GOCE Precise Science Orbits

Impact of GPS antenna phase center variations on the GOCE satellite orbits

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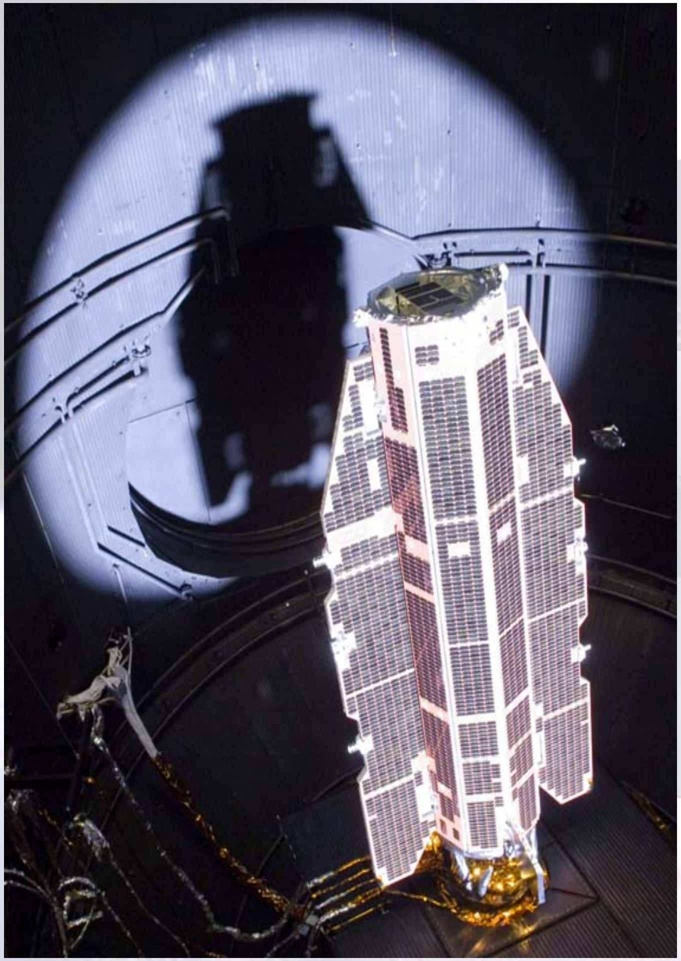
Outline

- GOCE satellite mission
- GOCE High-level Processing Facility (HPF)
    - Orbit products
- Precise Science Orbits (PSOs)
    - Antenna phase center variations (PCVs)
    - Results
- Summary

GOCE satellite mission (1)



Courtesy:ESA

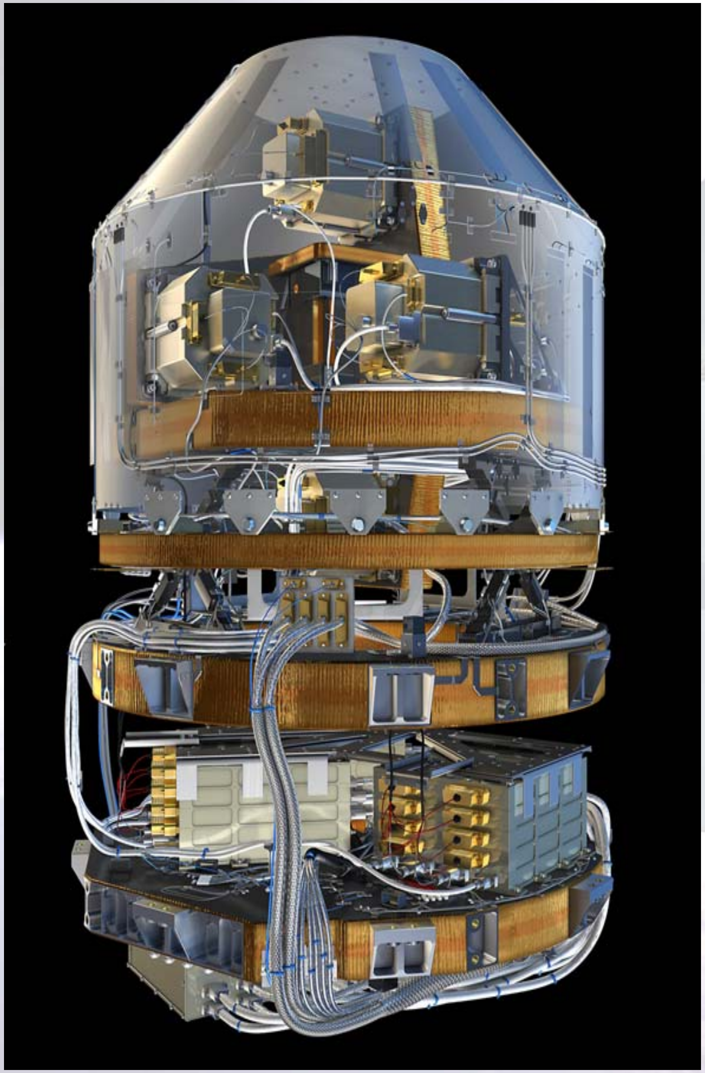
- Gravity and steady-state Ocean Circulation Explorer
- First Earth Explorer of the Living Planet Program of the European Space Agency
- Launch: **17 March 2009** from Plesetsk, Russia
- Sun-synchronous orbit with inclination of 96.5^{o}
- Altitude: 254.9 km
- Mass: 1050 kg at launch
- 5.3 m long, 1.1 m^2 cross section

GOCE satellite mission (2)

Courtesy:ESA

- 3 axis stabilised, 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

GOCE satellite mission (3)



Courtesy:ESA

Core Payload:

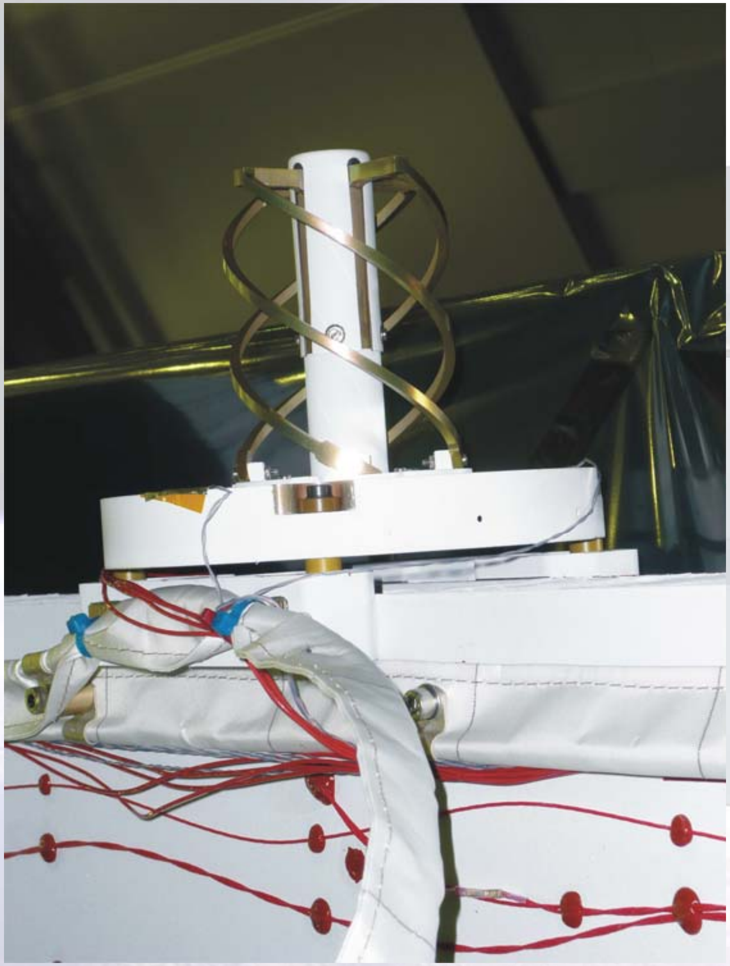
Electrostatic Gravity Gradiometer

- 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
- Determination of the geoid on the 1 cm-level with a spatial resolution of 100 km

GOCE satellite mission (4)



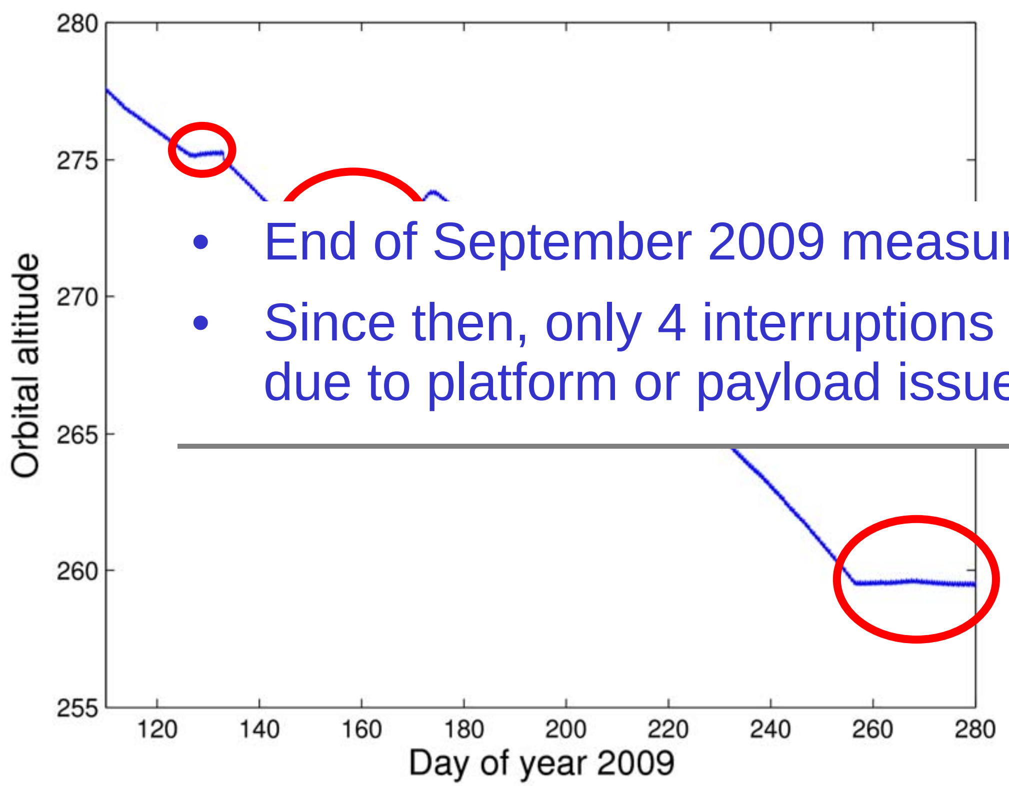
Courtesy:ESA

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
- Science and real time on board solution for navigation
- Hardly any data gaps

=> Mission requirement for precise science orbits: 2 cm (1D)

GOCE satellite mission (5)



- End of September 2009 measurement phase has started.
- Since then, only 4 interruptions of the measurement phase due to platform or payload issues occured.

GOCE „History“:

17 March:

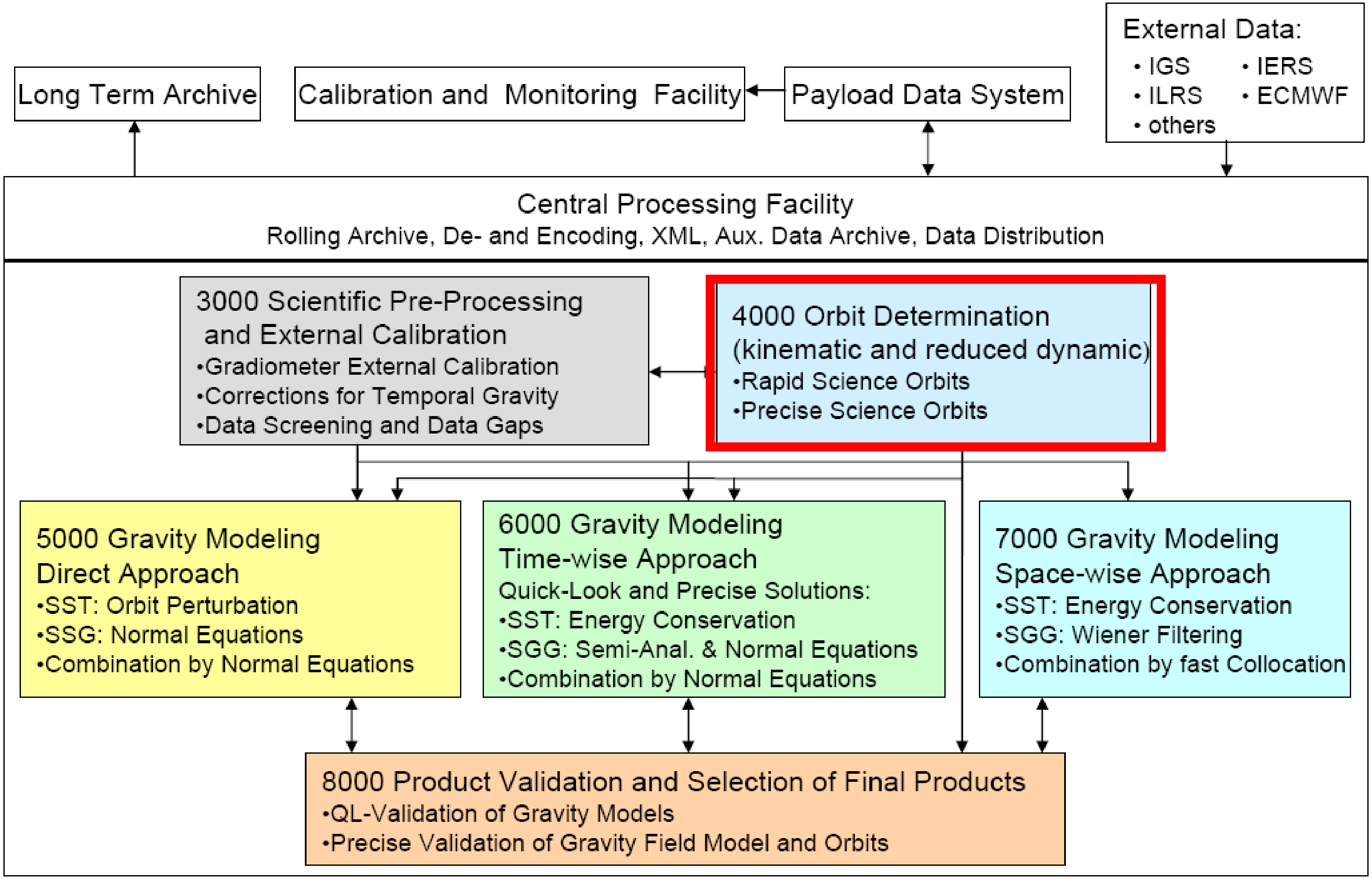
Launch into a sun-synchronous (i ~ 97°), dusk-dawn orbit at an altitude of 287.9 km

Second drag-free flight with various activities on gradiometer calibration

13/14 September:

Arrival at final orbital altitude of 259.6 km (254.9 km), start of drag-free flight for Measurement and Operational Phase (MOP)

GOCE High-level Processing Facility (HPF)



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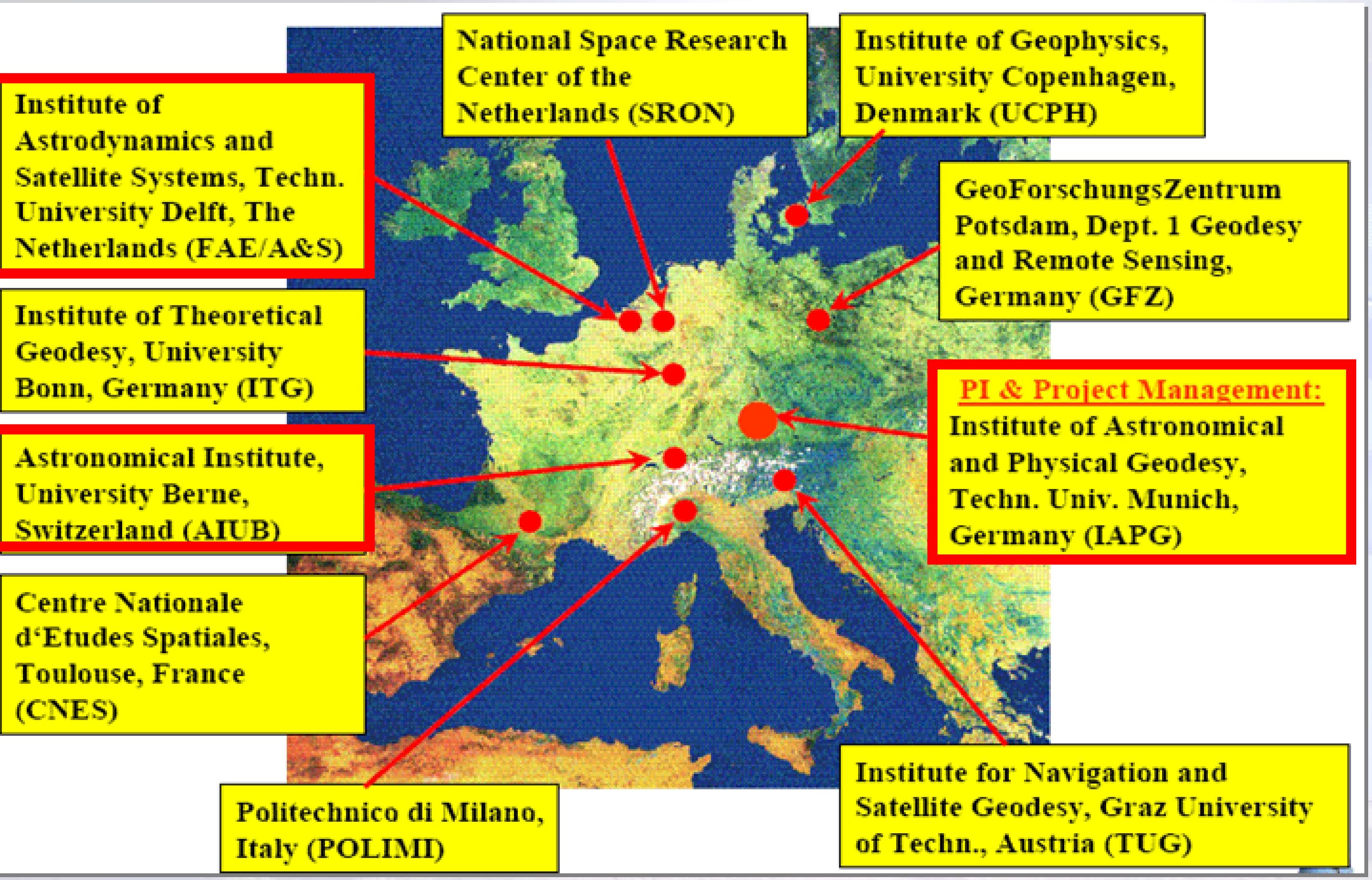


Responsibilities for orbit generation:

DEOS:

=> RSO (Rapid Science Orbit)

AIUB:

=> PSO (Precise Science Orbit)

IAPG:

=> Validation

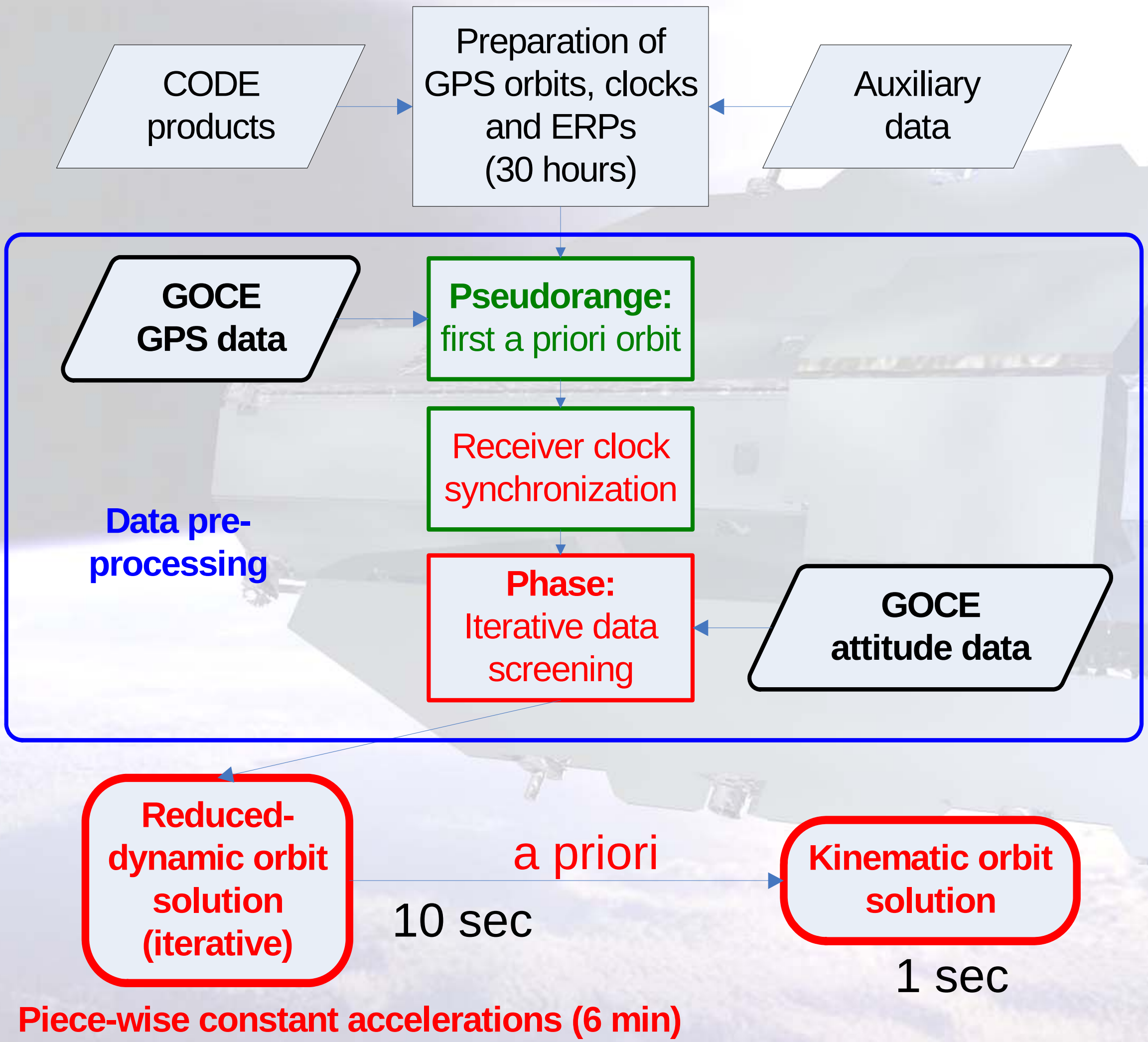
GOCE orbit generation

	Orbit solution	Software	GPS Observ.	GPS products	Sampling	Data batches	Latency
RSO	reduced-dynamic	GEODYN	triple-diff	IGS rapid	10 sec	30 h	1 day
	kinematic	GHOST	zero-diff	CODE rapid	1 sec	24 h	1 day
PSO	reduced-dynamic	BERNESE	zero-diff	CODE final	10 sec	30 h	7-10 days
	kinematic	BERNESE	zero-diff	CODE final	1 sec	30 h	7-10 days

Accuracy requirement:
50 cm

Accuracy requirement:
2 cm

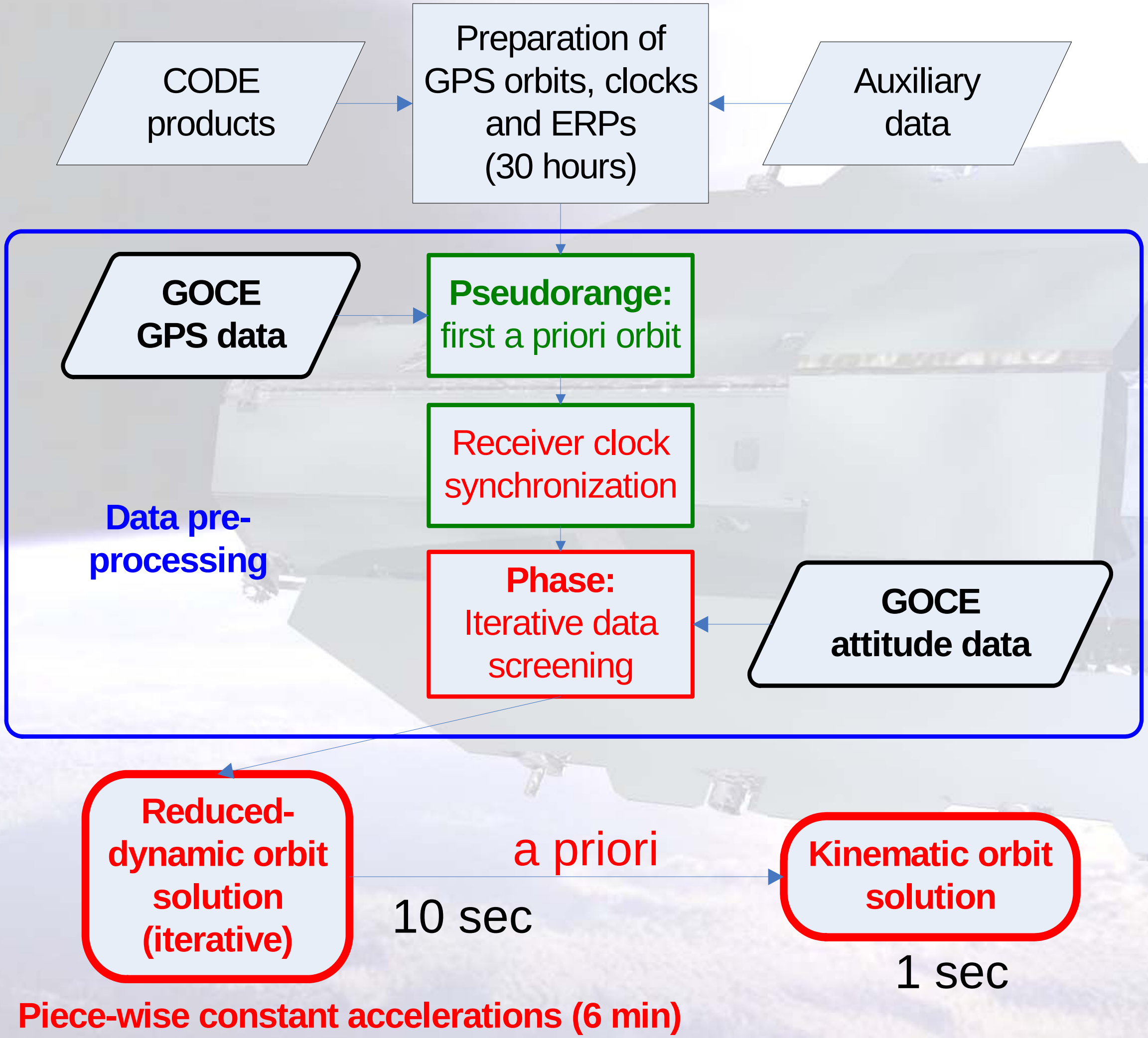
GOCE PSO procedure



- Tailored version of Bernese GPS Software used
- Un-differenced processing
- Automated procedure
- 30 h batches => overlaps
- CODE final products
- Consequent use of antenna phase center variation (PCV) map
- Final kinematic positions are only accepted, if five or more simultaneous observations were available

=> on average **only** 0.5% positions missing

GOCE PSO procedure



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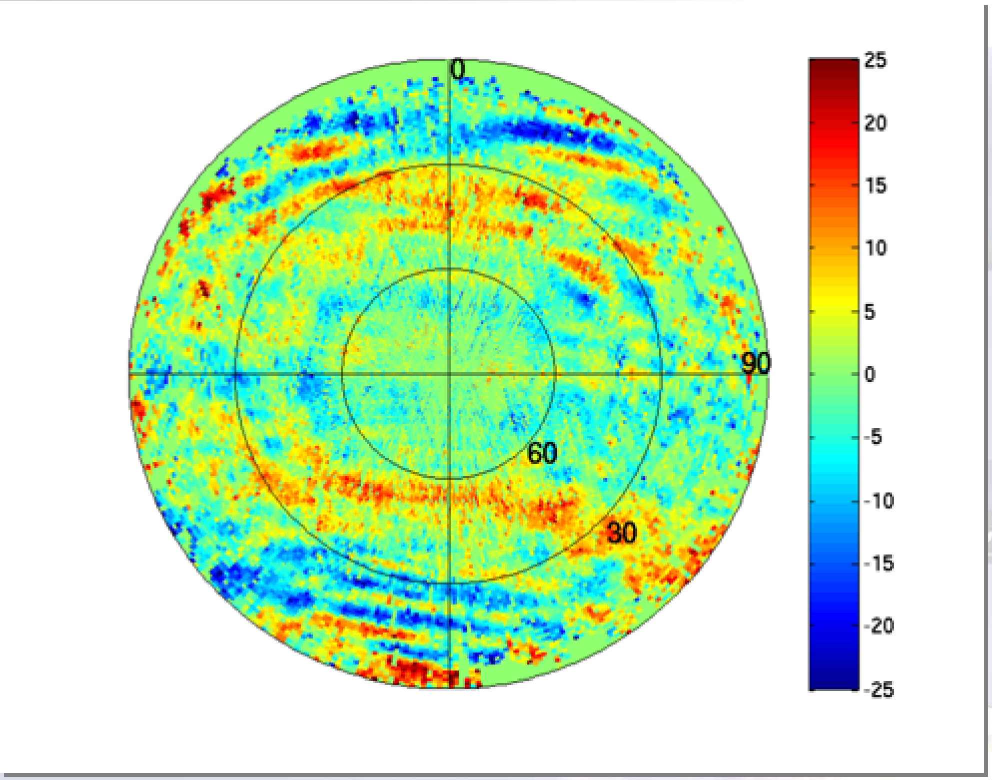
GOCE PSO procedure: PCV map

- Antenna PCVs are the most important systematic error source in LEO GPS data processing.
- They have to be taken into account to achieve a high accuracy level for POD.

- Ground calibration for the GOCE antenna is available but no improvement of the orbits could be achieved.
- Therefore, we decided to do an in-flight calibration of the GOCE antenna PCVs.

GOCE PSO procedure: PCV map



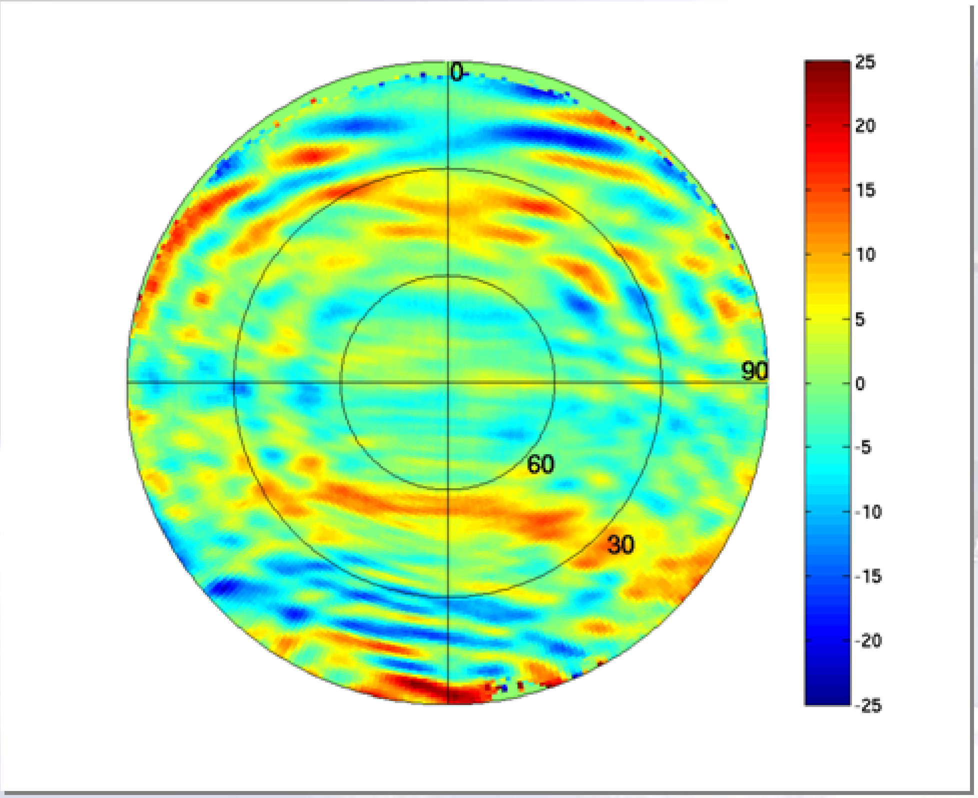
20 July 2010: Mean values of carrier phase observation residuals (ionosphere-free linear combination)

Generation of the PCV map:

1. Mean values of 154 days of carrier phase observation residuals from reduced-dynamic orbit determination => first PCV map
2. Use of PCV map for reduced-dynamic orbit determination of 154 days
3. Mean values of observation residuals => add-on to previous PCV map
4. Back to 2.

   => 10 iterations

GOCE PSO procedure: PCV map



PCV map from **first** iteration

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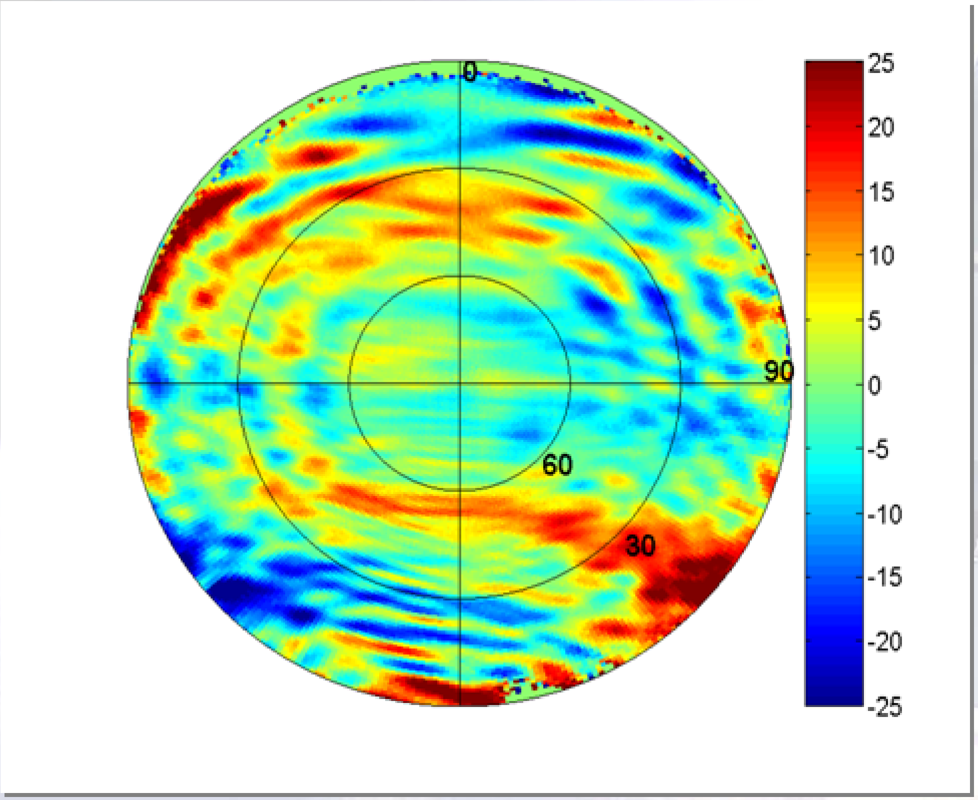
GOCE PSO procedure: PCV map



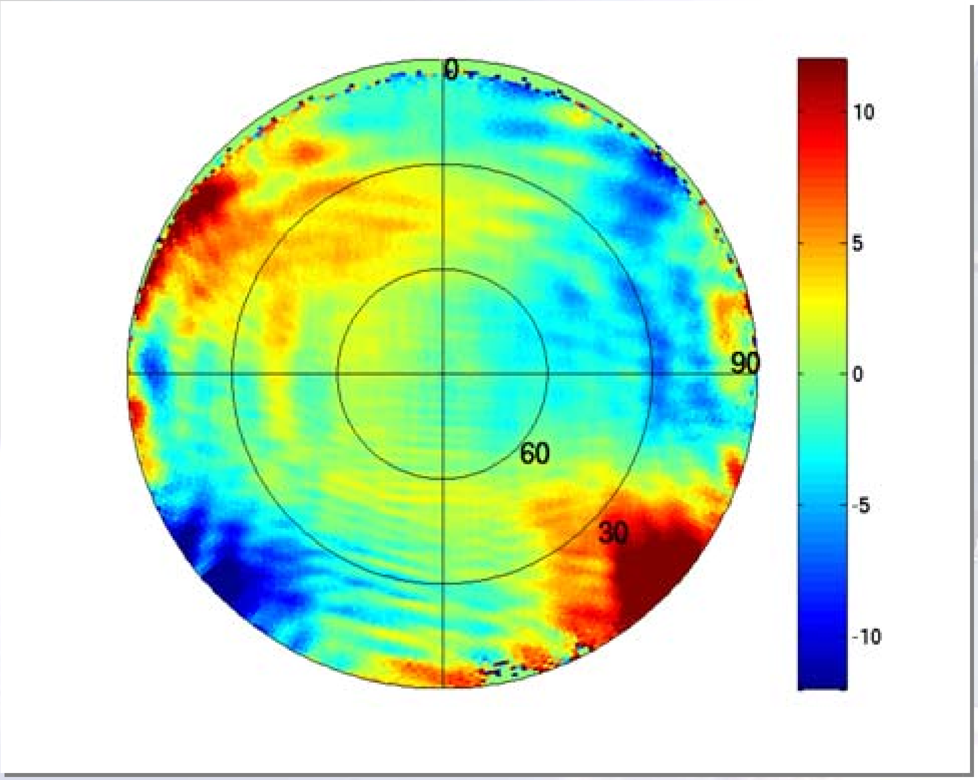
PCV map from **last** iteration

Generation of the PCV map:

1. Mean values of 154 days of carrier phase observation residuals from reduced-dynamic orbit determination => first PCV map
2. Use of PCV map for reduced-dynamic orbit determination of 154 days
3. Mean values of observation residuals => add-on to previous PCV map
4. Back to 2.

=> 10 iterations

GOCE PSO procedure: PCV map



Differences of PCV map from **last** to **first** iteration

Generation of the PCV map:

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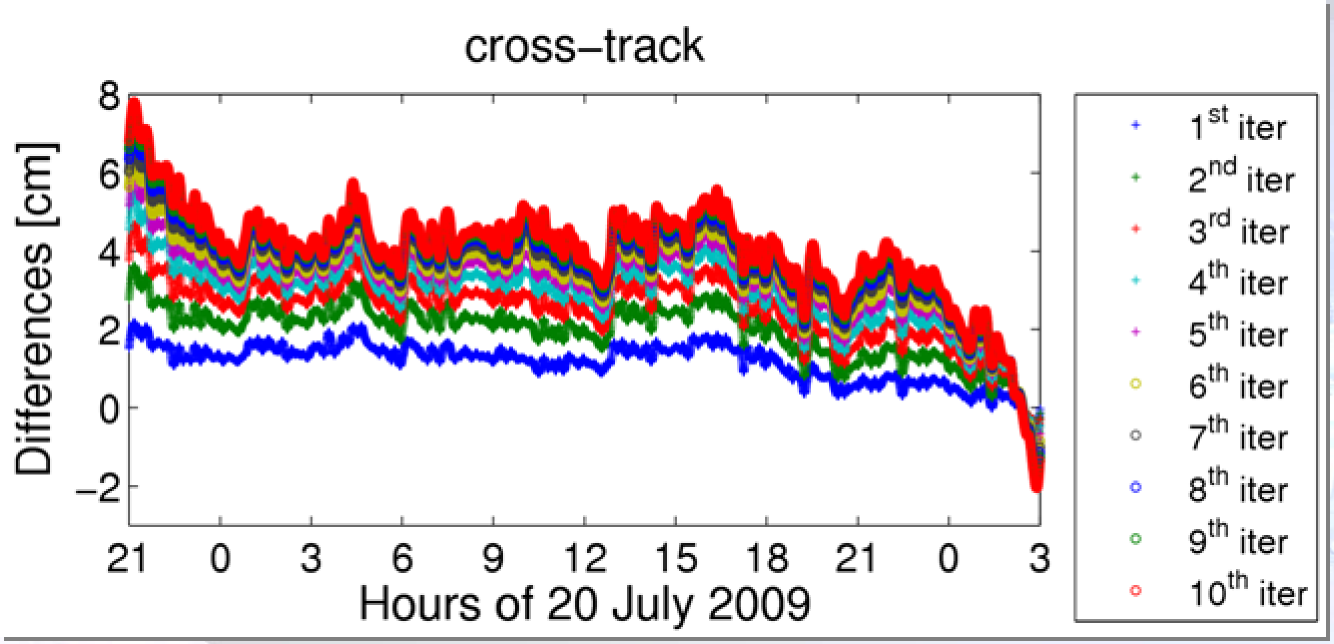
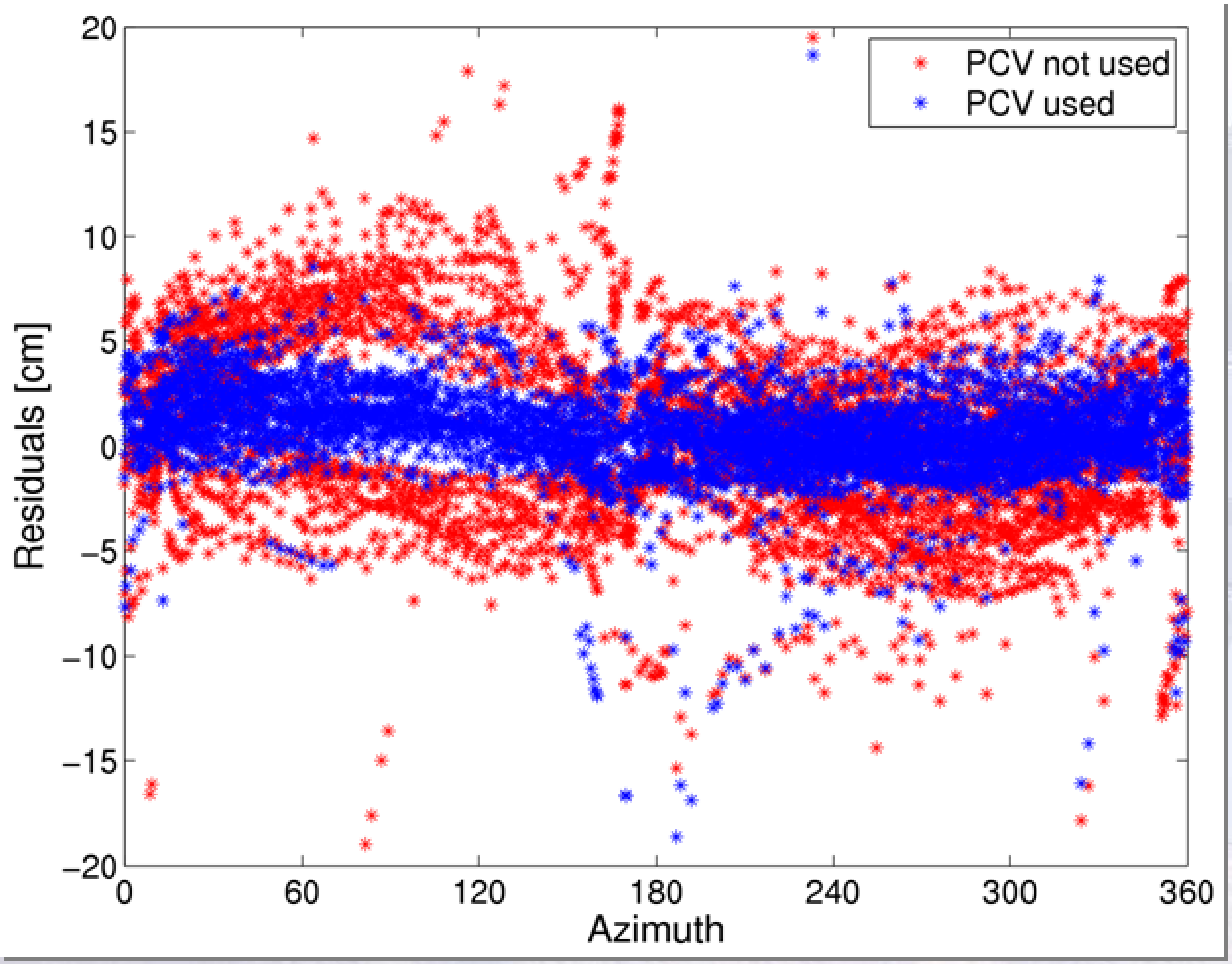
=> 10 iterations

GOCE PSO: Impact of PCV map



Orbit differences in **cross-track** direction between orbit generated without PCV map and the orbits from all iterations

GOCE PSO: Impact of PCV map

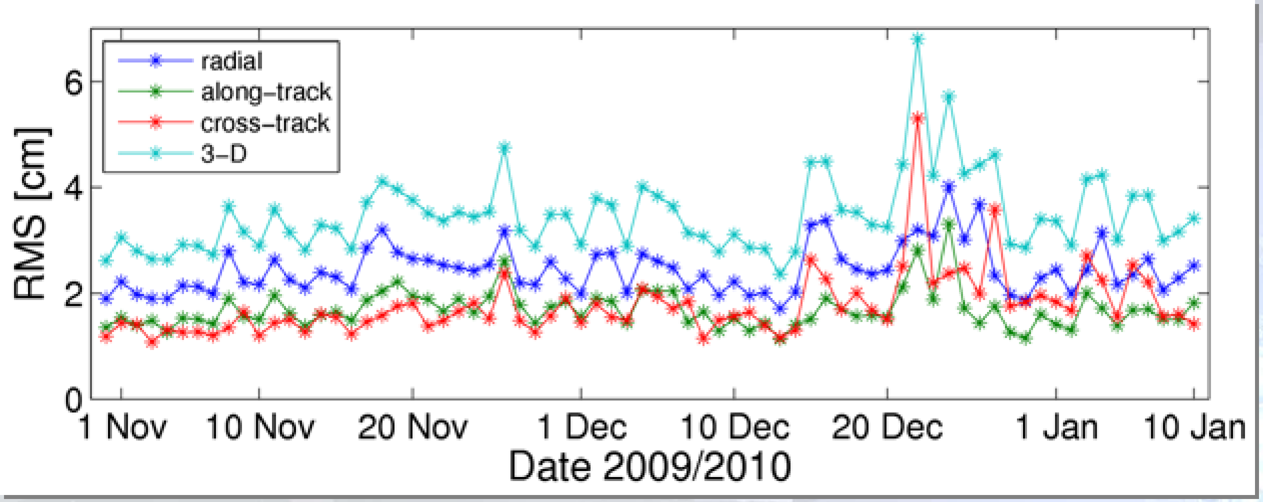


- GOCE SLR residuals as a function of the azimuth of the SLR stations
- Significant improvement of SLR residuals due to use of the PCV map
- Residuals from East/West-tracking at low elevations are significantly reduced

  => cross-track direction

PSO: Comparison reduced-dynamic ⬄ kinematic orbits

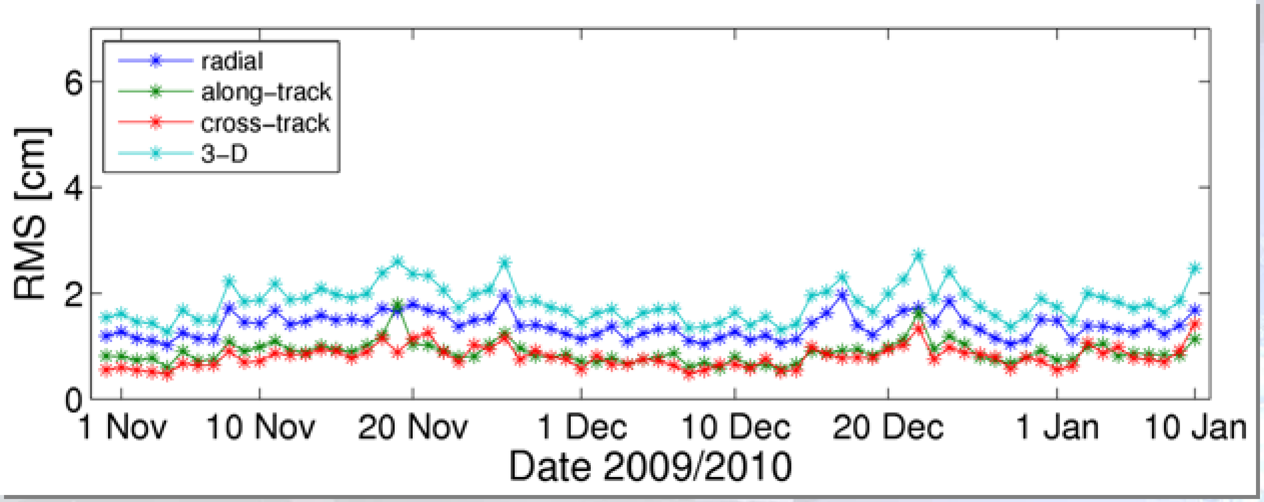
PCV map not used



- Orbit differences between reduced-dynamic and kinematic PSO solutions
- Orbit differences > 1 m removed (only 60 positions for the entire period)

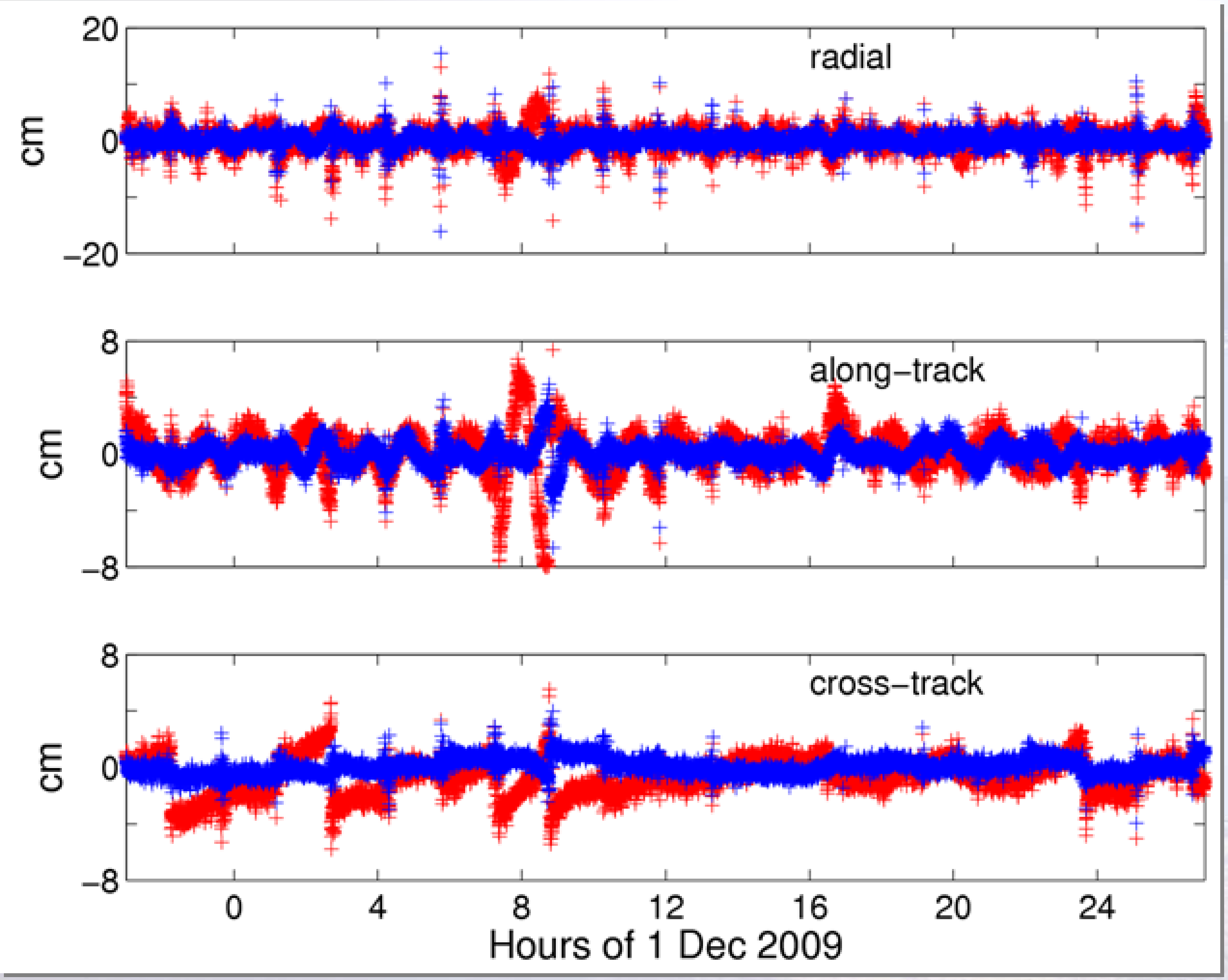
PSO: Comparison reduced-dynamic ⇔ kinematic orbits

PCV map used



- Orbit differences between reduced-dynamic and kinematic PSO solutions
- Orbit differences > 1 m removed (only 60 positions for the entire period)
- Consistency of reduced-dynamic and kinematic PSO is at 2 cm level
  => mean 3D-RMS 1.82 cm

PSO: Comparison reduced-dynamic ⬄ kinematic orbits



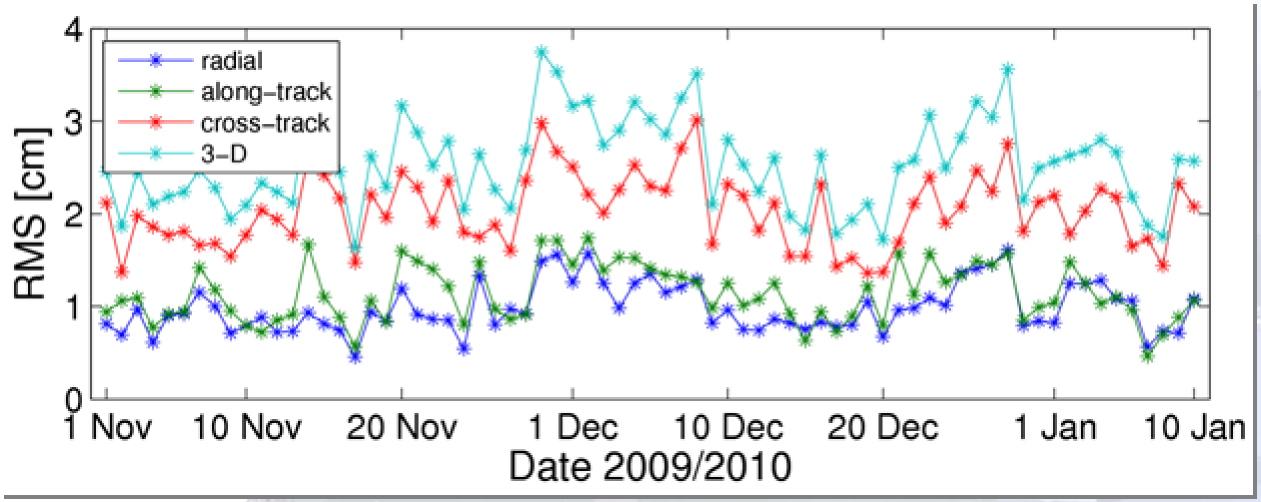
Typical example for orbit differences between reduced-dynamic and kinematic orbit (PSO)

PCV map not used
PCV map used

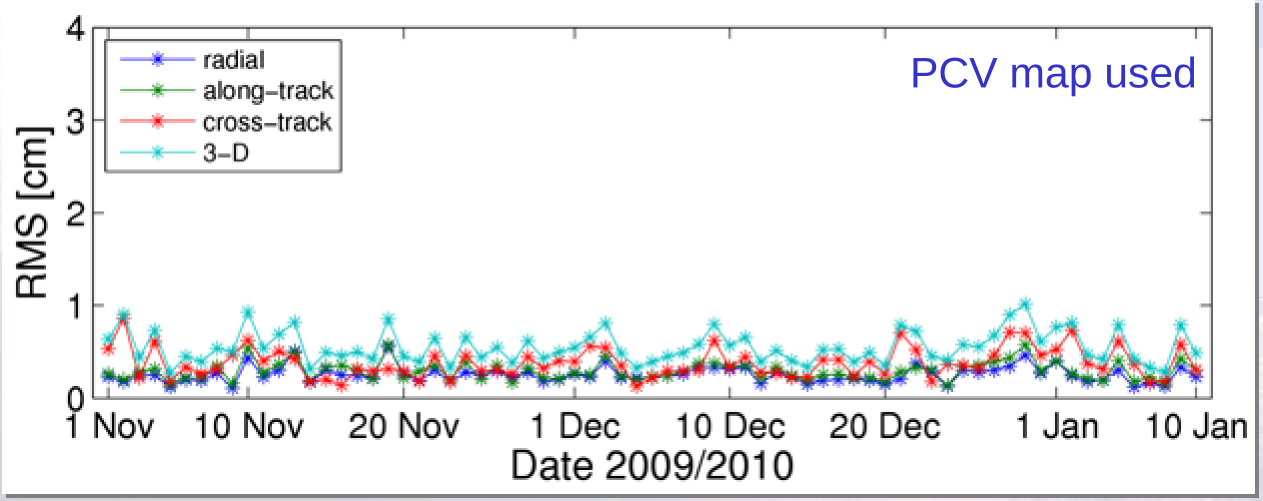
GOCE PSO: Overlaps reduced-dynamic orbits

5 h overlaps (21:30 – 02:30)

PCV map not used



Mean 3D-RMS:
2.54 cm

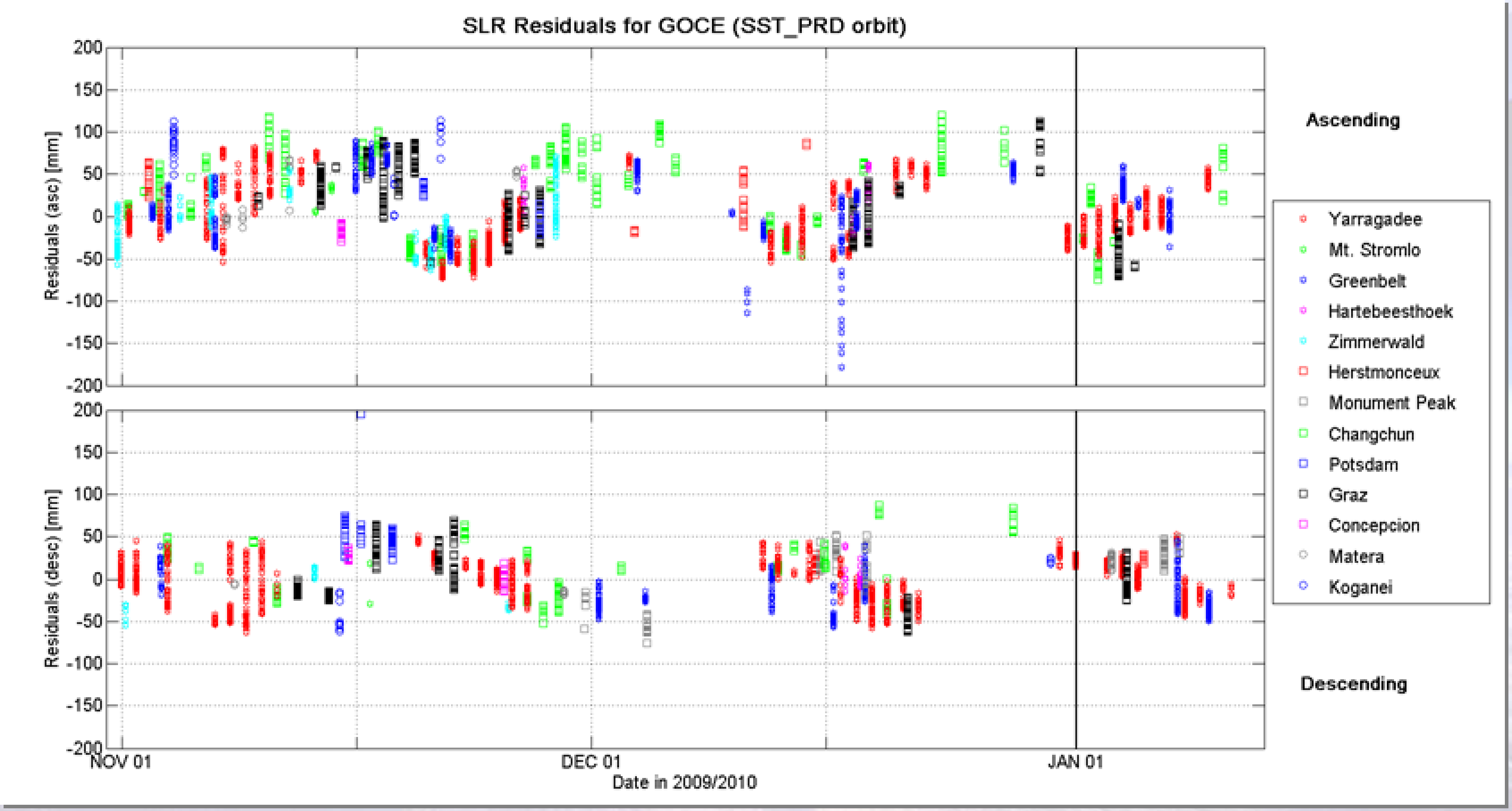


Mean 3D-RMS:
0.55 cm

Orbit validation with SLR

Reduced-dynamic orbits, PCVs not used

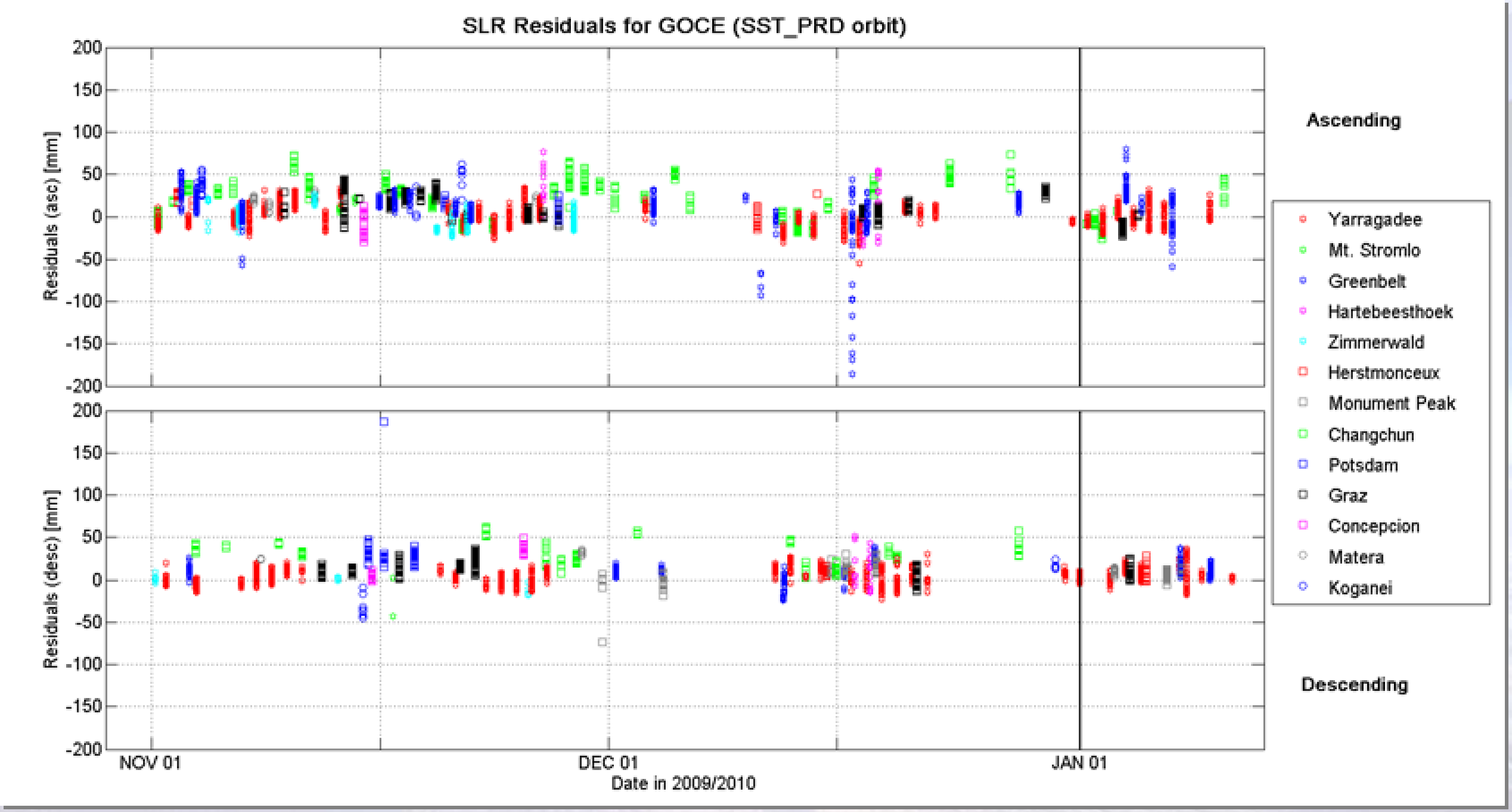
Mean: 0.78 cm, RMS: 3.95 cm



Orbit validation with SLR

Reduced-dynamic orbits, PCVs used

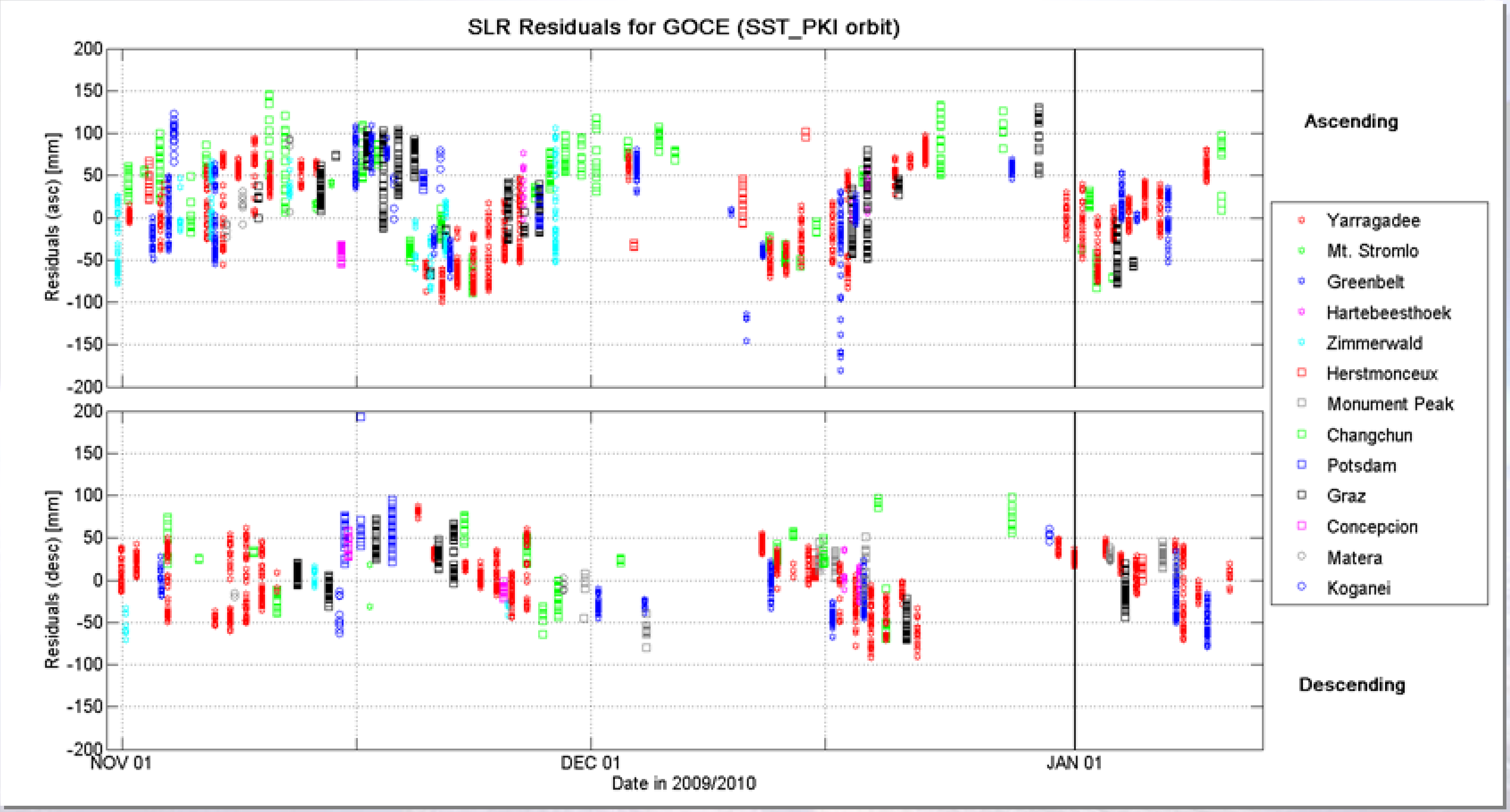
Mean: 0.88 cm, RMS: 2.05 cm



Orbit validation with SLR

Kinematic orbit, PCVs not used

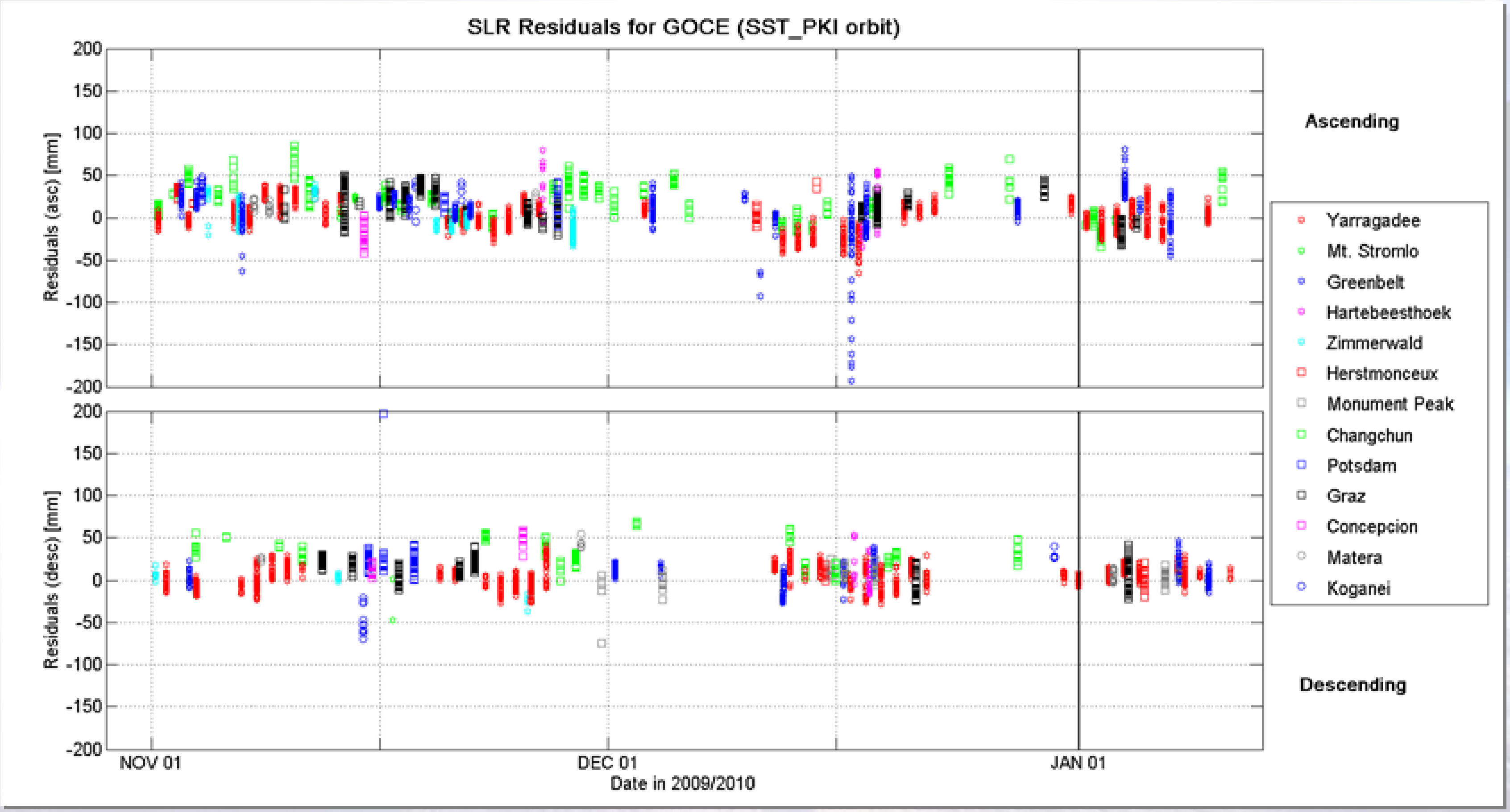
Mean: 0.85 cm, RMS: 4.61 cm



Orbit validation with SLR

Kinematic orbit, PCVs used

Mean: 0.88 cm, RMS: 2.23 cm



GOCE PSO procedure: PCV map

Additional studies to guarantee quality and independency of PCV map:

- Generation of PCV map
  - from different time interval (20 d, 30 d, other period, …)
  - from phase residuals from kinematic orbit determination
  - ⇒ qualitatively same result

- Use of PCV map for RSO computation with different software packages
  => improvement of orbit results

Summary

- GOCE, the first ESA Earth Explorer mission, is in orbit since 16 months and all science instruments are working excellently.
- Orbit generation is running fully automated.
- Antenna PCVs were generated in-flight and provide significant improvement for the orbits.
- Precise Science Orbits fulfil the mission requirement of 2 cm.