Extending the GPS satellite antenna patterns of the IGS to nadir angles beyond 14° using LEO data

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April 8, 2011

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University of Bern

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DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

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Institute of Astron. & Physical Geodesy
Technische Universität München

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European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

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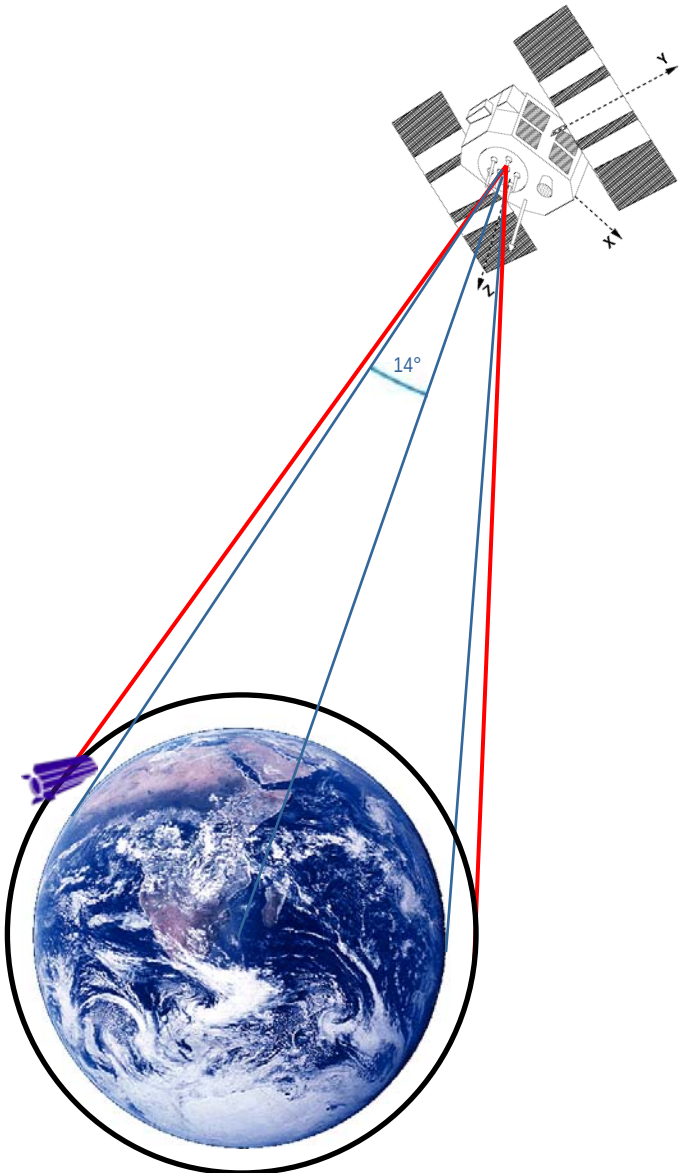
Introduction

Phase center variations (PCVs) of GPS transmitter antennas, e.g., as provided by the IGS, are restricted to nadir angles <=14°

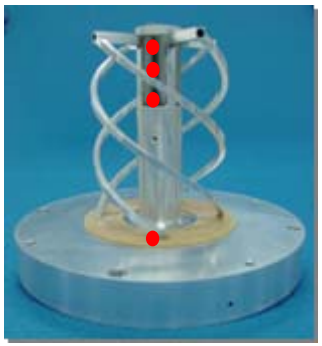
GPS data from Low Earth Orbiters (LEOs) may be used to extend the GPS PCVs to nadir angles <= 17°

LEO phase center offsets (PCOs) have to be precisely known, LEO PCVs need to be co-estimated



L2 PCO
L1 PCO
Lc PCO

antenna reference point



Input data & products

- LEO GPS data, undifferenced ionosphere-free
  (Jason-2, GRACE-A/B, GOCE, MetOp-A)
- GPS orbits and clock corrections from the CODE final product line, introduced as known
  (consistent with PCOs & PCVs from igs05.atx)
- LEO orbits from AIUB relying on the CODE final product line, introduced as known
  (not based on empirical PCVs --> unbiased PCV estimation)
- GPS PCOs and PCVs from igs05.atx, used as a priori values for the transmitter antennas
  (PCV values extended beyond 14° with constant values)
- LEO PCOs used at AIUB for POD, introduced as known for the LEO receiver antennas
  (no a priori LEO PCVs are used)

Estimated parameters & constraints

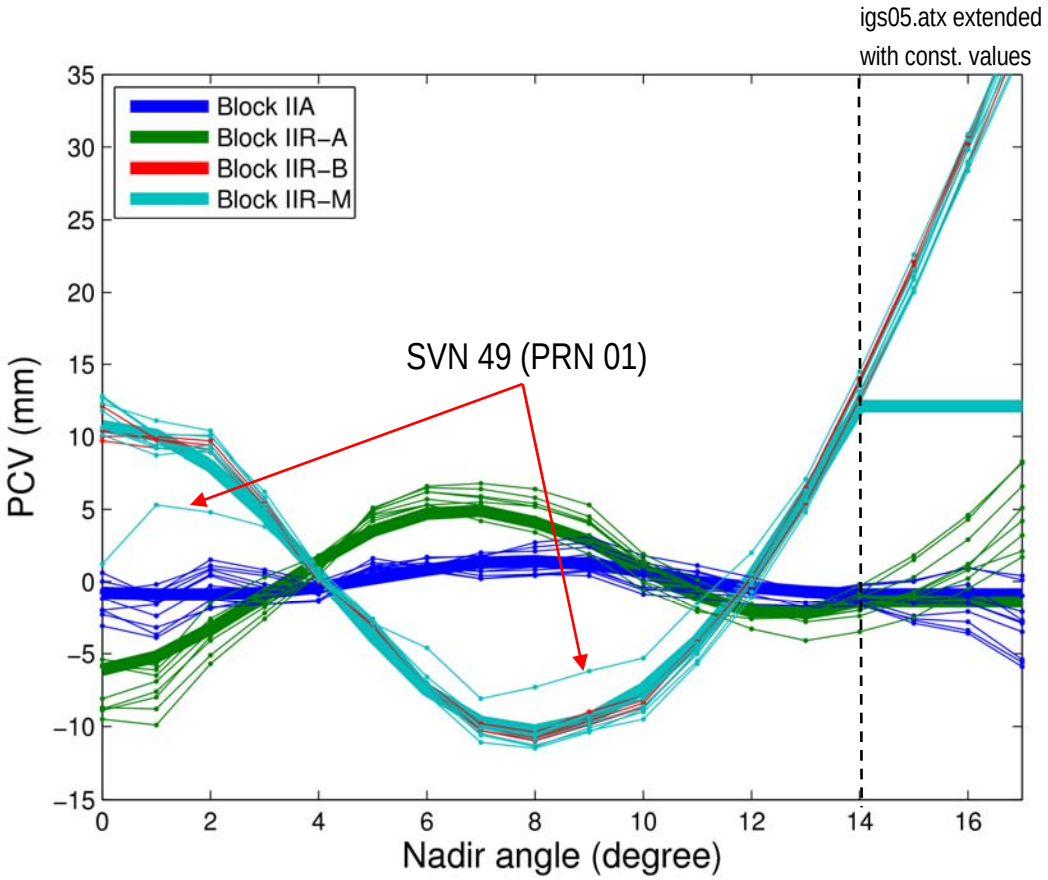
- PCVs for the GPS transmitter antennas
  (nadir-dependent, piecewise linear, satellite-specific)
  - zero-mean condition (for nadir angles <= 12°)
  - PCVs of two Block IIA SVs constrained to a priori due to the simultaneous estimation of LEO PCVs

- PCVs for the LEO receiver antennas
  (5°x 5° grid, piecewise linear, LEO-specific)
  - zero-mean condition over all grid points
  - weak overall constraint (in principle not necessary, just used to avoid unreasonably large values of weakly observed grid points)

Normal equations are assembled for different LEOs on a daily basis and accumulated to solve for the PCVs

Jason-2 solution

PCVs compared to igs05.atx



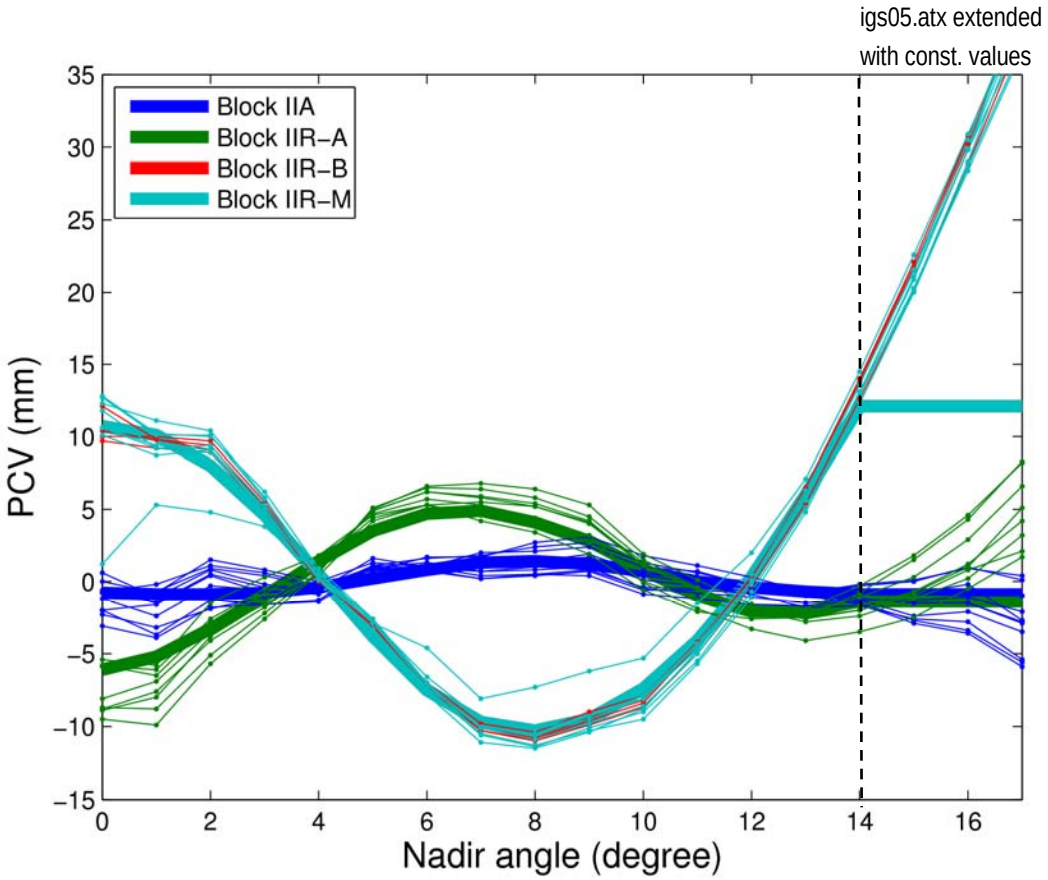
Data used:

30-sec GPS data from entire year 2009

Large differences to a priori PCVs beyond 14° (constant extension)

Jason-2 solution

PCVs compared to igs05.atx



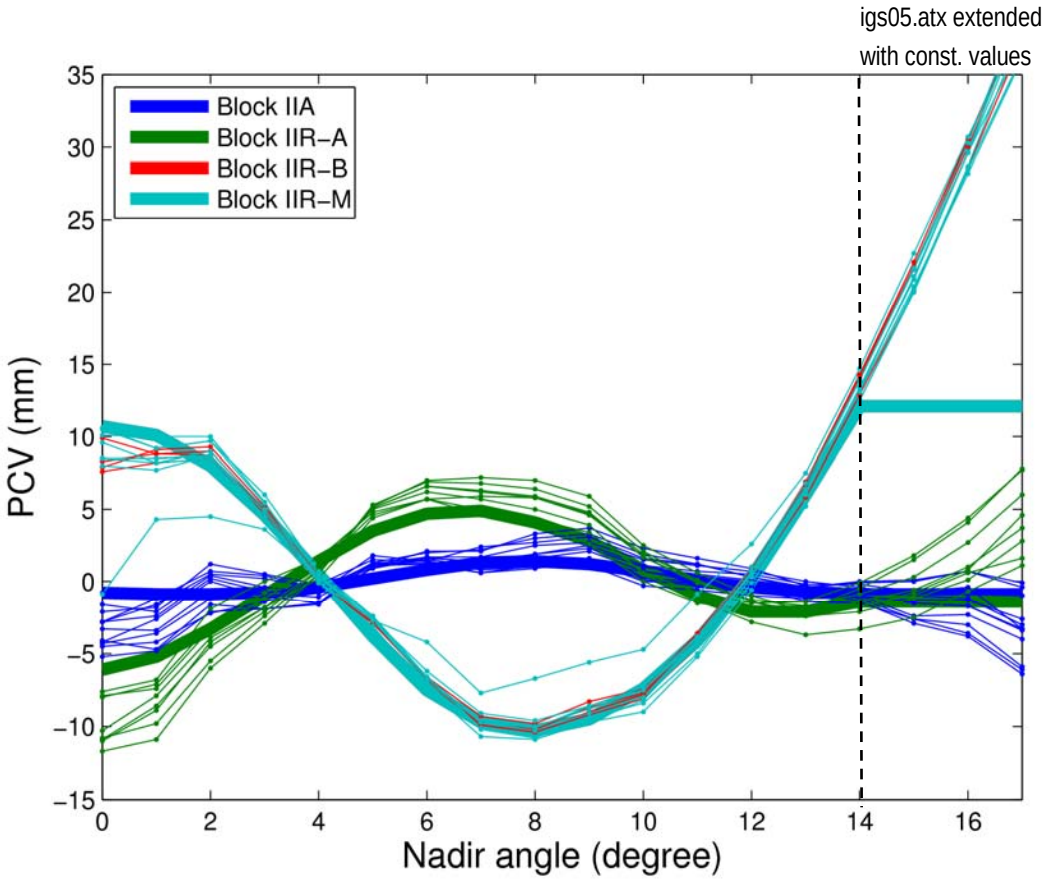
Constraint:

SVNs 25, 27

Completely different agreement with igs05.atx for different constraints

Jason-2 solution

PCVs compared to igs05.atx



Constraint:

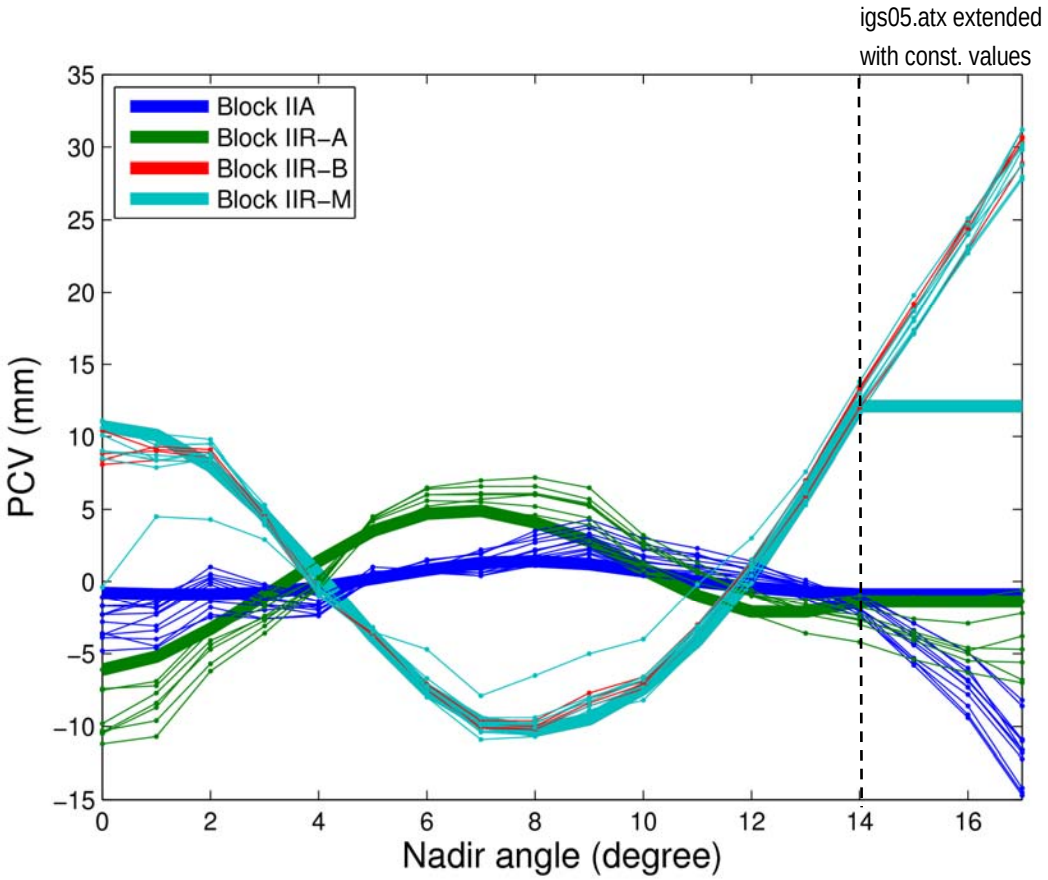
SVNs 25, 27

SVN 25

Completely different agreement with igs05.atx for different constraints

Jason-2 solution

PCVs compared to igs05.atx



Constraint:

SVNs 25, 27

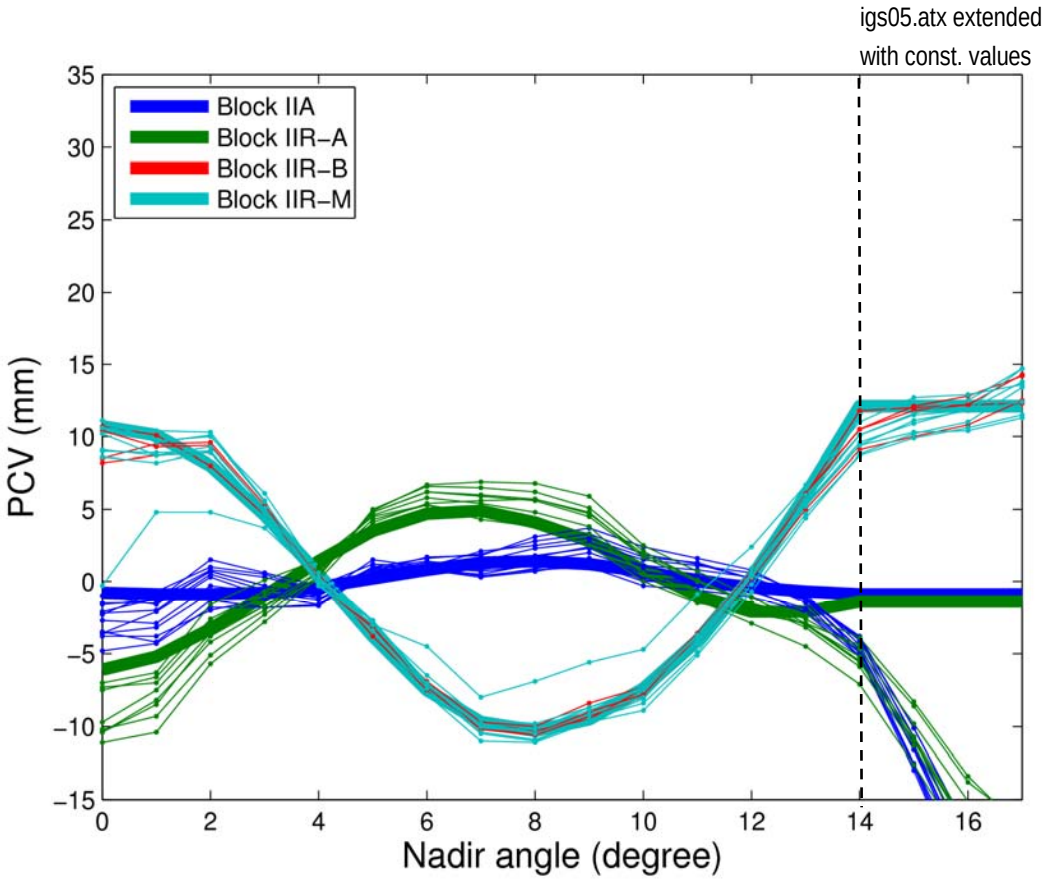
SVN 25

SVN 44

Completely different agreement with igs05.atx for different constraints

Jason-2 solution

PCVs compared to igs05.atx



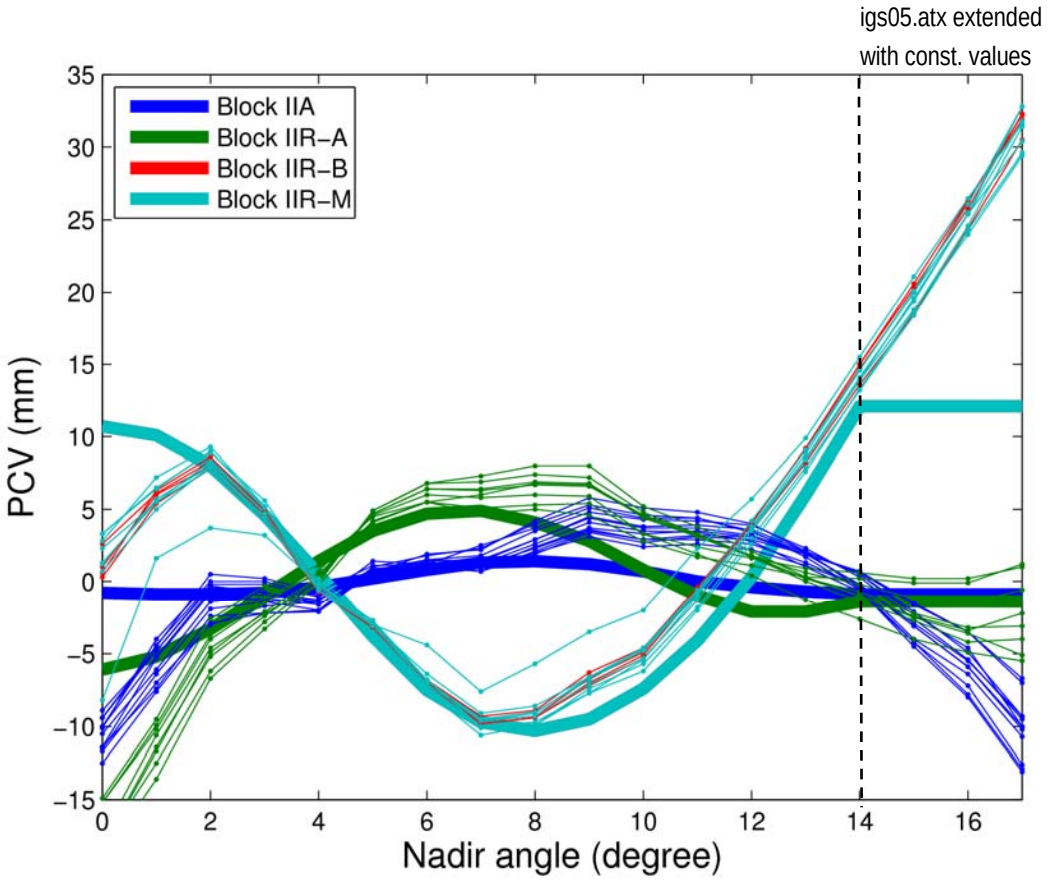
Constraint:

- SVNs 25, 27
- SVN 25
- SVN 44
- SVN 60

Completely different agreement with igs05.atx for different constraints

Jason-2 solution

PCVs compared to igs05.atx



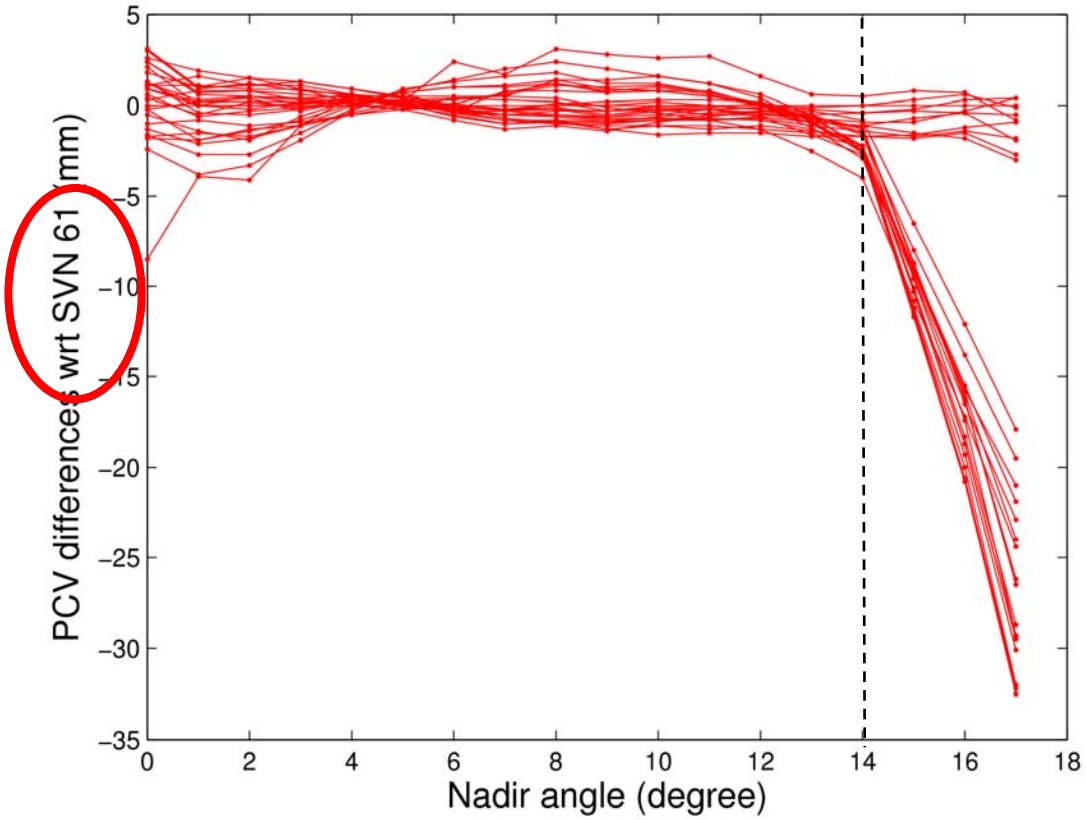
Constraint:

- SVNs 25, 27
- SVN 25
- SVN 44
- SVN 60
- none

Completely different agreement with igs05.atx for different constraints

Jason-2 solution

PCVs compared with each other



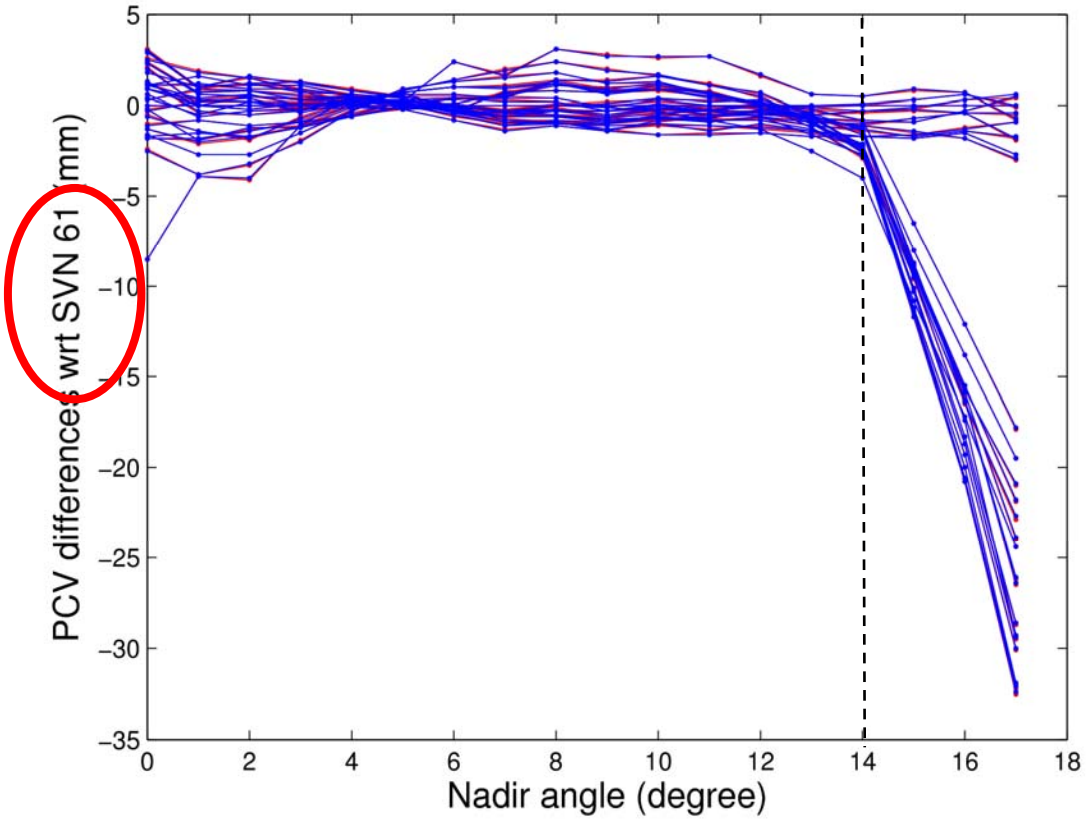
Constraint:

SVNs 25, 27

Sat.-to-sat. differences do not depend on the applied constraint

Jason-2 solution

PCVs compared with each other



Constraint:

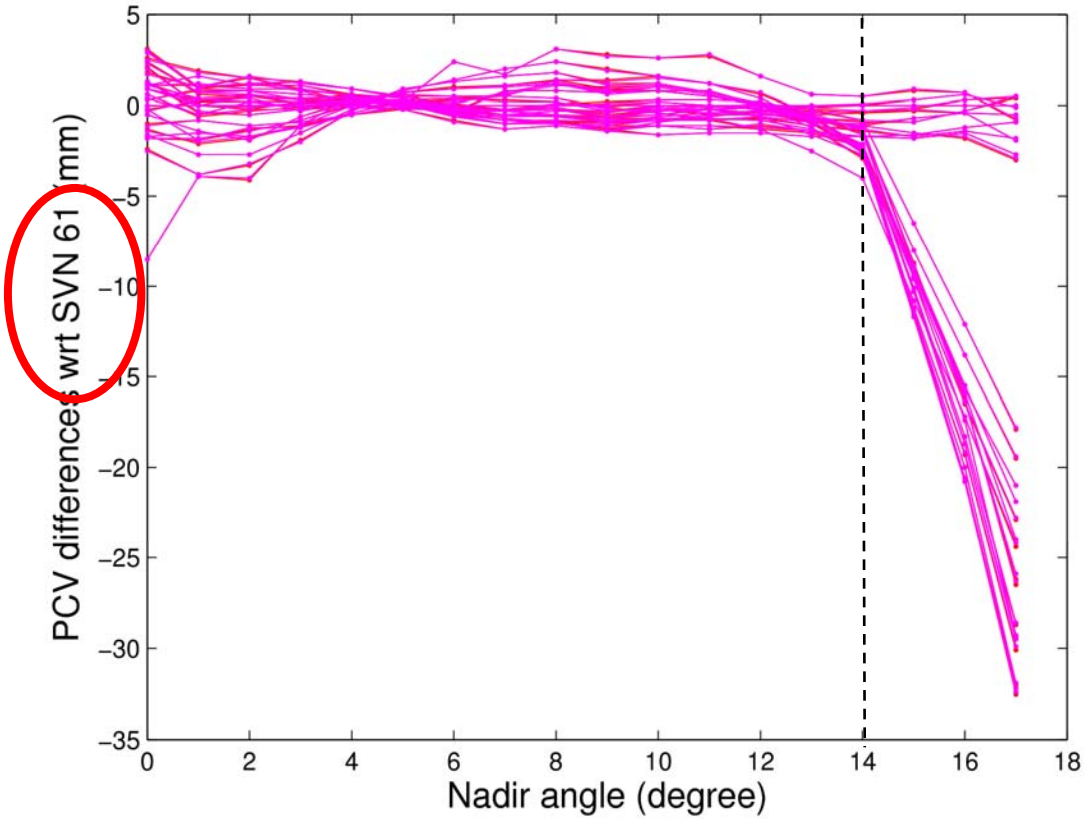
SVNs 25, 27

SVN 25

Sat.-to-sat. differences do not depend on the applied constraint

Jason-2 solution

PCVs compared with each other



Constraint:

SVNs 25, 27

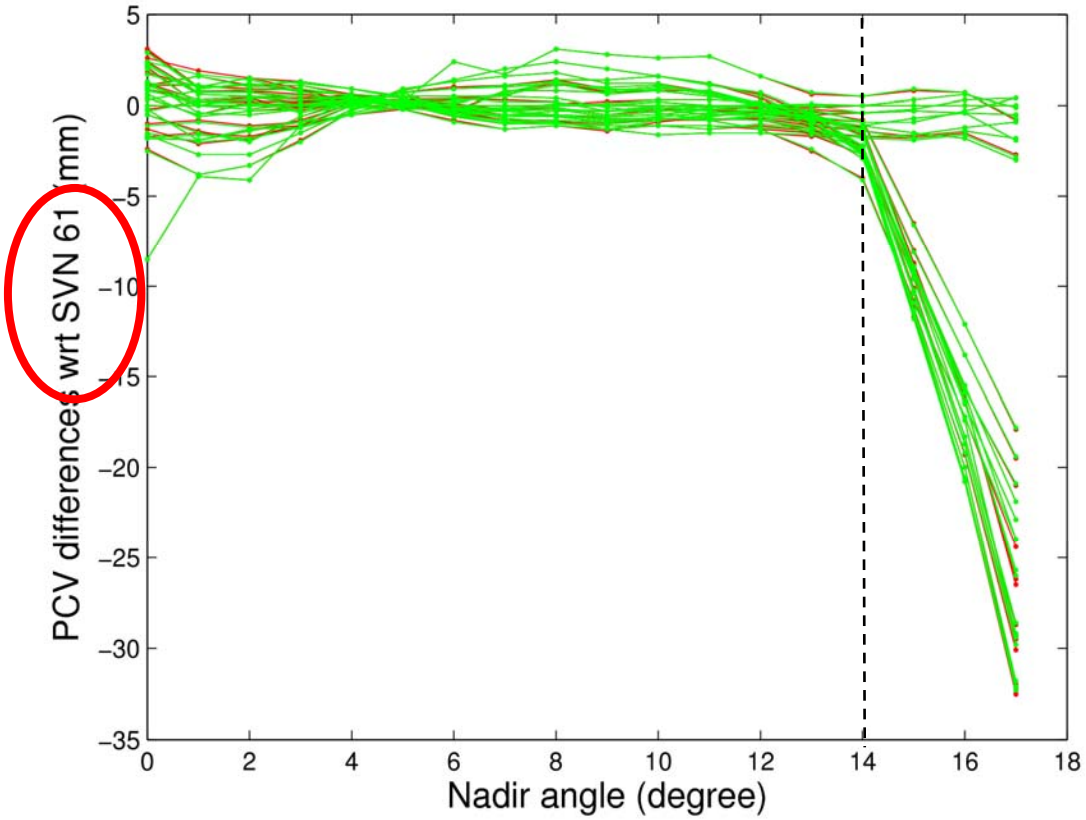
SVN 25

SVN 44

Sat.-to-sat. differences do not depend on the applied constraint

Jason-2 solution

PCVs compared with each other



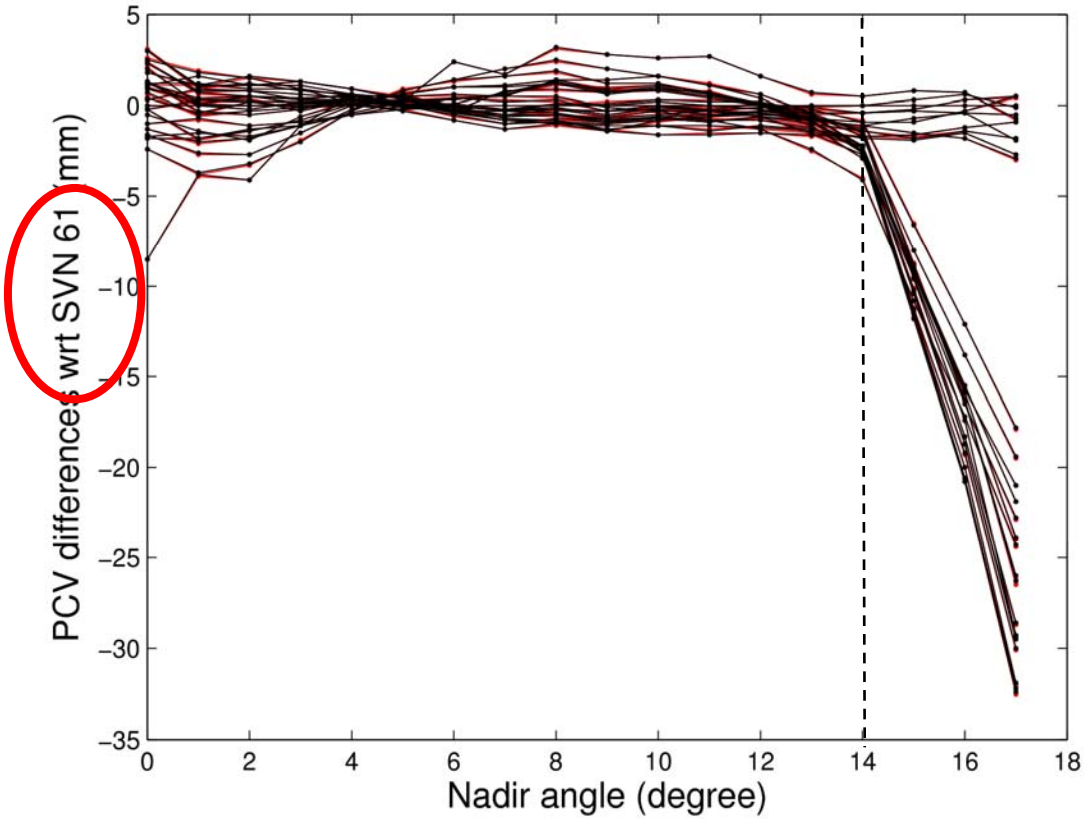
Constraint:

- SVNs 25, 27
- SVN 25
- SVN 44
- SVN 60

Sat.-to-sat. differences do not depend on the applied constraint

Jason-2 solution

PCVs compared with each other



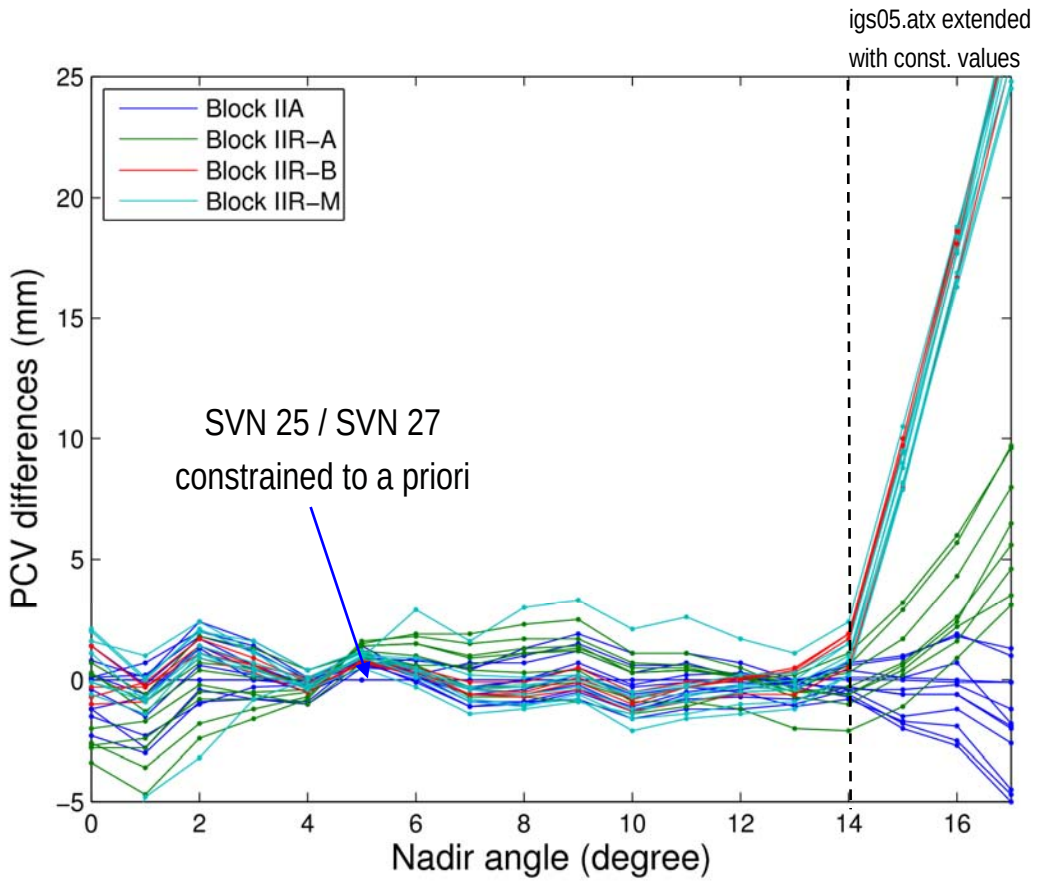
Constraint:

- SVNs 25, 27
- SVN 25
- SVN 44
- SVN 60
- none

Sat.-to-sat. differences do not depend on the applied constraint

Jason-2 solution

Differences compared to igs05.atx



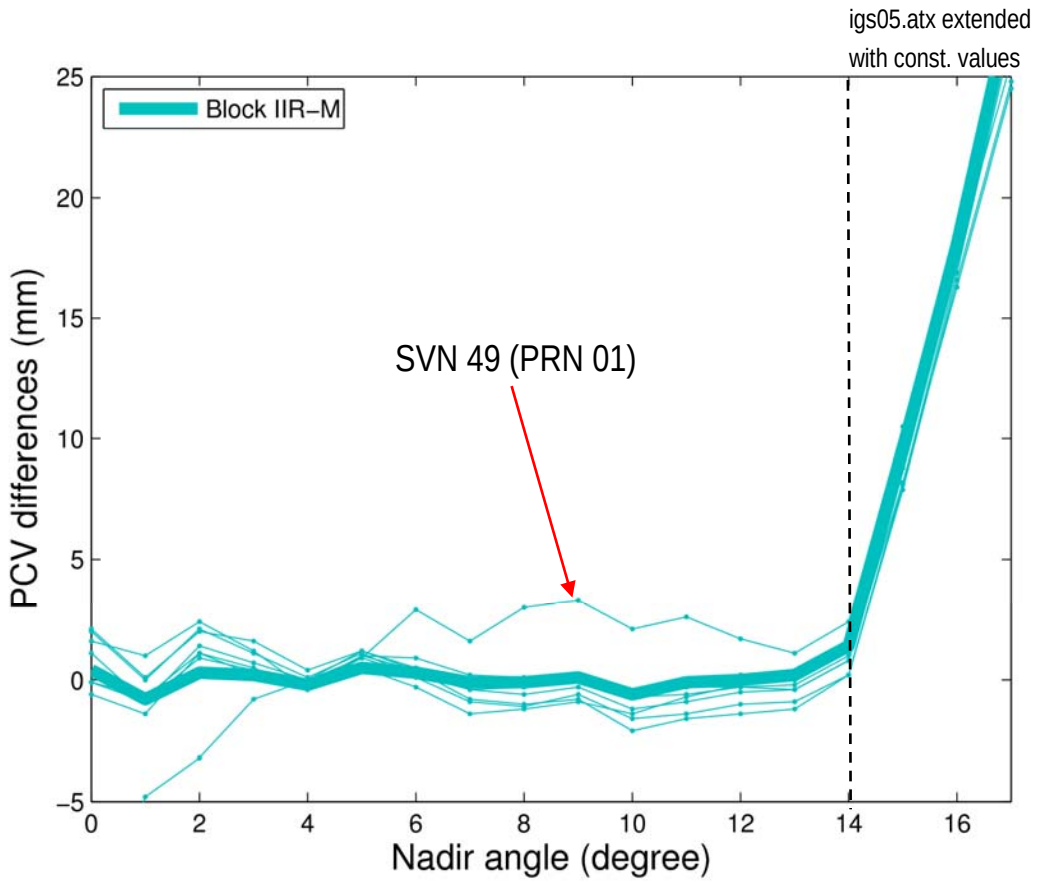
Data used:

30-sec GPS data from entire year 2009

Satellite-specific agreement of 2-3 mm with igs05.atx below 14°

Jason-2 solution

Differences compared to igs05.atx



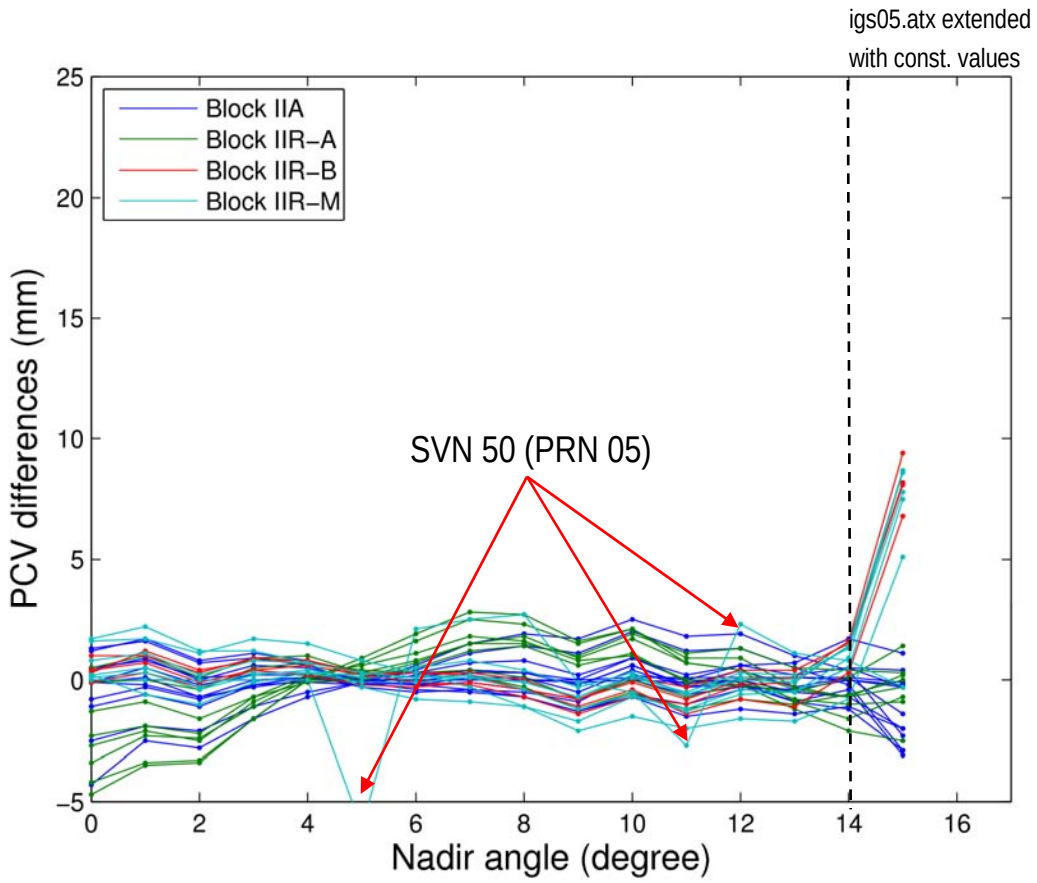
Data used:

30-sec GPS data from entire year 2009

Block-specific agreement of about 1 mm with igs05.atx below 14°

GRACE solution

Differences compared to igs05.atx



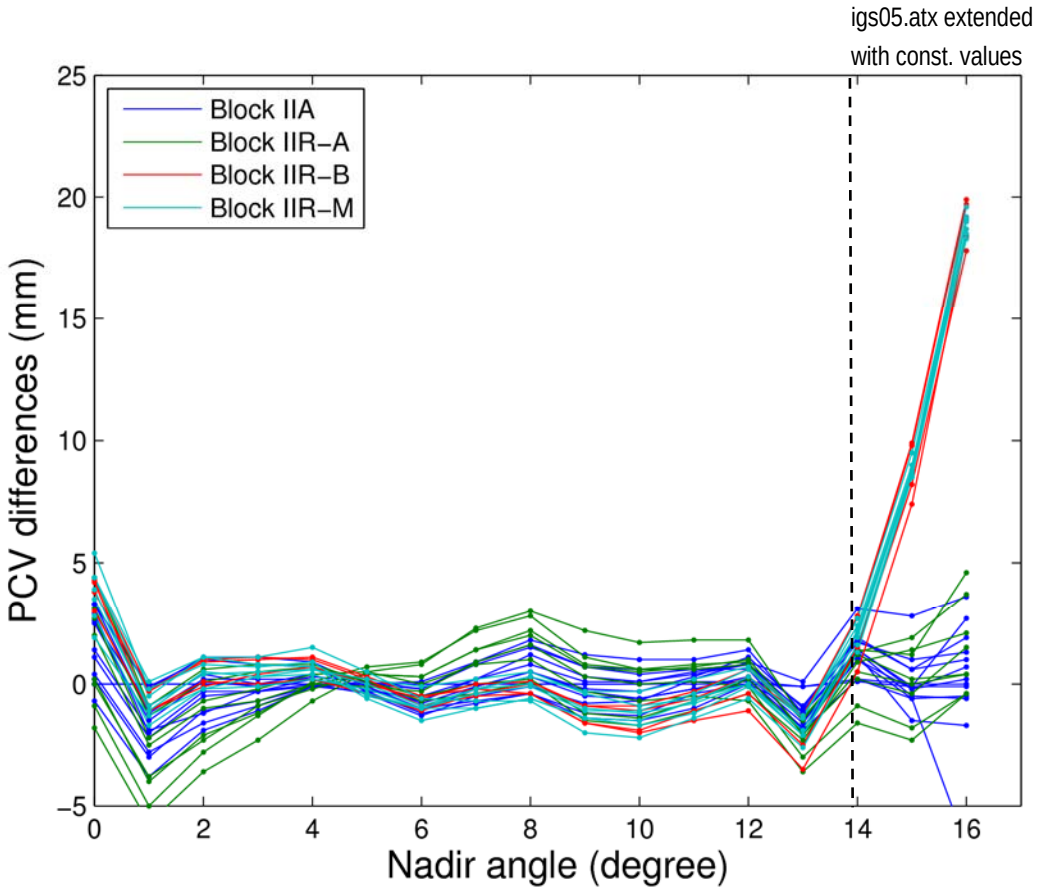
Data used:

30-sec GPS data from entire year 2009

Satellite-specific agreement of 2-3 mm with igs05.atx below 14°

MetOp-A solution

Differences compared to igs05.atx



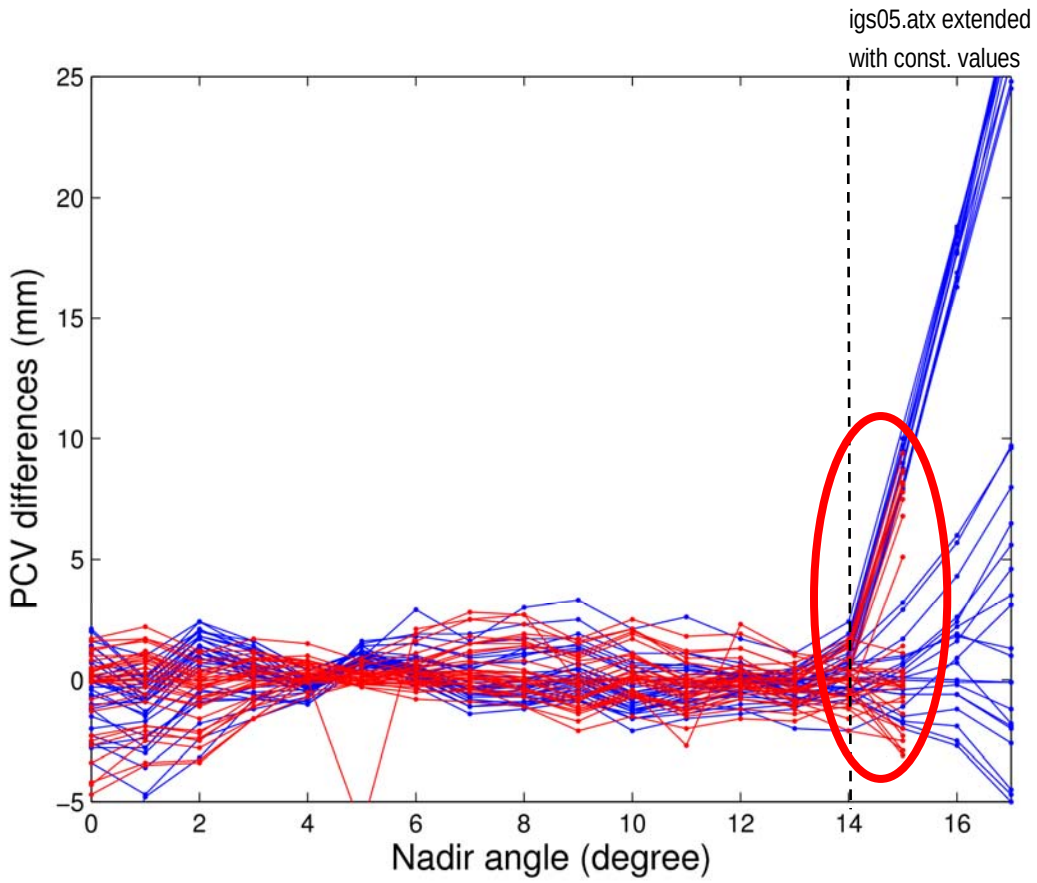
Data used:

30-sec GPS data from entire year 2009

Satellite-specific agreement of 3-5 mm with igs05.atx below 14°

Consistency of solutions

Differences compared to igs05.atx



LEO data:

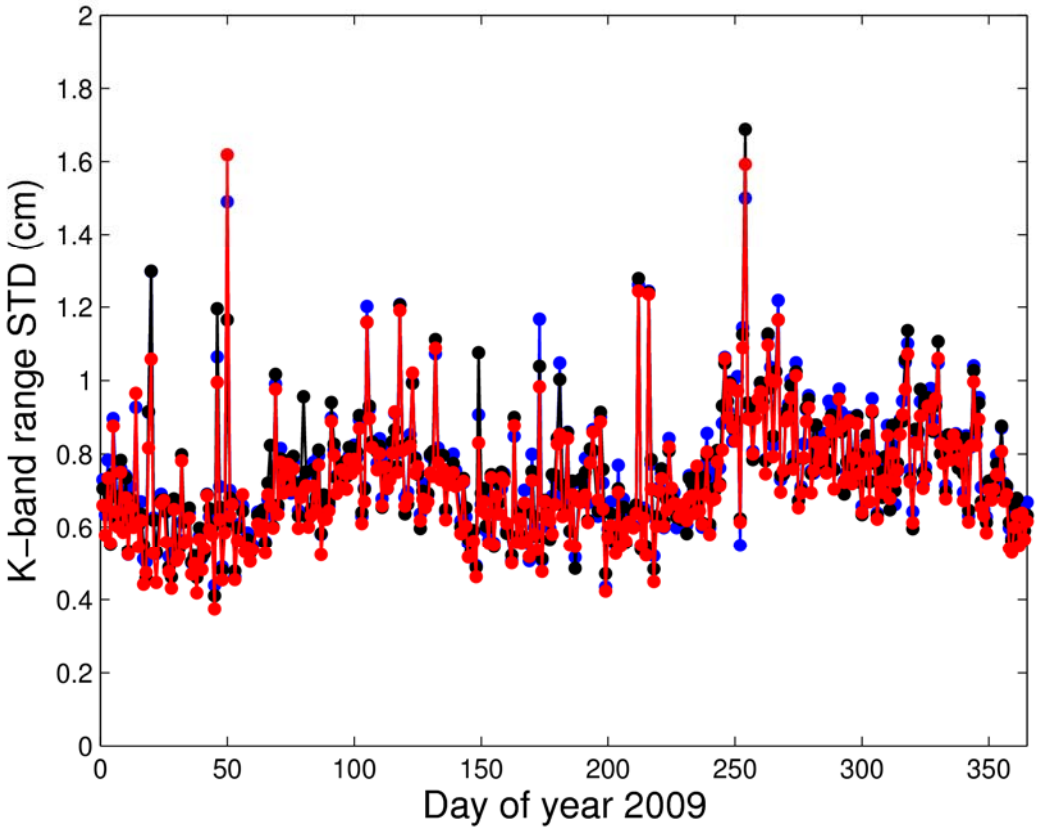
Jason-2

GRACE-A & B

Individual LEO solutions reasonably agree with each other …

Validation of GPS PCVs

Impact on GRACE orbit determination



Improved PCVs:

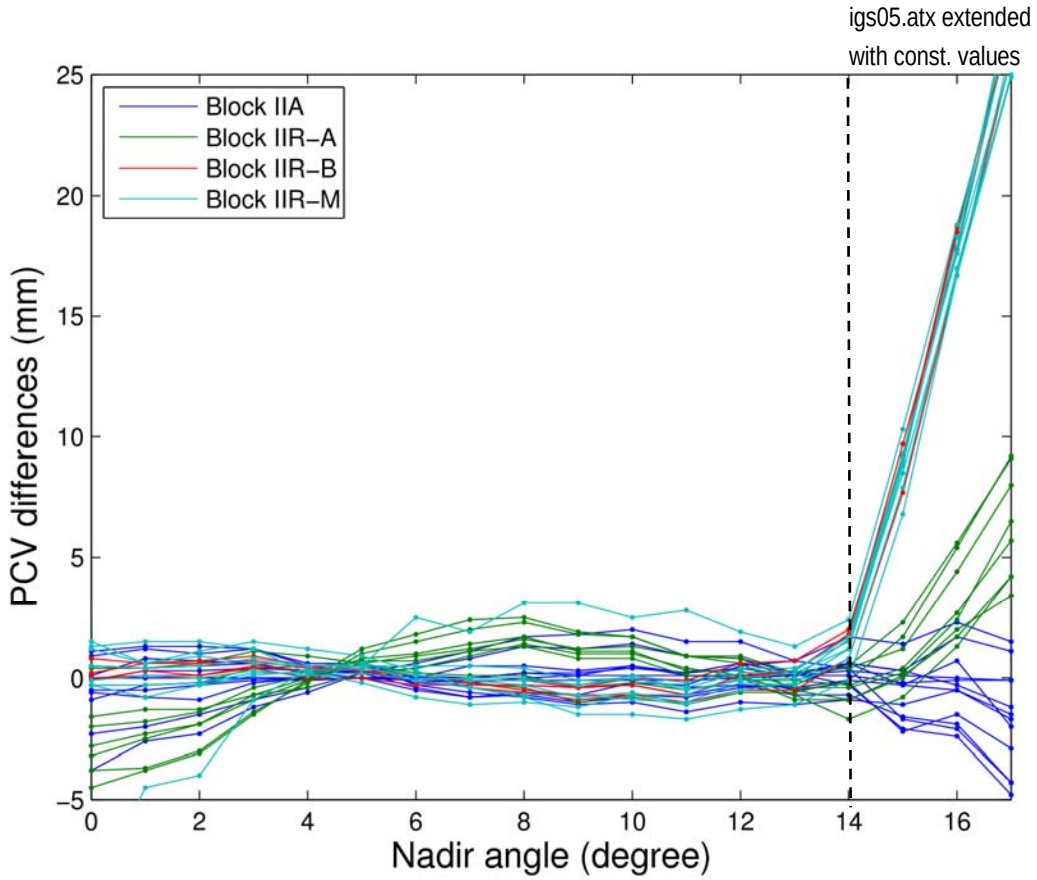
GRACE only

GRACE & GPS

Small improvement from 7.5 to 7.2 mm K-band range STD

Combined solution

Differences compared to igs05.atx



Data used:

Jason-2 (1 year)

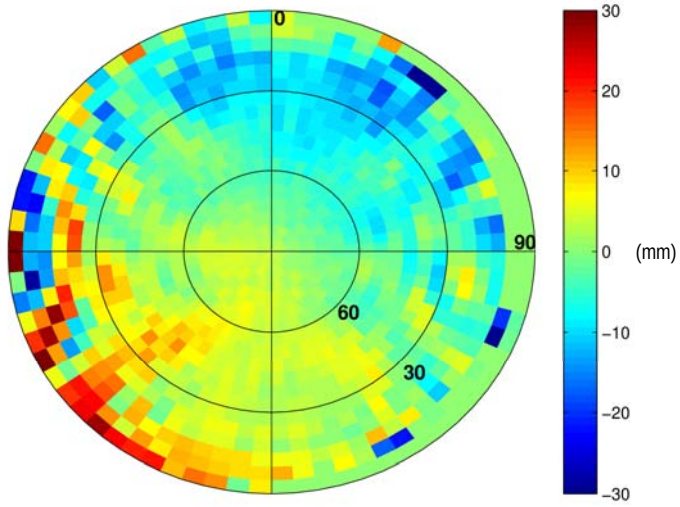
GRACE (1 year)

GOCE (0.5 year)

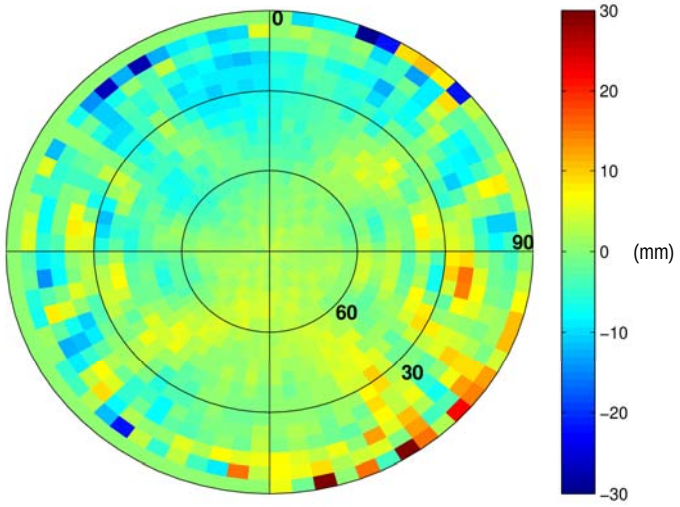
MetOp (23 days)

… and the combination further smoothes the estimates

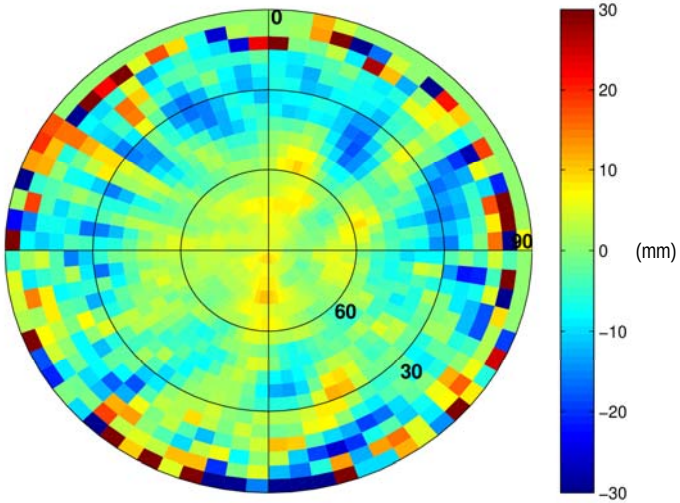
Estimated LEO PCVs



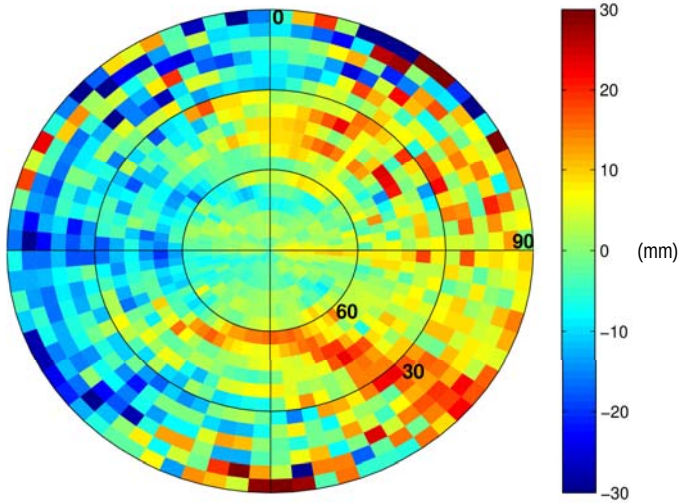
GRACE-A



GRACE-B



Jason-2



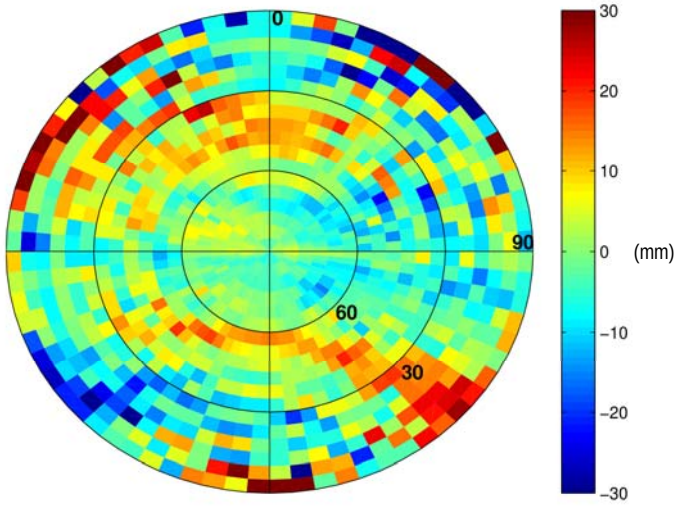
GOCE

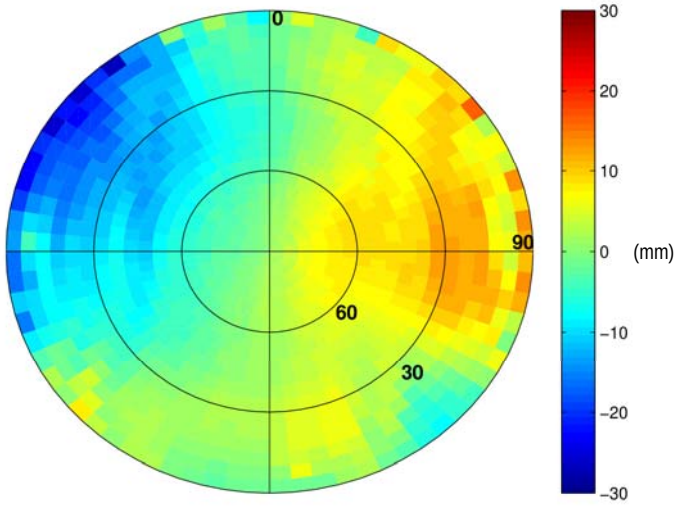
Impact of LEO orbit errors

Illustration with GOCE data

"unfair" experiment:

differences:





GOCE

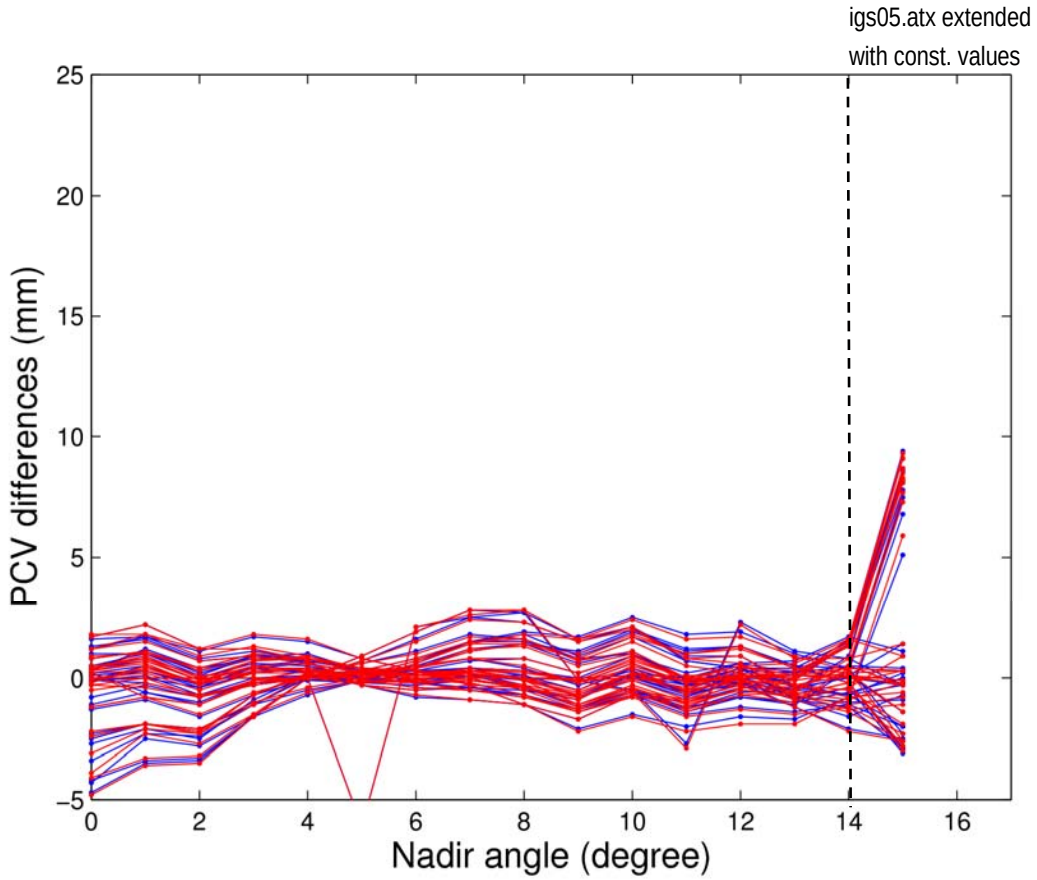
orbits generated with empirical LEO PCVs are introduced as known for PCV estimation

large-scale structures of LEO PCVs show pronounced differences (cross-track shifts)

Systematic LEO orbit errors affect the estimated LEO PCVs …

Impact of LEO orbit errors

Illustration with GRACE data



GRACE orbits:

w/o emp. PCVs

with emp. PCVs

… but they hardly affect the estimated GPS PCVs

Conclusions

- Satellite-specific GPS PCVs were simultaneously estimated with LEO PCVs from pure LEO GPS data
- Constraints are required to enable the simultaneous estimation of GPS and LEO PCVs when using only LEO GPS data
- Simultaneous PCV estimation is required to avoid mapping of mismodeled LEO PCVs into the GPS PCVs
- Satellite-specific GPS PCVs may be consistently estimated to igs05.atx, the agreement is about 2-3 mm below 14°
- Block-specific values may be generated a posteriori, they show an agreement with igs05.atx of about 1 mm below 14°
- Block-specific values could be used to consistently extend IGS GPS PCVs beyond 14°
- For a future re-estimation of GPS PCVs the combination with LEO NEQs should be considered

Thank you for your attention!