GOCE Precise Science Orbits for the entire mission and their use for Gravity Field Recovery

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PSD.1

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- Precise Science Orbit (PSO) Determination
  - Bock et al. (2014): GOCE: precise orbit determination for the entire mission, *J Geod*, available online
- Gravity Field Recovery from PSO positions
  - Jäggi et al. (2014): GOCE: assessment of GPS-only gravity field determination, *J Geod*, in review
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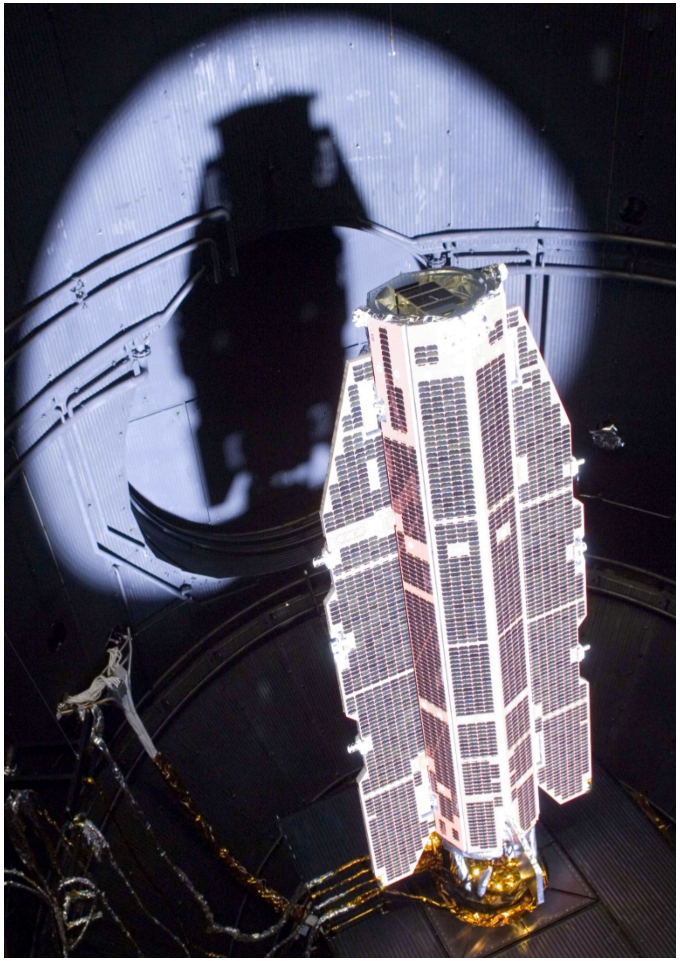
- Summary

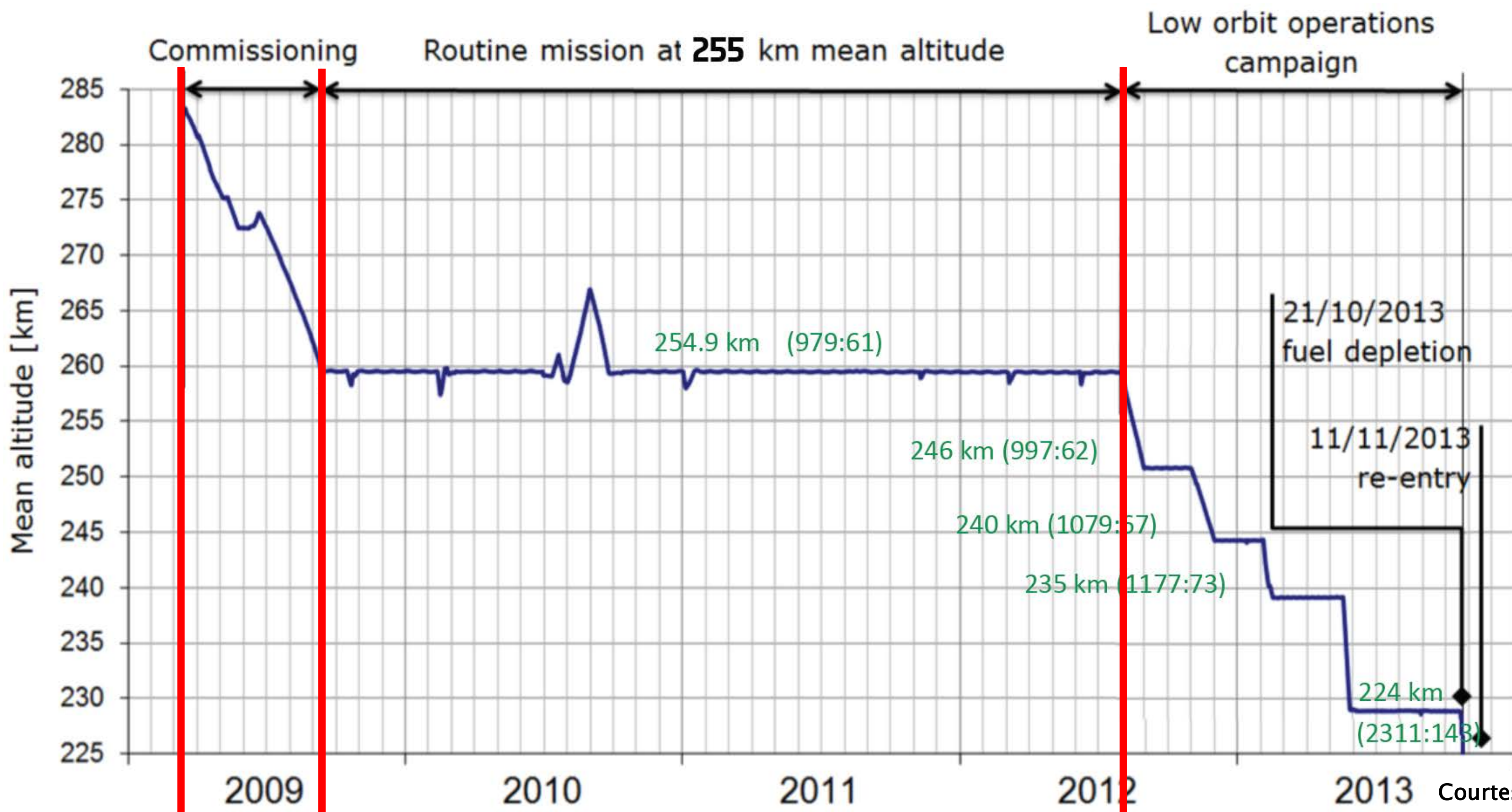
GOCE satellite mission (1)



Courtesy: ESA

- Gravity and steady-state Ocean Circulation Explorer
- First Earth Explorer of the Living Planet Program of the European Space Agency
- Launch: 17 March 2009 from Plesetsk, Russia
- Sun-synchronous orbit
- Altitude: 255 km (lowered later on)
- Mass: 1050 kg at launch
- 5.3 m long, 1.1 m^2 cross section
- Re-entry: 11 November 2013 near the Falkland Islands

GOCE satellite mission (2)



Courtesy: ESA

- 01/11/2009
- 30/03/2009
- 01/08/2012

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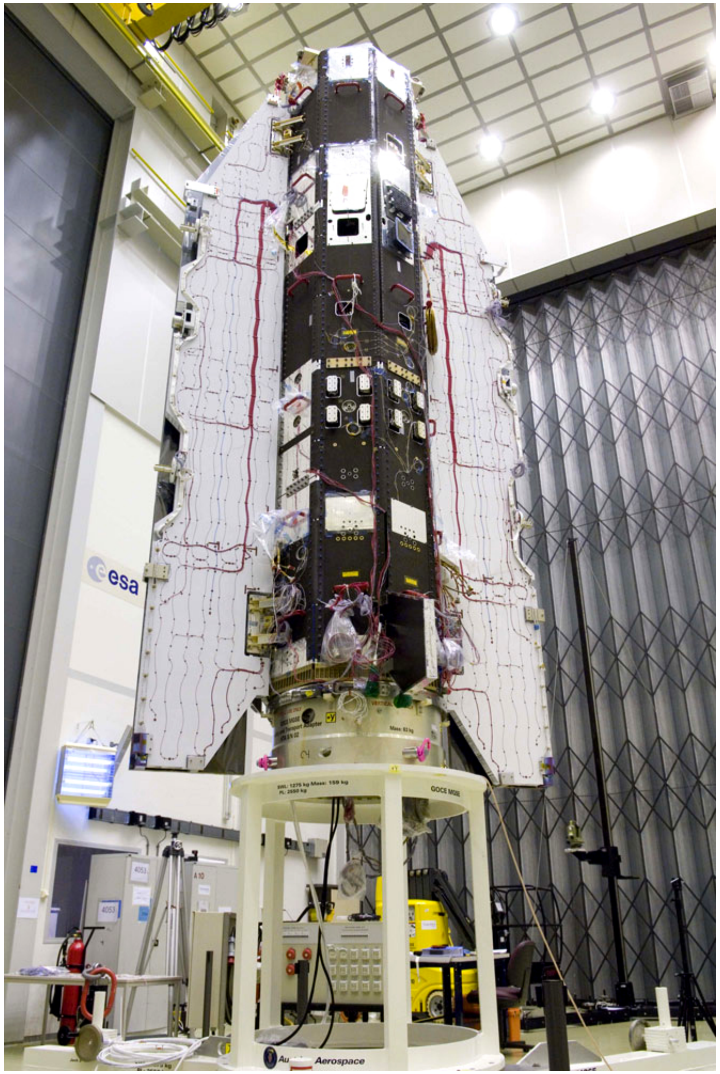
GOCE satellite mission (3)



Courtesy: ESA

- **Three axes stabilized, nadir pointing, aerodynamically shaped satellite**
- **Drag-free attitude control (DFAC) in flight direction employing a proportional Xe electric propulsion system**
- **Very rigid structure, no moving parts**
- **Attitude control by magnetorquers**
- **Attitude measured by star cameras**

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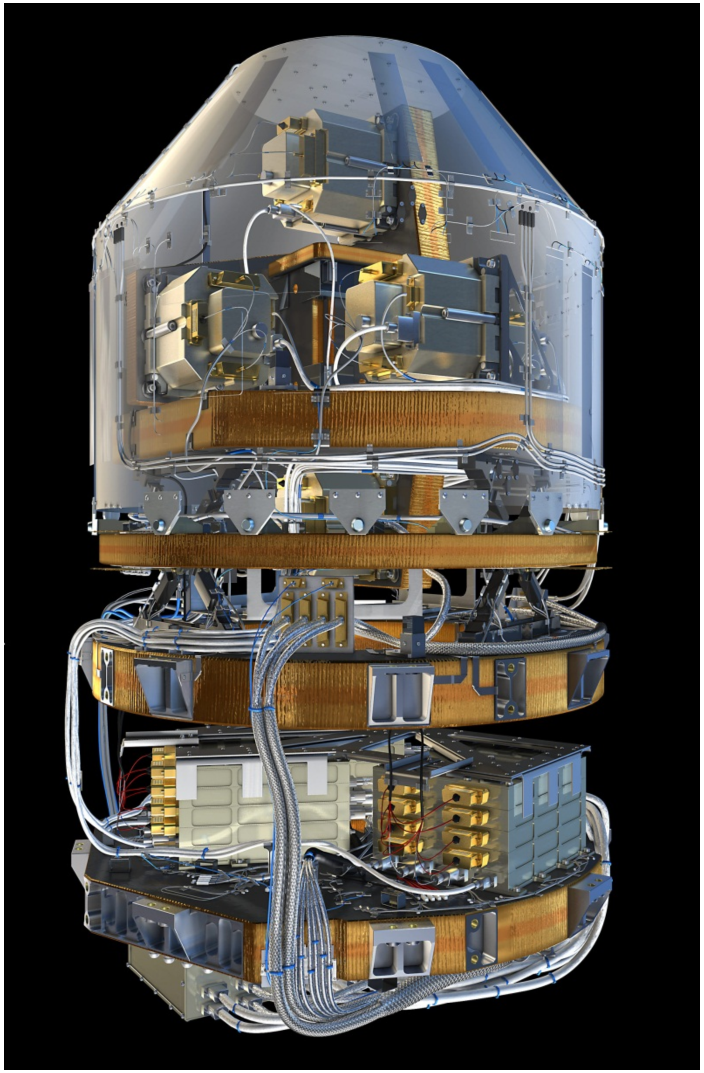
GOCE satellite mission (4)



Courtesy: ESA

Main mission goal:

Determination of the Earth's gravity field with an accuracy of 1mGal (= 10^{-5} m/s^2) at a spatial resolution of 100 km using the concept of space gradiometry

Released Gravity Field Models:

R1: 01/11/2009 – 11/01/2010 (TIM,DIR,SPW)

R2: 01/11/2009 – 05/07/2010 (TIM,DIR,SPW)

R3: 01/11/2009 – 17/04/2011 (TIM,DIR)

R4: 01/11/2009 – 19/06/2012 (TIM,DIR)

R5: 01/11/2009 – 20/10/2013 (TIM,DIR)

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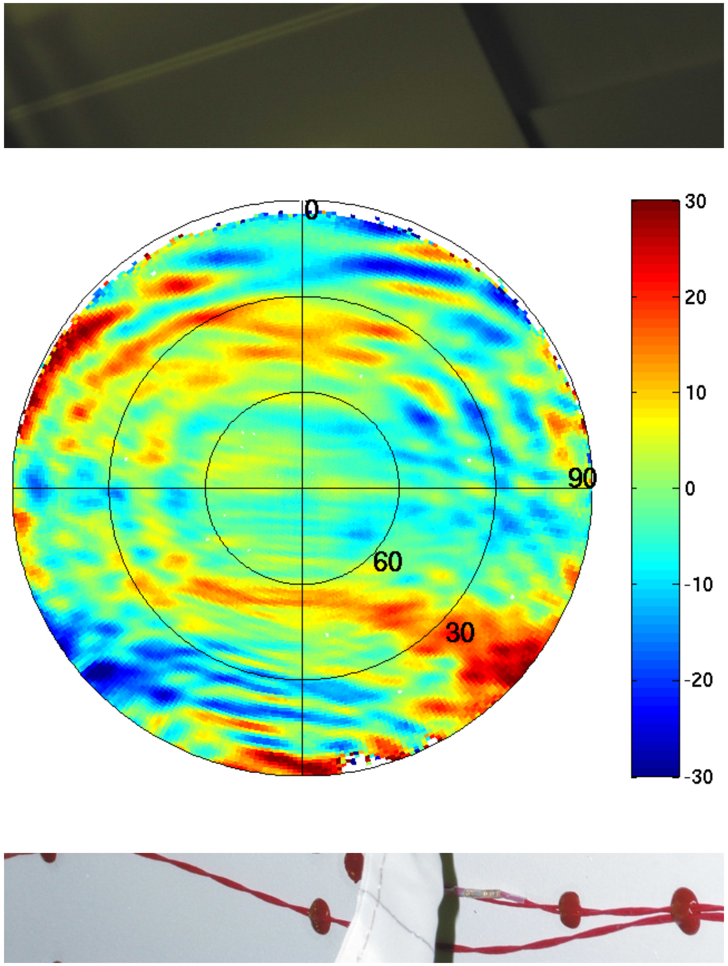
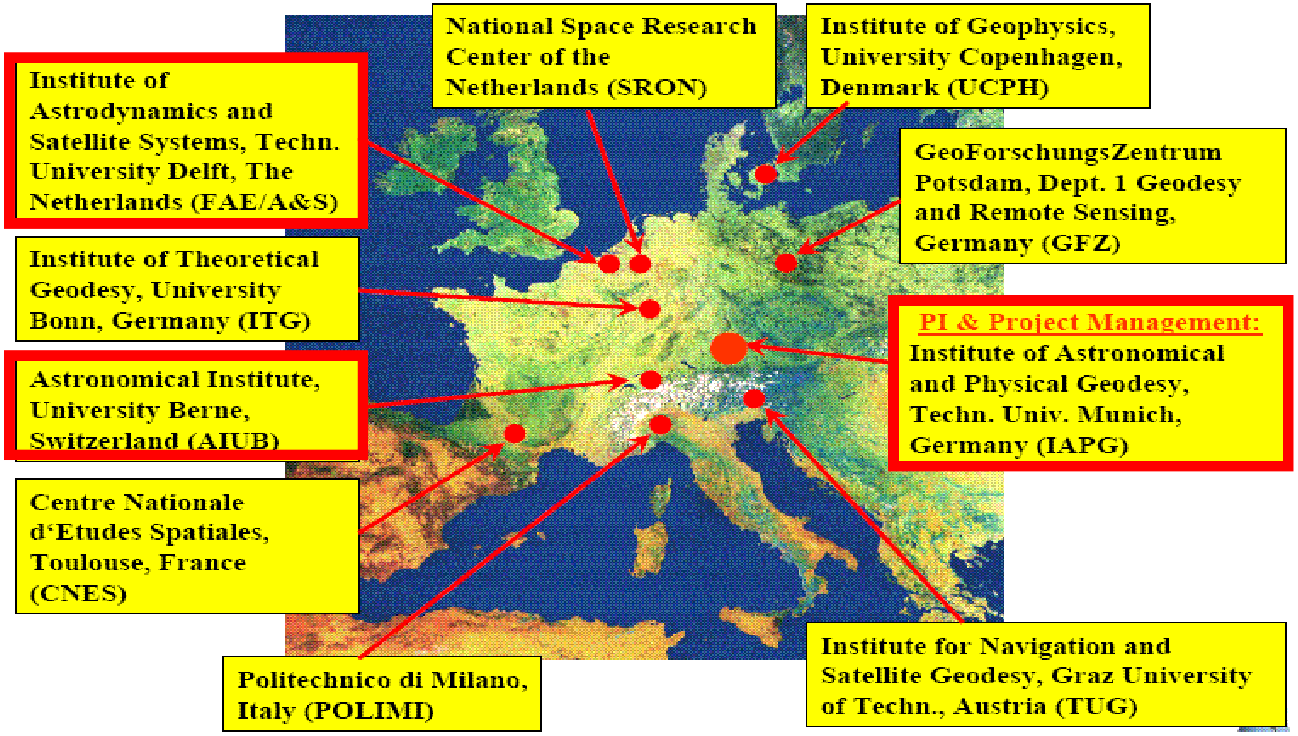
GOCE satellite mission (5)



Courtesy: ESA

- **Satellite-to-Satellite Tracking Instrument (SSTI)**
- **Dual-frequency L1, L2**
- **12 channel GPS receiver**
- **1 Hz data rate**
- **=> Primary instrument for orbit determination**
- **Antenna phase center variations amount up to ±3cm on ionosphere-free linear combination**
- **=> Mission requirement for precise science orbits: 2 cm (1D RMS)**

GOCE High-level Processing Facility (HPF)



- **Responsibilities for orbit generation:**
- **DEOS:**

  => RSO (Rapid Science Orbit)
- **AIUB:**

  => PSO (Precise Science Orbit)
- **IAPG:**

  => Validation

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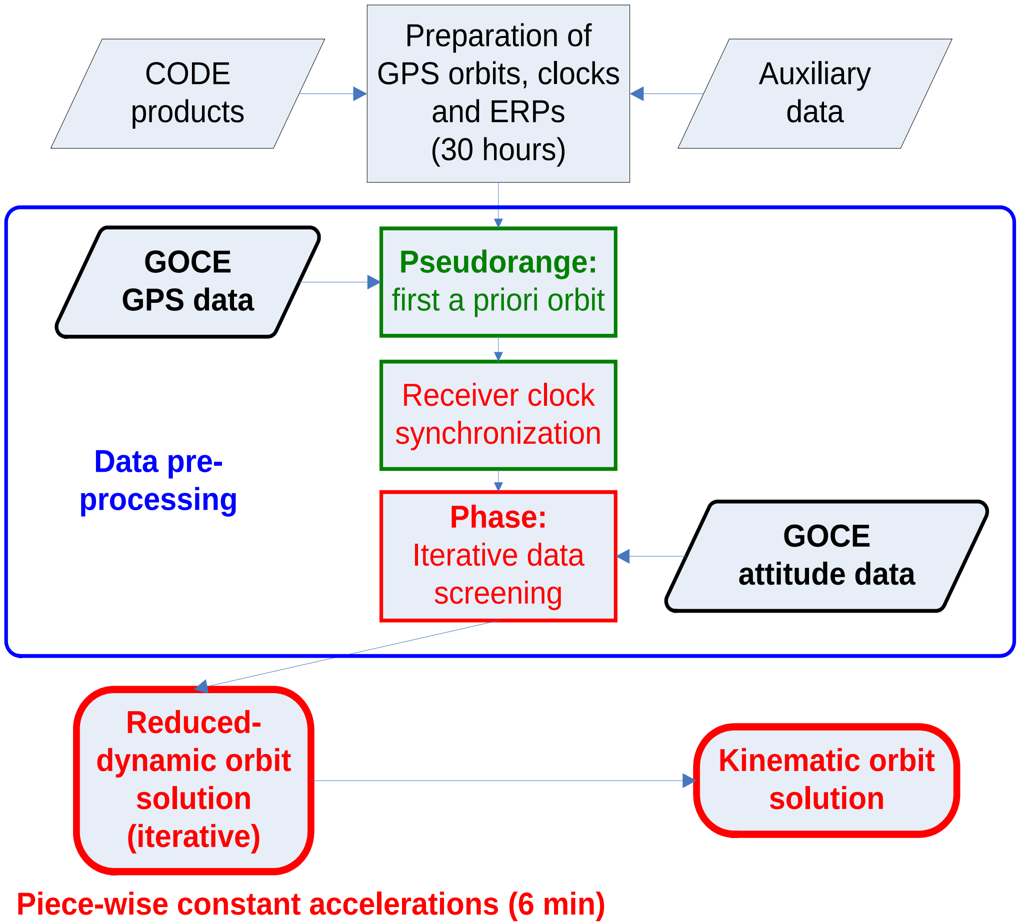
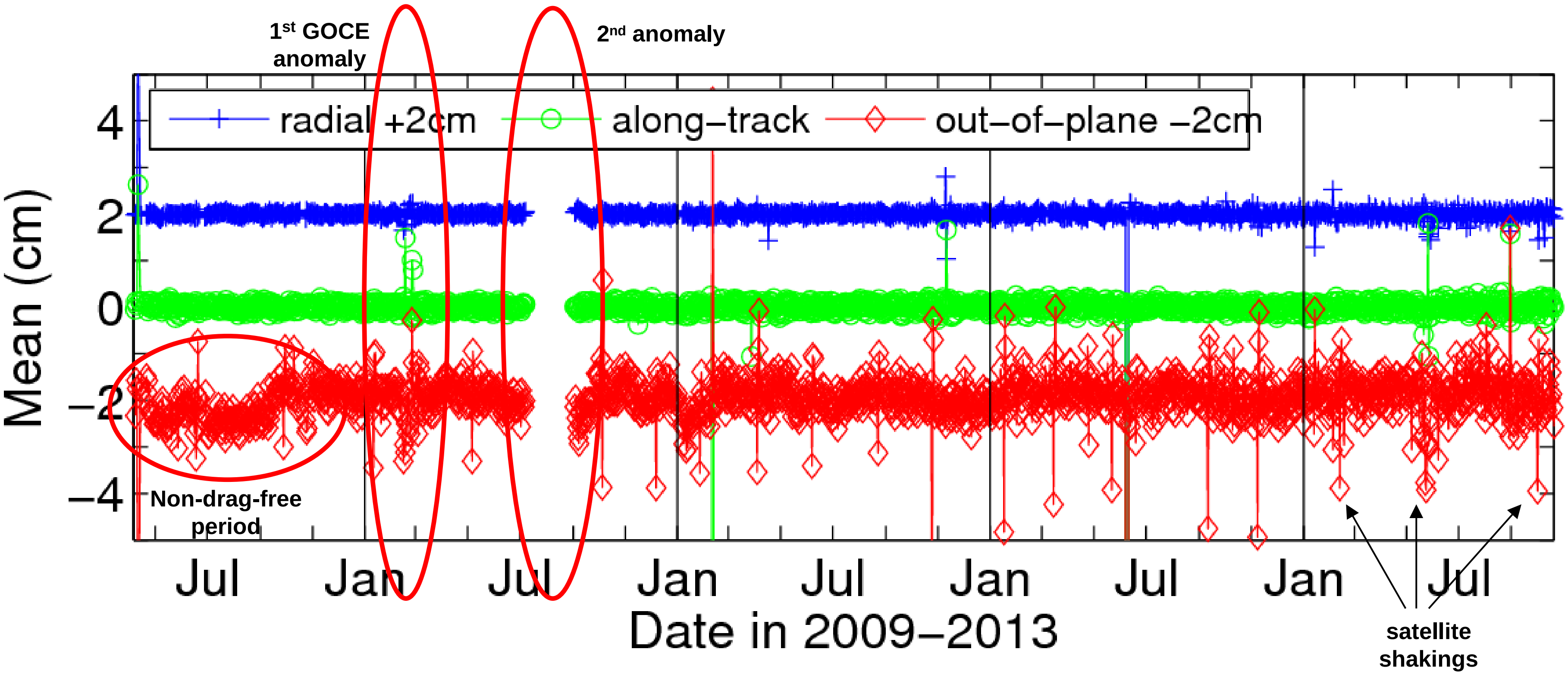
GOCE PSO procedure



- **Tailored version of Bernese GPS Software used**
- **Undifferenced processing**
- **Automated procedure**
- **30 h batches => overlaps**
- **CODE final products**
- **Reduced-dynamic and kinematic orbit solutions are computed**

Overlaps of reduced-dynamic PSO solutions



The results are based on 5h overlaps (21:30–02:30) and reflect the internal consistency of subsequent reduced-dynamic solutions.

The same orbit determination settings were used for the operational PSO computation over the entire mission period.

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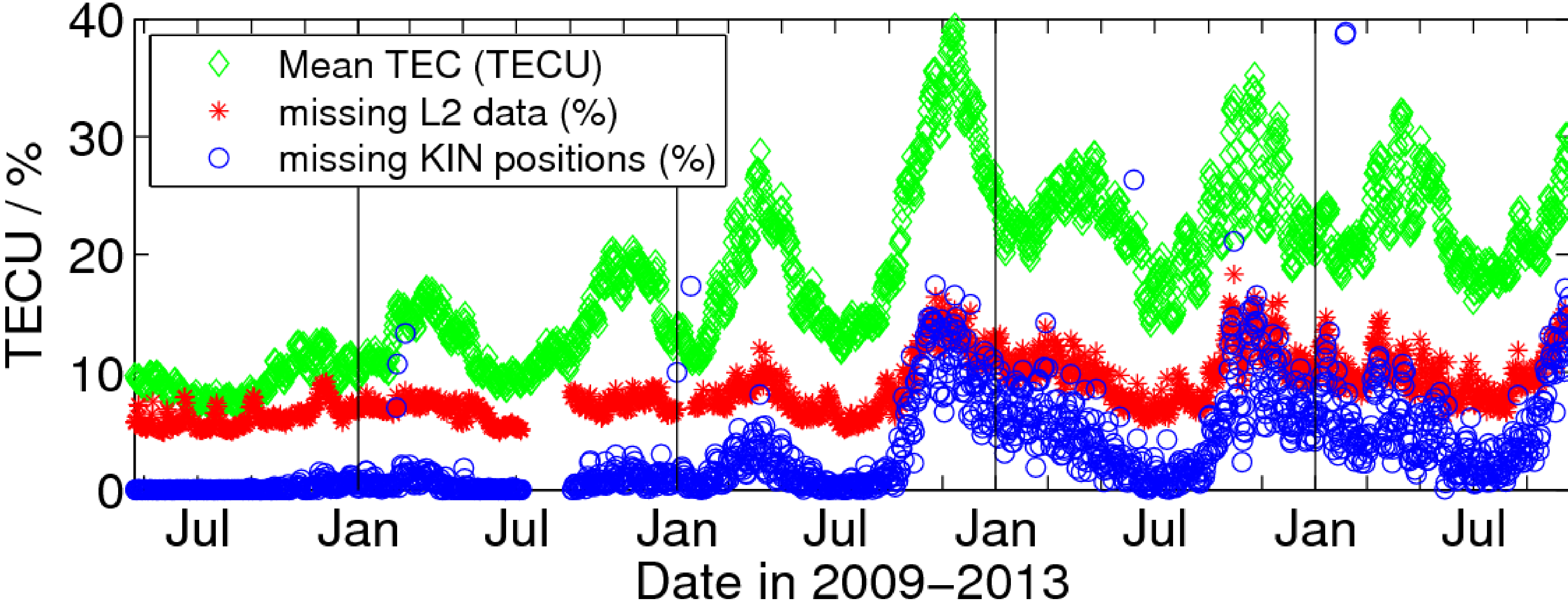
Differences reduced-dynamic vs. kinematic (1)



The results show the consistency between both orbit-types and mainly reflect the quality of the kinematic orbits.

A high correlation with ionosphere activity and L2 data losses is observed.

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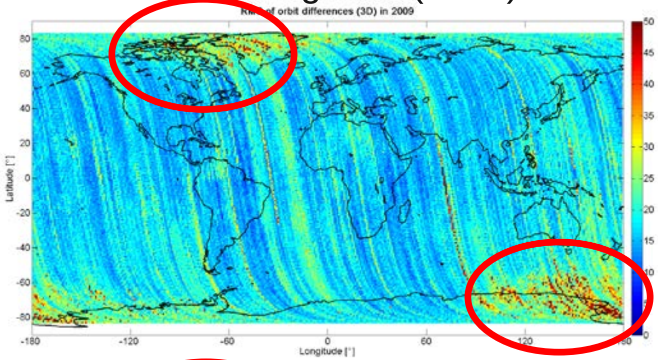
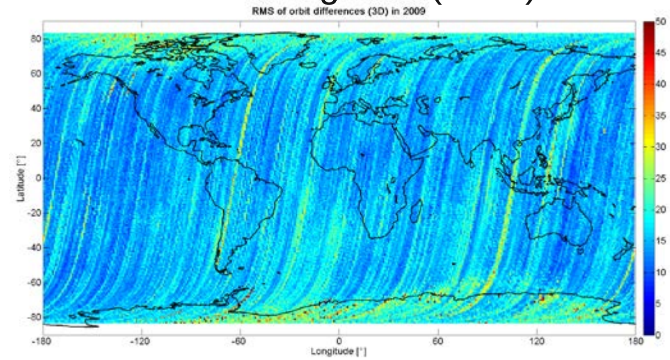
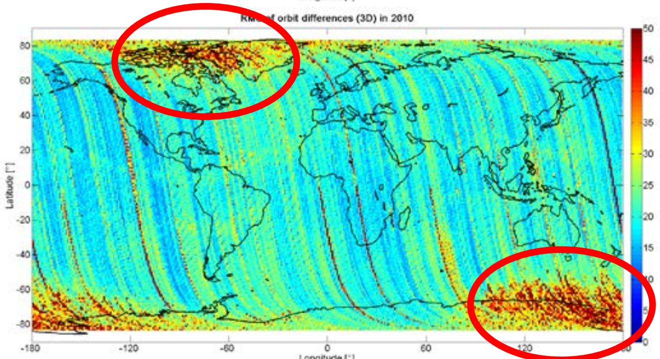
Differences reduced-dynamic vs. kinematic (2)

Ascending arcs (RMS) | Descending arcs (RMS)

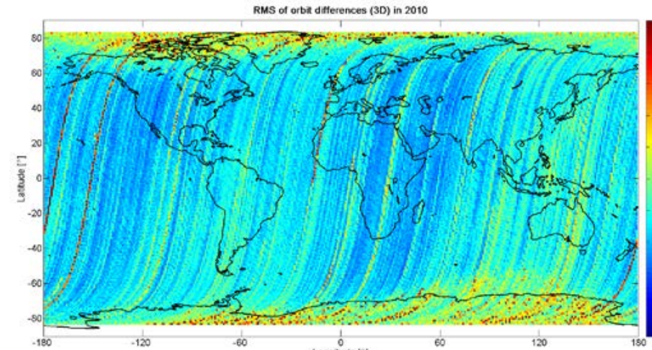


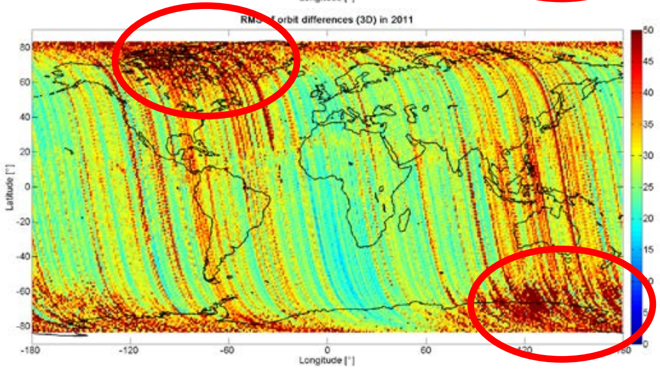
2009



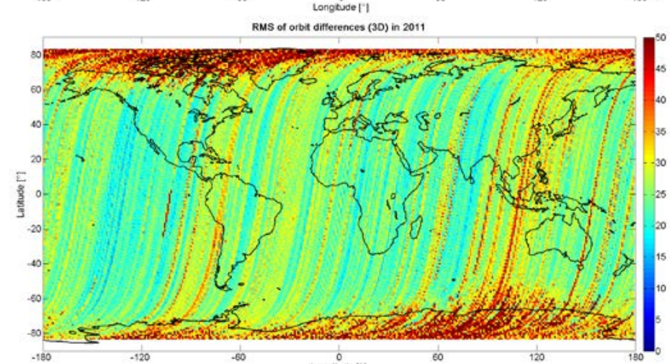


2010





2011



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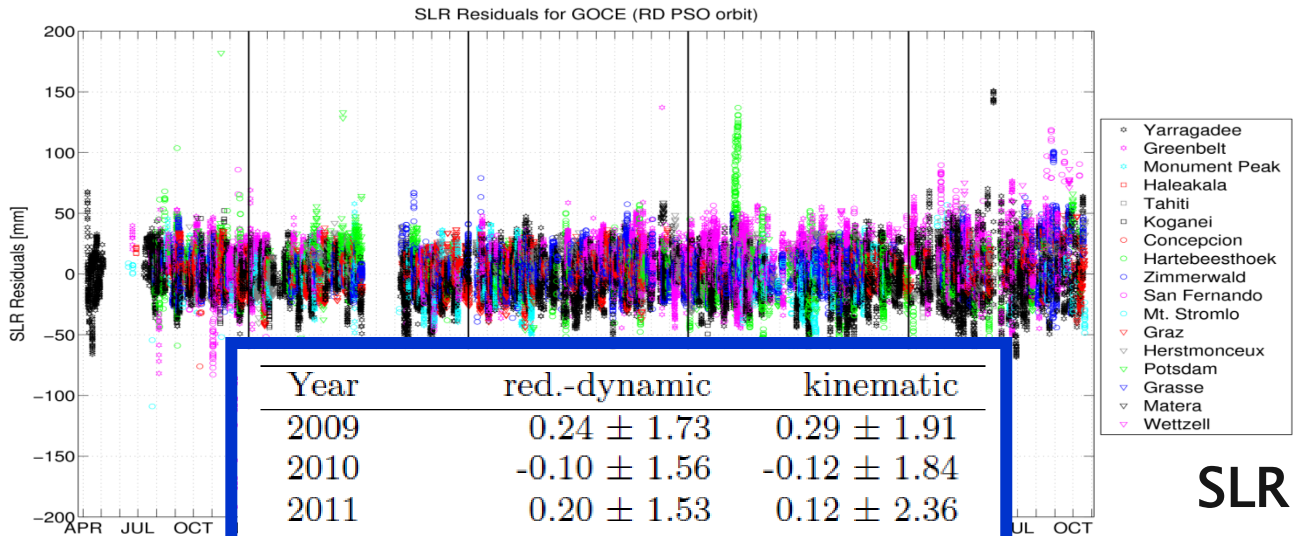
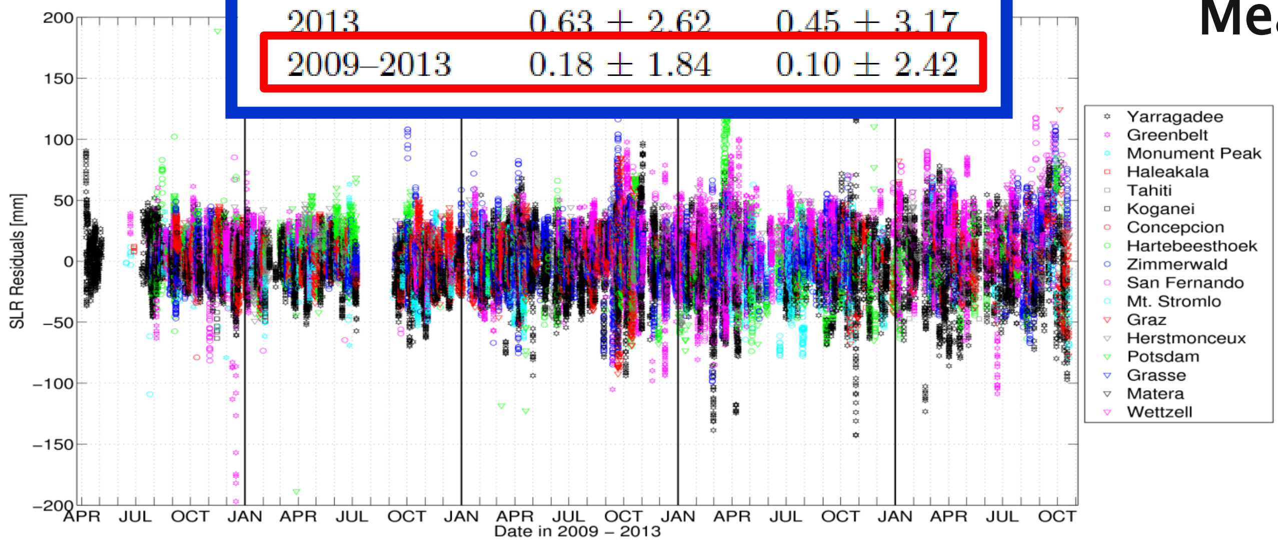
AIUB

Orbit validation with SLR



Reduced-dynamic



Kinematic

Year	red.-dynamic	kinematic
2009	0.24 ± 1.73	0.29 ± 1.91
2010	-0.10 ± 1.56	-0.12 ± 1.84
2011	0.20 ± 1.53	0.12 ± 2.36
2012	0.10 ± 1.94	-0.05 ± 2.78
2013	0.63 ± 2.62	0.45 ± 3.17
2009–2013	0.18 ± 1.84	0.10 ± 2.42

SLR statistics:

Mean ± RMS (cm)

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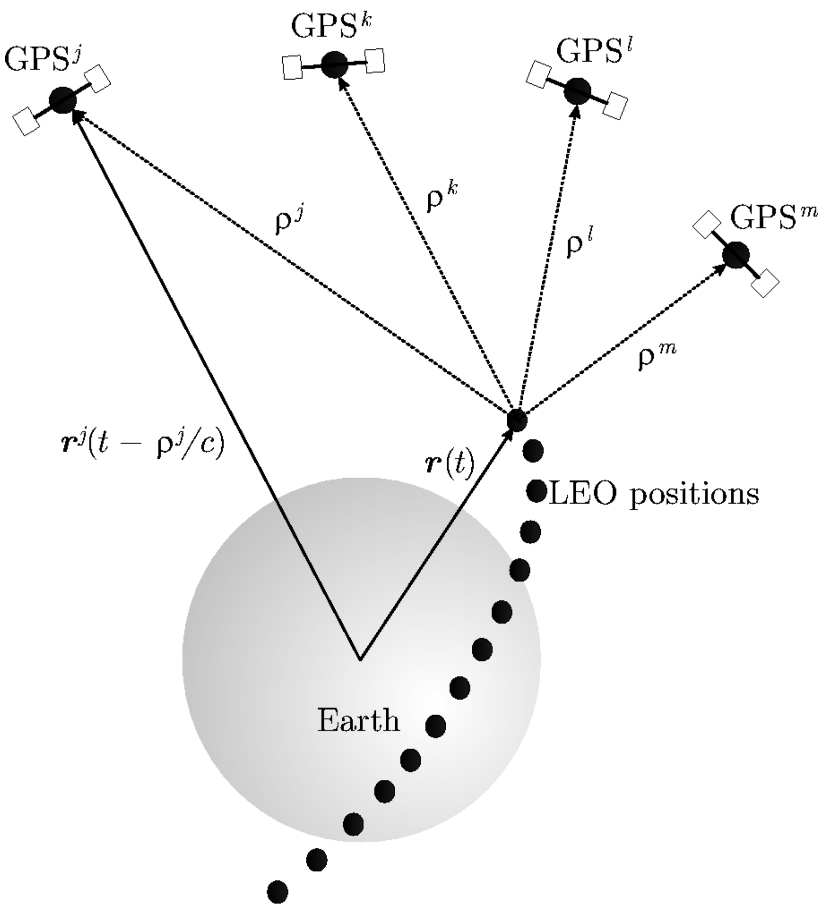
Gravity field recovery from orbital positions



- **Kinematic GOCE positions contain independent information about the long-wavelength part of the Earth's gravity field**
- **1-sec kinematic positions serve as pseudo-observations together with covariance information to set-up an orbit determination problem, which also includes gravity field parameters**
- **Non-gravitational forces are absorbed by empirical parameters in the course of the generalized orbit determination problem, accelerometer data are not used for the results shown in this presentation**
- **Gravity field coefficients are solved without applying any regularization**

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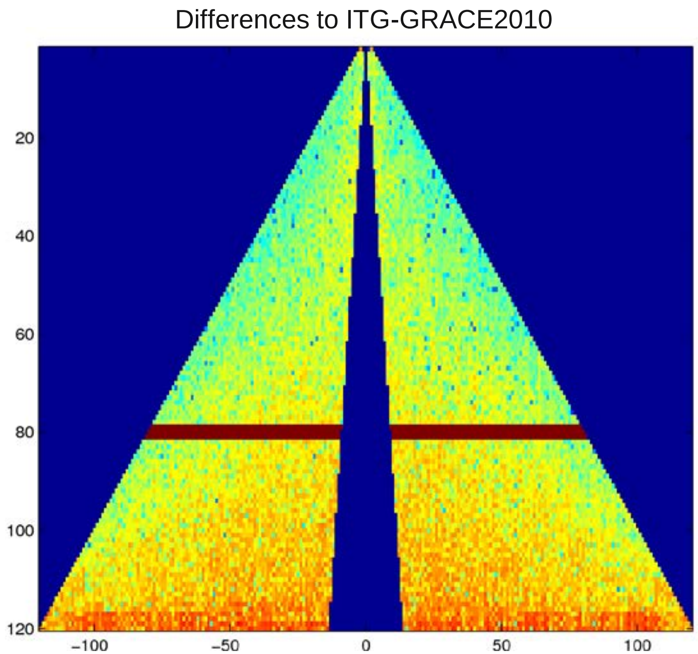
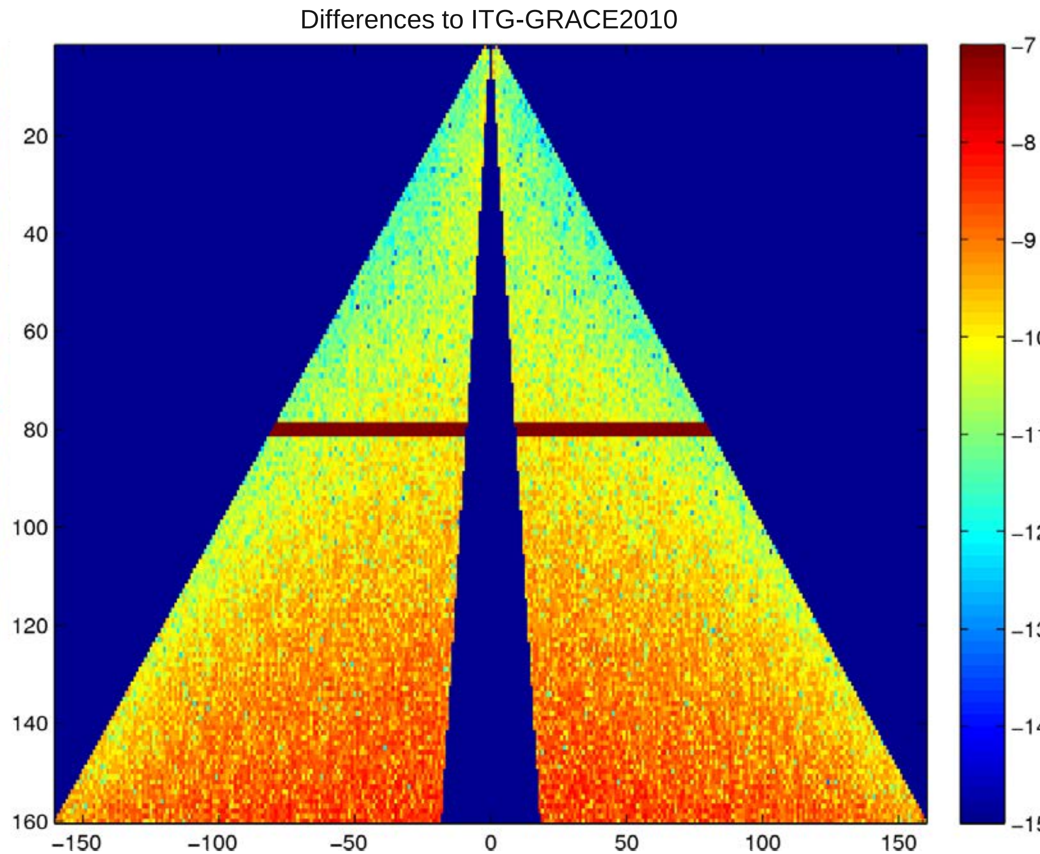
Impact of polar gap



$$\delta d_i \doteq \sqrt{\sum_{m=0}^{i} \left(\Delta\bar{C}_{i,m}^2 + \Delta\bar{S}_{i,m}^2\right)}$$



- **δd_i is dominated by zonal and near-zonal terms, degradation depends on max. d/o**
- **=> exclusion according to the rule of thumb by van Gelderen & Koop (1997)**

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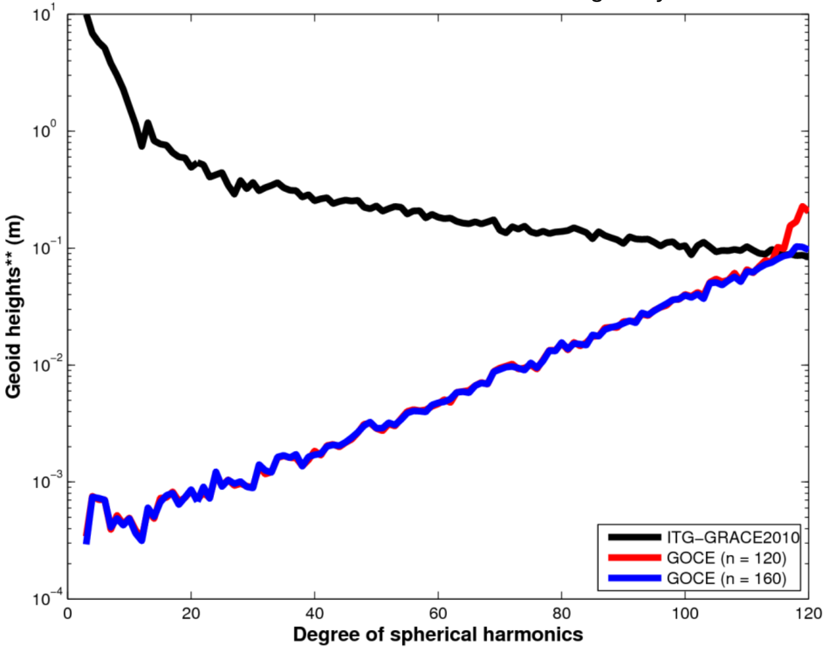
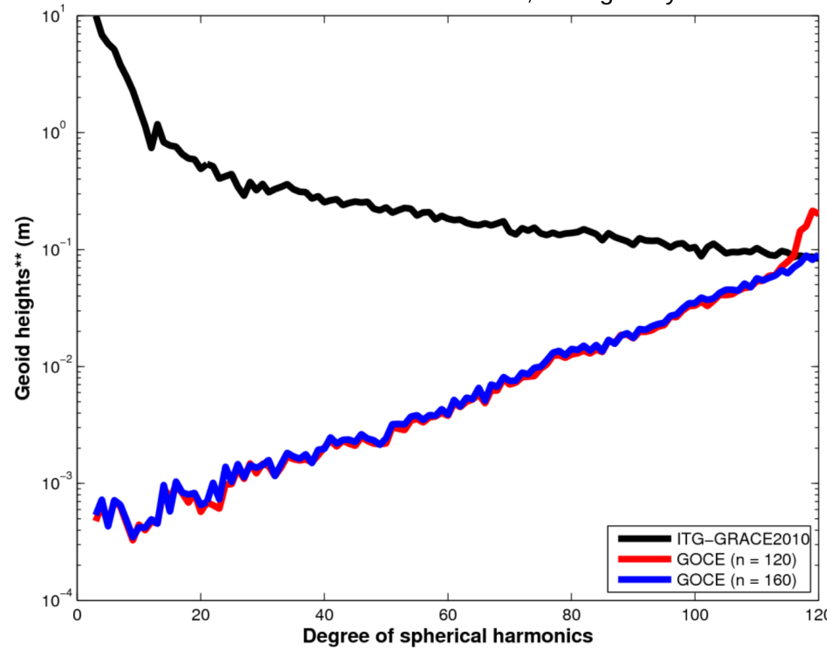
Impact of maximum resolution

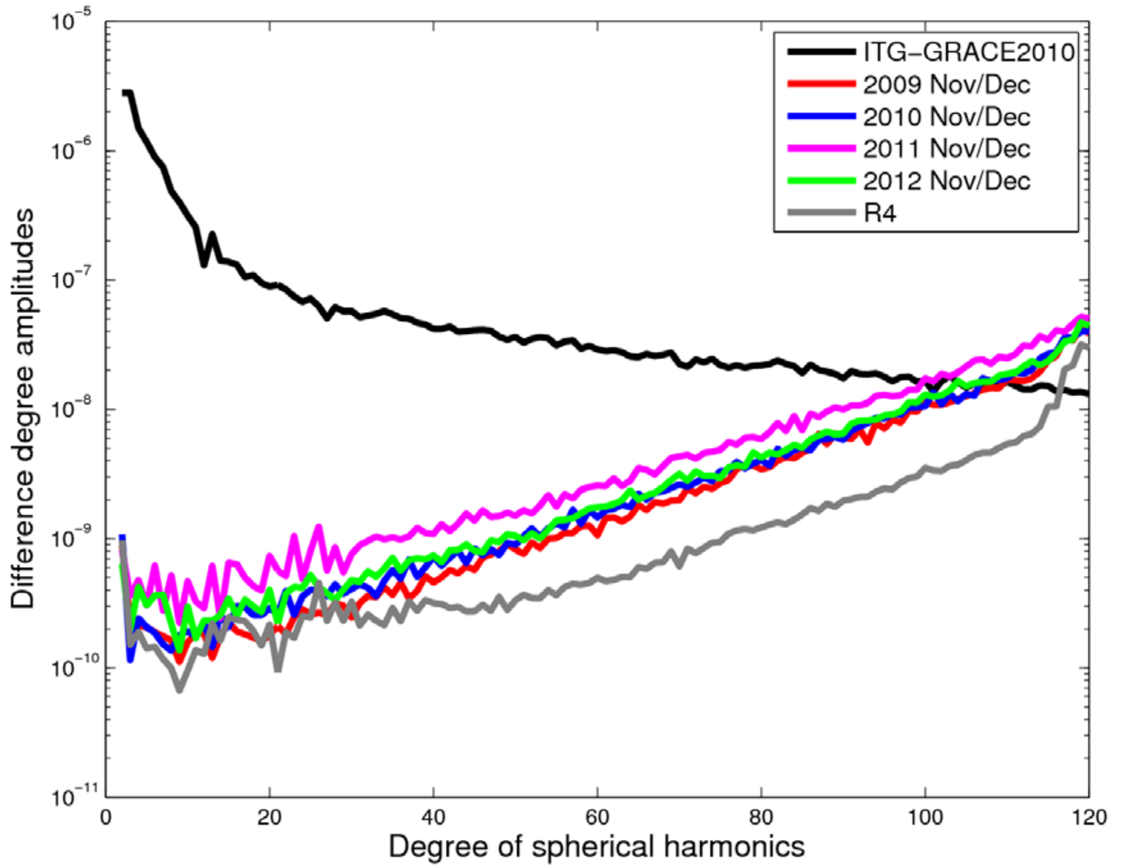


- **ommission errors are avoided, …**
- **…, but artifacts appear at low degrees**
- **Artifacts are restricted to near-zonal coefficients. Rule of thumb needs to be enlarged**



- **Stronger artifacts in 2010 , …**
- **…, but again mostly related to near-zonal coefficients, which are very sensitive to the increasing data problems such as the L2 losses**

Assessment of solutions for nominal altitude



The bi-monthly solution for 2009 shows the best quality, slightly worse qualities are obtained for 2010 and 2012, the most degraded solution is obtained for 2011.

The long-term solution R4 shows no significantly improved quality with respect to the bi-monthly solutions below degree 30.

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Systematic effects in the orbits (1)

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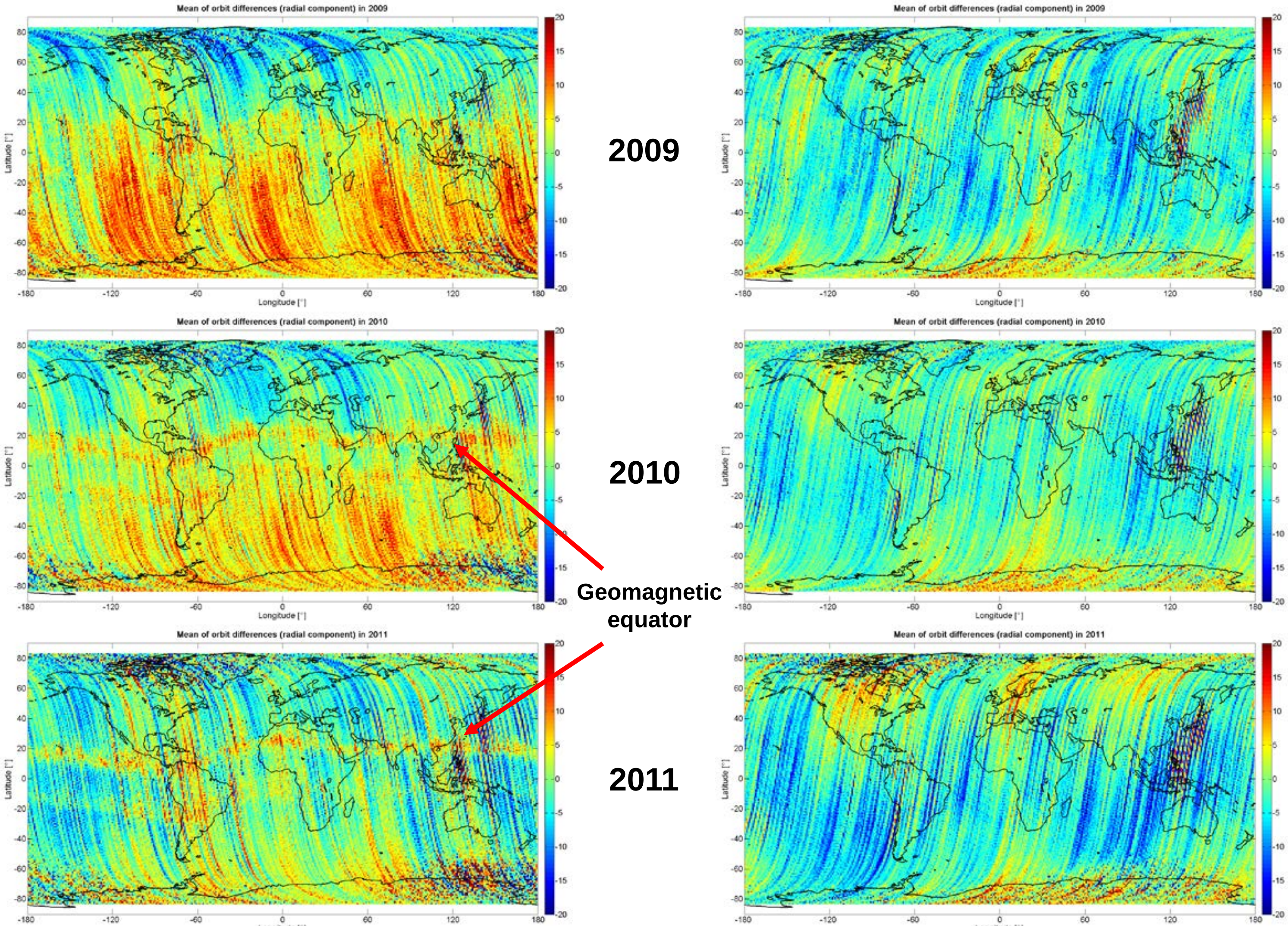
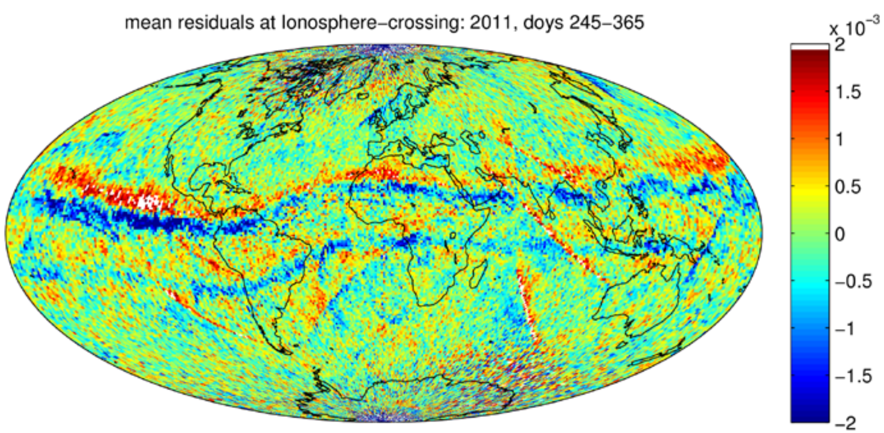
Ascending arcs (mean) | Descending arcs (mean)

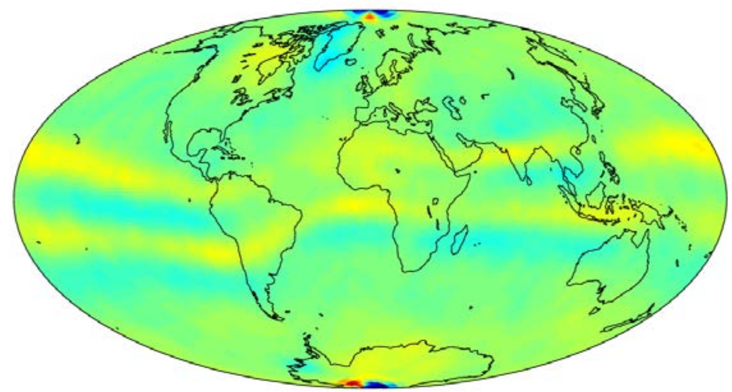


Systematic effects in the orbits (2)

- Systematic effects around the geomagnetic equator are present in the ionosphere-free GPS phase residuals => affects kinematic positions
- Degradation of kinematic positions around the geomagnetic equator propagates into gravity field solutions.



Phase observation residuals (– 2 mm … +2 mm) mapped to the ionosphere piercing point



Geoid height differences (–5 cm … 5 cm); TIM-R4 model

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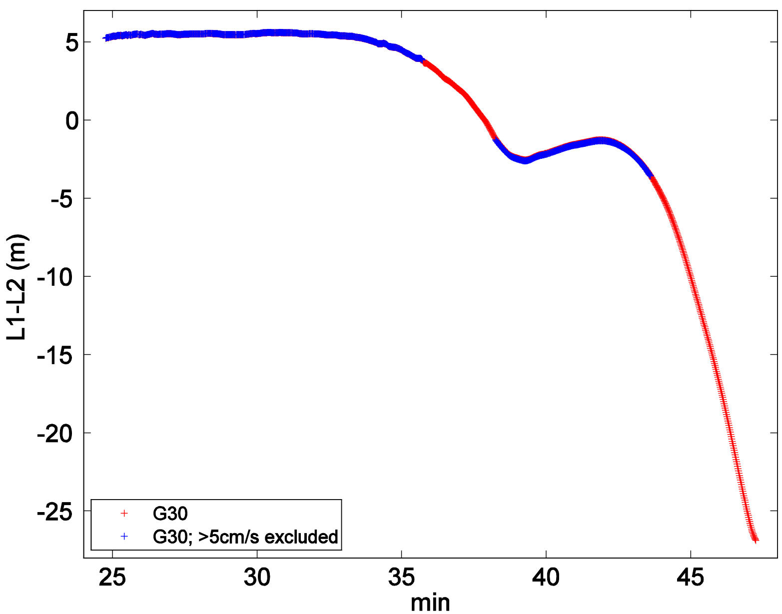
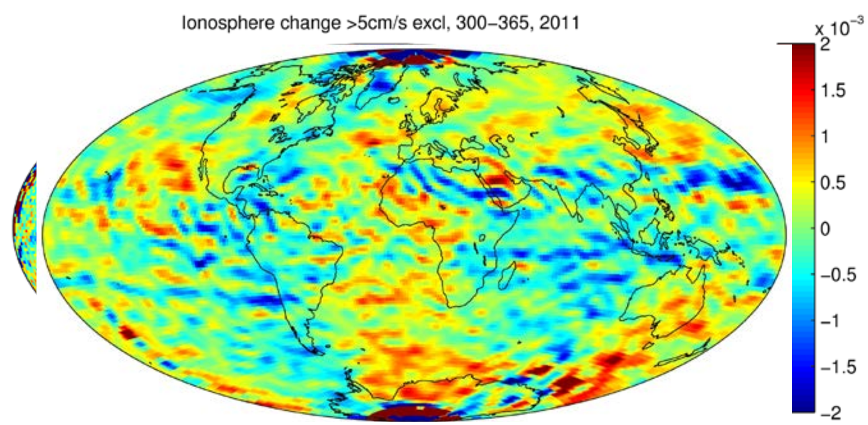
Removal of systematic effects (1)

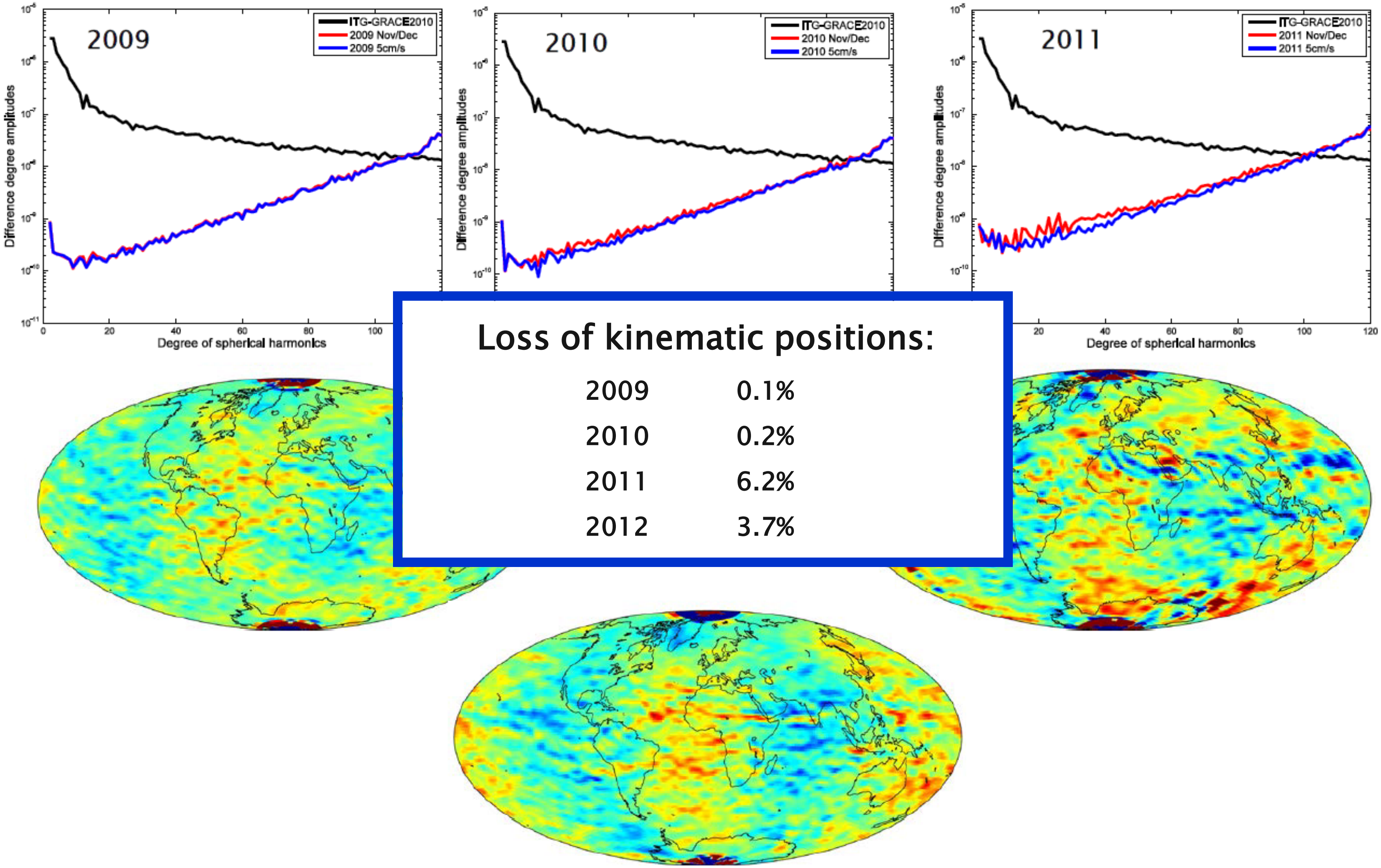
- One possible cause is the neglection of the higher order ionosphere (HOI) correction terms.
- First tests using HOI correction terms did, however, not show any improvement in the results.
- But an empirical approach can be adopted:
  - Removal of observations, which have large ionosphere changes from one epoch to the next (e.g. >5cm/s).





Geoid height differences (Nov/Dec 2011)

Removal of systematic effects (2)



Loss of kinematic positions:

2009	0.1%
2010	0.2%
2011	6.2%
2012	3.7%

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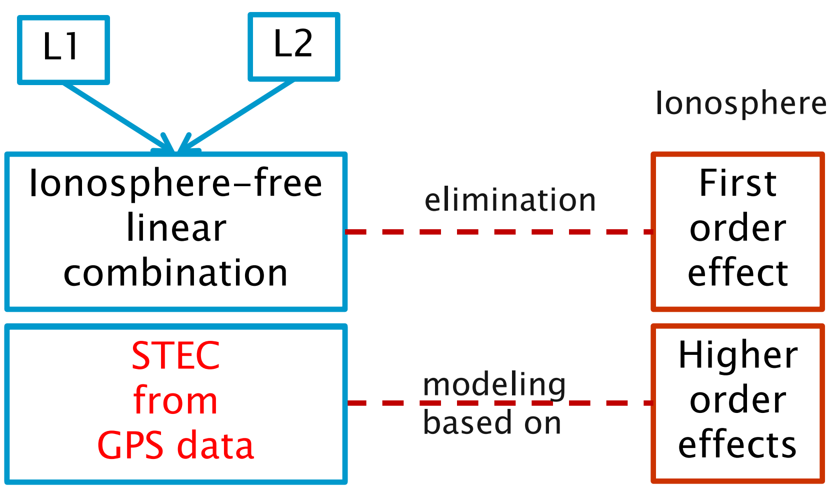
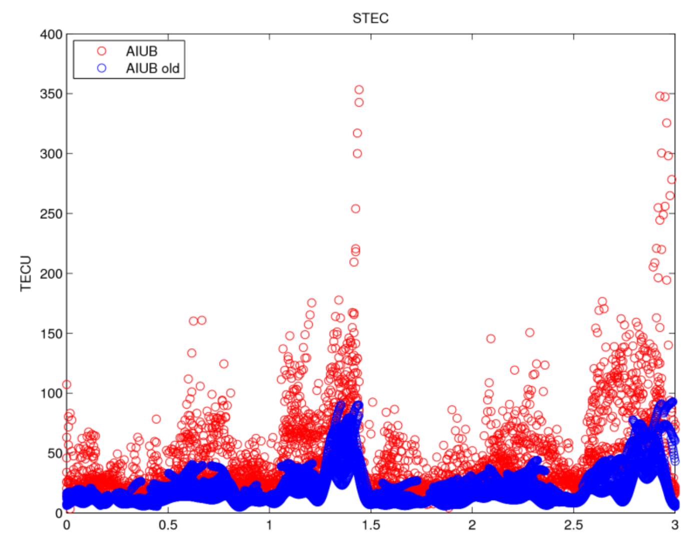
Attempts to model the systematic effects (1)

- **Conventional modeling of HOI correction terms does not show any improvements. Also the application of further HOI correction terms than recommended by the IERS Conventions 2010 does not bring any further improvements.**
- **Ionosphere delays (= slant TEC) need to be directly derived from the geometry-free linear combination to compute more realistic HOI correction terms.**





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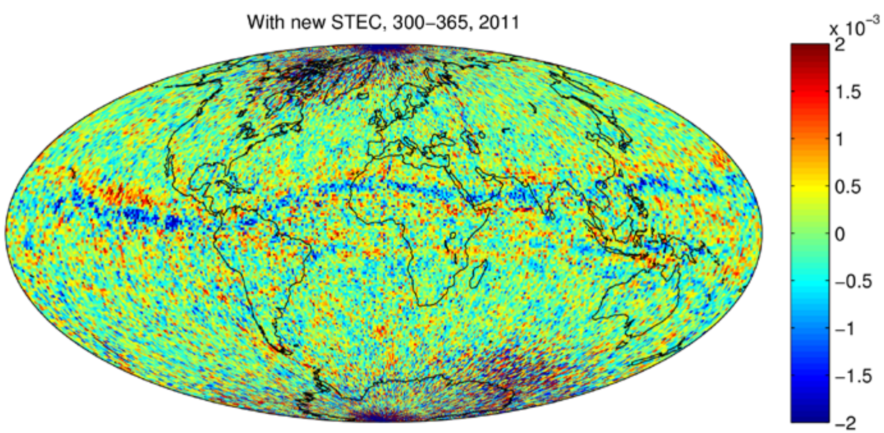
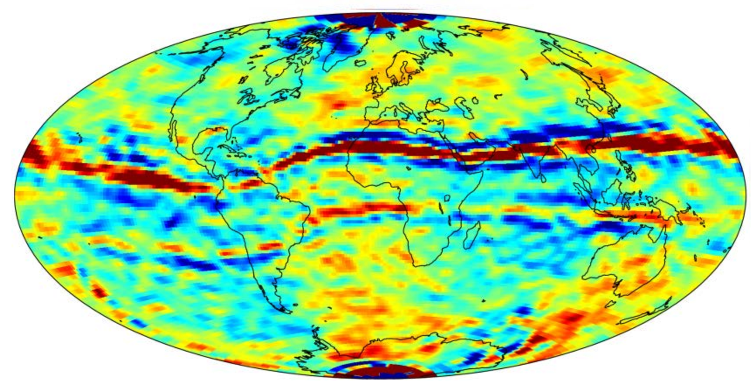
Attempts to model the systematic effects (2)

- STEC estimations are fed into the kinematic orbit determination instead of the global ionosphere map
- HOI correction terms are computed based on the STEC estimations
- Only partial reduction achieved so far in gravity field solutions



Phase observation residuals (– 2 mm … +2 mm) mapped to the ionosphere piercing point



Geoid height differences (–5 cm … 5 cm); Nov–Dec 2011

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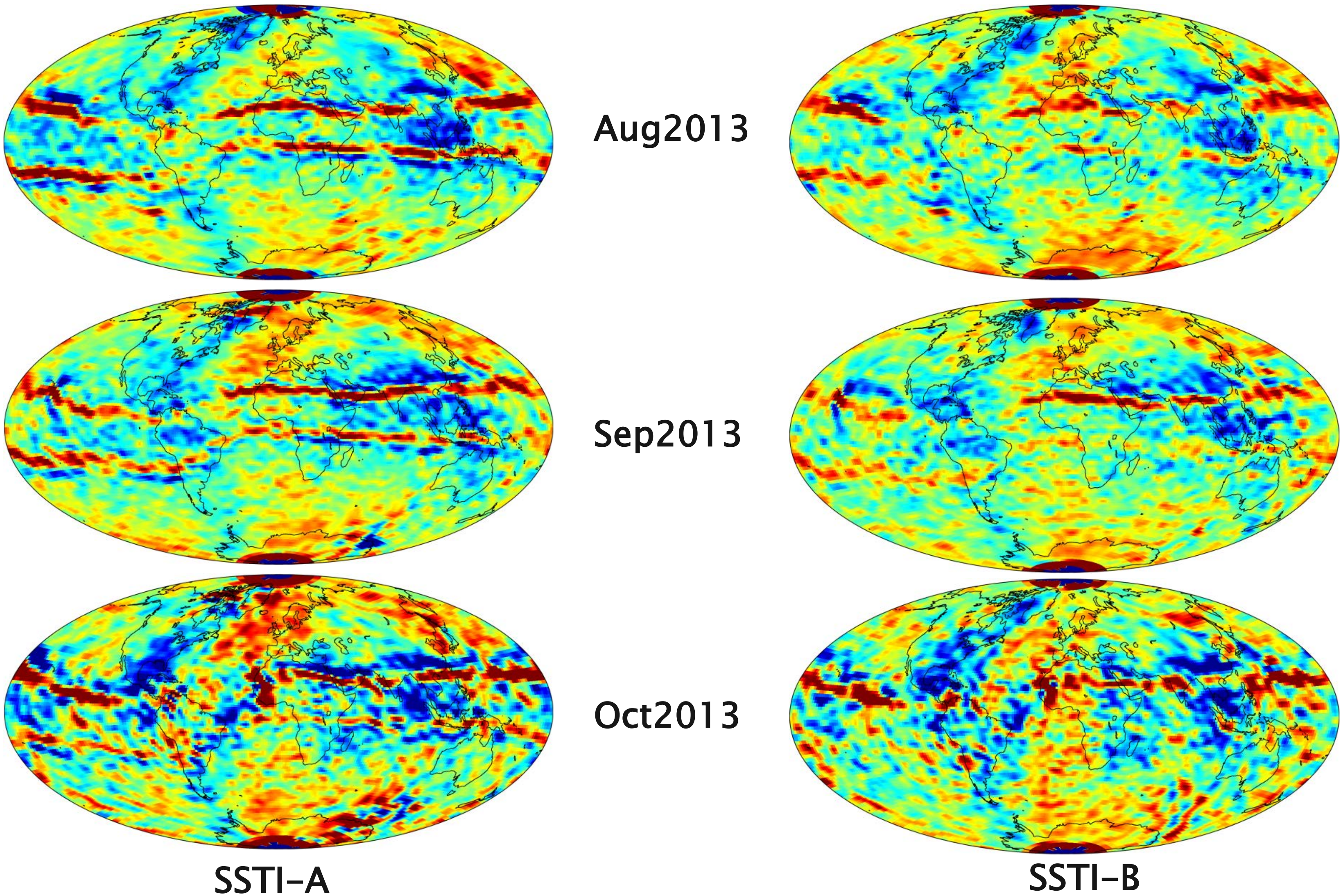
Solutions from different antennas



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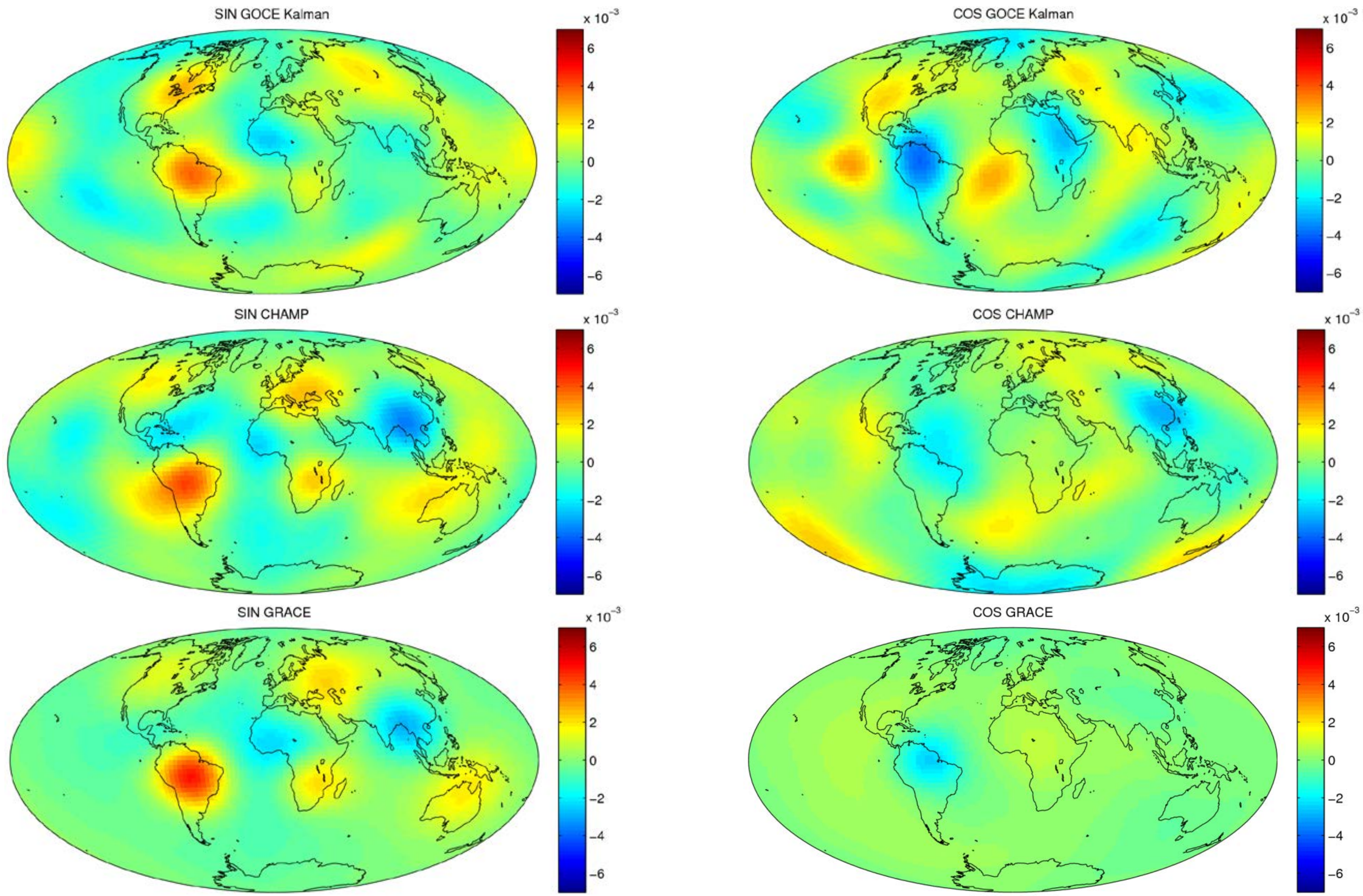
Time variability from GOCE, CHAMP, GRACE (1)



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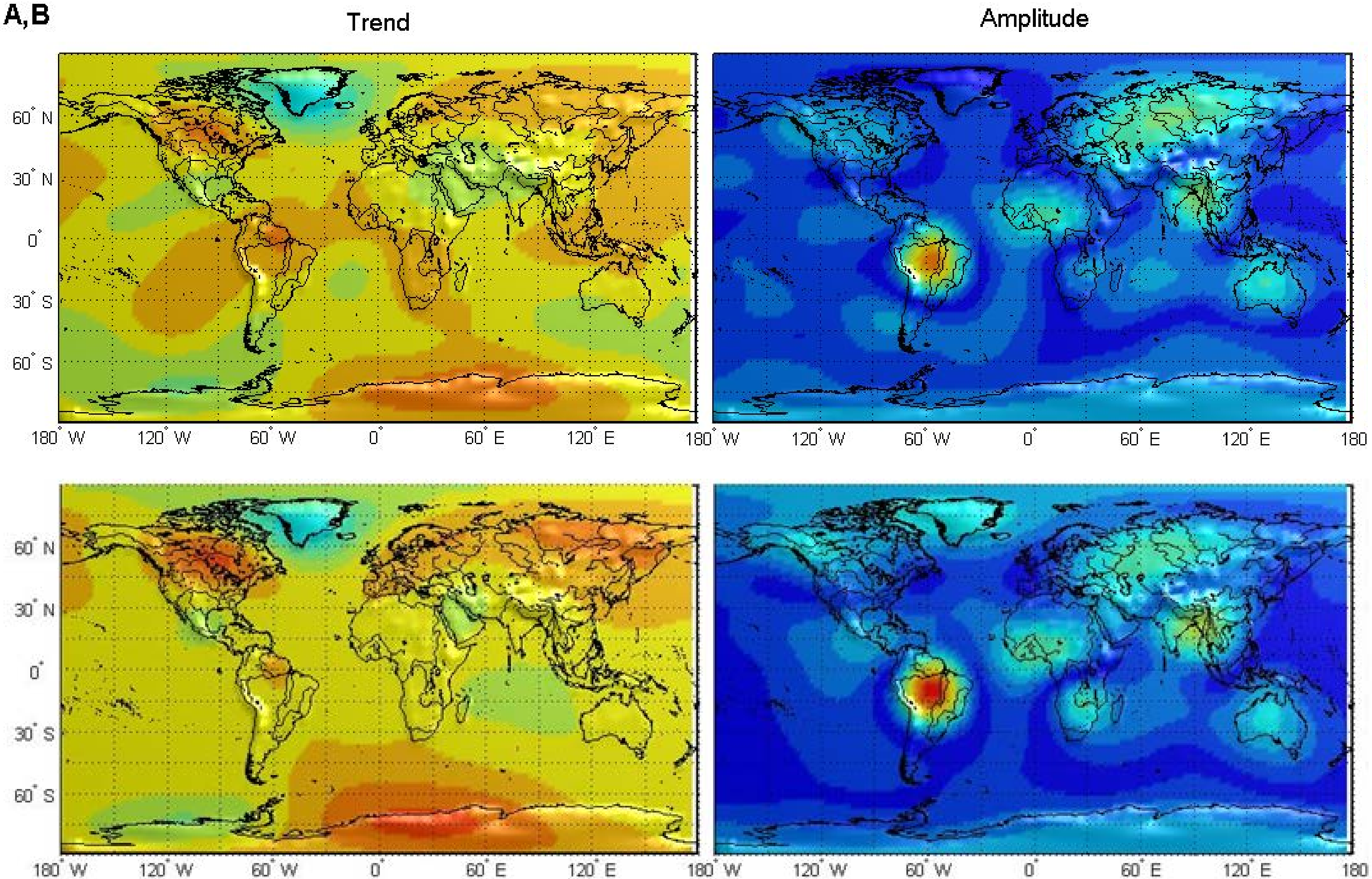
Time variability from GOCE, CHAMP, GRACE (2)

GOCE
GRACE A,B
CHAMP

GRACE
GFZ
Rel05a



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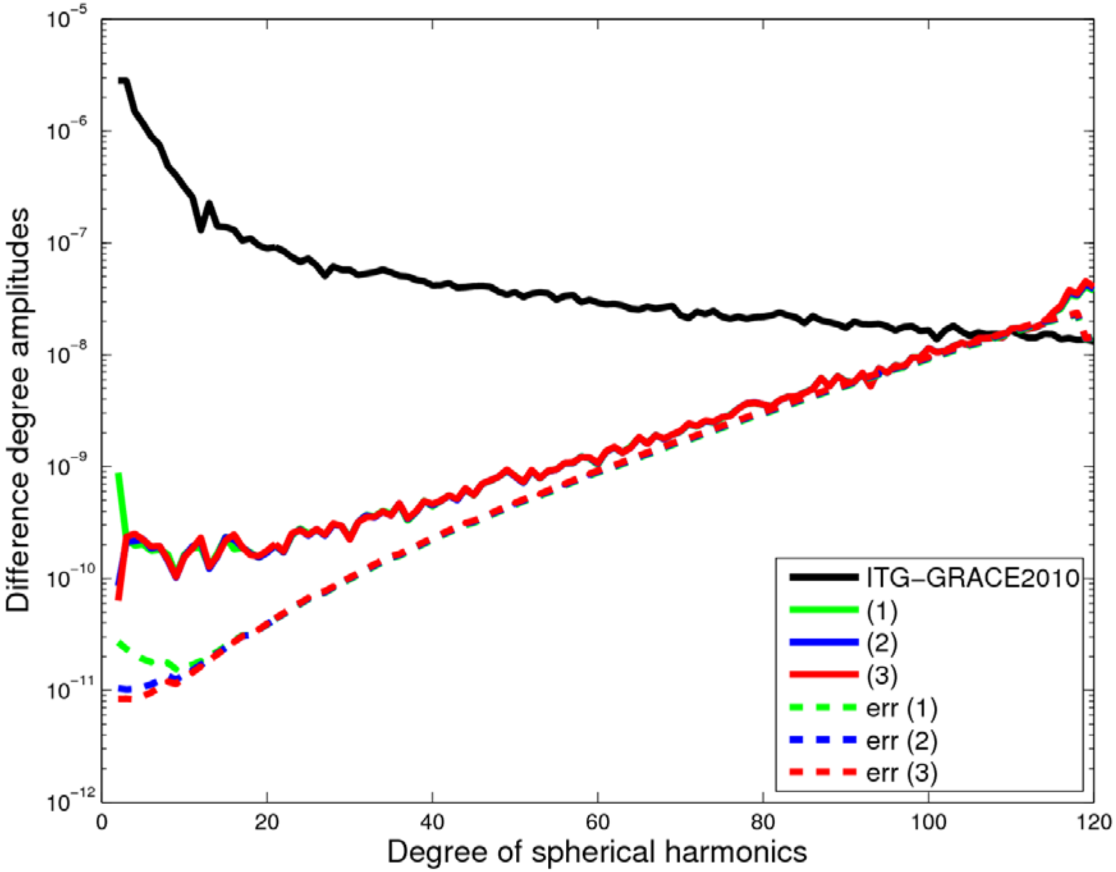
Summary

- Precise Science Orbits are of excellent quality
  - 1.84 cm SLR RMS for reduced-dynamic orbits
  - 2.42 cm SLR RMS for kinematic orbits
- Orbit quality is correlated with ionosphere activity
  - L2 losses over geomagnetic poles
  - Systematic effects around geomagnetic equator
- GPS-only gravity field solutions
  - Sensitivity at least up to d/o 120 (static part)
  - Limited sensitivity to annual time variable signals

Backup



Impact of accelerometer data and optimal constraining of empirical parameters.

=> Only very low degrees are affected.