Results of the GOCE Reprocessing Campaign

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
- L2 Products: Precise GOCE Orbits, Gravity Gradients, GOCE Gravity Field Models, Ionosphere Products, Thermosphere Products
Outline

1. GOCE Reprocessing
   - Why?
   - Overview

2. Results
   - Orbits
   - Gradients (ref. C. Siemes)
   - Gravity Field Models (ref. J.M. Brockmann, C. Förste)
   - New Products

3. Summary & Future Perspective
GOCE Reprocessing – Why?

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

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

New applications of GOCE data

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

Courtesy: J.M. Brockmann
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.

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).
- See Poster Friday Session B6.01: Precise Orbit Determination

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

ESA Living Planet Symposium, Milano, 13.5.2019
The TEC and ROTI product has 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

See Poster Wednesday Session A7.03: Space Weather

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
- See Poster Wednesday Session A7.01: Geospace System Science

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

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- **GOCE-DIR1, GOCE-DIR2, GOCE-DIR3, GOCE-DIR4, GOCE-DIR5, GOCE-DIR6**
  - Oral Presentation (Förste et al)

- **GOCE-TIM1, GOCE-TIM2, GOCE-TIM3, GOCE-TIM4, GOCE-TIM5, GOCE-TIM6**
  - Oral Presentation (Brockmann et al)

- **GOCE-SPW1, GOCE-SPW2, GOCE-SPW4, GOCE-SPW5, GOCE-SPW6**
  - Poster Presentation (Reguzzoni et al)
GOCE Reprocessing Results – Gravity Fields

Signal GOCE Models

Full signal up to degree 205-220
GOCE Reprocessing Results – Gravity Fields

Estimated Errors GOCE Models

per degree (global average)

accumulated (global average)

Square Root Error Degree Variance in Geoid [m]

Cumulative Error in Geoid [m]

1.5 cm TIM6@100km

1.0 cm DIR6@100km
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*

DIR Models

TIM Models

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

**Summary:**
- **DIR Models:**
  - DIR6@100km: 2.4 cm
  - DIR6@105km: 1.8 cm

- **TIM Models:**
  - TIM6@100km: 2.4 cm
  - TIM6@105km: 1.8 cm

*Graphs show RMS geoid height differences in meters for different degree truncations.*
GOCE Reprocessing Results – Gravity Fields

Error Assessment of GOCE Rel. 6 Model^s in Germany

ΔN = h - H - (N + NHF)

- Total Error: 1.8 cm
- GNSS Height Error: 1.0 cm
- Spirit Levelling Error: 1.0 cm
- GOCE Model Error: x cm
- Residual Omission Error: 0.5 cm

Error Propagation TIM6: x = 1.0 cm @ 105 km
TIM6^: x = 1.7 cm @ 100 km
TIM5: x = 1.5 cm @ 105 km

consistent to geoid error map of TIM6:
1.15 cm @105 km
1.55 cm @ 100 km
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].
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%;

New HPF products based on GOCE+ and SWARM+ studies also reprocessed.

Reprocessed gravity gradients, orbits ionosphere and thermosphere products already available.

Rel. 6 GOCE and combined gravity field models available in May/June 2019.

Reprocessed gravity gradient grids before summer 2019.
TIM1 (d/o 224)

Data: 2 Months GOCE
TIM2 (d/o 250)
Data: 6 Months GOCE
TIM3 (d/o 250)
Data: 1 Year GOCE
TIM4 (d/o 250)

Data: 2 Years GOCE
TIM5 (d/o 280)

Data: 4 Years GOCE

GOCE European Geoid
TIM6 (d/o 300)

Data: 4 Years GOCE (Reprocessed)

GOCE European Geoid
GOCE European Geoid

ITG-GRACE2018 (d/o 200)

Data: 15 Years GRACE
XGM2016 (d/o 719)

Data:
13 Years GRACE
4 Years GOCE
Terrestrial Gravity (15’)
Altimetric Gravity (15’)

GOCE European Geoid
PGM2017 (d/o 2190)

Data:
13 Years GRACE
4 Years GOCE
Terrestrial Gravity (5’)
Altimetric Gravity (5’)

GOCE European Geoid
Gravity Field from Space – Future Perspective

**Time-variable Field**

- Decades of observations needed for Earth system monitoring (GRACE, GRACE-FO, NGGM, MOBILE, Gradiometry) – see Poster Pail et al.

- Mission & instrument concepts:
  - Multi-pair SST missions (low-low, high-low) and/or gradiometer missions;
  - Laser ranging; Cold-atom accelerometers.

**Static Field**

- Increased spatial resolution needed for homogeneous global observations.

- Mission and instrument concept:
  - Gradiometer; very low orbit
  - Accelerometers: higher sensitivity; extended measurement bandwidth (long and short wavelengths)