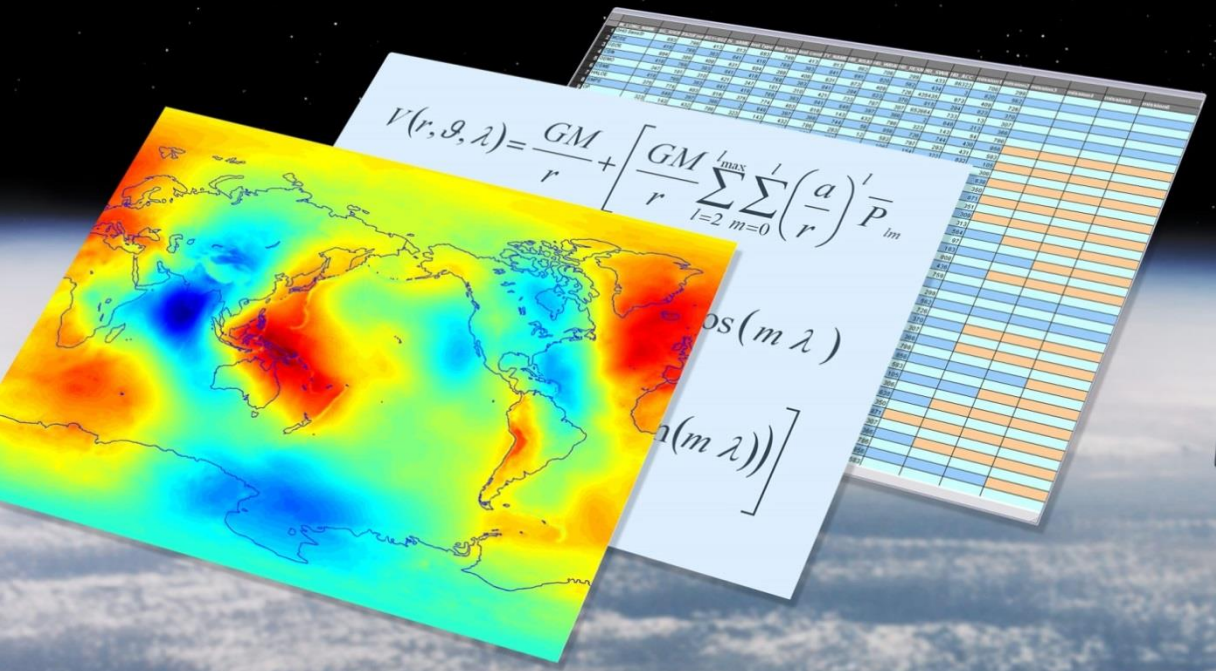
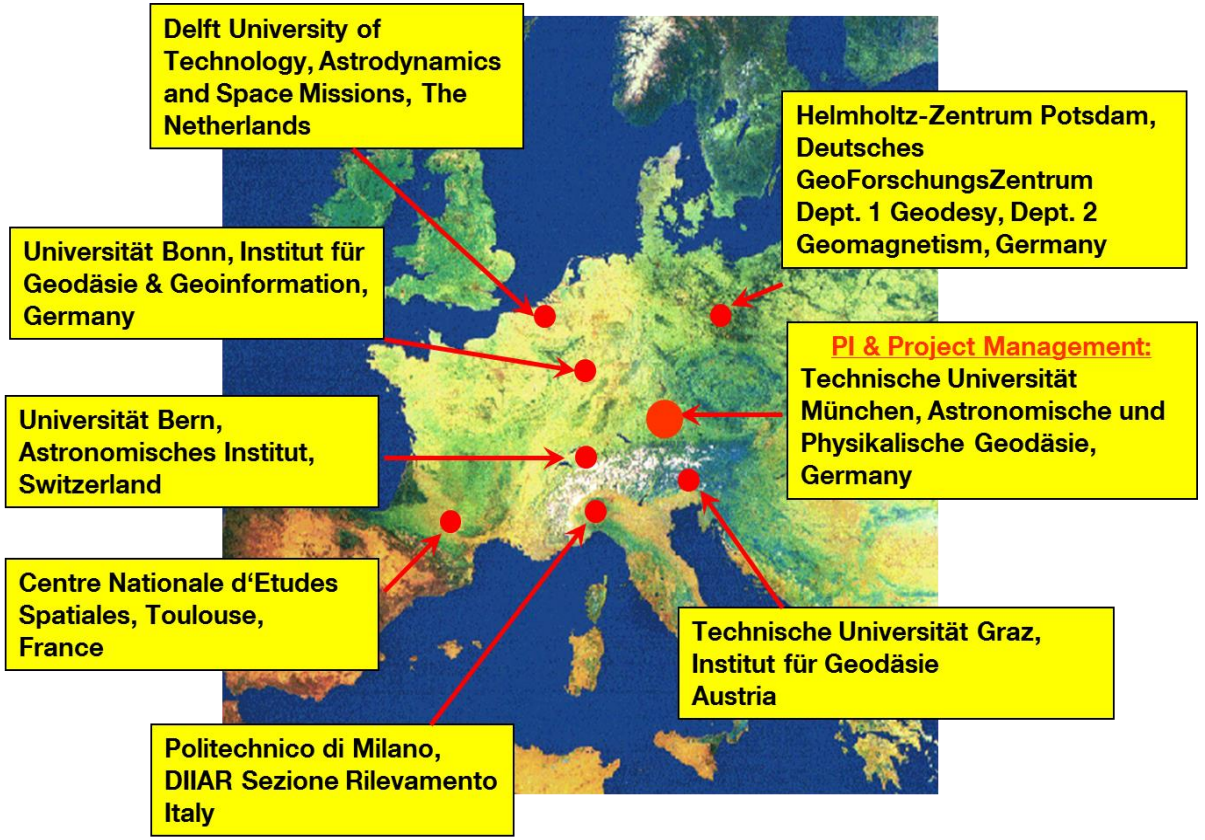
GOCE Release 6 Products and Performance

Th. Gruber & High Level Processing Facility (HPF) Team
Institute of Astronomical & Physical Geodesy (IAPG), Technical University of Munich



High Level Processing Facility

- 15 years of successful collaboration
- In charge of complete L1 to L2 Processing and L2 Products
- Implementation of revised L0 to L1 Processor
- L2 Products:
  Precise GOCE Orbits
  Gravity Gradients
  GOCE Gravity Field Models
  Ionosphere Products
  Thermosphere Products



Outline

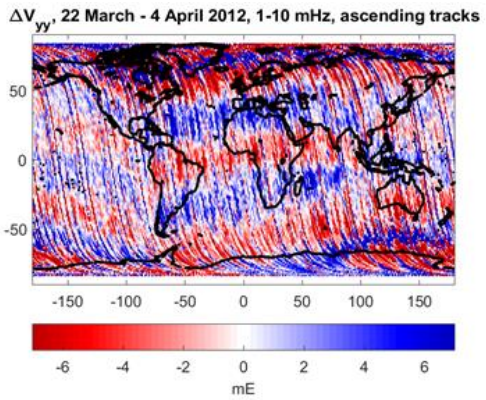
1. GOCE Reprocessing

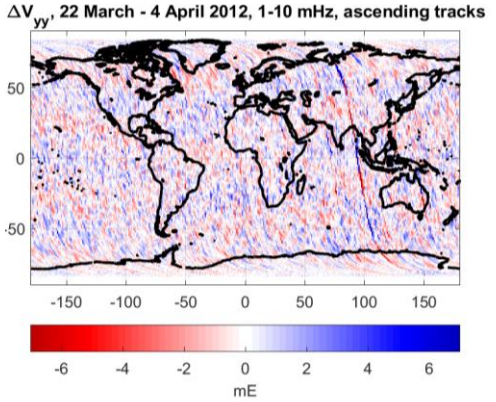
- ❑ Why ?
- ❑ Overview

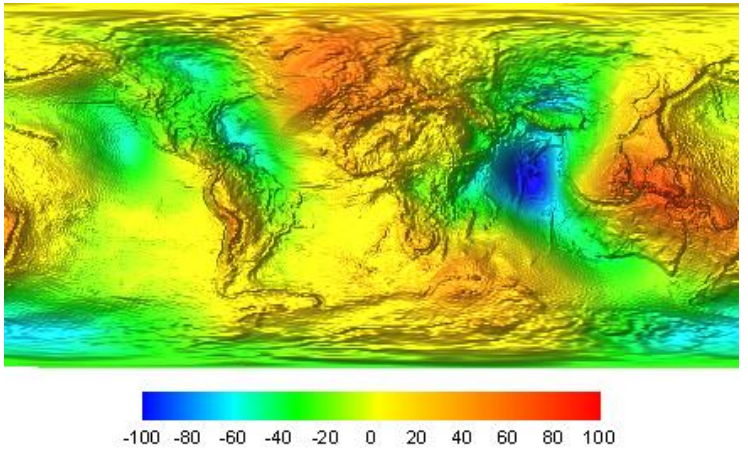
2. Results of Reprocessing

- ❑ Gradients
- ❑ Orbits
- ❑ Ionosphere & Thermosphere
- ❑ Gravity Field Models & Performance

3. Summary

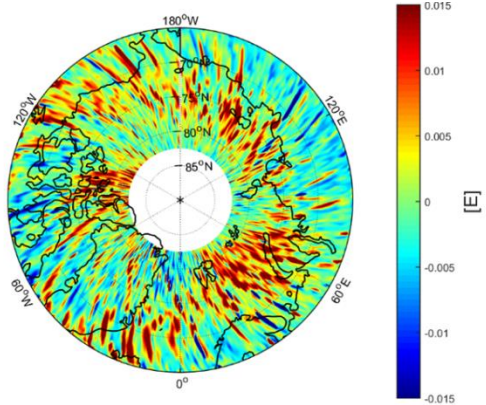






GOCE Reprocessing – Why?

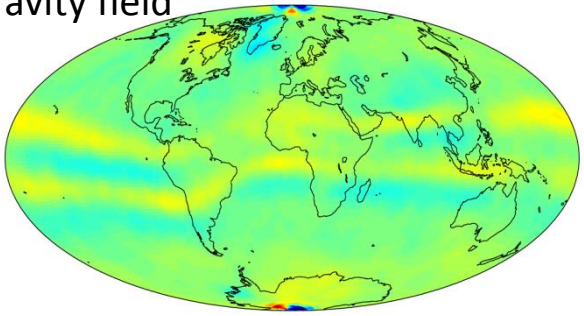
Increased residuals for cross-track gradients (V_{yy}) and others around geomagnetic poles



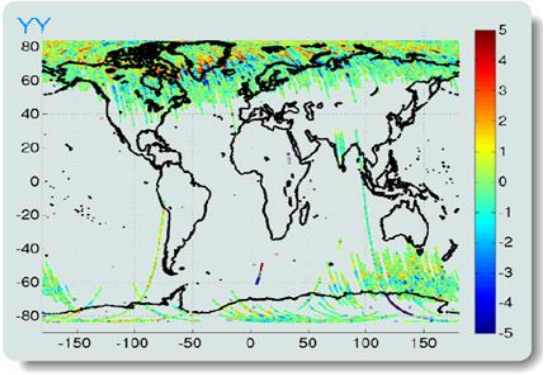
Courtesy: A. Schlicht

Kinematic orbits show systematic effects around the geomagnetic equator because of degraded GPS data – impact on gravity field

Geoid differences (-5 cm +5 cm) wrt. TIM Rel. 4 Model; Courtesy: A. Jäggi



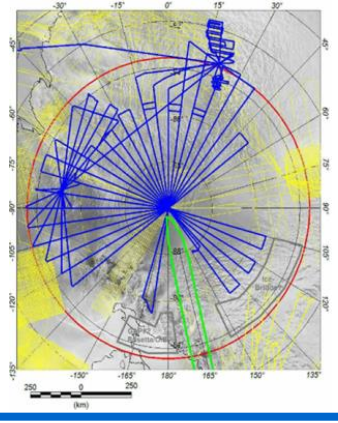
Reduced performance of gravity field in these areas because of outlier rejection i.e. less data for gravity field computation



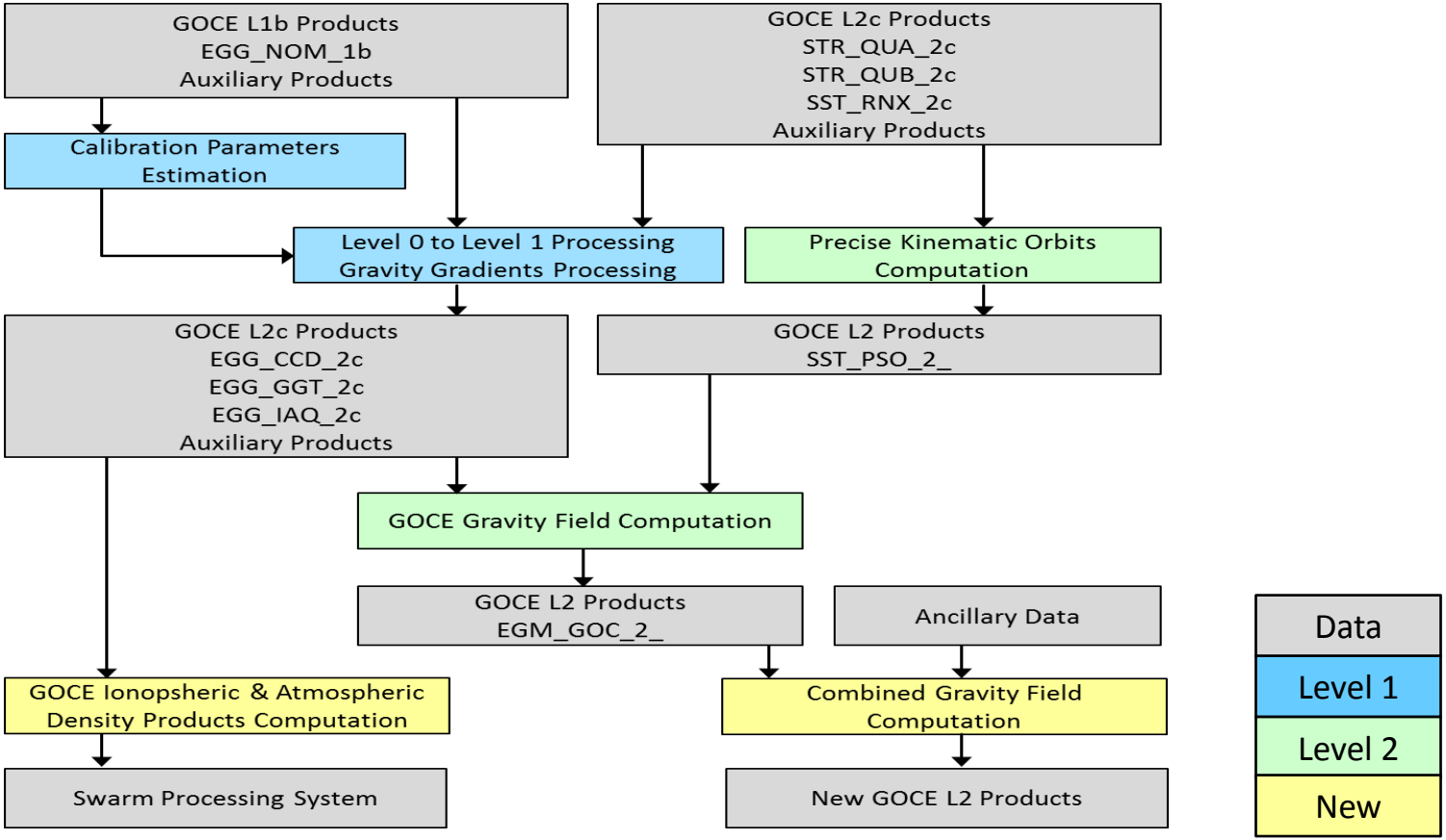
Courtesy: J.M. Brockmann

New applications of GOCE data

- Ionospheric and atmospheric density profiles.
- New combined gravity field models with new gravity data from ESA Antarctic airborne campaign.

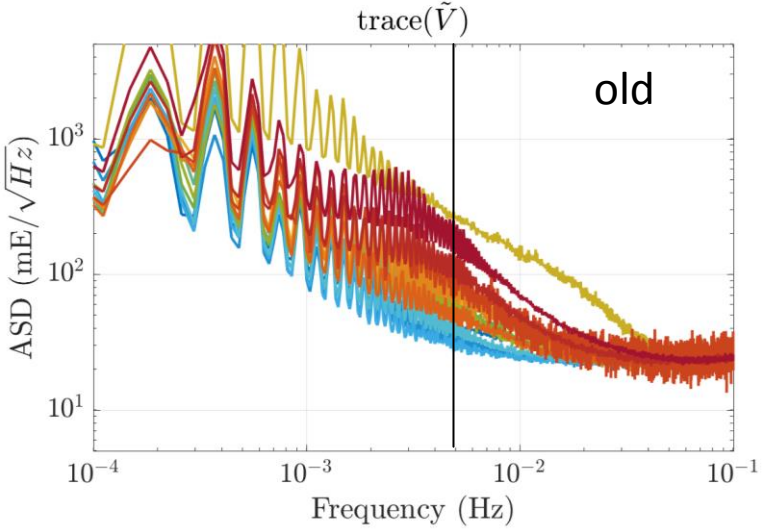


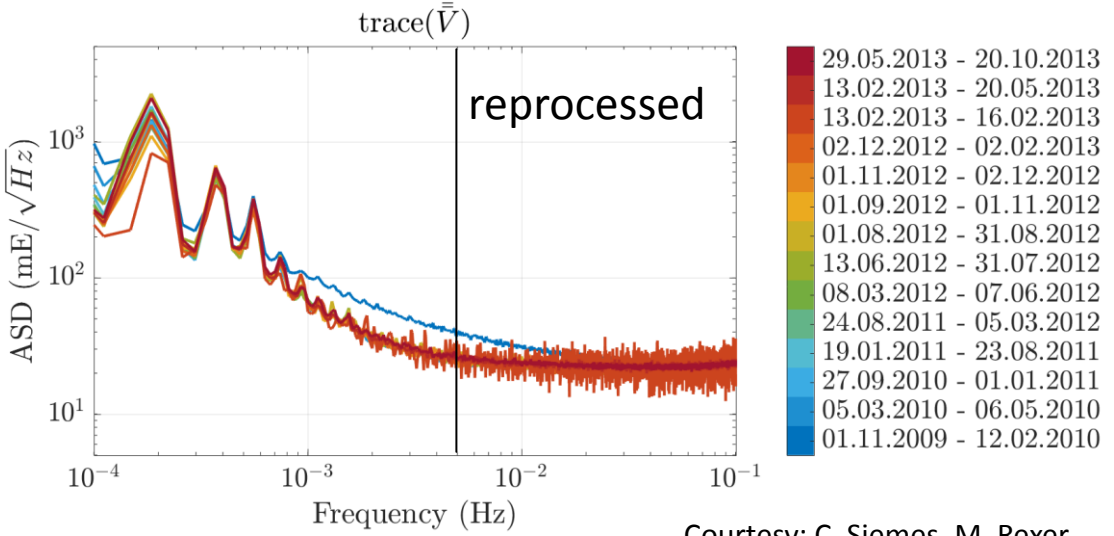
GOCE Reprocessing Overview



GOCE Reprocessing Results - Gradients

- New gradiometer calibration scheme by estimating additional quadratic factors for the differential mode accelerations.
- Temperature dependent Star tracker attitude bias estimated per measurement epoch.
- Angular rate reconstruction with moving optimal filter frequency between star tracker and gradiometer angular accelerations.
- Refer to previous presentation by C. Siemes.



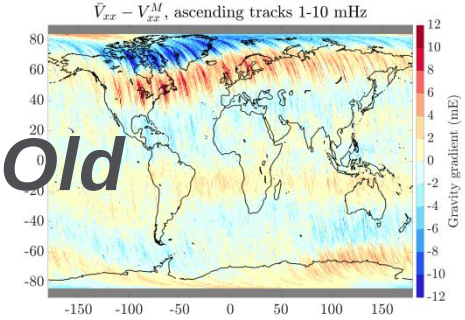


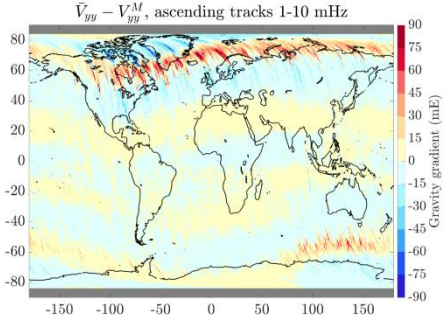
Courtesy: C. Siemes, M. Rexer

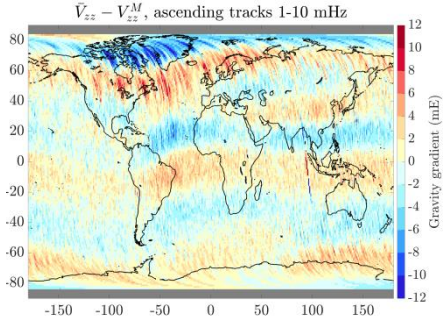
GOCE Reprocessing Results - Gradients

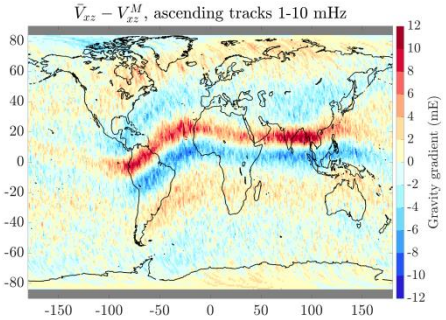
Gravity Gradient Residuals to GRACE Gravity Field Model

Old

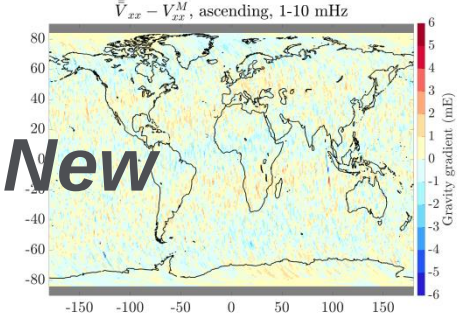


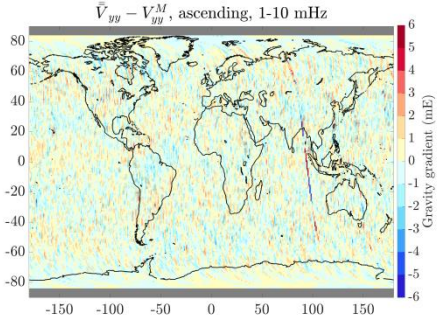


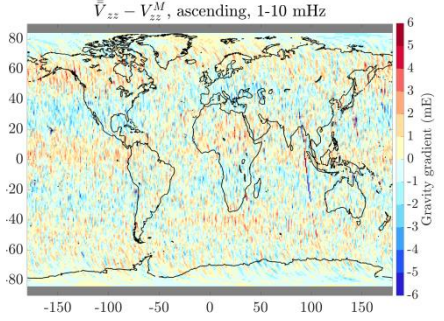


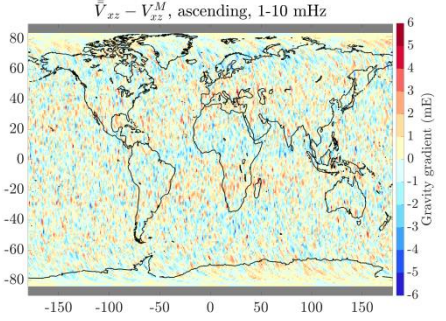


New







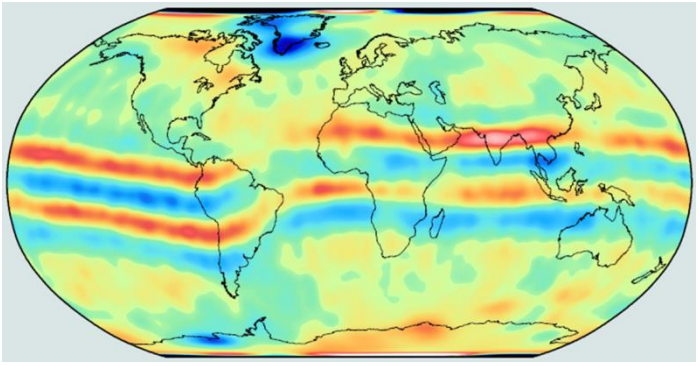


Courtesy: C. Siemes, M. Rexer

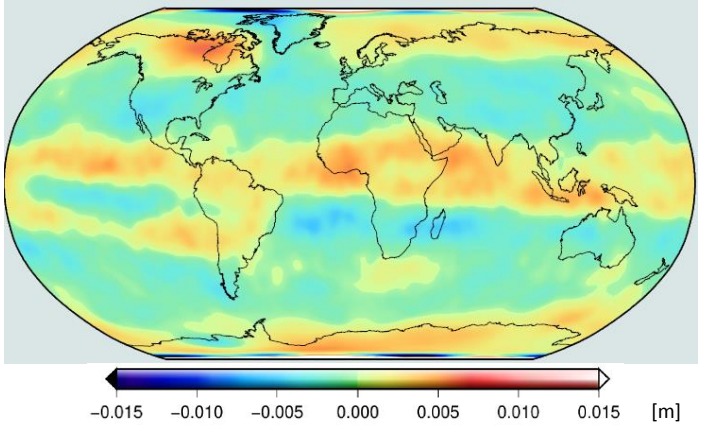
GOCE Reprocessing Results - Orbits

- Orbits for the entire time span (April 7, 2009 - October 20, 2013) have been reprocessed both from unweighted and weighted GPS data
- Improved strategy to mitigate ionosphere-induced artefacts by down-weighting affected GPS observations instead of eliminating.
- Additional screening of kinematic positions based on variances.
- GPS-only gravity field models derived from reprocessed kinematic orbits are significantly improved (see figures with differences to XGM2016).

Rel. 5 Precise Science Orbits



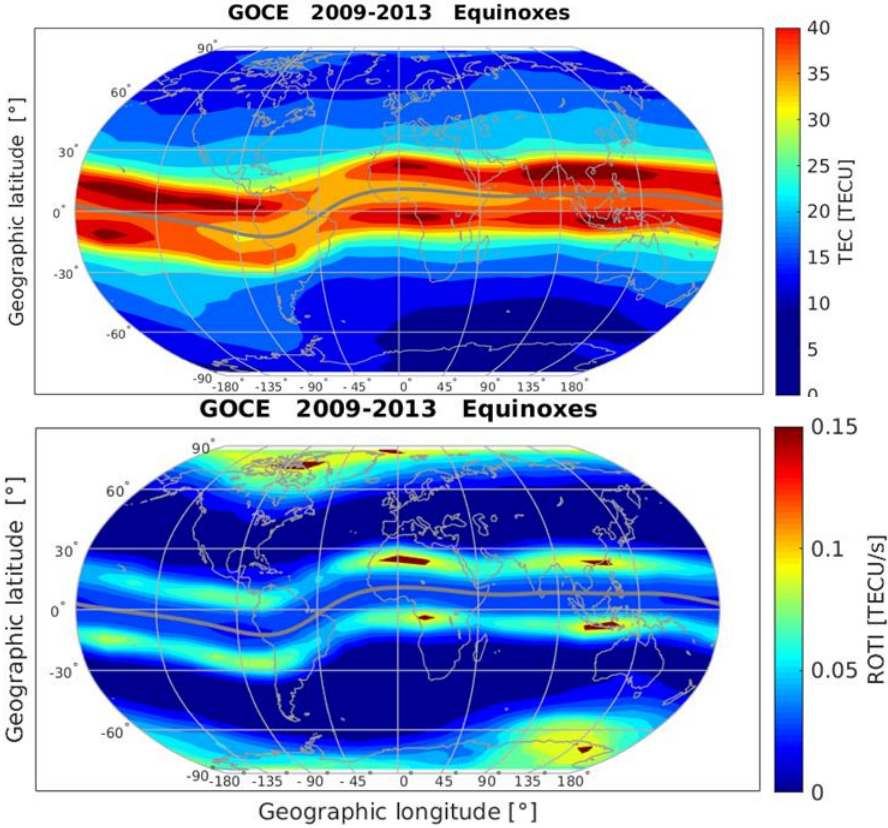
Rel. 6 Precise Science Orbits



Courtesy: D. Arnold, T. Grombein, J.M. Brockmann

GOCE Reprocessing Results – Ionosphere

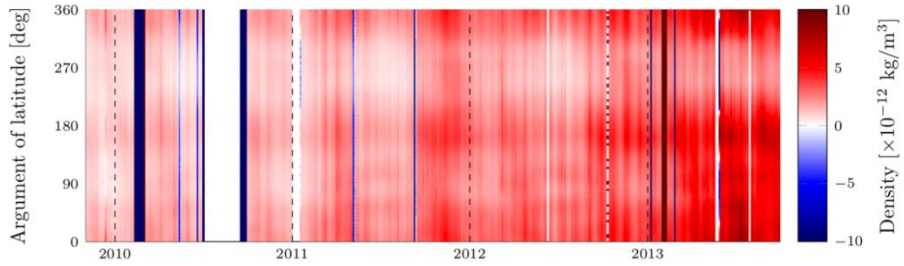
- The TEC and ROTI products have been successfully derived, which provides unique dataset for the space weather study at 250 km.
- The characteristics of TEC and ROTI from GOCE satellite agrees well with previous findings from ground-based and other LEO missions.
- Attention should be paid when using ROTI to identify small-scale ionospheric irregularities.
- Product Access via GOCE Virtual Archive at: http://eo-virtual-archive1.esa.int/Index.html



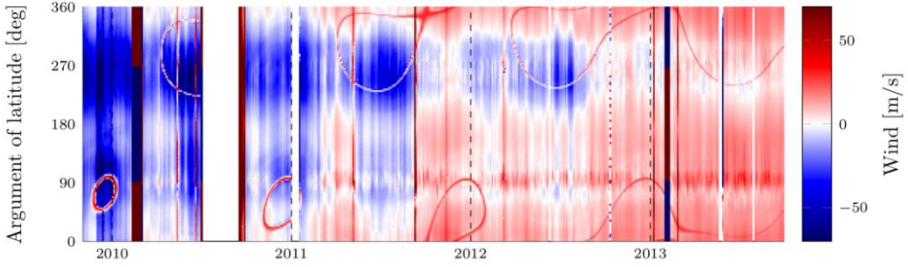
Courtesy: C. Xiong, C. Stolle, G. Kervalishvili – GFZ Potsdam; J. van den Ijssel - TU Delft

GOCE Reprocessing Results – Thermosphere

- Use newly reprocessed GOCE L1B data
- New more flexible processor implemented based on linear and angular accelerations
- New high fidelity satellite geometry model
- Satellite aerodynamic gas-surface interaction model
- New unique acceleration-derived vertical wind data set
- Thermosphere observations from the GOCE deorbit phase special dataset
- Product Access via GOCE Virtual Archive at: http://eo-virtual-archive1.esa.int/Index.html



Density Differences Reprocessed vs. Original (Signal 0-150)



Horizontal Crosswind Differences Reprocessed vs. Original (Signal ±1000)

Courtesy: T. Visser, G. March, E. Doornbos and P. Visser - TU Delft

GOCE Reprocessing Results – Gravity Fields

Overview of ESA GOCE Models

Model	D/O	2M	6M	1Y	2Y	3Y	4Y	5Y	6Y	7Y	8Y	9Y	>10Y	Terr.
GOCE-DIR1	240													
GOCE-DIR2	240													
GOCE-DIR3	240													
GOCE-DIR4	260													
GOCE-DIR5	300													
GOCE-DIR6	300													
GOCE-TIM1	224													
GOCE-TIM2	250													
GOCE-TIM3	250													
GOCE-TIM4	250													
GOCE-TIM5	280													
GOCE-TIM6	300													
GOCE-SPW1	210													
GOCE-SPW2	240													
GOCE-SPW4	280													
GOCE-SPW5	330													
GOCE-SPW6	330													

GOCE
GRACE
CHAMP
SLR
Terr.

See Oral Presentation (Ince et al)

See also Oral Presentation (Kvas et al)

See Poster (Reguzzoni et al)

Rel. 6 GOCE Models

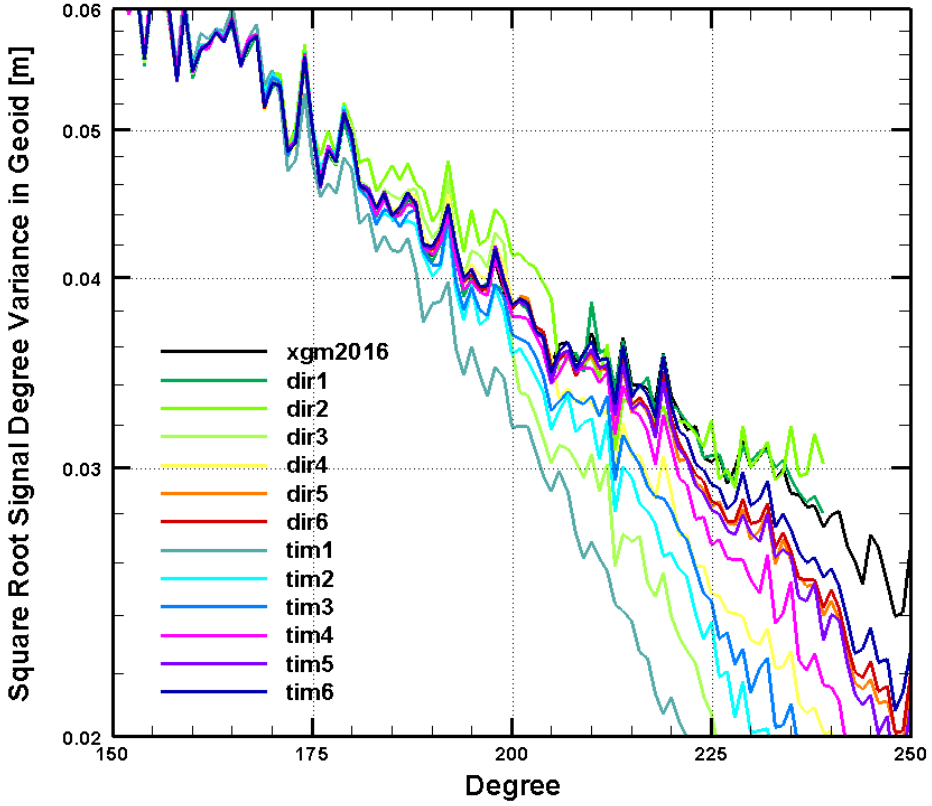
GOCE Reprocessing Results – Gravity Fields

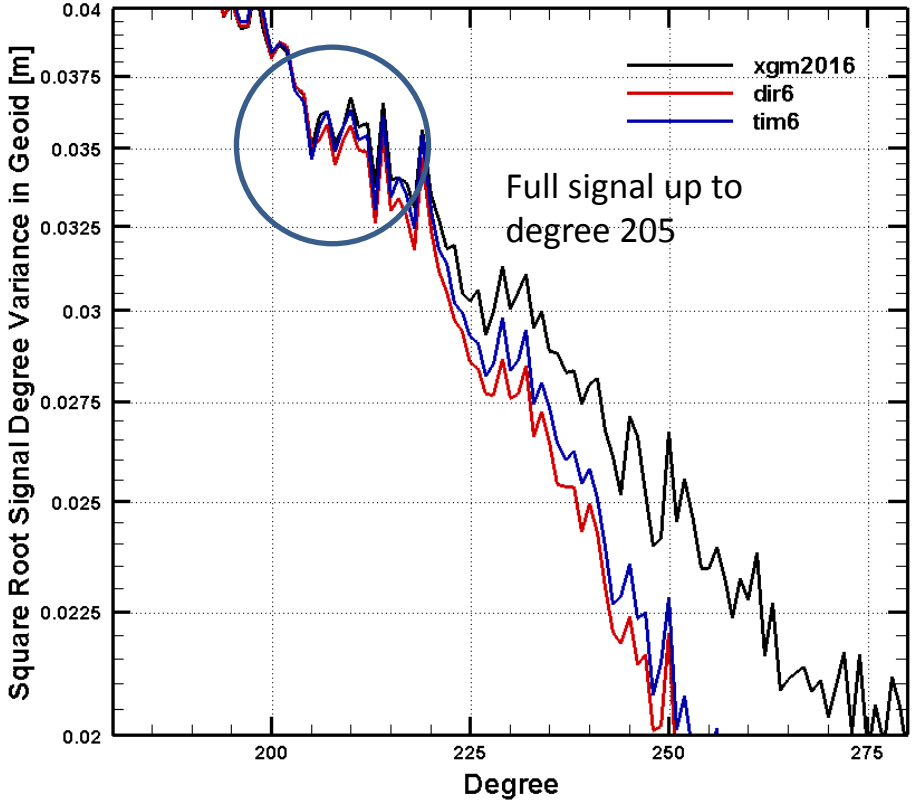
Overview of ESA GOCE Models

	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 Reprocessing Results – Gravity Fields

Signal GOCE Models

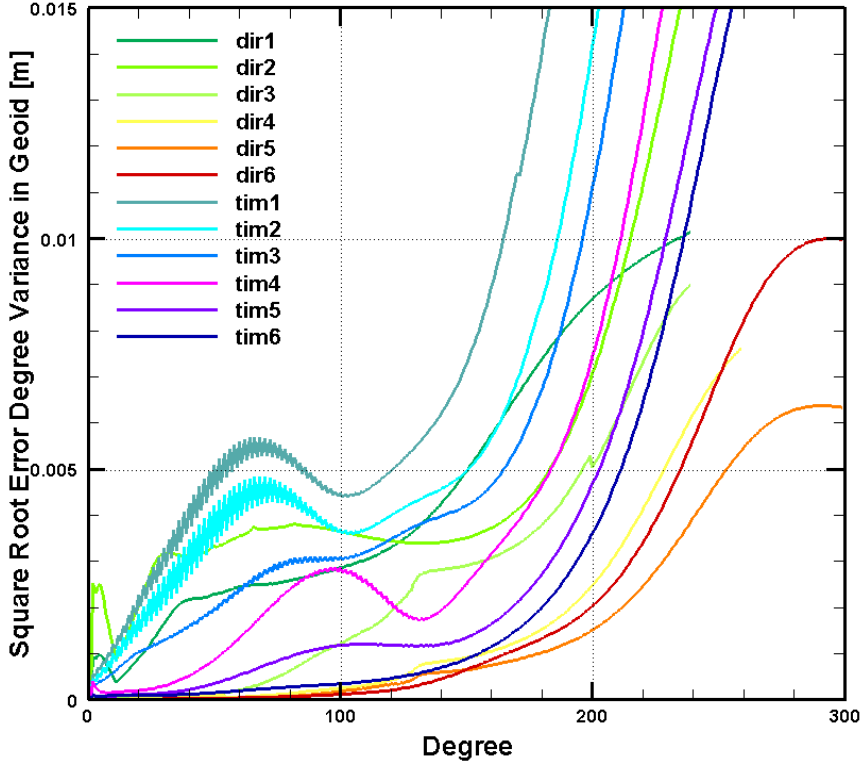




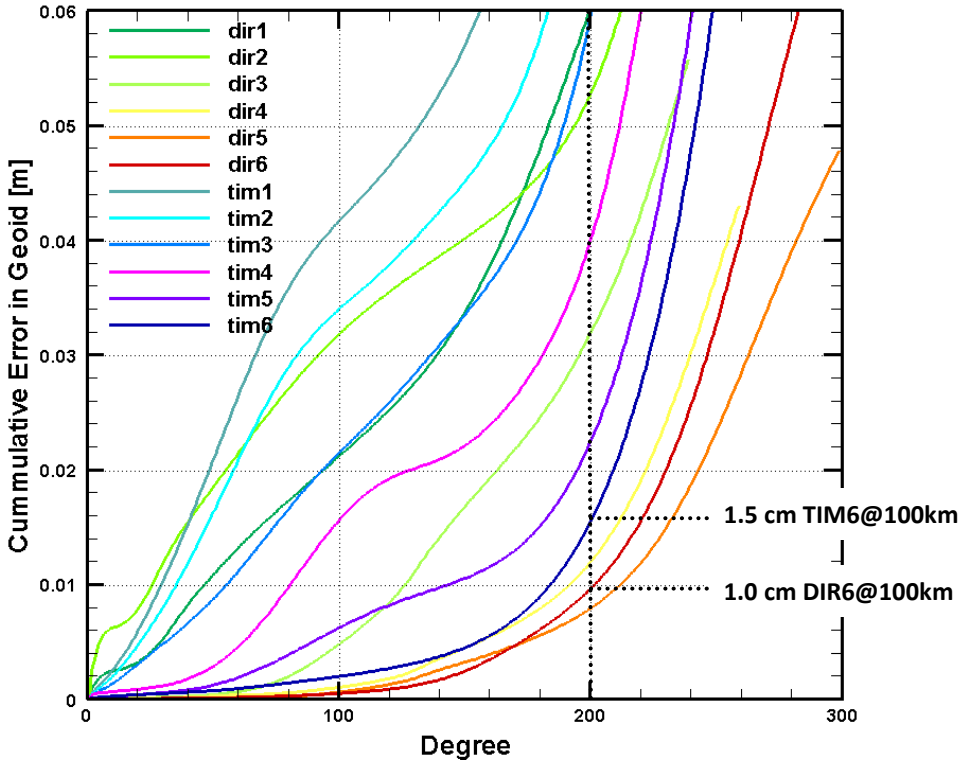
GOCE Reprocessing Results – Gravity Fields

Estimated Errors GOCE Models

per degree (global average)



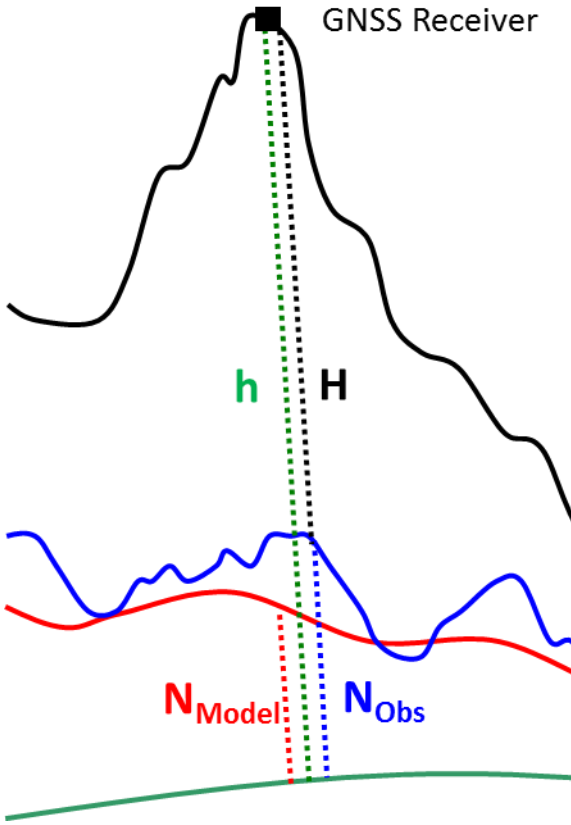
accumulated (global average)



GOCE Reprocessing Results – Gravity Fields

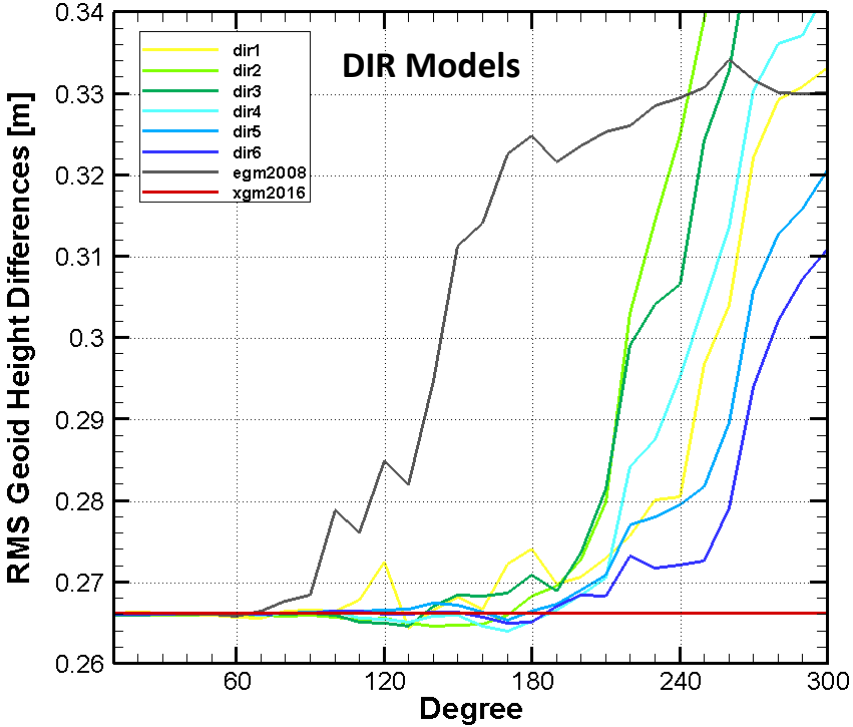
GNSS-Levelling Validation Procedure

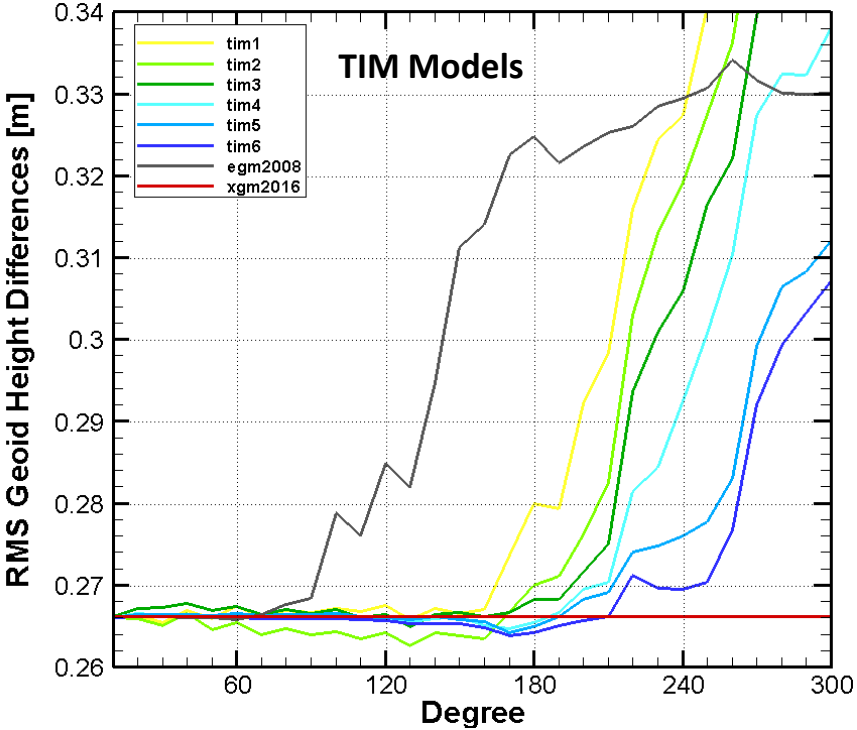
- Compute height anomaly at GNSS-levelling station from global model up to degree and order N.
- Estimate omitted signal from existing HR-model from degree N+1 to 2160 (2190).
- Estimated omitted signal above 2160 from residual topographic gravity field model. (ERTM2160, Hirt et al, 2014)
- If necessary, convert from height anomalies to geoid undulations (Rapp, 1997).
- Compare with geoid height / height anomaly at GNSS-levelling station computed from h-H
- Systematic differences between model and observed geoid heights are possible (definition of local height systems).
- Apply correction surface (planar fit to differences)
- Compute differences of corrected GNSS-levelling geoid heights to model geoid heights.



GOCE Reprocessing Results – Gravity Fields

GNSS-Levelling Differences per Truncation Degree – Brazil*

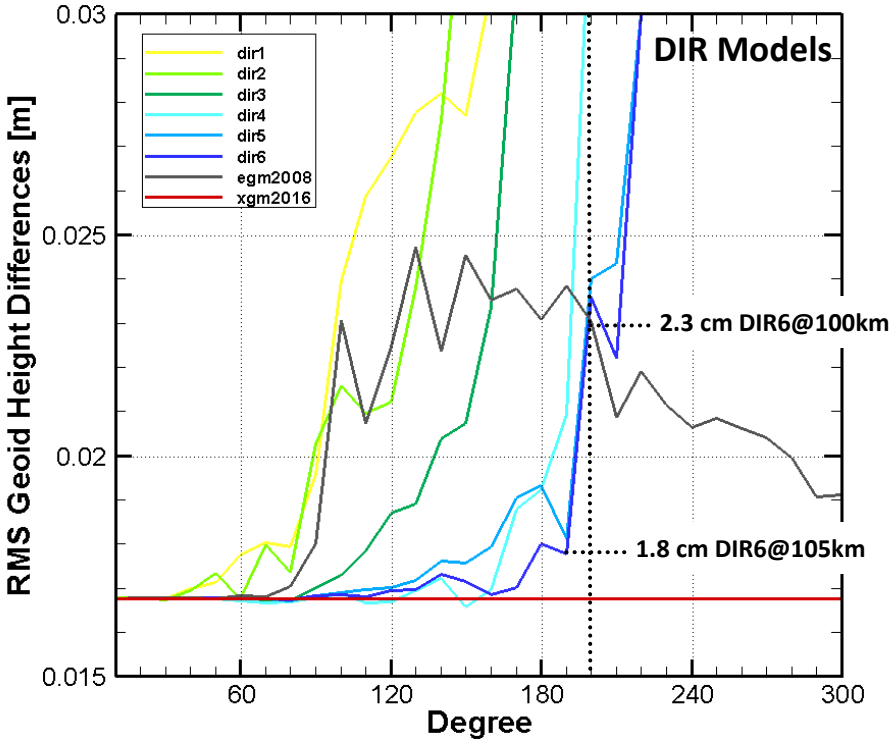


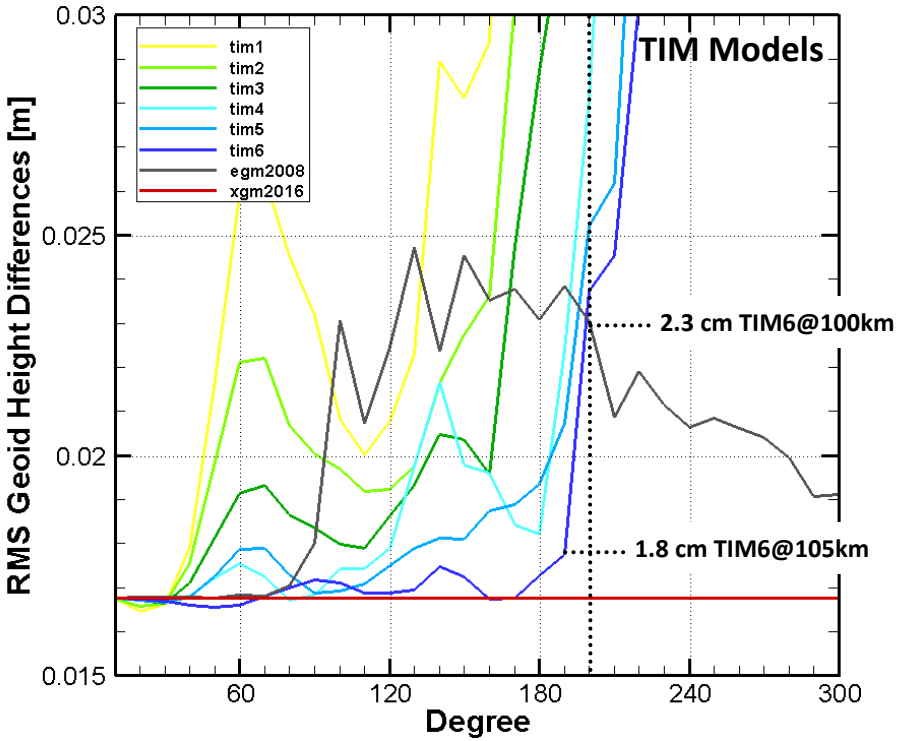


* Brazilian Institute of Geography and Statistics - IBGE, Directorate of Geosciences - DGC, Coordination of Geodesy – CGED, 2012, 683 Points

GOCE Reprocessing Results – Gravity Fields

GNSS-Levelling Differences per Truncation Degree – Germany DHHN2016*





*© GeoBasis-DE / Geobasis NRW, 2018, 470 Points

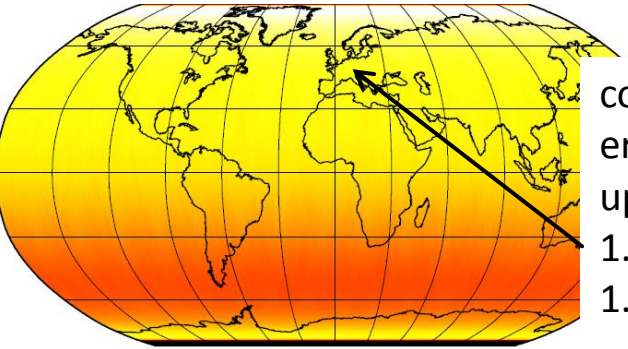
GOCE Reprocessing Results – Gravity Fields

Error Assessment of GOCE Rel. 6 Models in Germany

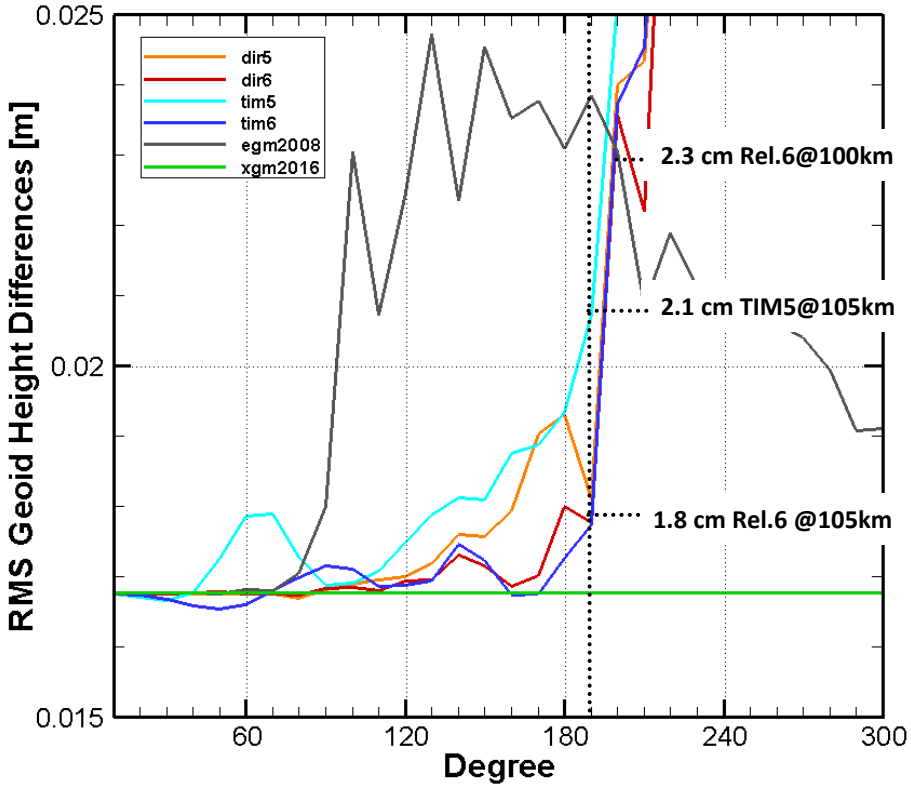
$$\Delta N = h - H - (N + N^{HF})$$

Total Error	=	GNSS Height Error	+	Spirit Levelling Error	+	GOCE Model Error	+	Residual Omission Error
1.8 cm		1.0 cm		1.0 cm		x cm		0.5 cm

Error Propagation Rel.6: **x = 1.0 cm** @ 105 km
Rel.6: **x = 1.7 cm** @ 100 km
TIM5: **x = 1.5 cm** @ 105 km

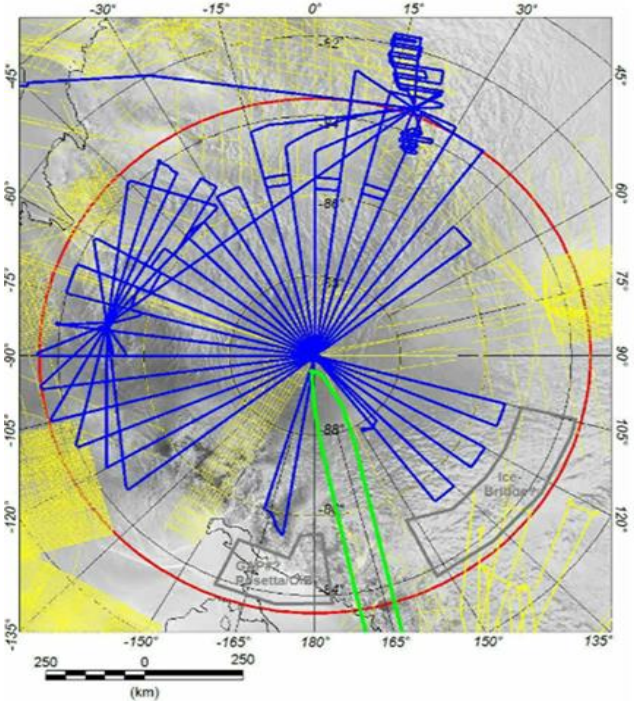


consistent to geoid error map of TIM6 up to d/o 200:
1.15 cm @105 km
1.55 cm @ 100 km

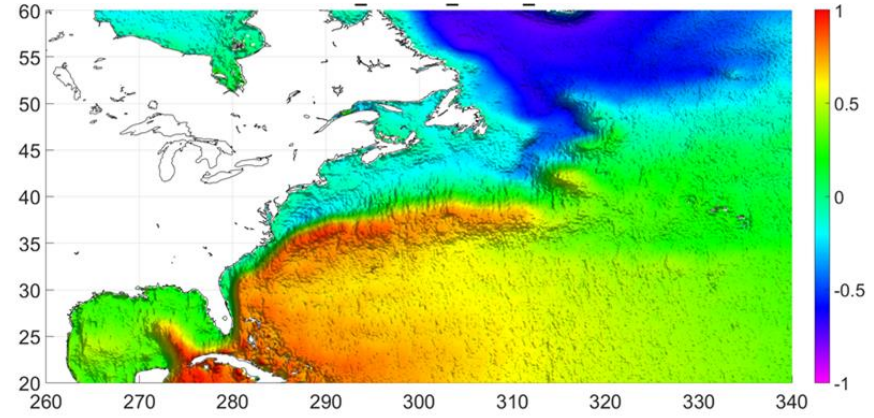


GOCE Reprocessing Results – Gravity Fields

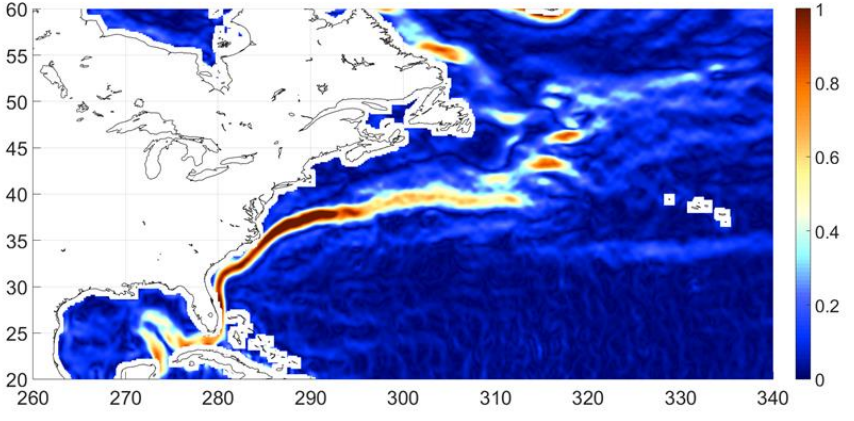
Combined Gravity Fields



Airborne gravity observations taken by the PolarGAP project (10-2015 to 04-2017)



MDT from DTU15MSS and extended XGM2016 [m] and derived Geostrophic current velocities [m/s].



GOCE Rel. 6 Products Summary

- Rel. 5 GOCE gravity field models already meet mission requirements.
- Reprocessing of L1B gradients by improved calibration scheme, star tracker combination and angular rate reconstruction. Improved GPS data screening.
- Improvements of gravity gradients and GOCE models between 15% and 20%; Geoid accuracy: 1 cm @ 105 km, 1.7 cm @ 100 km.
- New HPF products TEC/ROTI and Thermosphere Densities based on GOCE+ and SWARM+ studies also reprocessed.
- Reprocessed GOCE models, gravity gradients, orbits ionosphere and thermosphere products available via ESA and ICGEM.
- Combined gravity field models and reprocessed gravity gradient grids available soon.