GOCE Precise Science Orbits and their Contribution to Gravity Field Recovery

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PSD.1

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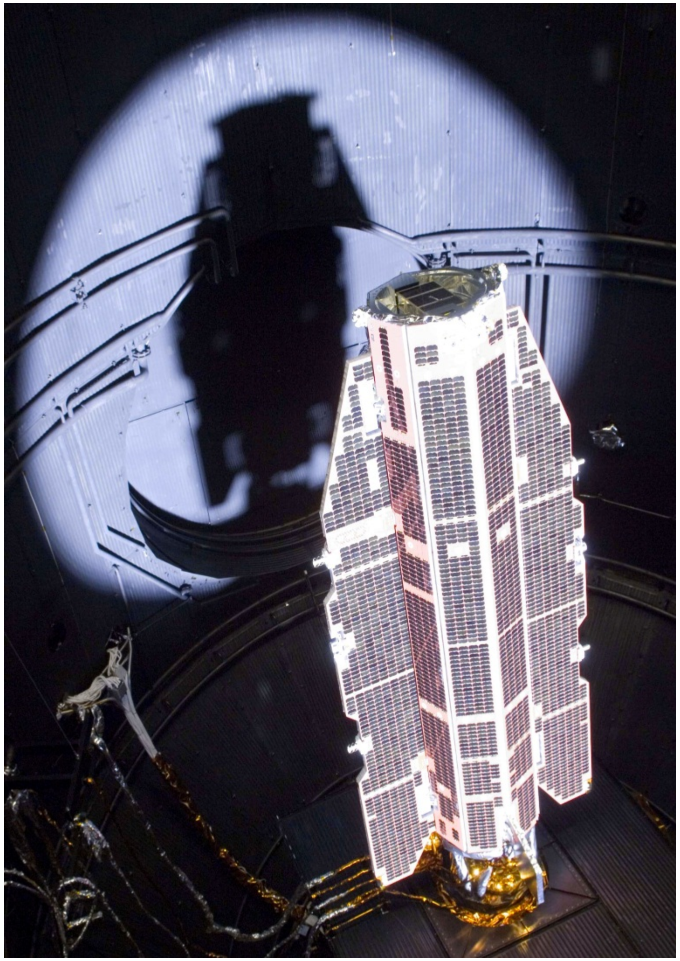
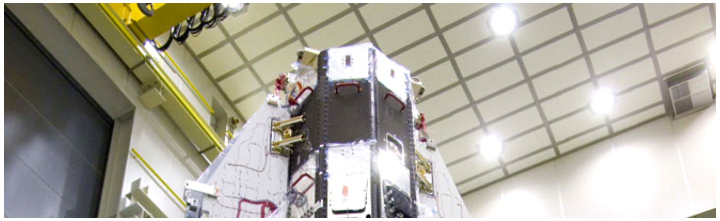
GOCE satellite mission (1)

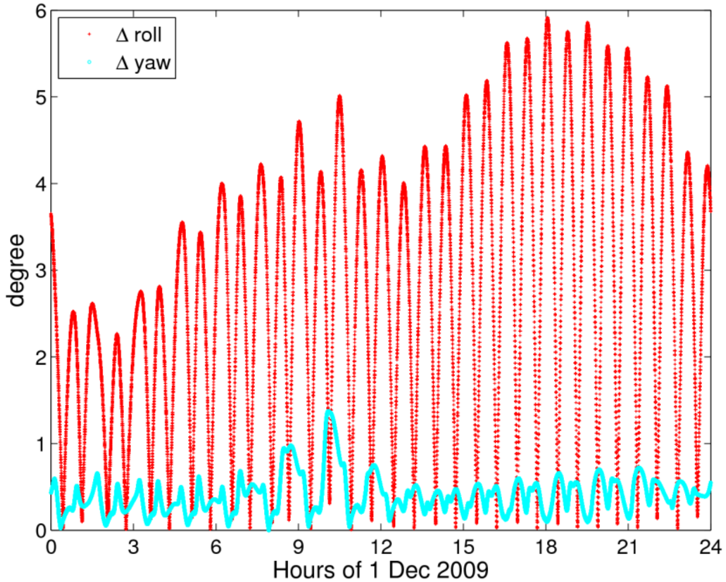


Courtesy: ESA

- **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 with inclination of 96.5^{o}**
- **Altitude: 254.9 km**
- **Mass: 1050 kg at launch**
- **5.3 m long, 1.1 m^2 cross section**

GOCE satellite mission (2)

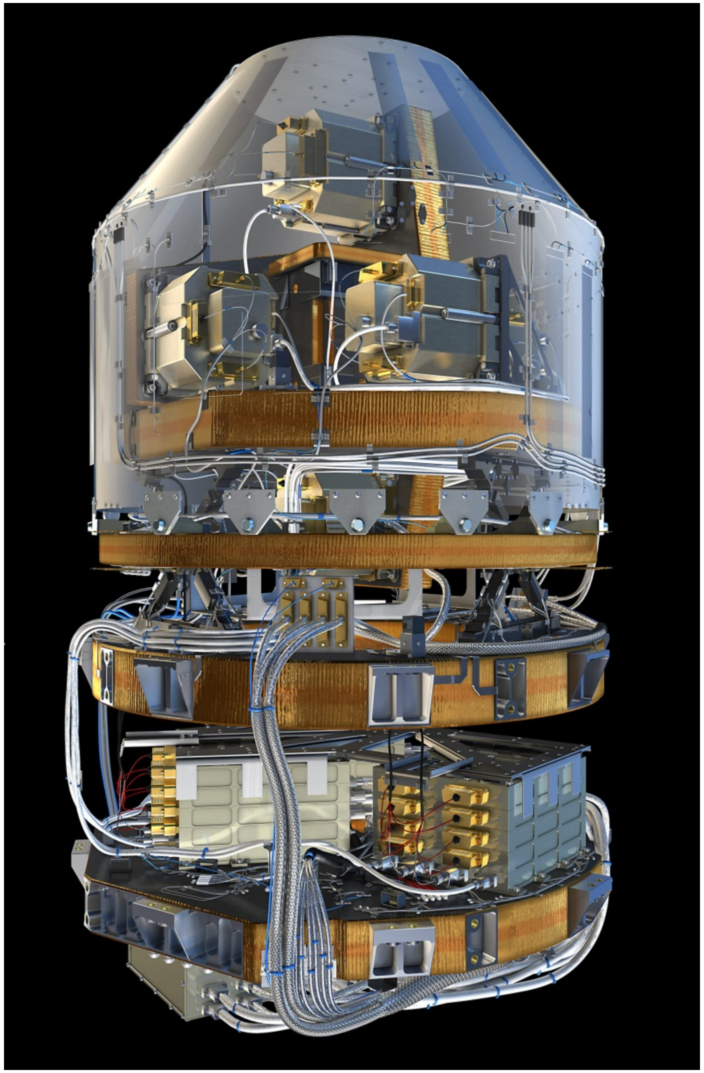




Courtesy: ESA

- **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**
- **=> used for orbit determination**

GOCE satellite mission (3)



Courtesy: ESA

Core Payload:

Electrostatic Gravity Gradiometer

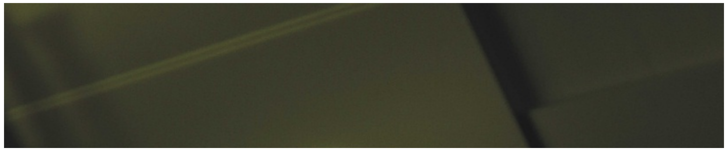
three pairs of accelerometers

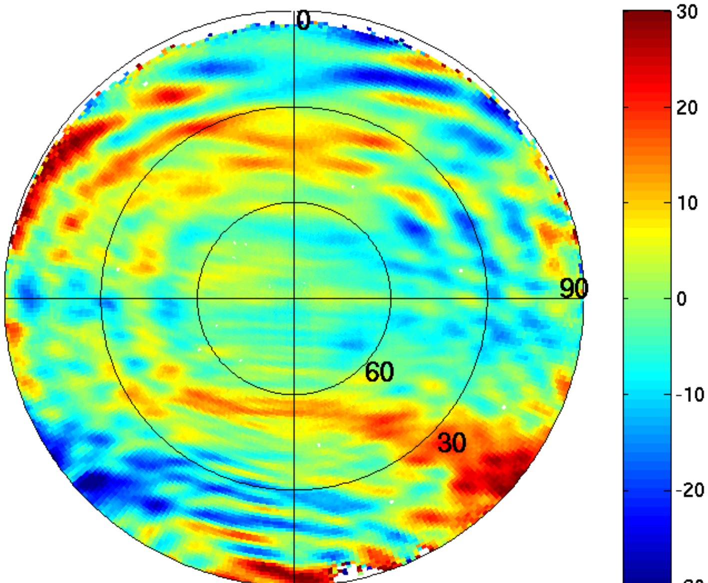
0.5 m arm length

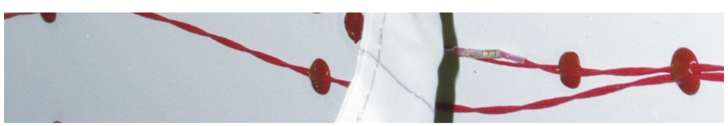
Main mission goals:

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

GOCE satellite mission (4)



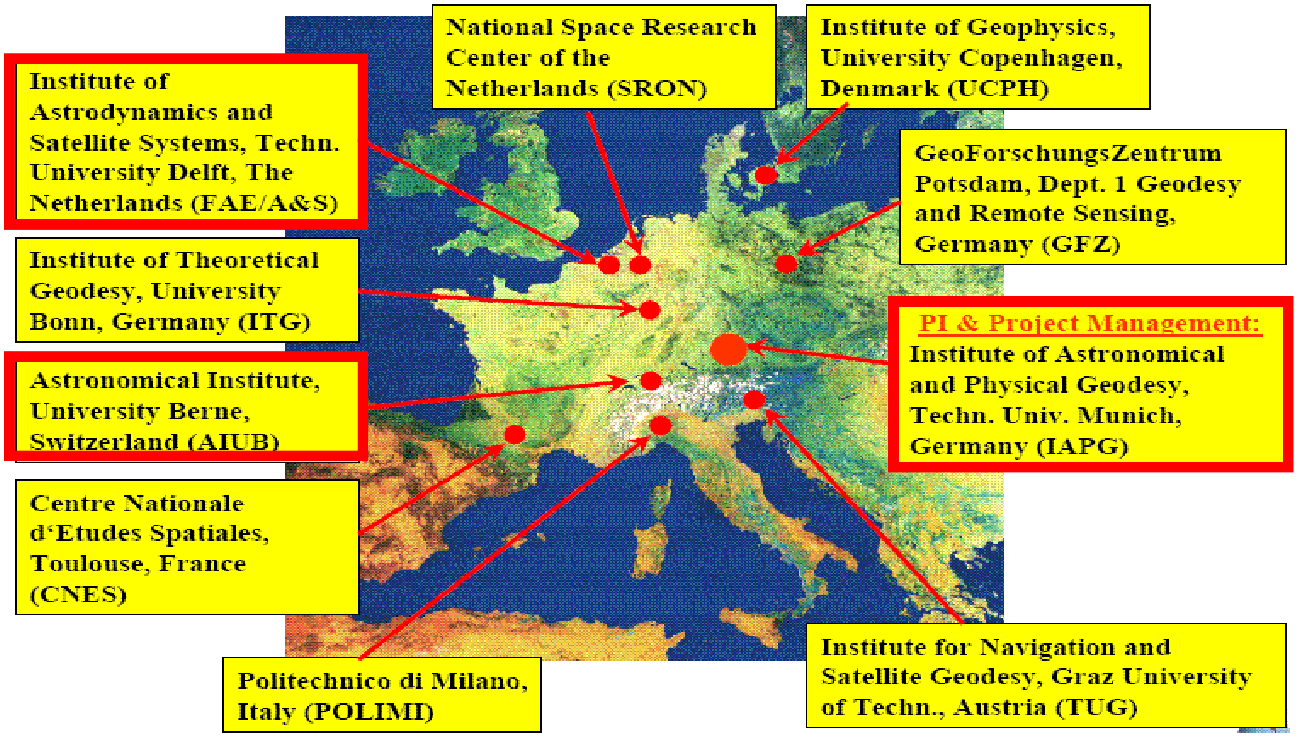




Courtesy: ESA

- Satellite-to-Satellite Tracking Instrument (SSTI)
- Dual-frequency L1, L2
- 12 channel GPS receiver
- Real time position and velocity (3D, 3 sigma < 100 m, < 0.3 m/s)
- 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)



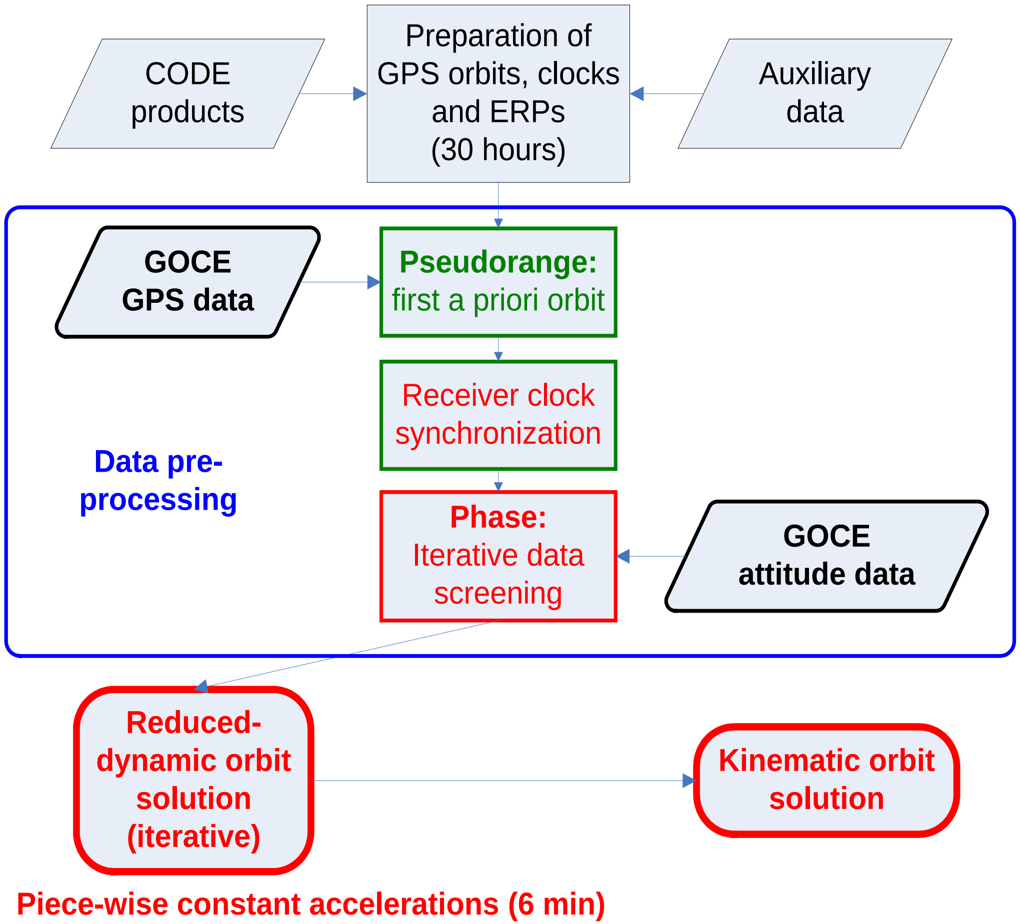
- **Responsibilities for orbit generation:**
- **DEOS:**

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

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

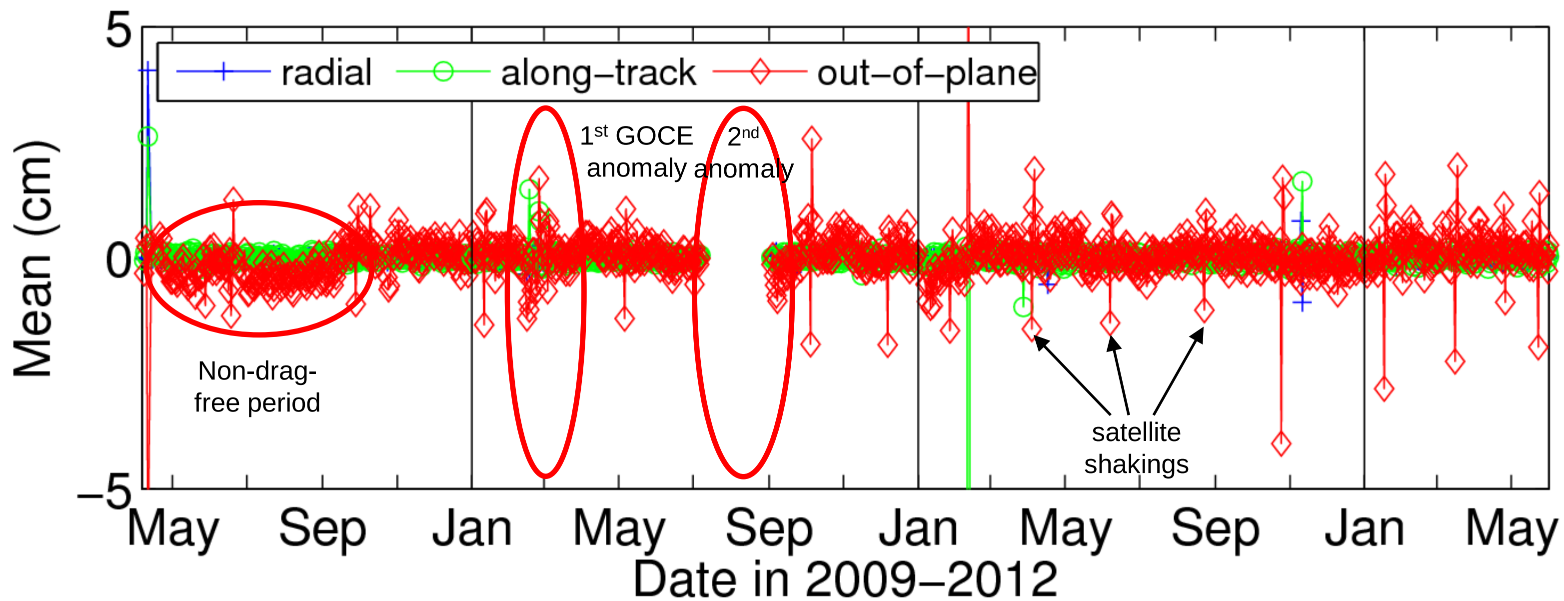
  => Validation

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**

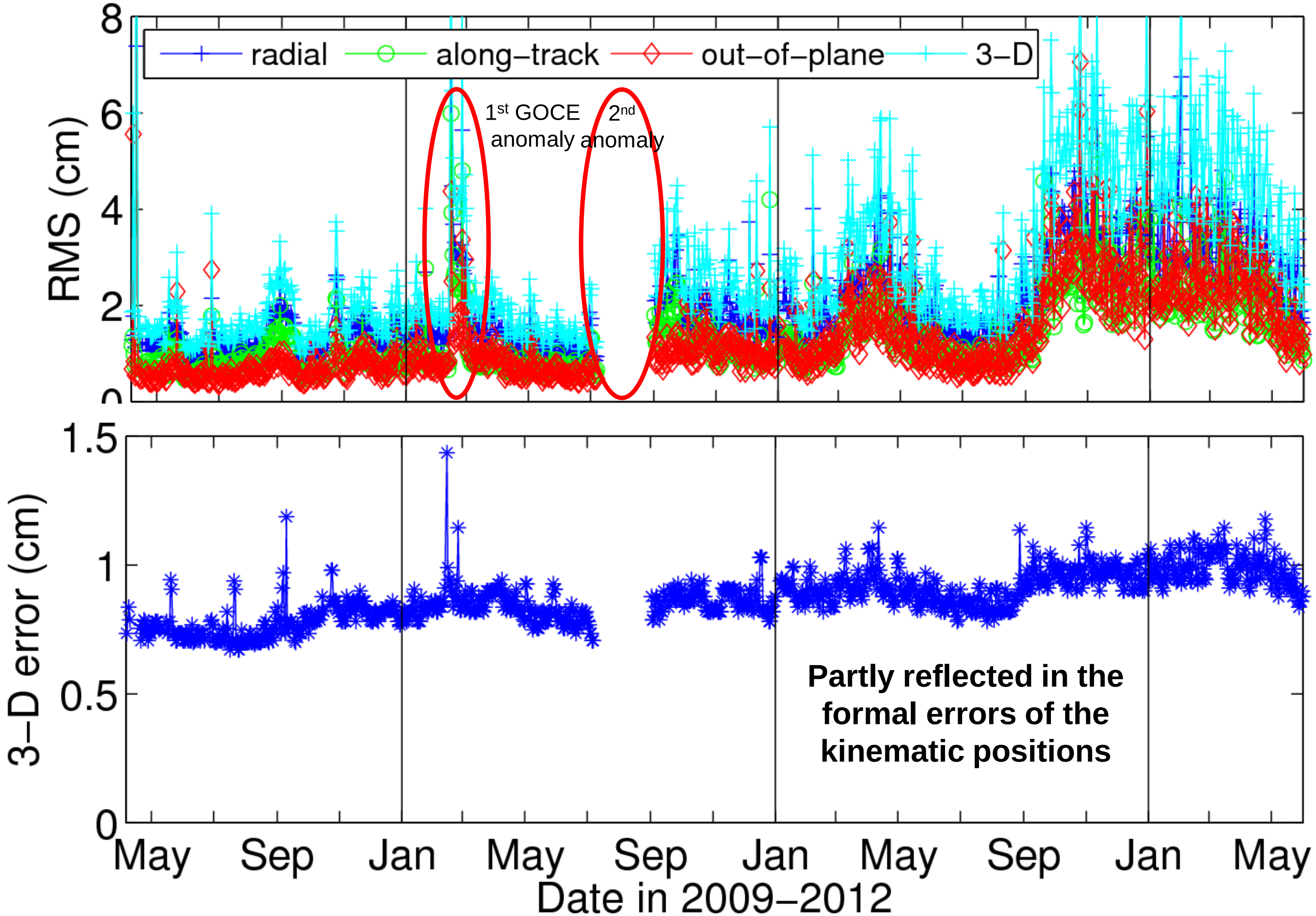
Overlaps of reduced-dynamic solutions



	2009:	2010:	2011:	2012:
RMS:	6.7 mm	6.8 mm	6.8 mm	7.1 mm
Mean: Out-of-plane	-1.5 mm	0.7 mm	0.2 mm	1.5 mm

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

Differences reduced-dynamic vs. kinematic

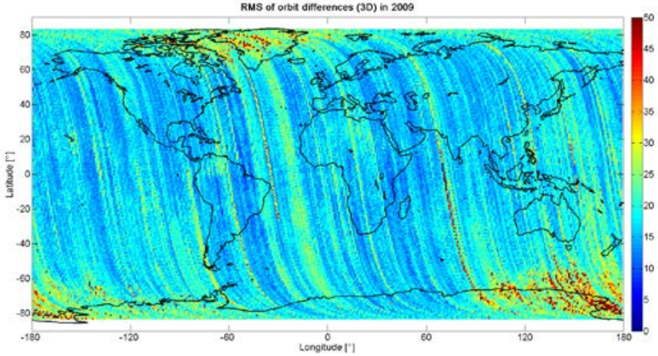


Partly reflected in the formal errors of the kinematic positions

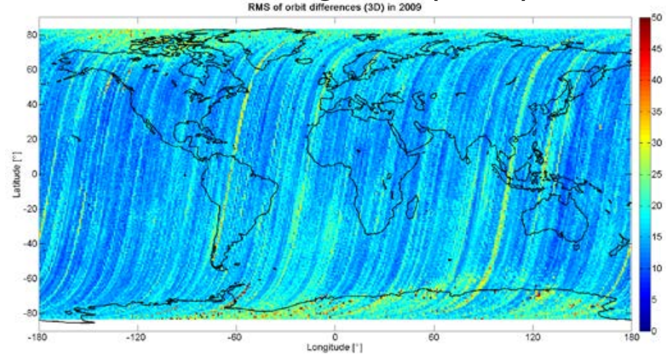
Differences reduced-dynamic vs. kinematic

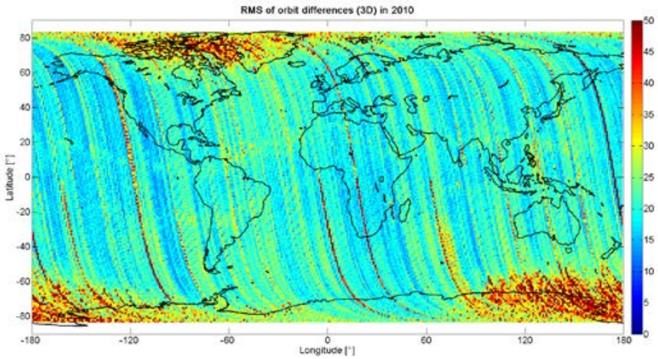
Ascending arcs (RMS)

Descending arcs (RMS)

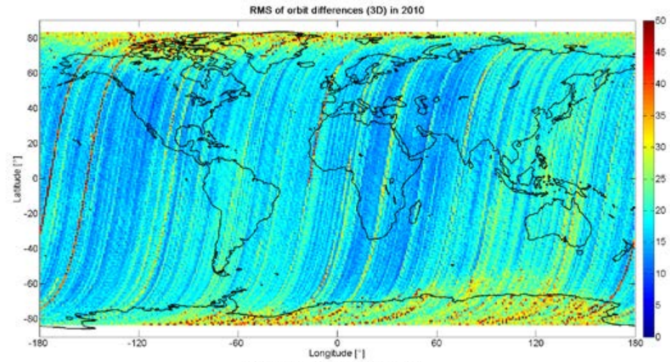


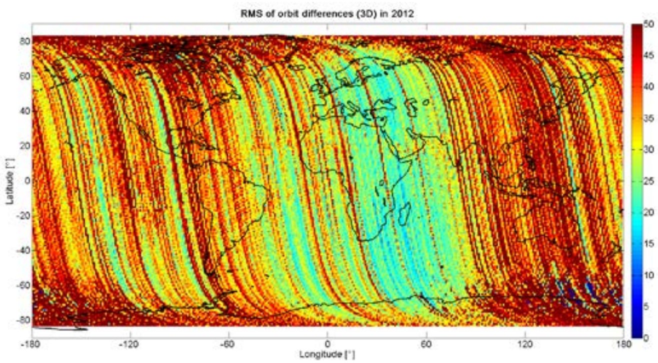
2009



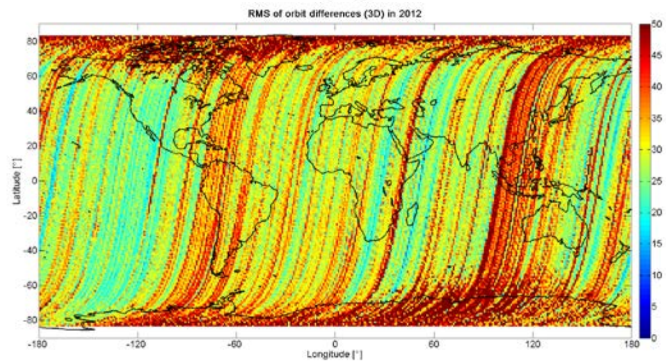


2010

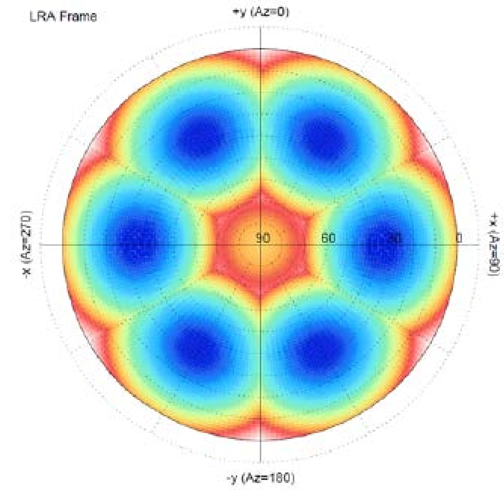




2012



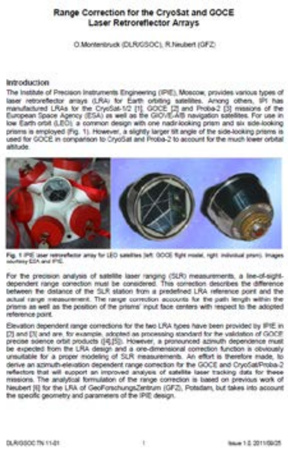
Orbit validation with SLR



Improved modeling of SLR observations:

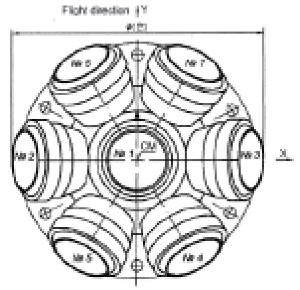
- **use of SLRF2008 coordinate set**
- **application of azimuth- & nadir-dependent range corrections**

Range corrections exhibit total variations of 5-7mm about the mean value. Details may be found in a Technical Note about the „Range Correction for the CryoSat and GOCE Laser Retro-reflector Arrays“ (Montenbruck & Neubert, 2011, DLR/GSOC TN 11-01).


Range Correction for the CryoSat and GOCE Laser Retroreflector Arrays

O.Montenbruck (DLR/GSOC), R.Neubert (GFZ)

Introduction

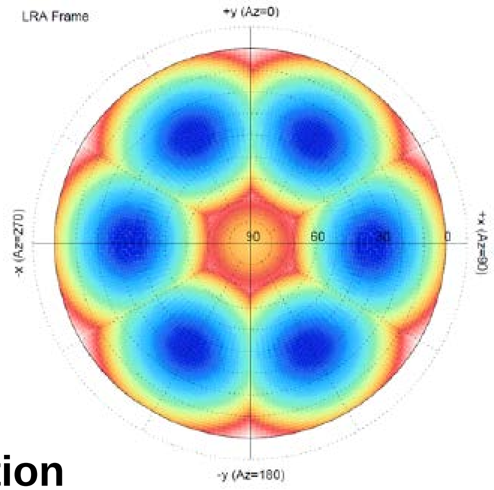


$$\Delta\rho_i = \left[L_i\sqrt{n_g^2 + (e^T n_i)^2 - 1}\right] - \left[e^T r_i\right]$$

Orbit validation with SLR

Improved modeling of SLR observations:

- **use of SLRF2008 coordinate set**
- **application of azimuth- & nadir-dependent range corrections**



(A): - SLRF2005
- no correction

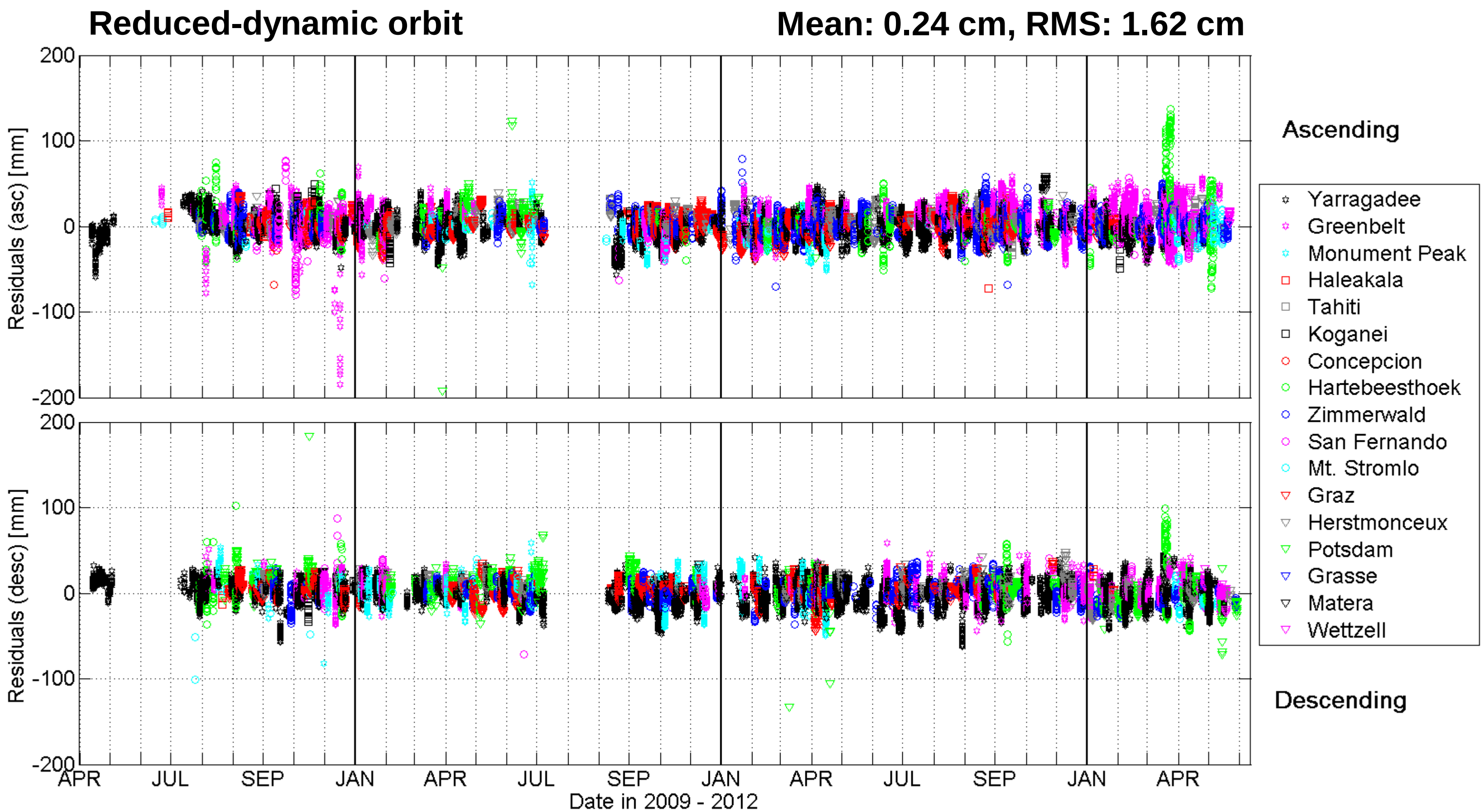
(B): - SLRF2008
- no correction

(C): - SLRF2008
- with correction

SLR validation (cm) of red.-dyn. solutions (DOYs 251,2010 – 226,2011):

	Mean	**STD**
(A)	**0.37**	**1.62**
(B)	**0.52**	**1.45**
(C)	**0.01**	**1.44**

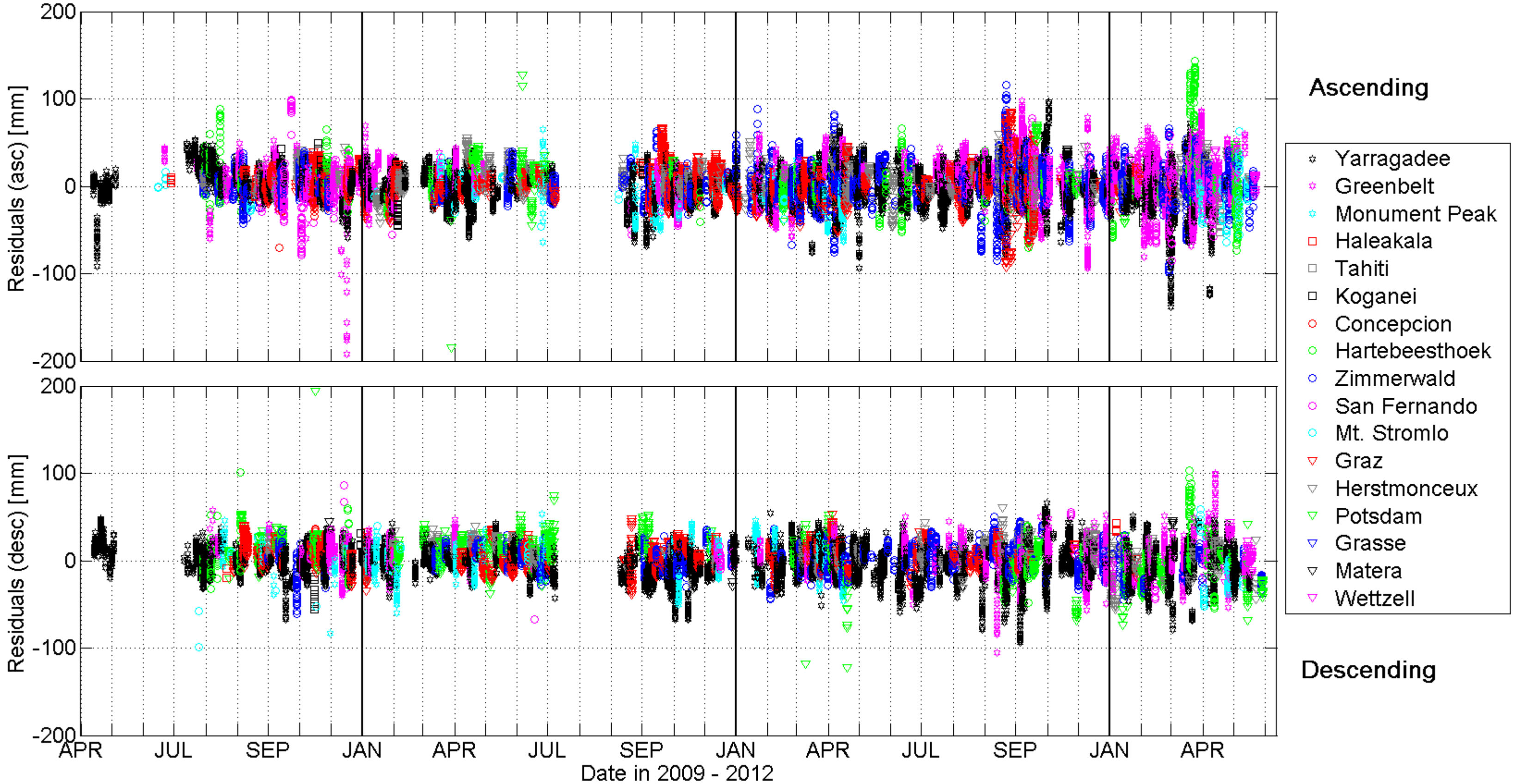
Orbit validation with SLR



	2009:	2010:	2011:	2012:
RMS:	1.61 cm	1.44 cm	1.99 cm	2.05 cm
Mean:	0.46 cm	0.13 cm	0.25 cm	0.13 cm

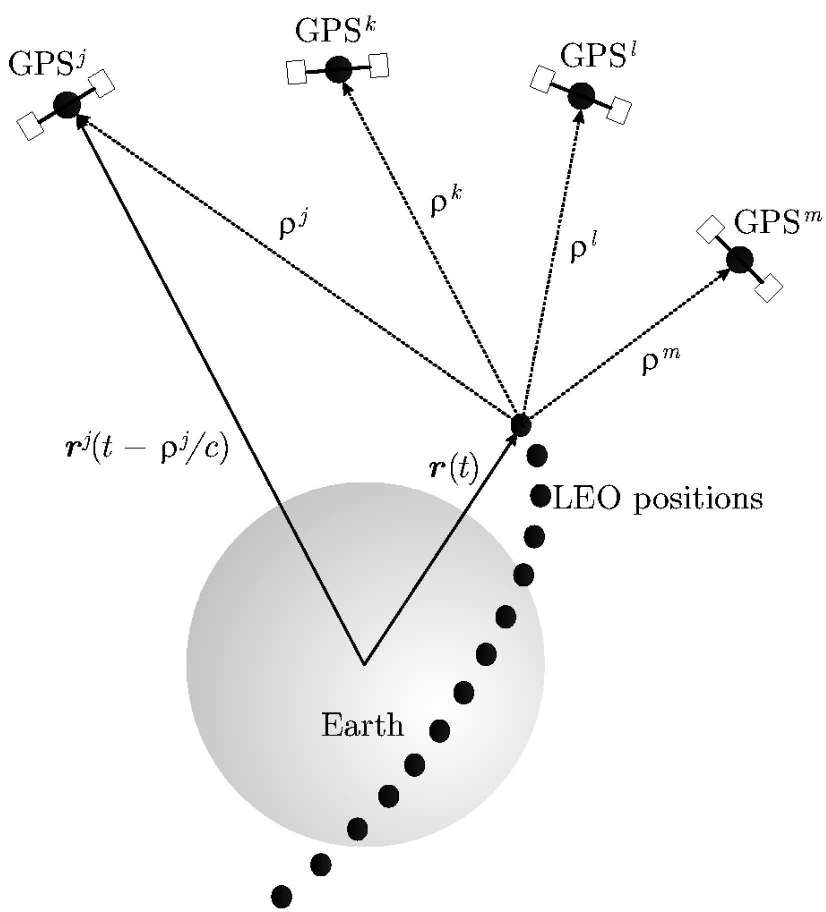
Orbit validation with SLR

Kinematic orbit **Mean: 0.15 cm, RMS: 2.23 cm**



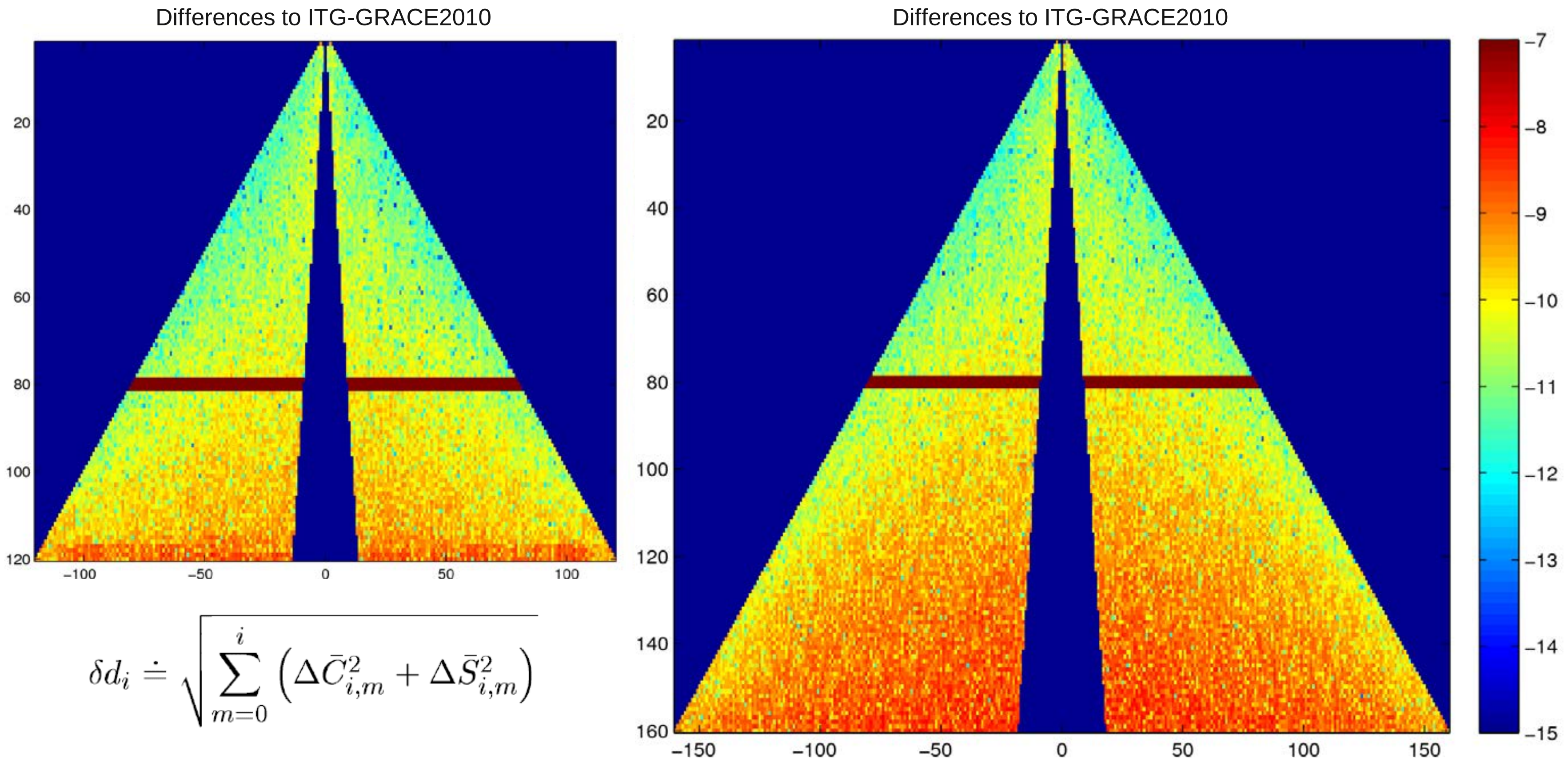
	2009:	2010:	2011:	2012:
RMS:	1.89 cm	1.76 cm	2.63 cm	3.00 cm
Mean:	0.49 cm	0.10 cm	0.15 cm	-0.24 cm

Gravity field recovery



- **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**
- **Gravity field coefficients are either solved for up to d/o 120 or d/o 160 without applying any regularization**

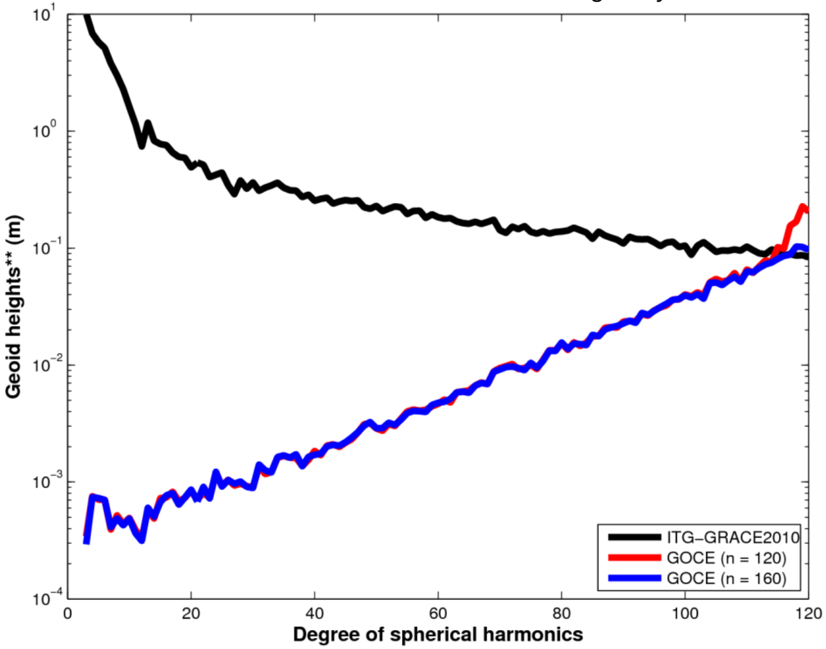
Impact of polar gap



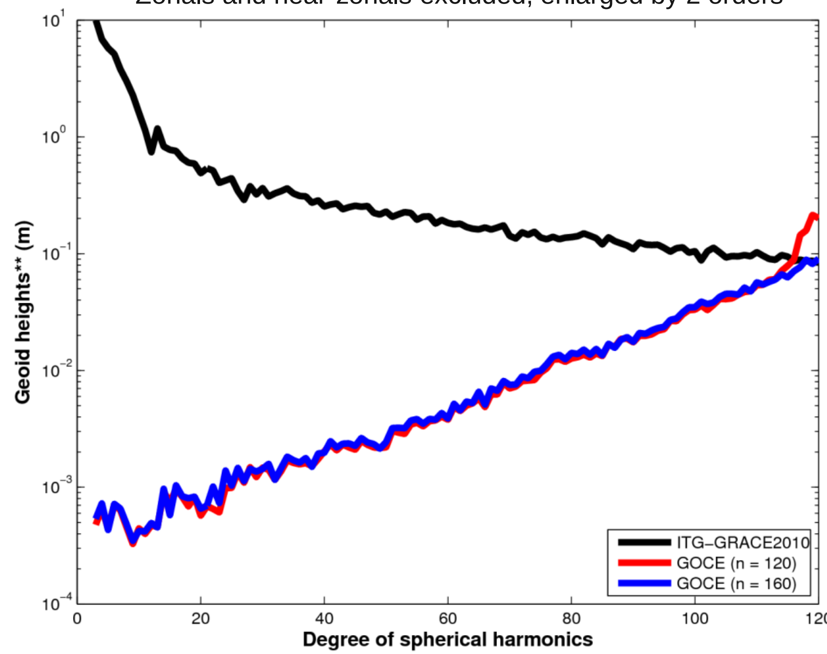
$$\delta d_i \doteq \sqrt{\sum_{m=0}^{i} \left(\Delta \bar{C}_{i,m}^2 + \Delta \bar{S}_{i,m}^2 \right)}$$

- **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)**

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

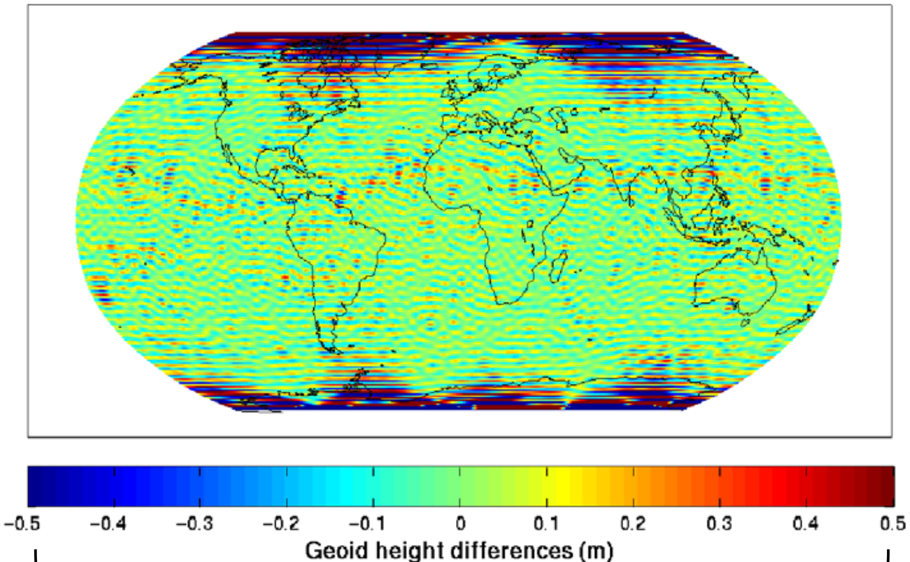


- Stronger artifacts in 2010 , …
- …, but again mostly related to near-zonal coefficients, which are very sensitive to the increasing data problems such as the L2 losses

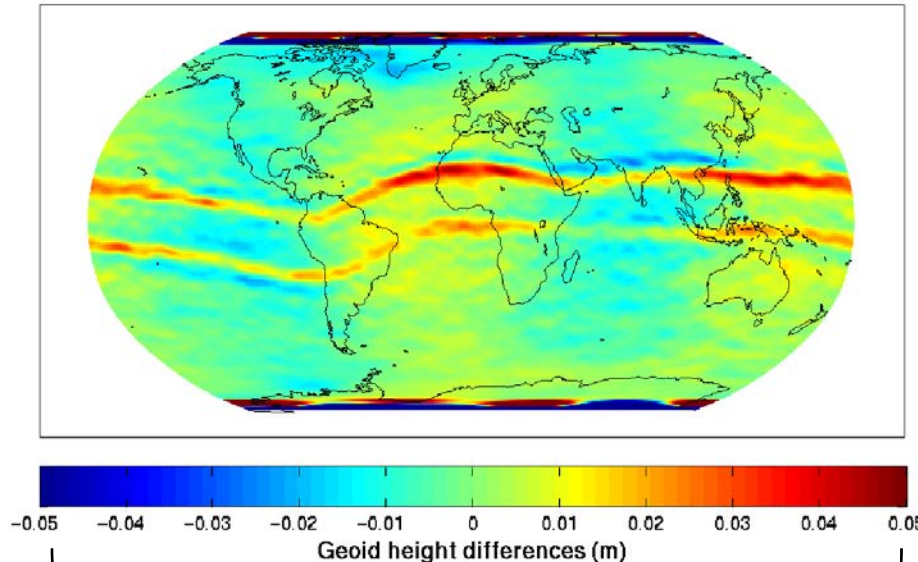
Solution characteristics

Differences to ITG-GRACE2010

unfiltered, d/o 100



300 km Gauss-filtered



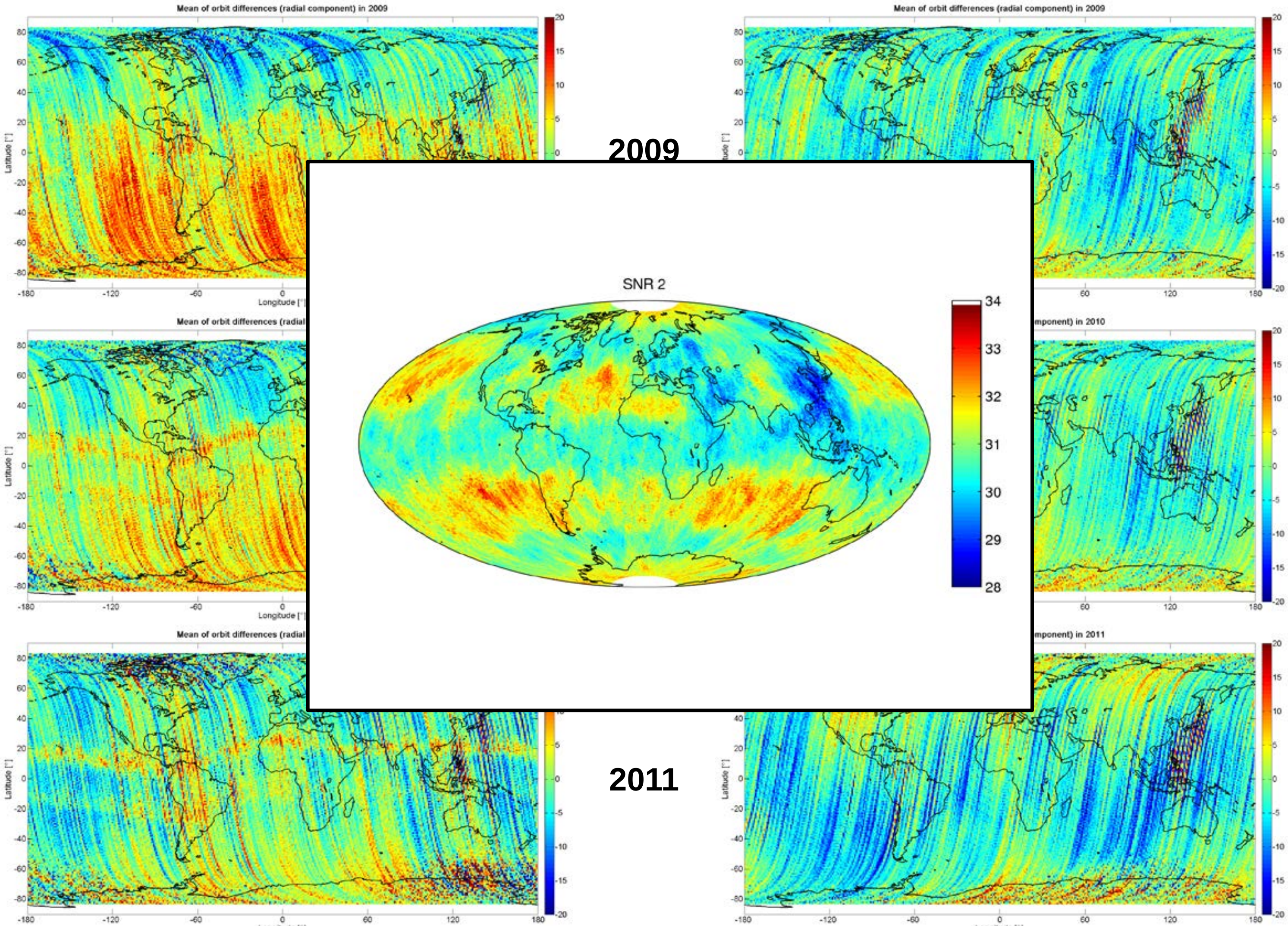
increased noise over polar regions

magnetic equator visible

	2009:	**2009-10:**	**2009-11:**
RMS (unfiltered):	113.3 cm	76.1 cm	38.9 cm
RMS (filtered):	4.9 cm	3.1 cm	2.0 cm

Differences reduced-dynamic vs. kinematic

Ascending arcs (mean) | Descending arcs (mean)



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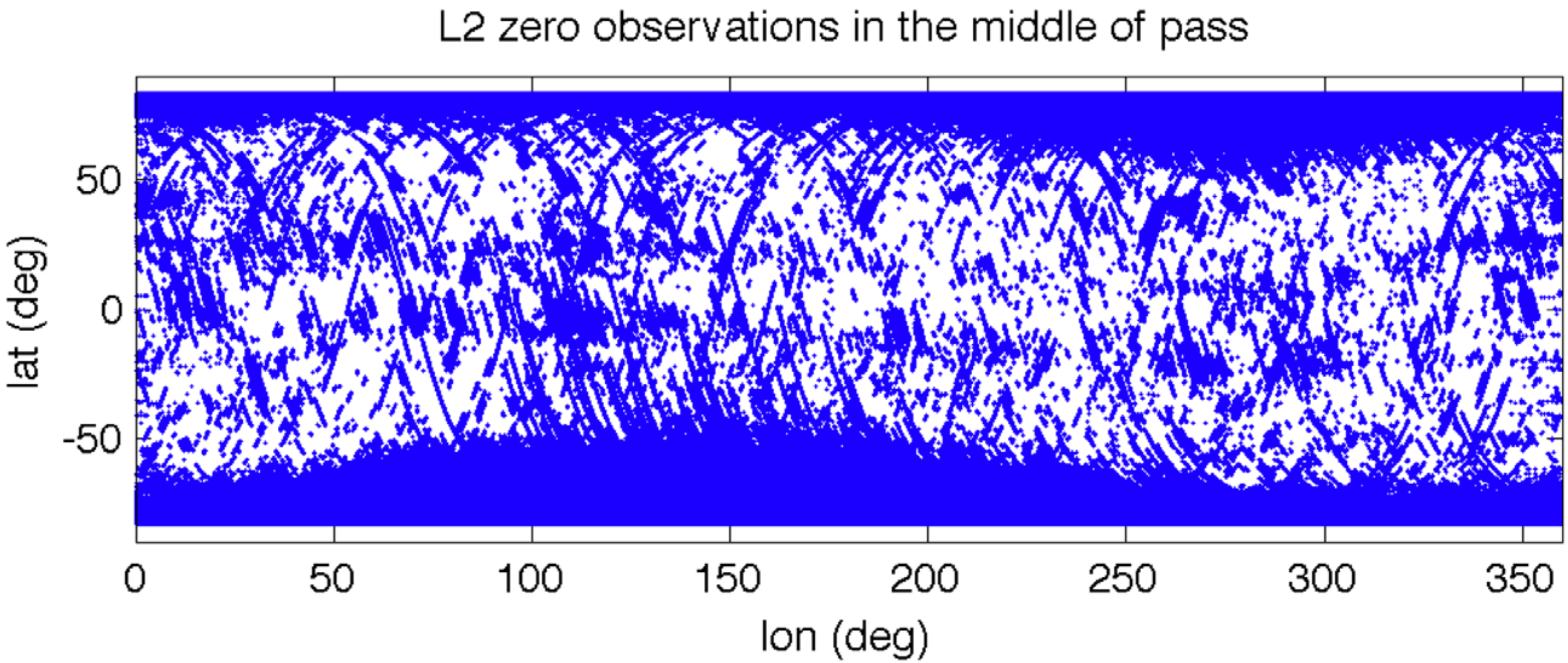
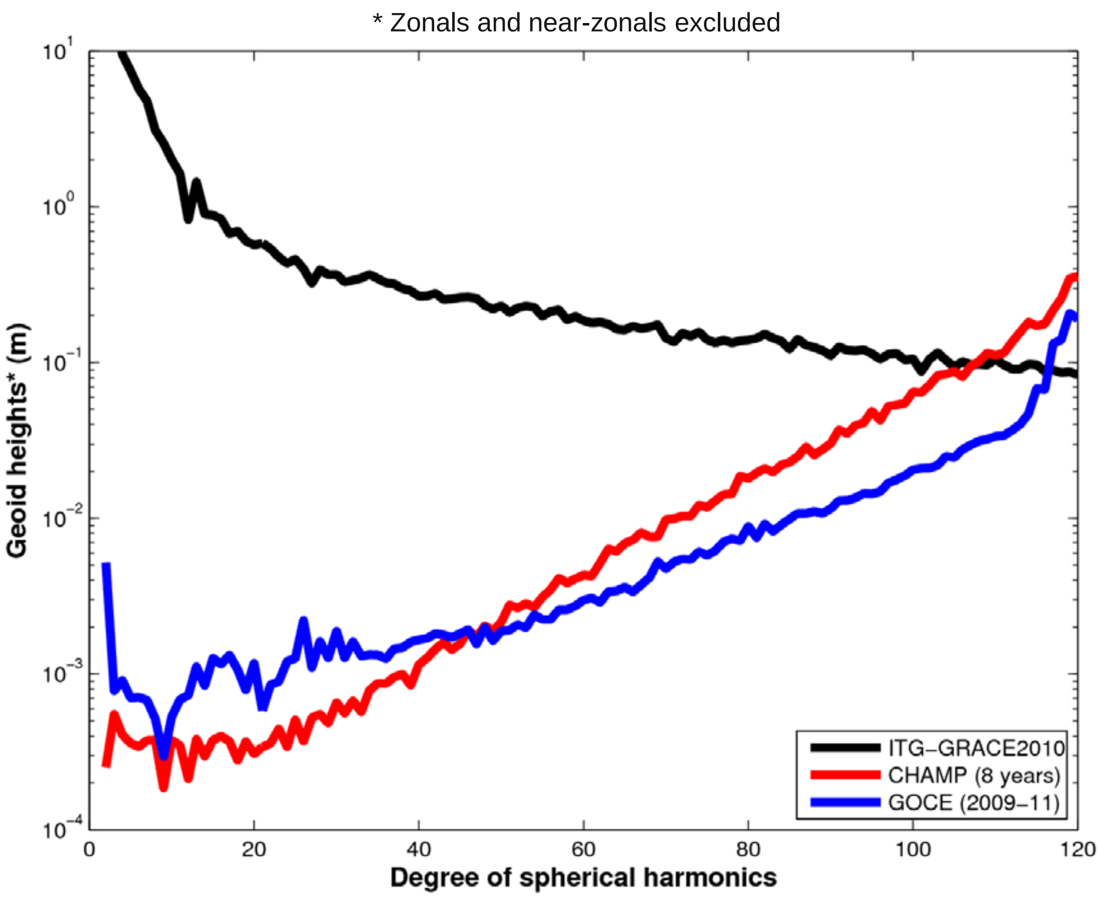
Missing L2 data



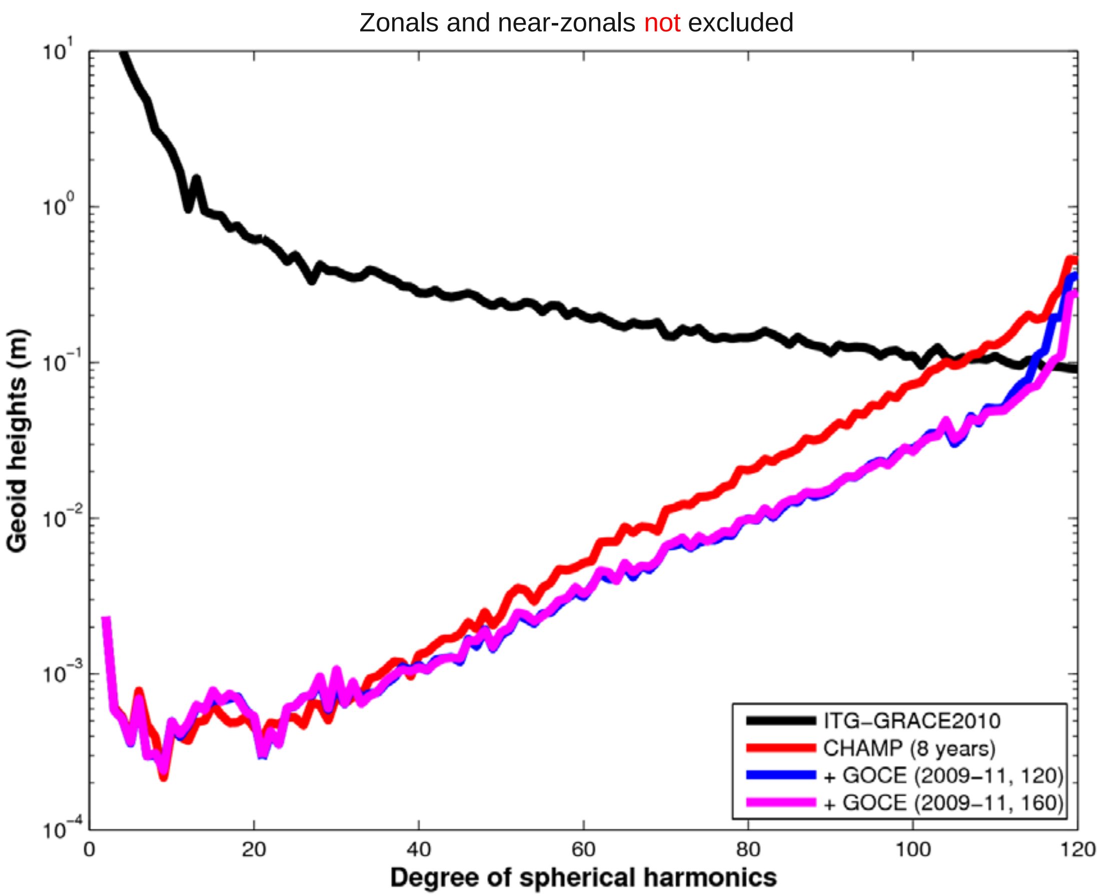
Zero L2 observations during middle of a pass mostly occur at geomagnetic poles as well as on both sides of the geomagnetic equator

Comparison with CHAMP gravity field recovery



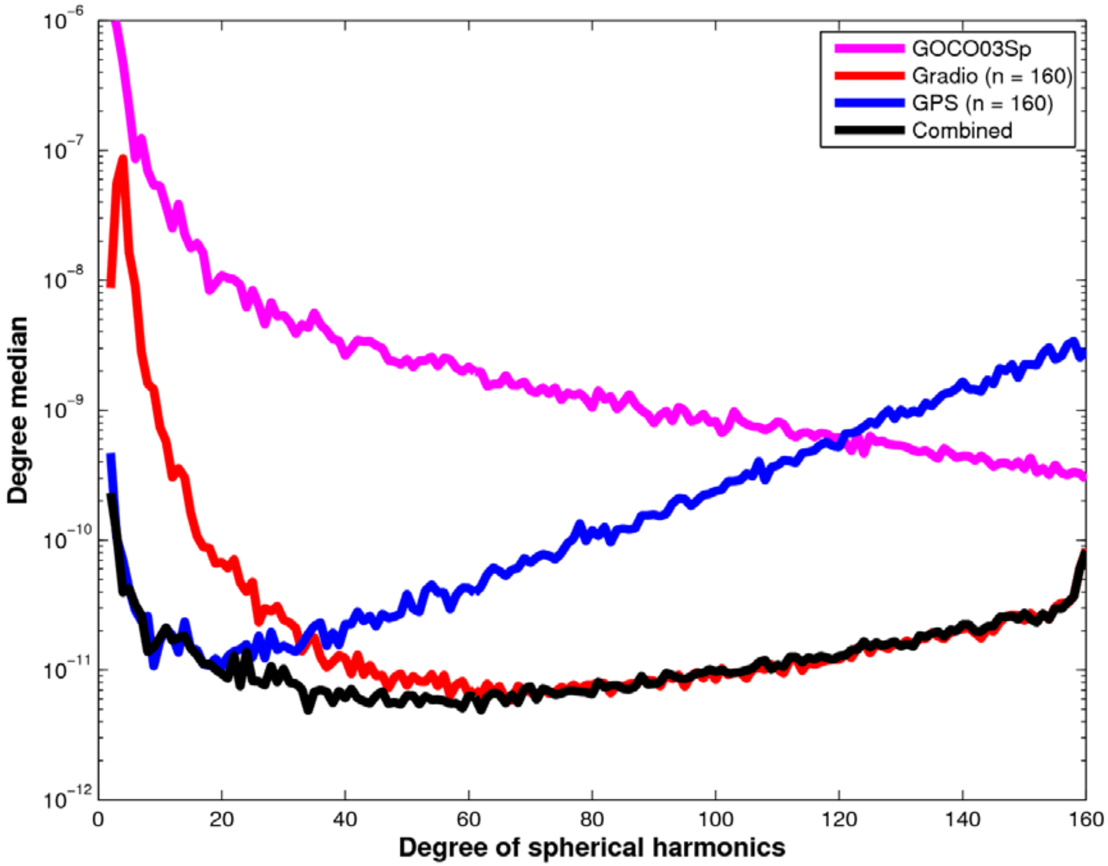
- Better recovery of high degrees from GOCE due to lower orbital altitude
- Better recovery of low degrees from CHAMP due to longer data period

Combination with CHAMP multi-year solution



- **Down-weighting of the GOCE normal equations is required due to an only marginal contribution of the 1-sec data wrt 5-sec sampled data**
- **No degradation due to the polar gap in the combined solution**
- **Small degradation when including the most recent GOCE data**

Impact on gradiometer solution



- **8 months of GPS and gradiometer data used**
- **GPS dominates the combination up to about degree 20 and contributes up to about degree 70**
- **No omission artifacts in the combined solution when using GPS beyond degree 120. No need to artificially down-weight the GPS contribution**

Conclusions

- Precise Science Orbits are of excellent quality
  - 1.62 cm SLR RMS for reduced-dynamic orbits
  - 2.23 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
  - Contribution to gradiometer solution up to d/o 70