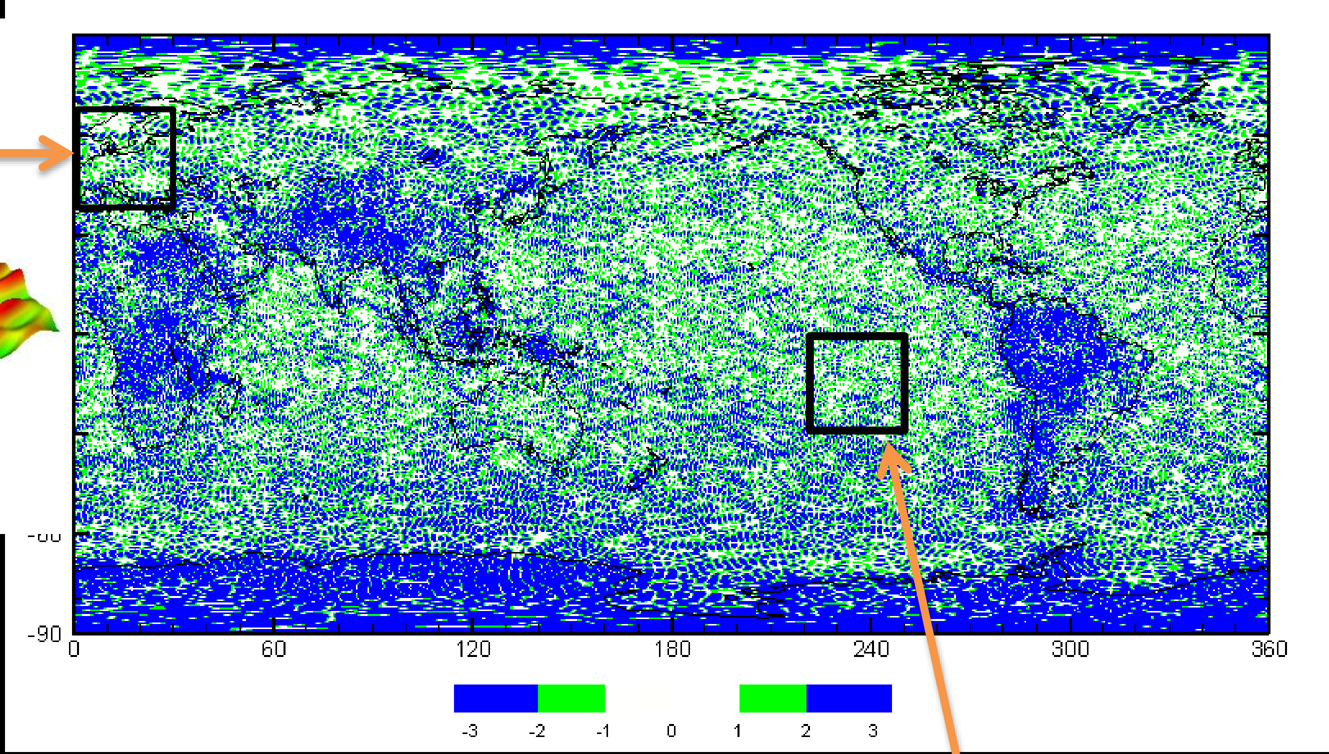
	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14					
DIR	1.07					

GOCE Gravity Field Models

GOCE TIM2 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)



Gravity Anomalies Signal in Europe (TIM2 d/o 250)

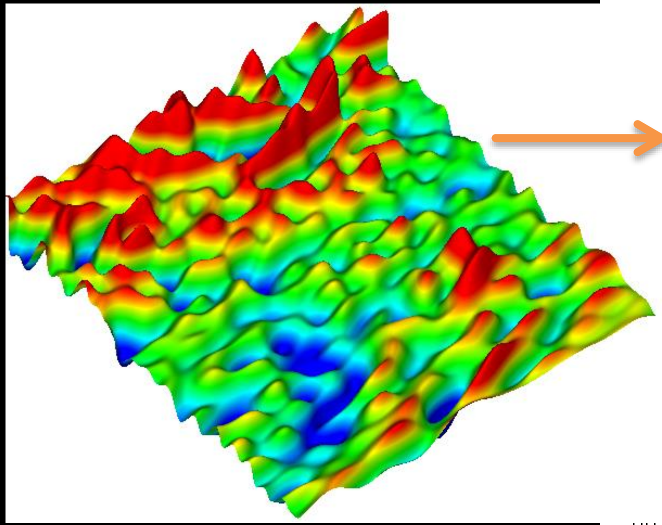


RMS of Differences in Test Area [mgal]

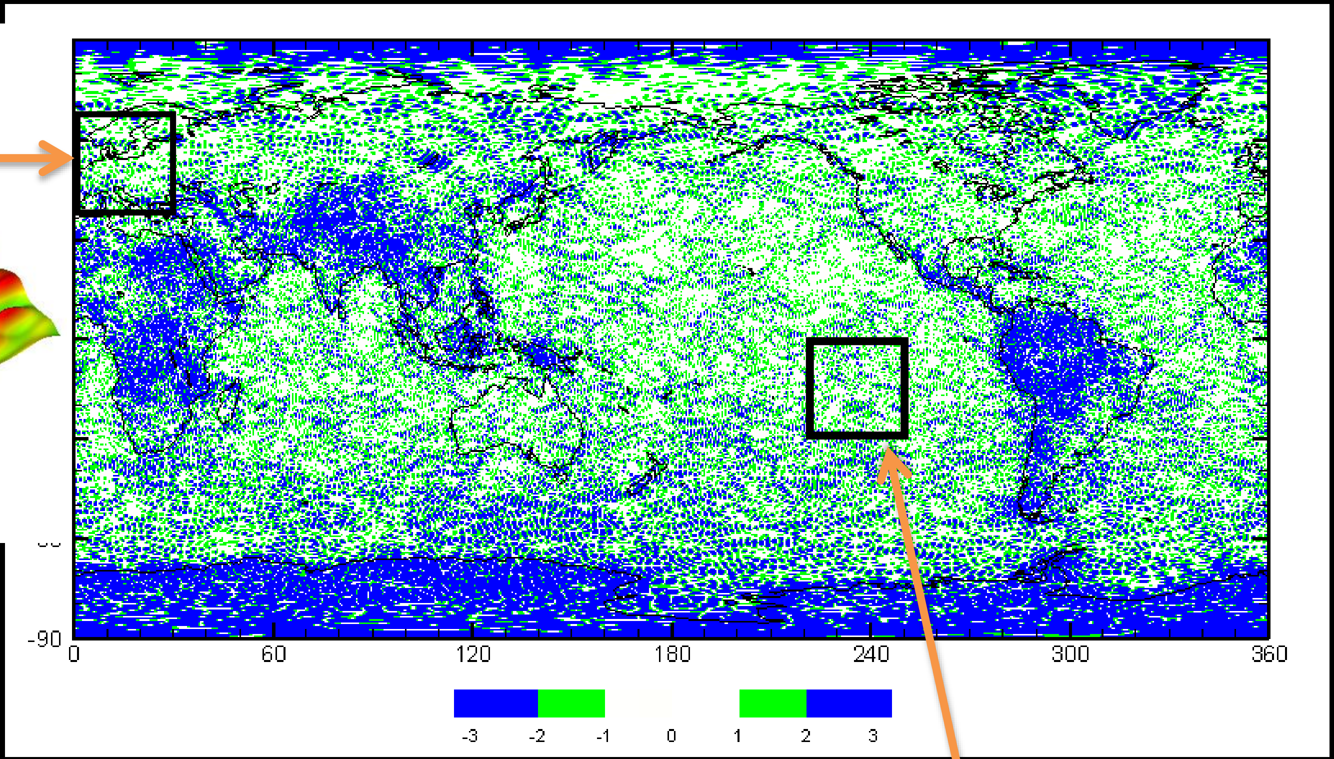
	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14	2.05				
DIR	1.07	2.28				

GOCE Gravity Field Models

GOCE TIM3 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)



Gravity Anomalies Signal in Europe (TIM3 d/o 250)

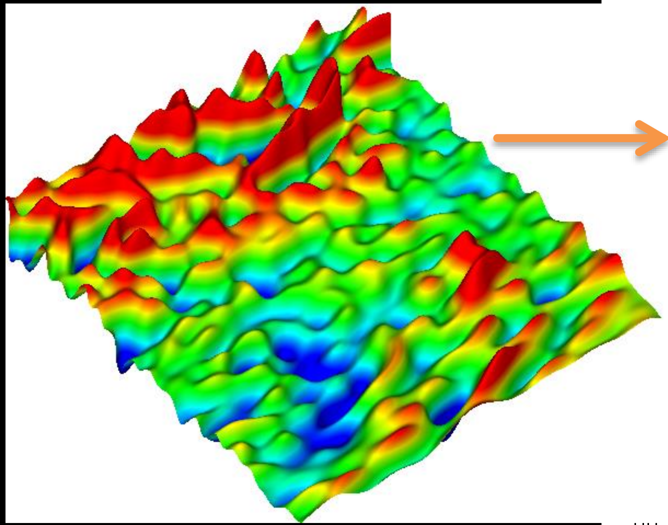


RMS of Differences in Test Area [mgal]

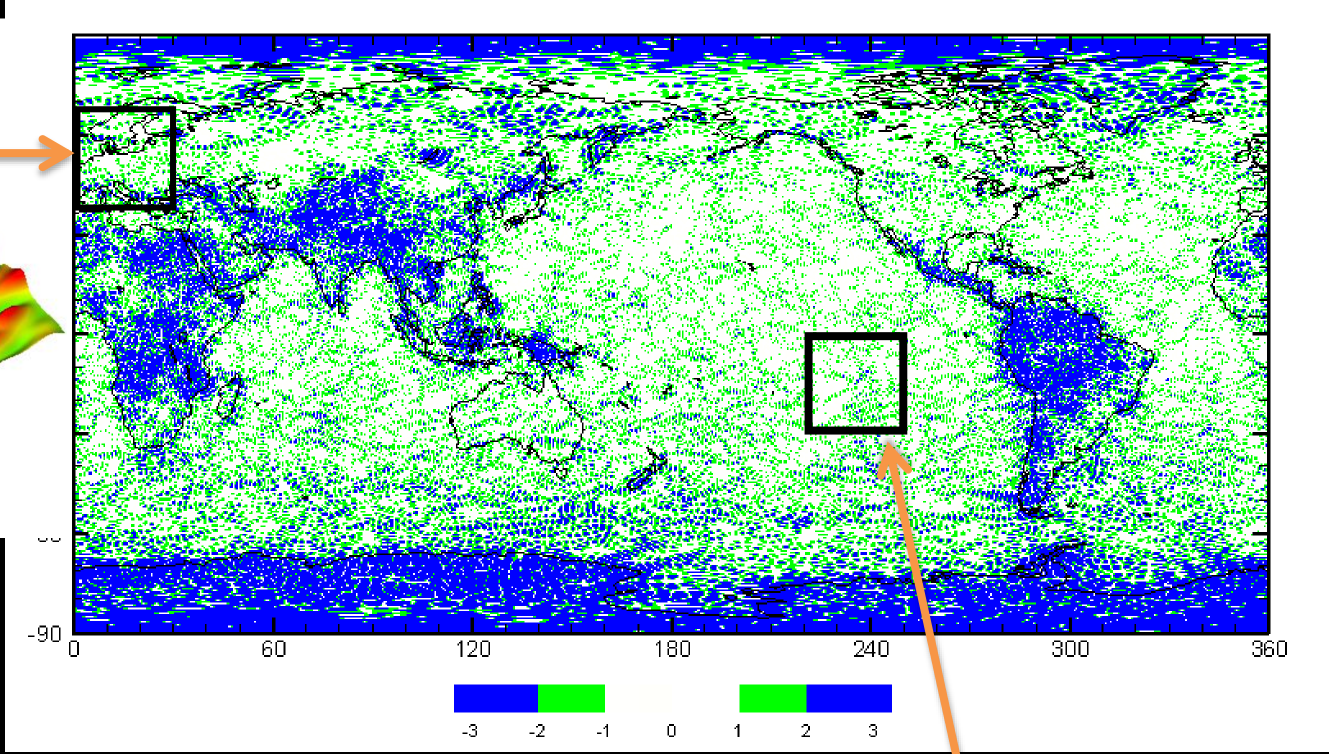
	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14	2.05	1.55			
DIR	1.07	2.28	1.85			

GOCE Gravity Field Models

GOCE TIM4 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)



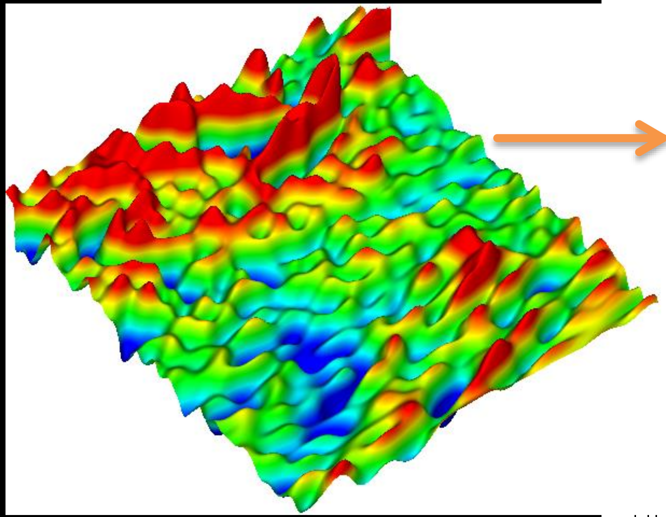
Gravity Anomalies Signal
in Europe (TIM4 d/o 250)



RMS of Differences in Test Area [mgal]

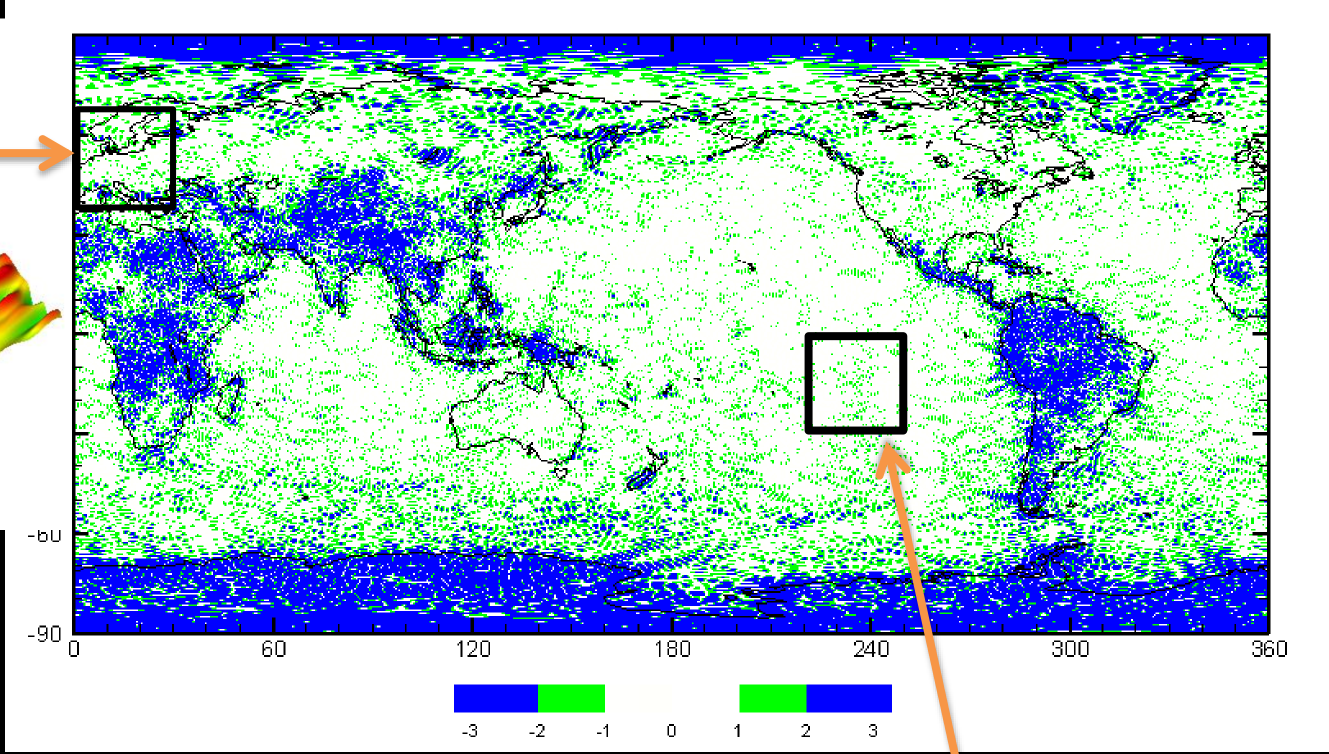
	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14	2.05	1.55	1.03		
DIR	1.07	2.28	1.85	1.00		

GOCE Gravity Field Models



Gravity Anomalies Signal in Europe (TIM5 d/o 280)

GOCE TIM5 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)

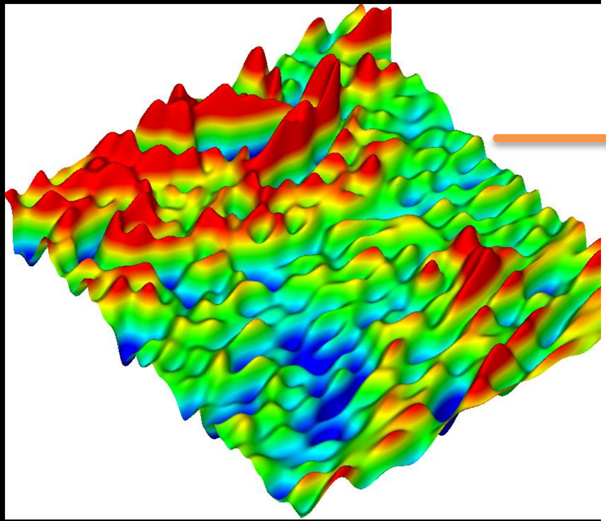


RMS of Differences in Test Area [mgal]

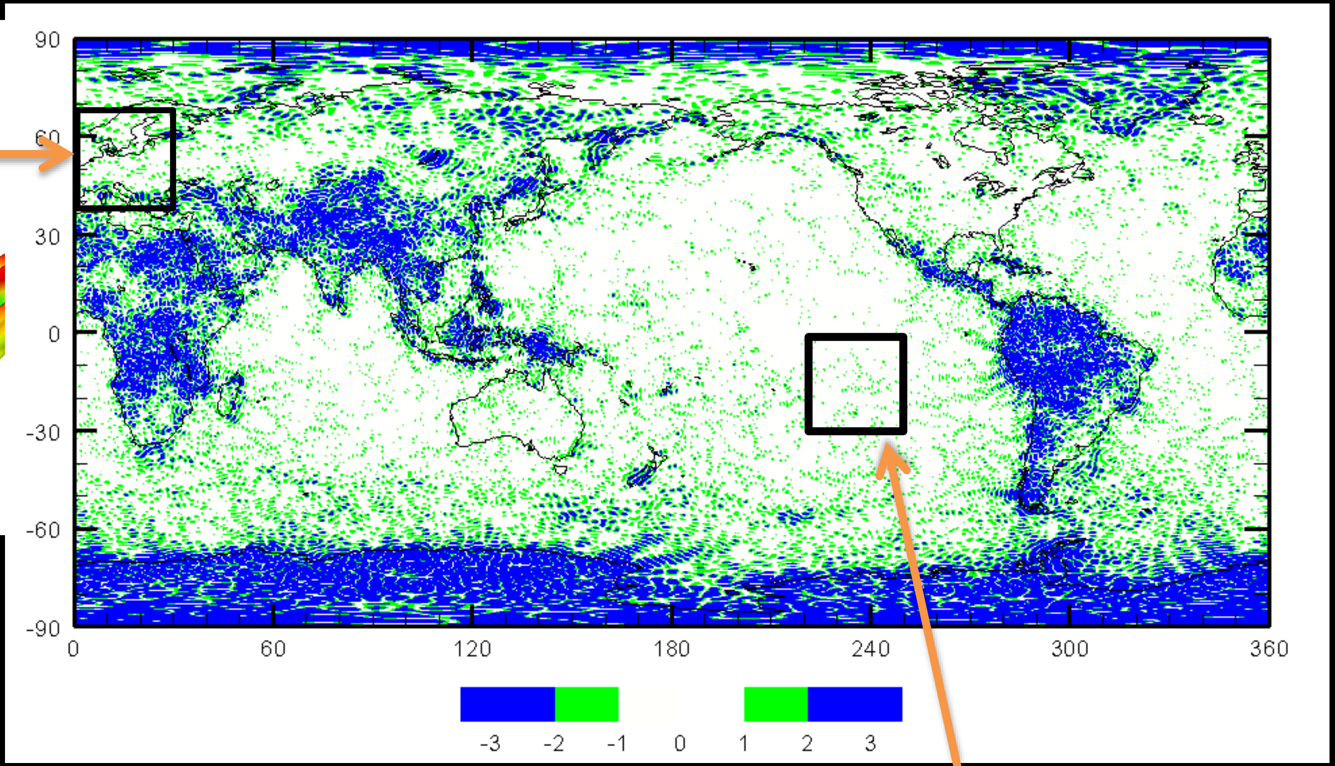
	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14	2.05	1.55	1.03	0.71	
DIR	1.07	2.28	1.85	1.00	0.70	

GOCE Gravity Field Models

GOCE TIM6 vs. EGM2008 Gravity Anomalies [mgal] (up to d/o 200)



Gravity Anomalies Signal in Europe (TIM6 d/o 300)



RMS of Differences in Test Area [mgal]

	Rel. 1	Rel. 2	Rel. 3	Rel. 4	Rel. 5	Rel. 6
TIM	3.14	2.05	1.55	1.03	0.71	0.63
DIR	1.07	2.28	1.85	1.00	0.70	0.65

Summary

- Satellite Gradiometry with current electrostatic accelerometers can observe the static gravity field with medium resolution with cm geoid or 1 mGal accuracy.
- High precision accelerometers are needed (at least in the order of $1x10^{-12}$ Sensitivity). Ideally new technology with better performance at long wavelengths shall be considered.
- Drag compensation and high precision attitude information is required.
- Sophisticated ground processing system is required in order to convert raw observations into gravity gradients.
- Calibration at the level of accelerometers and/or gravity gradients to be performed during ground processing (next to the instrument calibration).
- GOCE successfully delivered a 1-2 cm geoid globally (except at the polar areas due to orbit design).