

# Extending the GPS satellite antenna patterns of the IGS to nadir angles beyond $14^\circ$ using LEO data

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O. Montenbruck, R. Schmid, Y. Andres

April 8, 2011

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***AIUB***

Astronomical Institute  
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  
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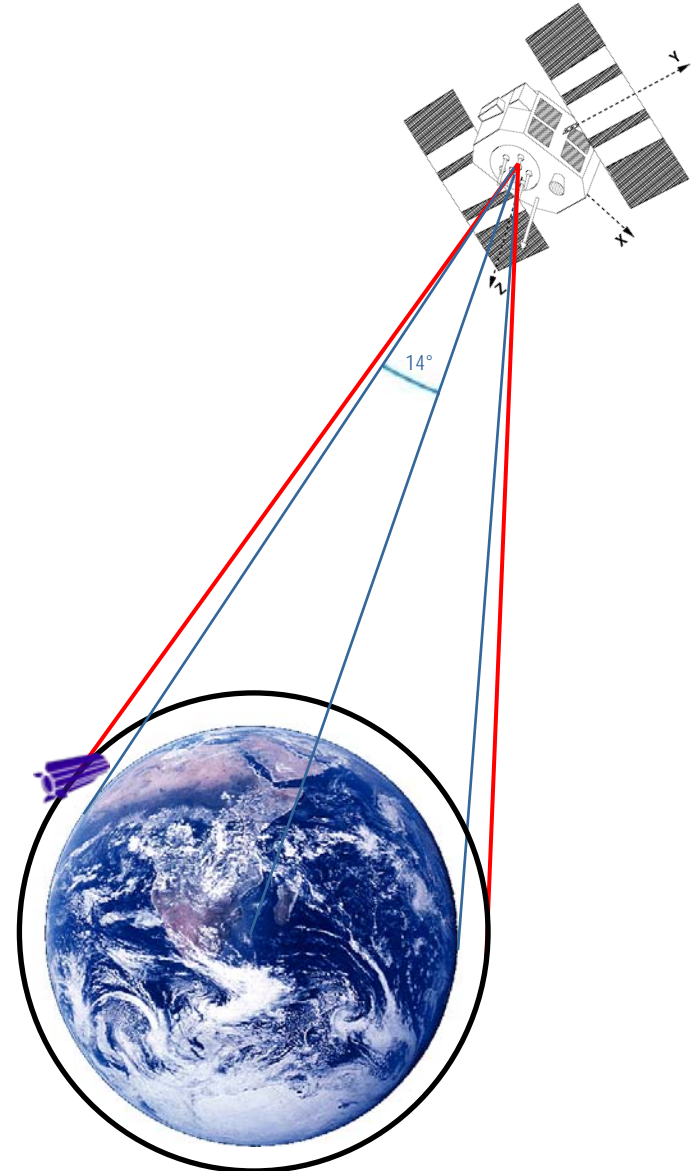
European Organisation for the Exploitation  
of Meteorological Satellites (EUMETSAT)

# Introduction

Phase center variations (PCVs) of GPS transmitter antennas, e.g., as provided by the IGS, are restricted to nadir angles  $\leq 14^\circ$

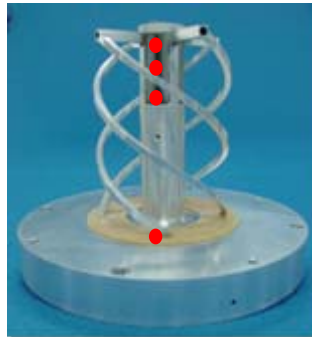
GPS data from Low Earth Orbiters (LEOs) may be used to extend the GPS PCVs to nadir angles  $\leq 17^\circ$

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  $14^\circ$  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

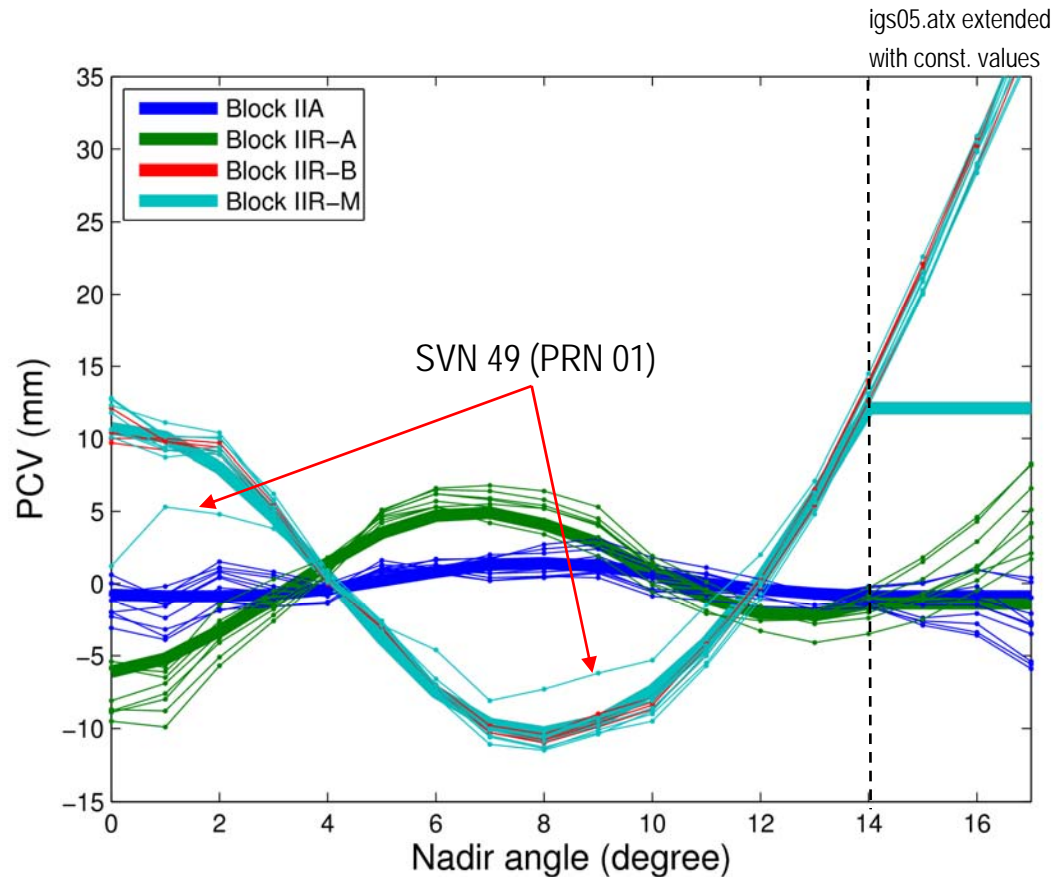
- **PCVs for the GPS transmitter antennas**  
(nadir-dependent, piecewise linear, satellite-specific)
  - zero-mean condition (for nadir angles  $\leq 12^\circ$ )
  - PCVs of two Block IIA SVs **constrained to a priori** due to the simultaneous estimation of LEO PCVs
- **PCVs for the LEO receiver antennas**  
( $5^\circ \times 5^\circ$  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

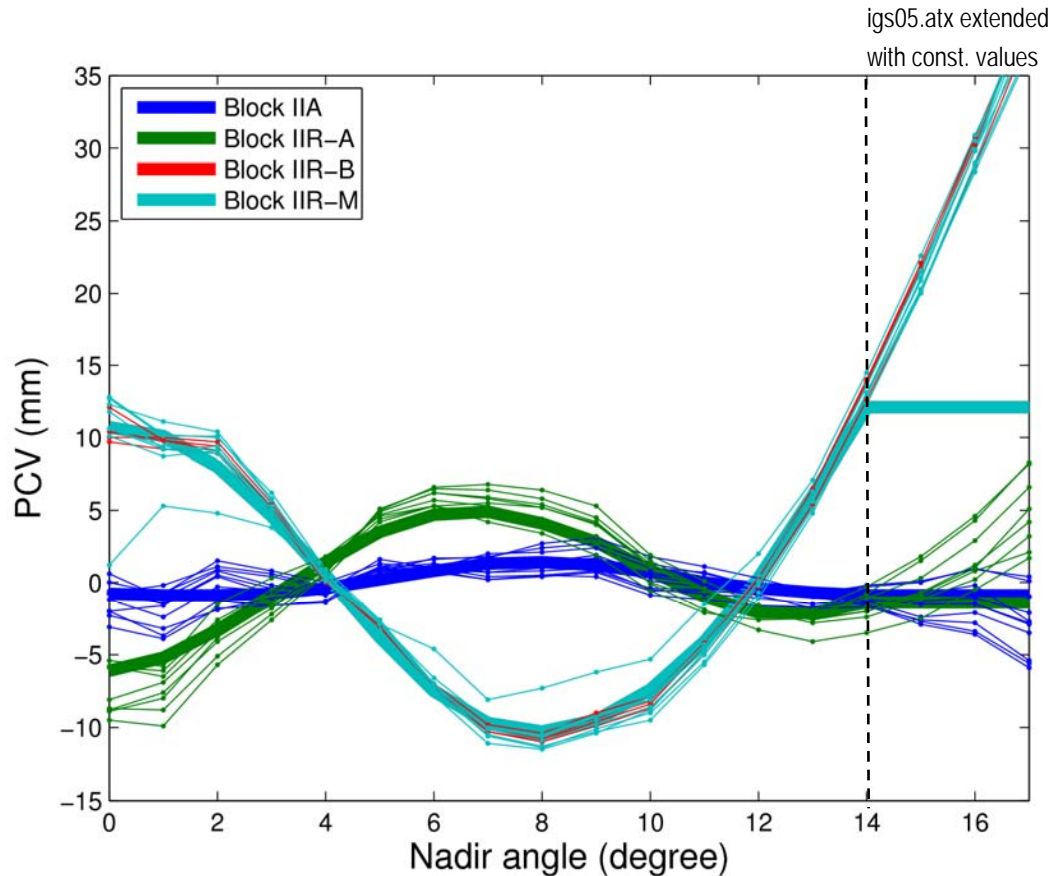


Data used:  
30-sec GPS data  
from entire year  
2009

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

# Jason-2 solution

PCVs compared to igs05.atx

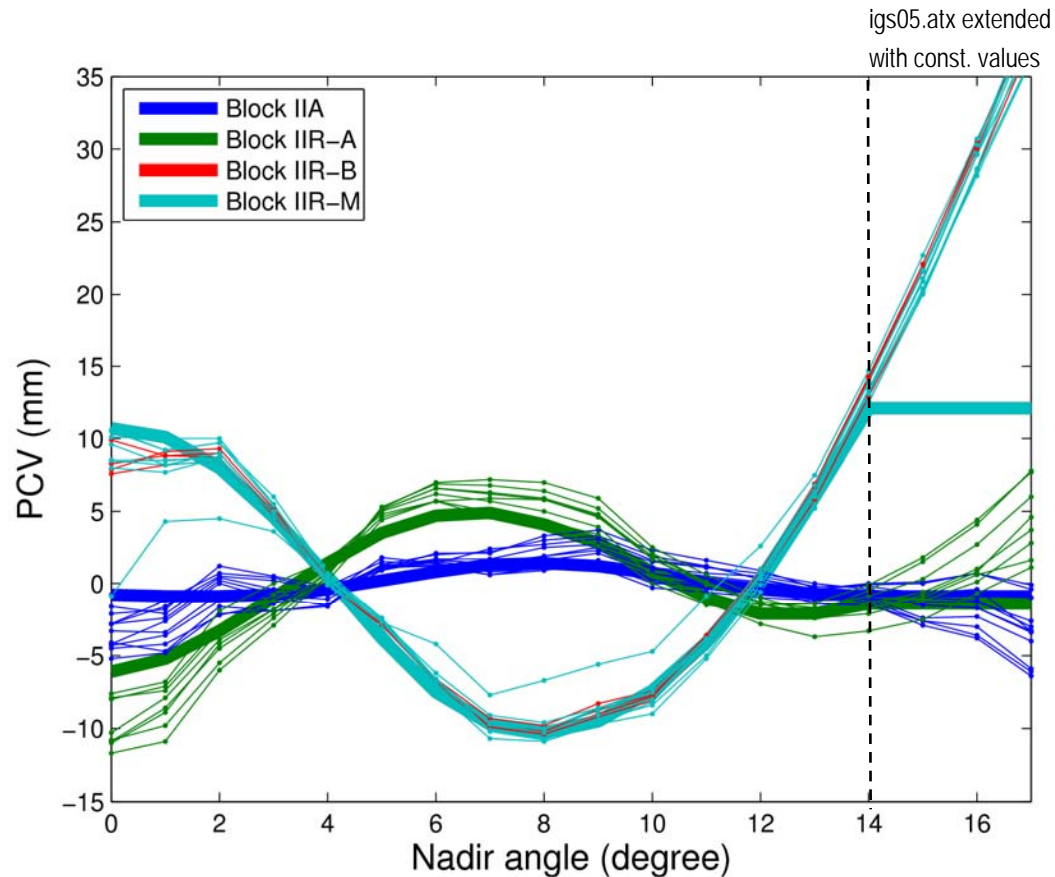


Constraint:  
SVNs 25, 27

Completely different agreement with igs05.atx for different constraints

# Jason-2 solution

PCVs compared to igs05.atx



Constraint:

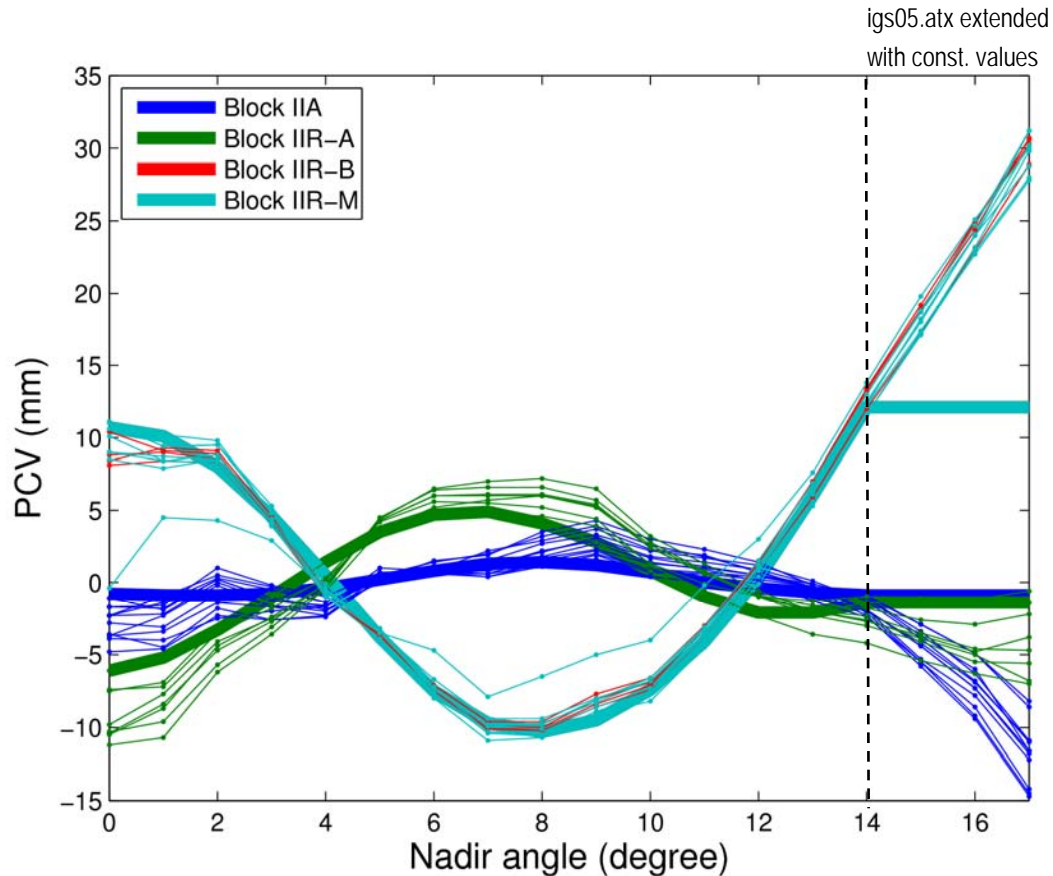
SVNs 25, 27

SVN 25

Completely different agreement with igs05.atx for different constraints

# Jason-2 solution

PCVs compared to igs05.atx



Constraint:

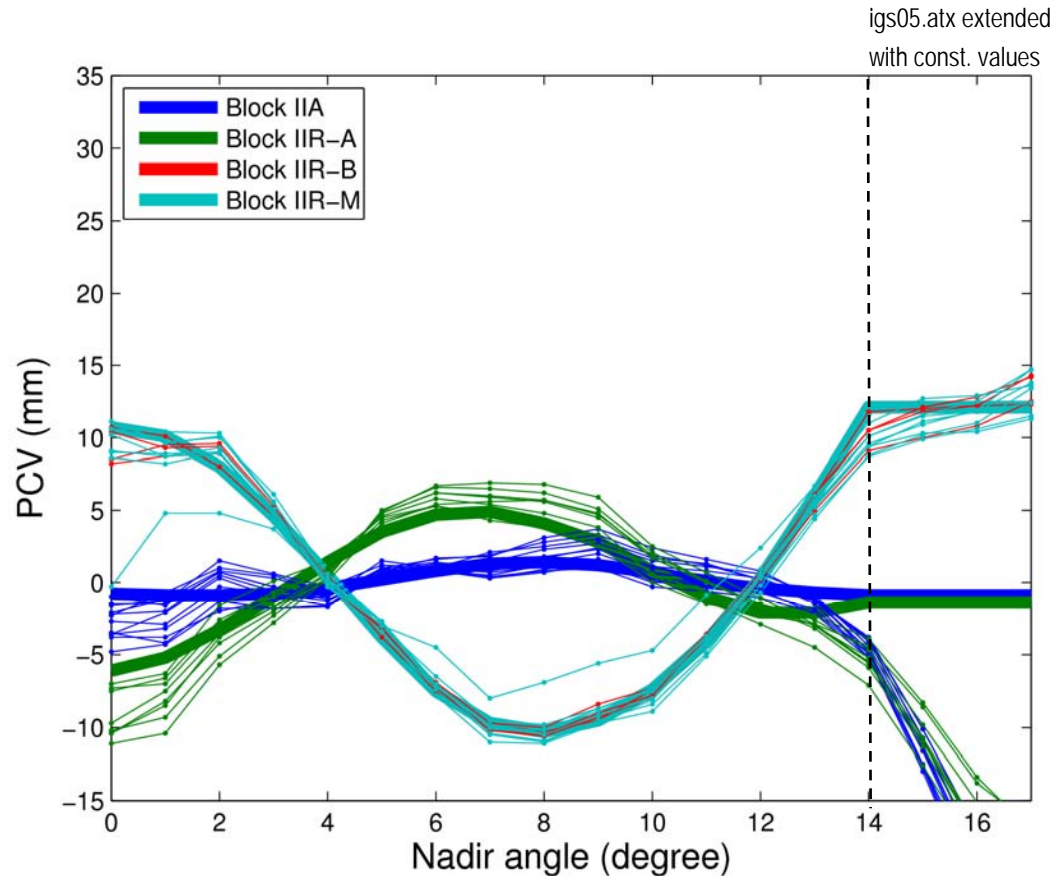
SVNs 25, 27

SVN 25

SVN 44

# Jason-2 solution

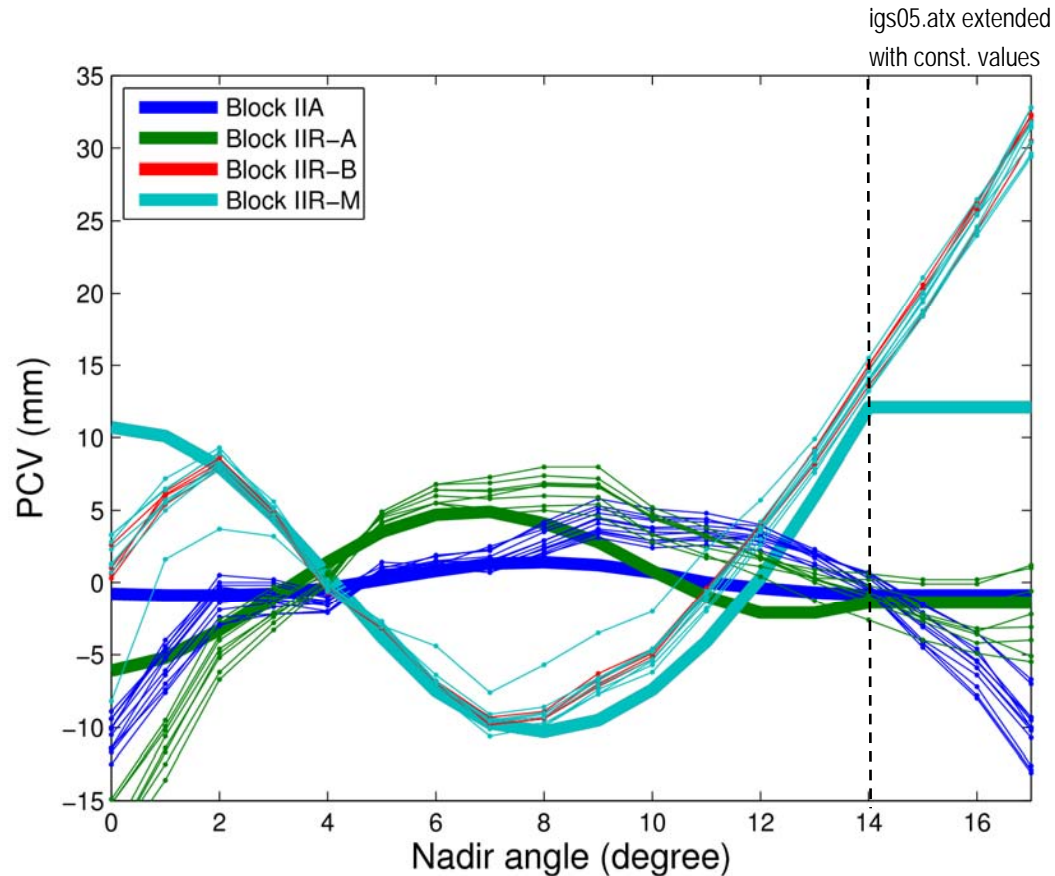
PCVs compared to igs05.atx



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

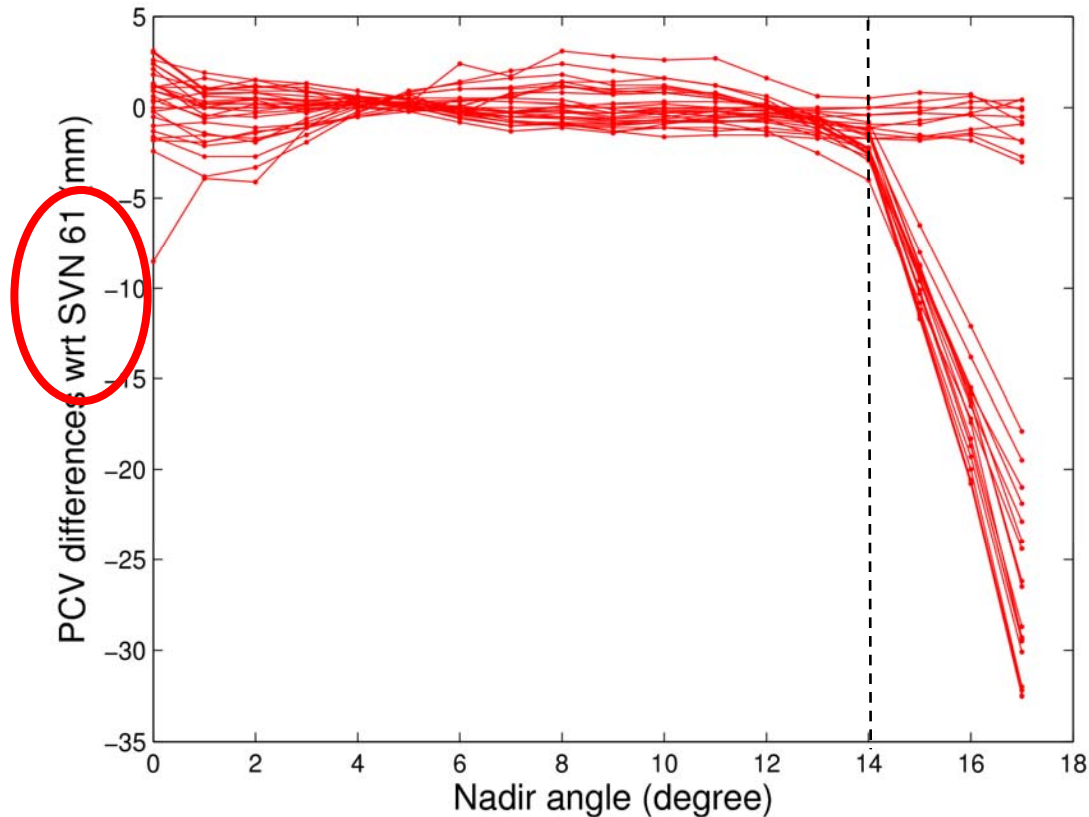
SVN 60

none

Completely different agreement with igs05.atx for different constraints

# Jason-2 solution

PCVs compared with each other



Constraint:

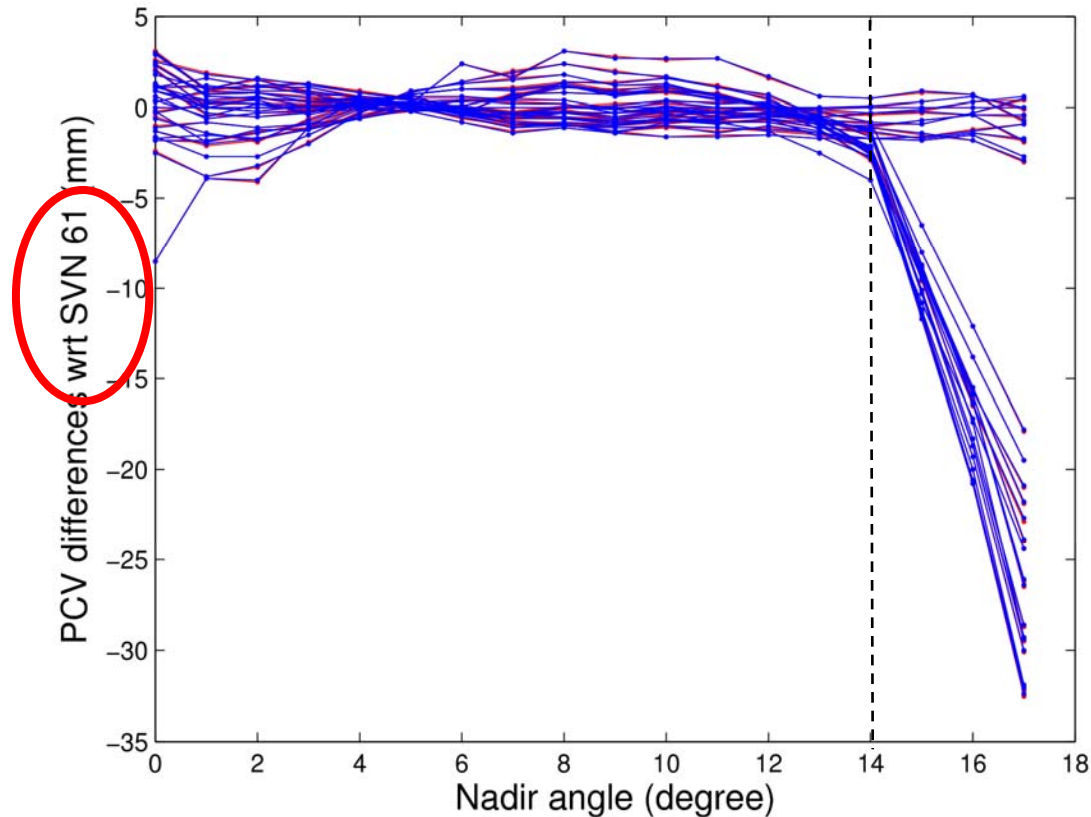
SVNs 25, 27

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



# Jason-2 solution

PCVs compared with each other



Constraint:

SVNs 25, 27

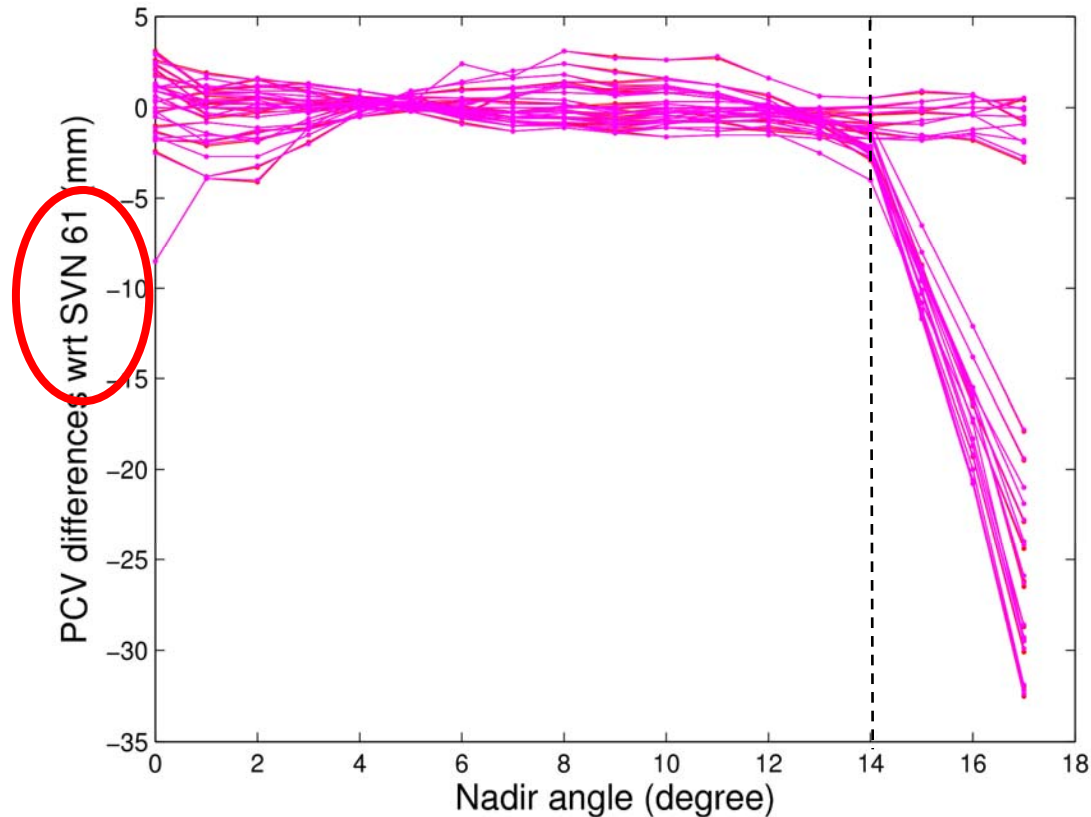
SVN 25

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



# Jason-2 solution

PCVs compared with each other



Constraint:

SVNs 25, 27

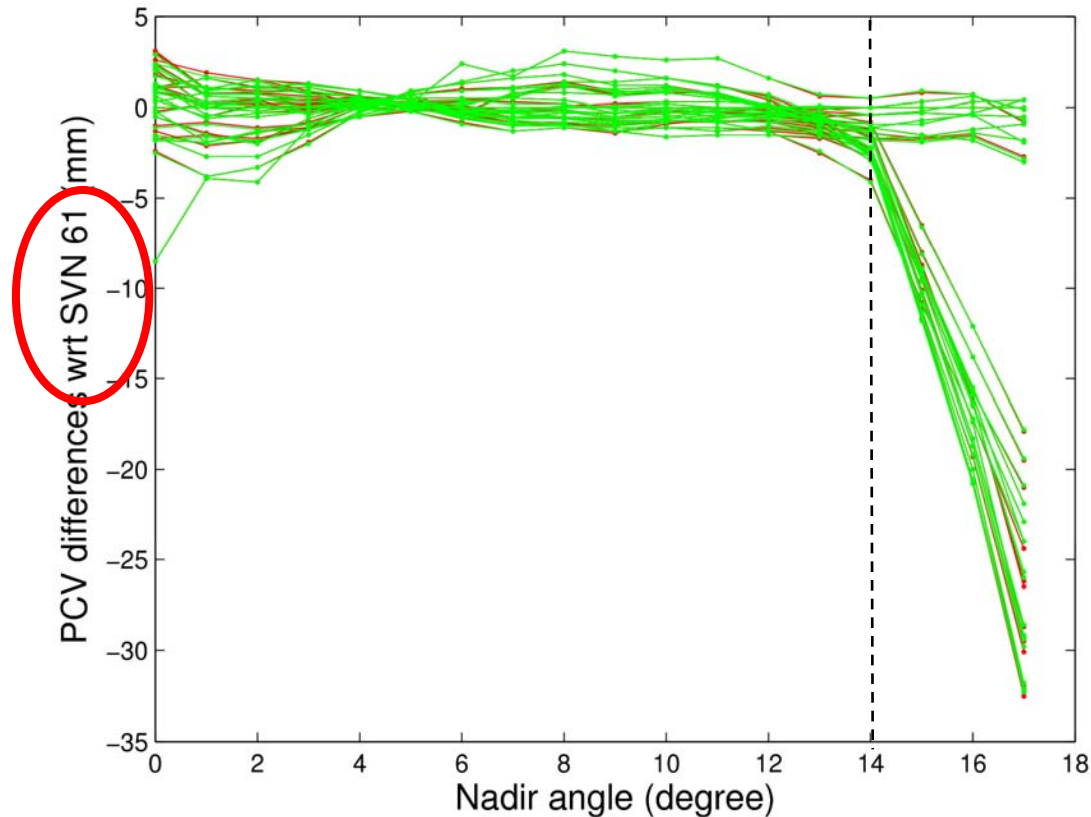
SVN 25

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

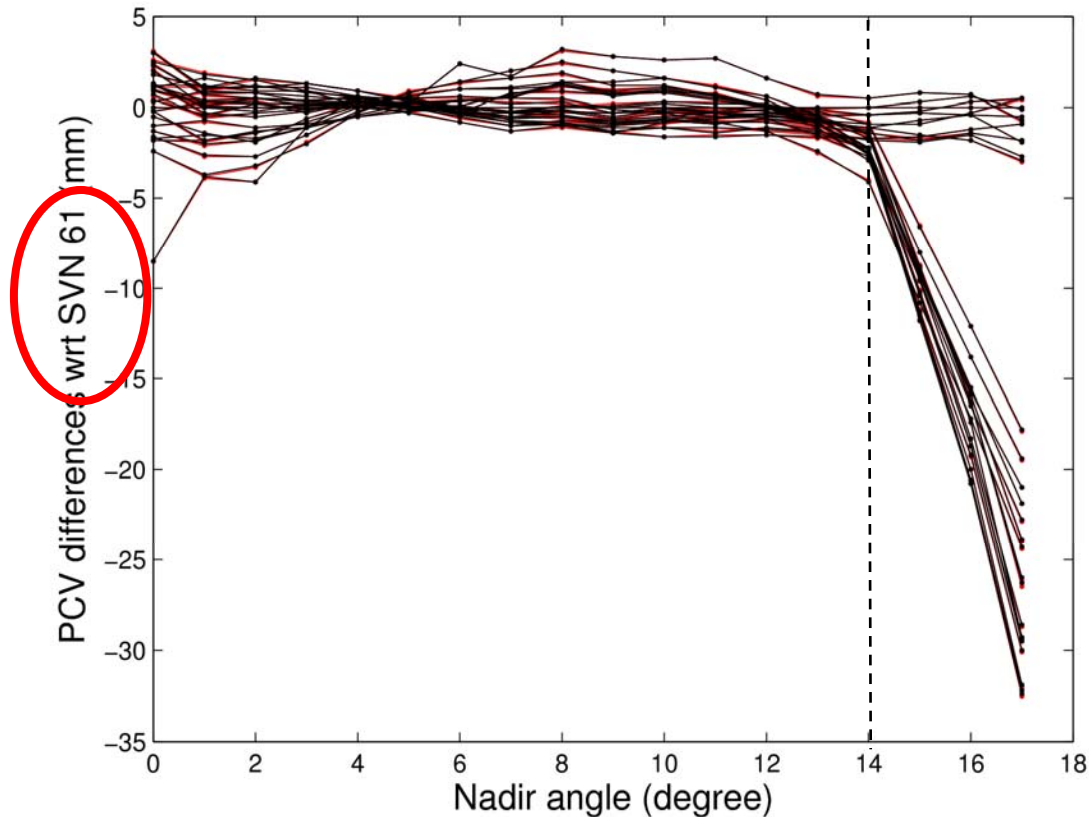
SVN 44

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

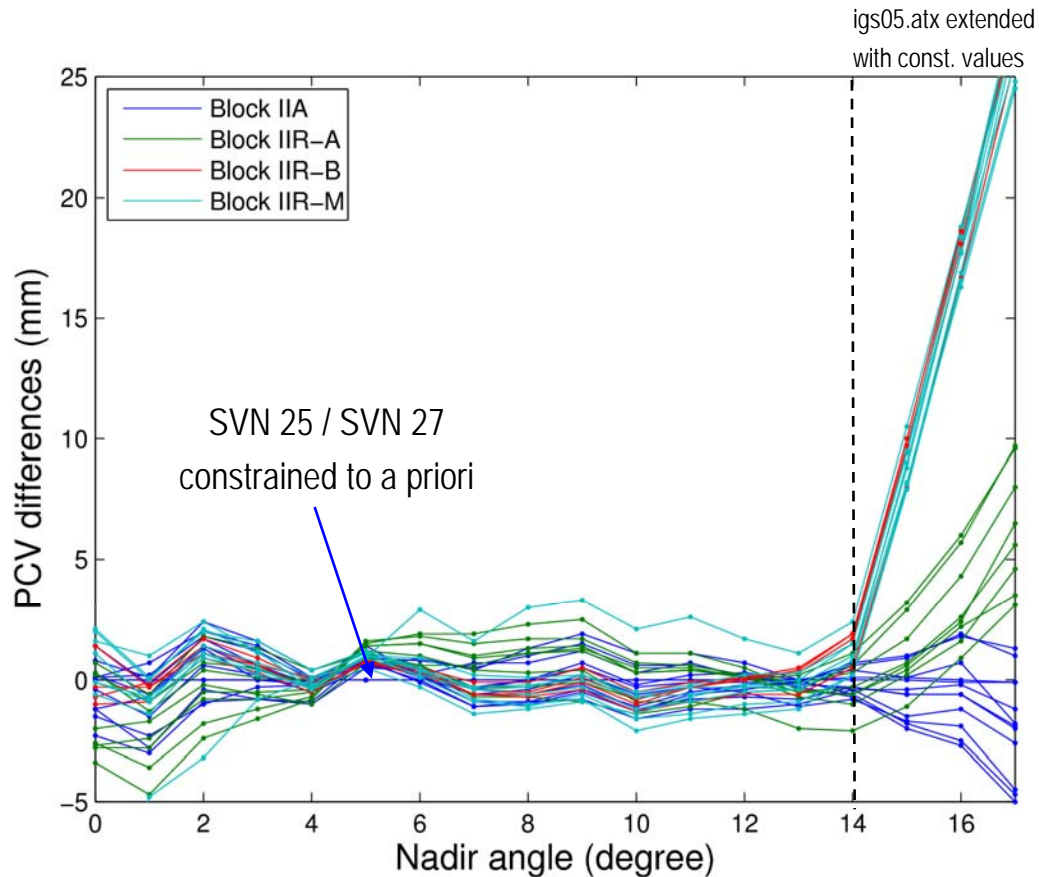
SVN 60

none

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

# Jason-2 solution

Differences compared to igs05.atx

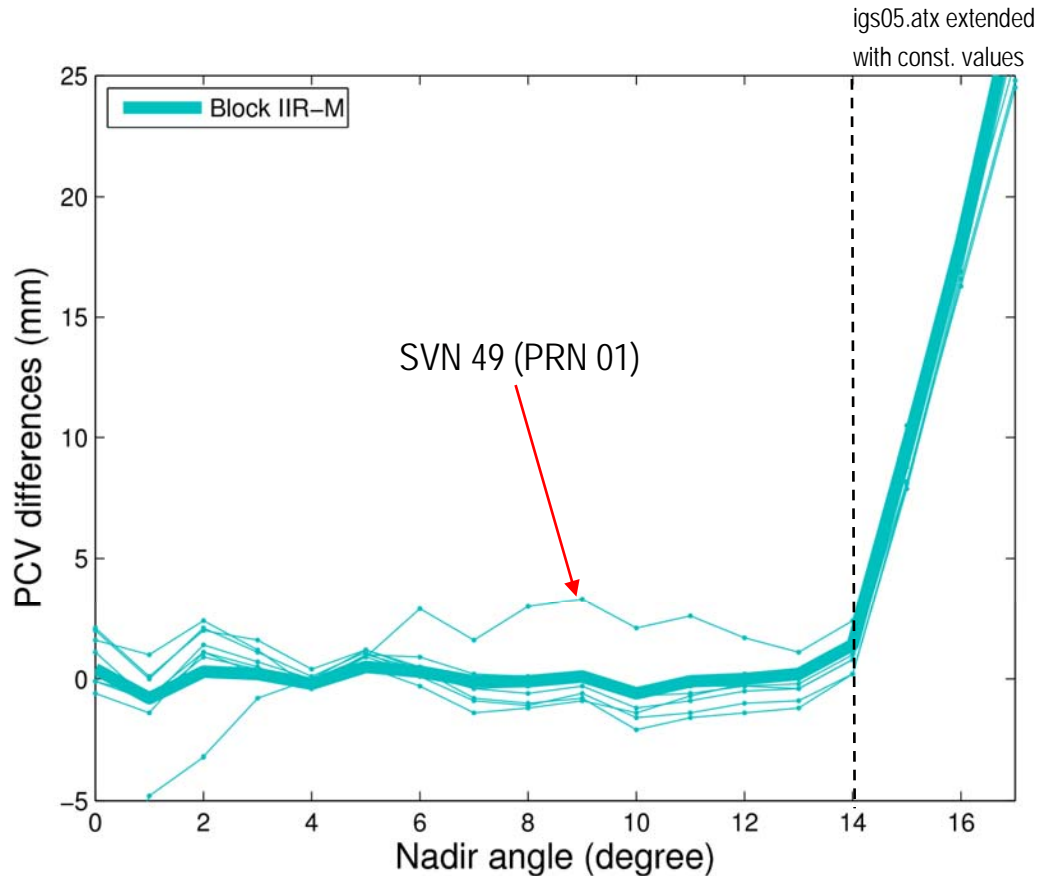


Data used:  
30-sec GPS data  
from entire year  
2009

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

# Jason-2 solution

Differences compared to igs05.atx

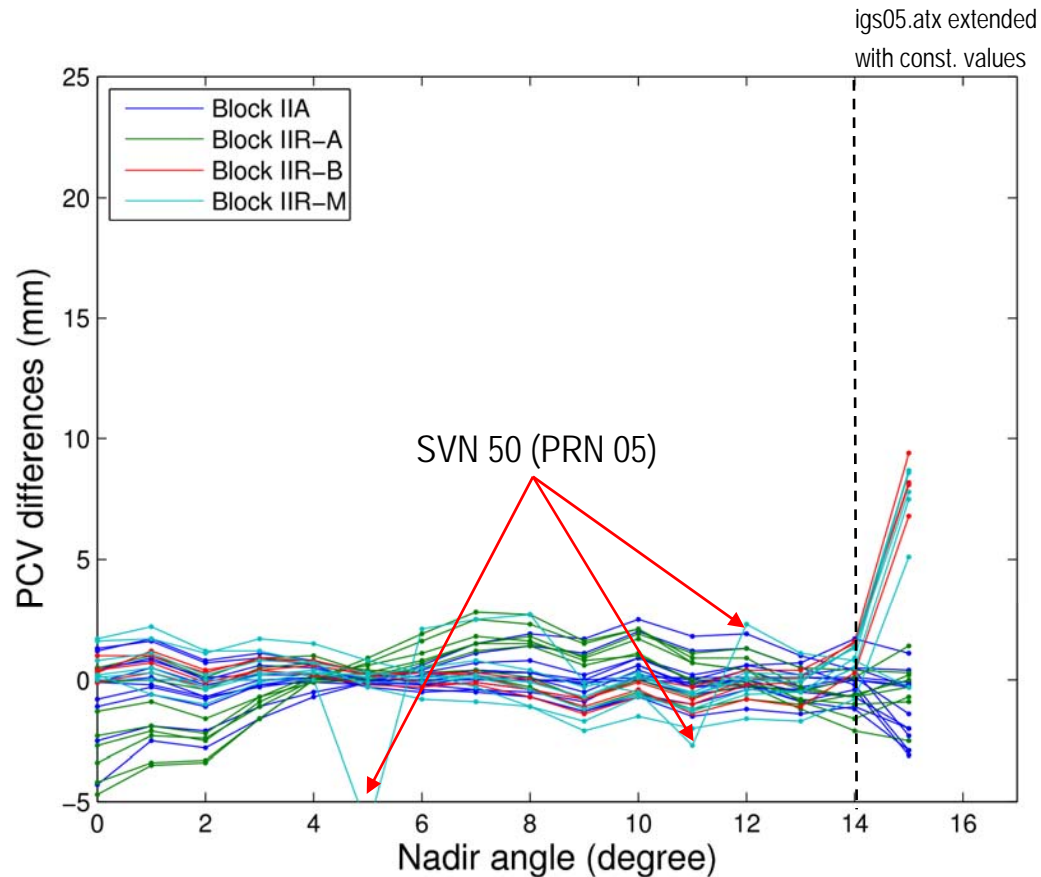


Data used:  
30-sec GPS data  
from entire year  
2009

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

# GRACE solution

Differences compared to igs05.atx

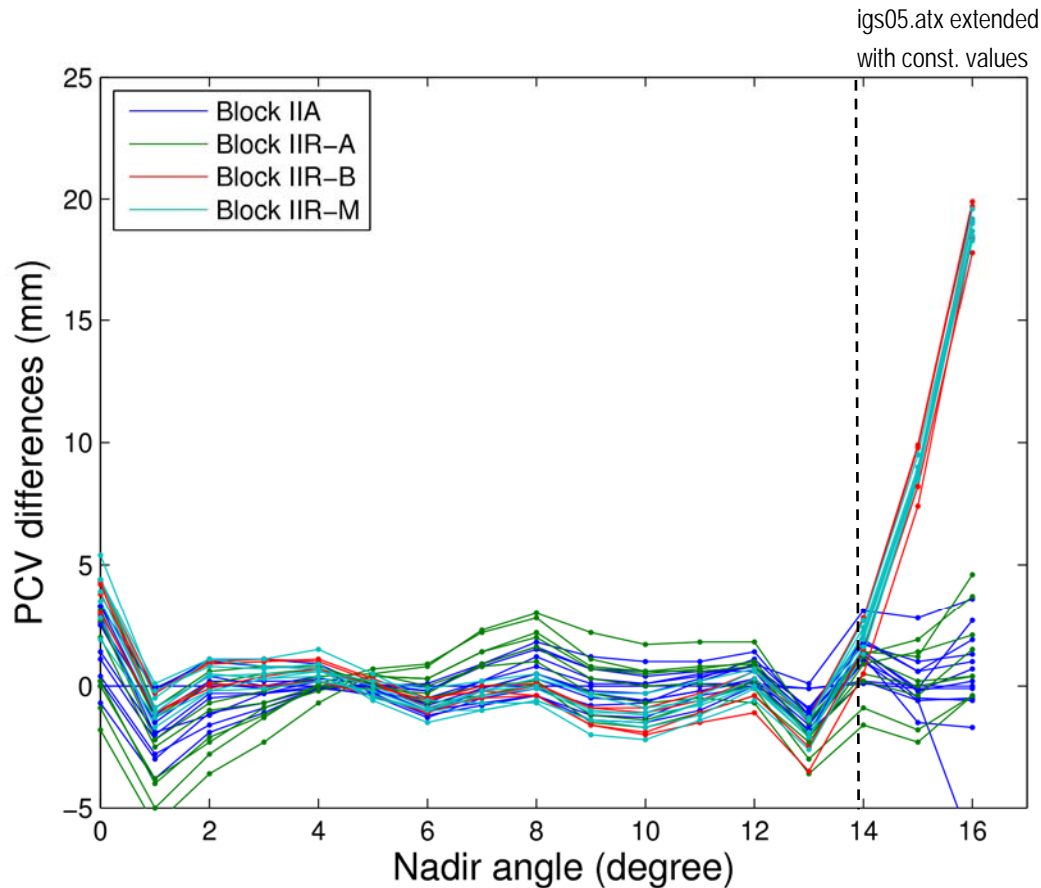


Data used:  
30-sec GPS data  
from entire year  
2009

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

# MetOp-A solution

Differences compared to igs05.atx

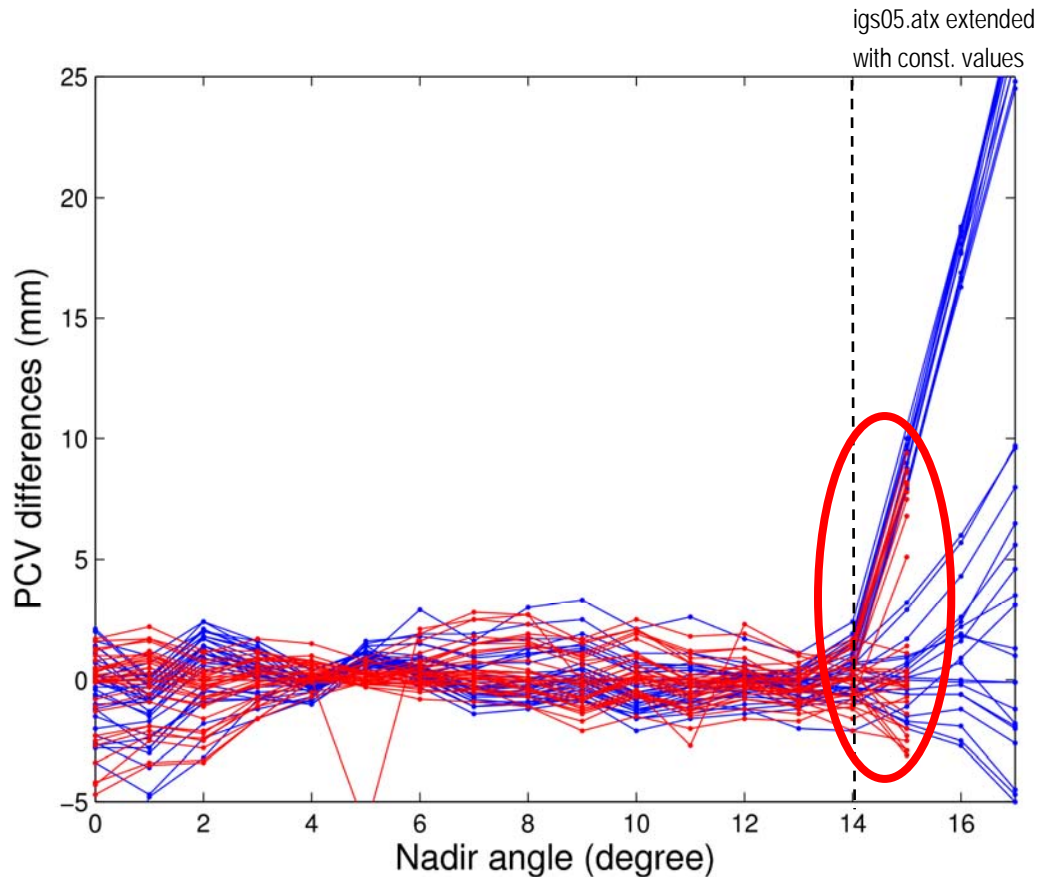


Data used:  
30-sec GPS data  
from entire year  
2009

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

# Consistency of solutions

Differences compared to igs05.atx



LEO data:

Jason-2

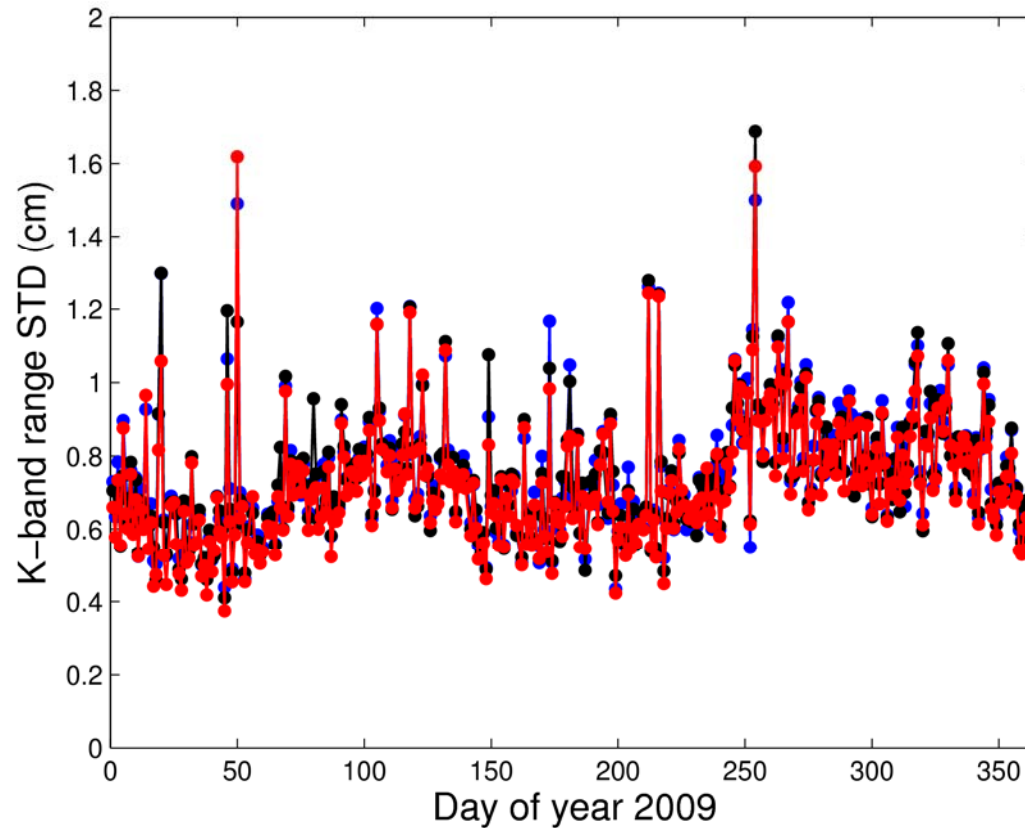
GRACE-A & B

Individual LEO solutions reasonably agree with each other ...



# Validation of GPS PCVs

Impact on GRACE orbit determination



Improved PCVs:

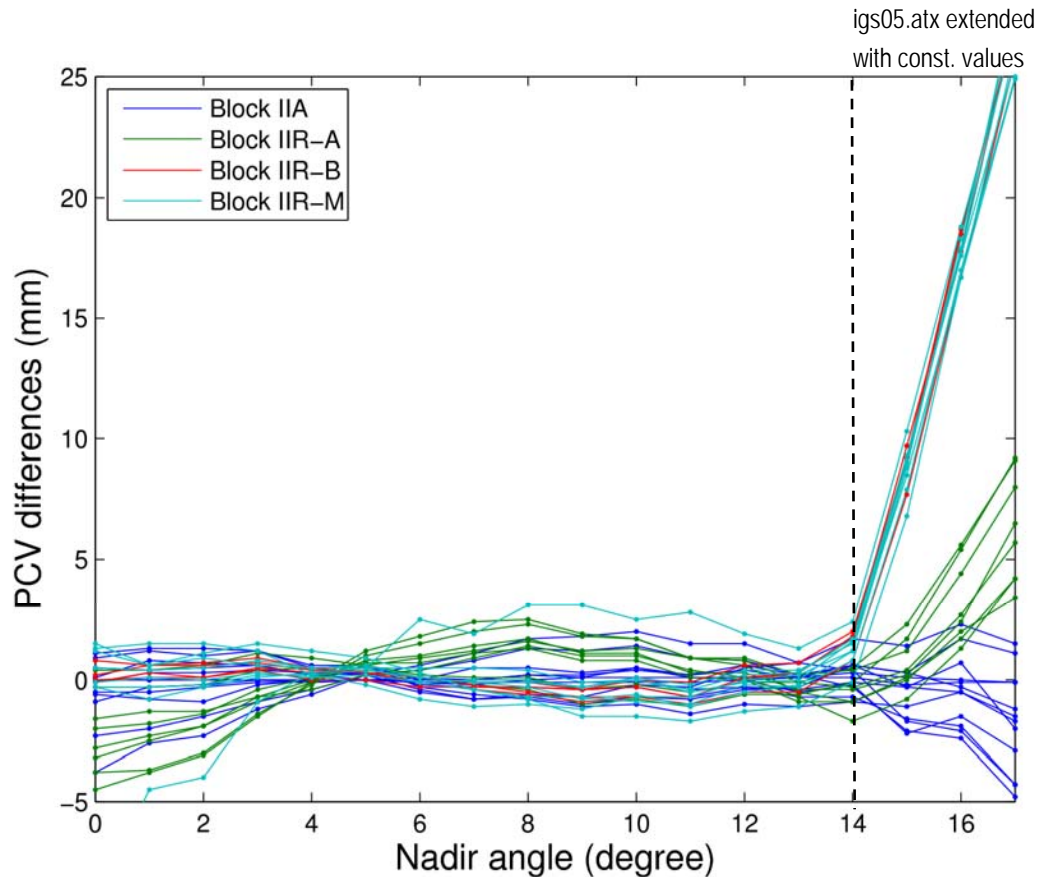
GRACE only

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)

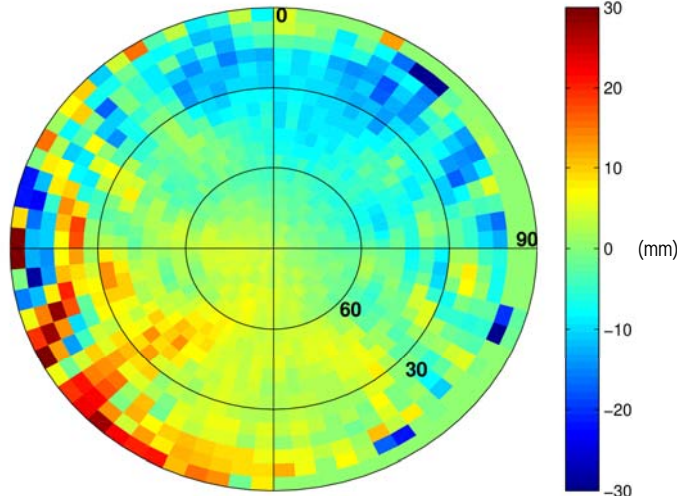
GRACE (1 year)

GOCE (0.5 year)

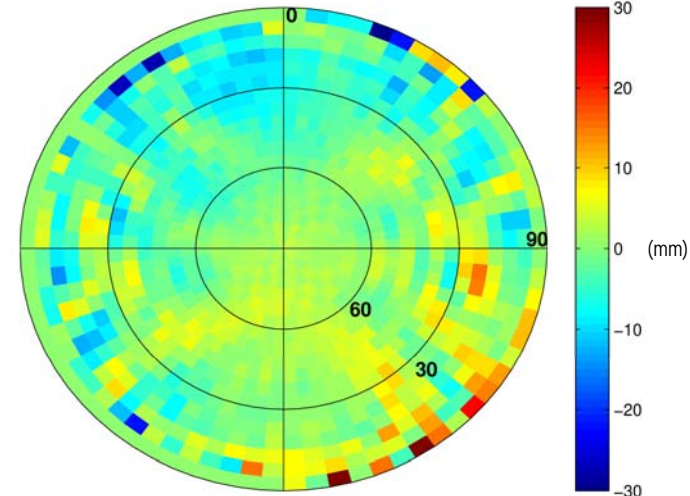
MetOp (23 days)

... and the combination further smoothes the estimates

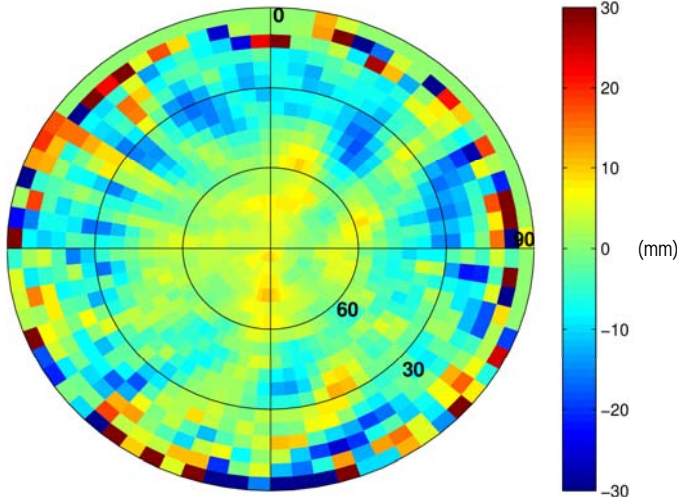
# Estimated LEO PCVs



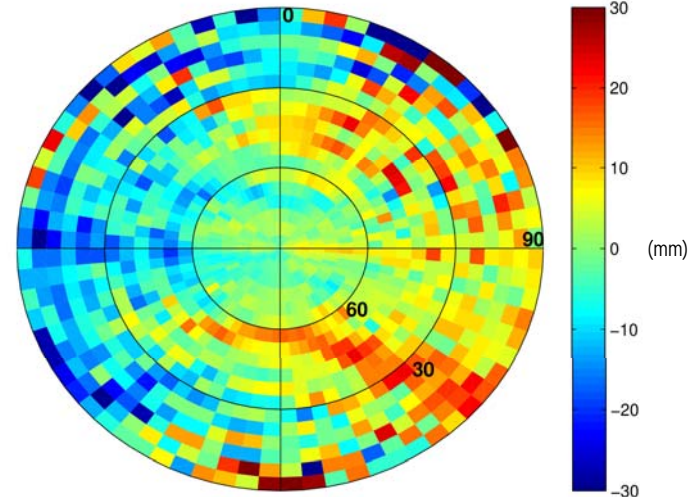
GRACE-A



GRACE-B



Jason-2

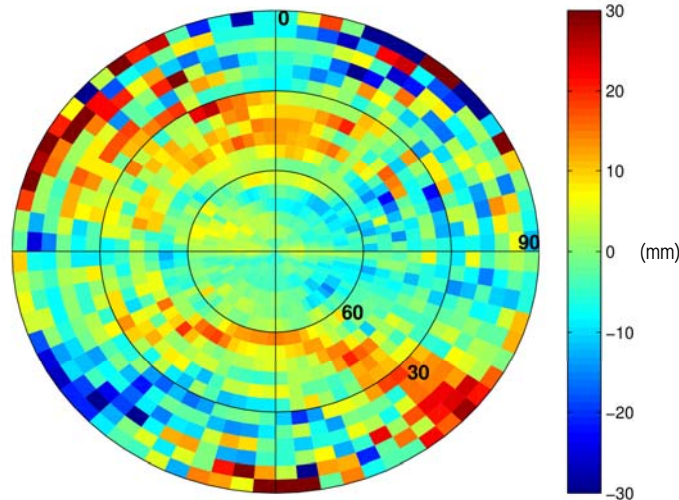


GOCE

# Impact of LEO orbit errors

Illustration with GOCE data

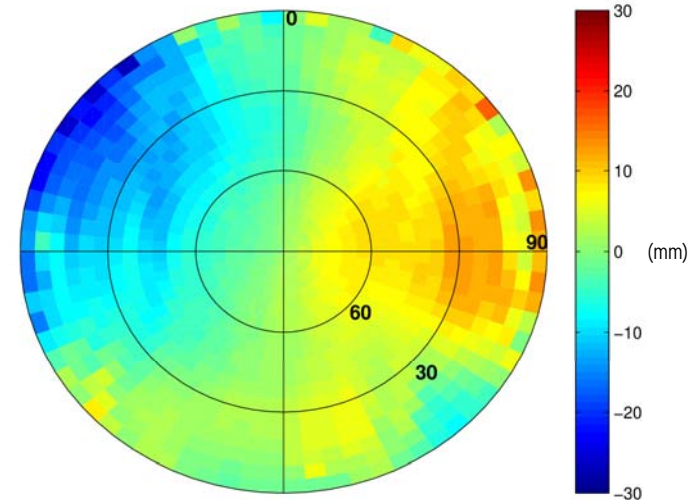
"unfair" experiment:



GOCE

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

differences:

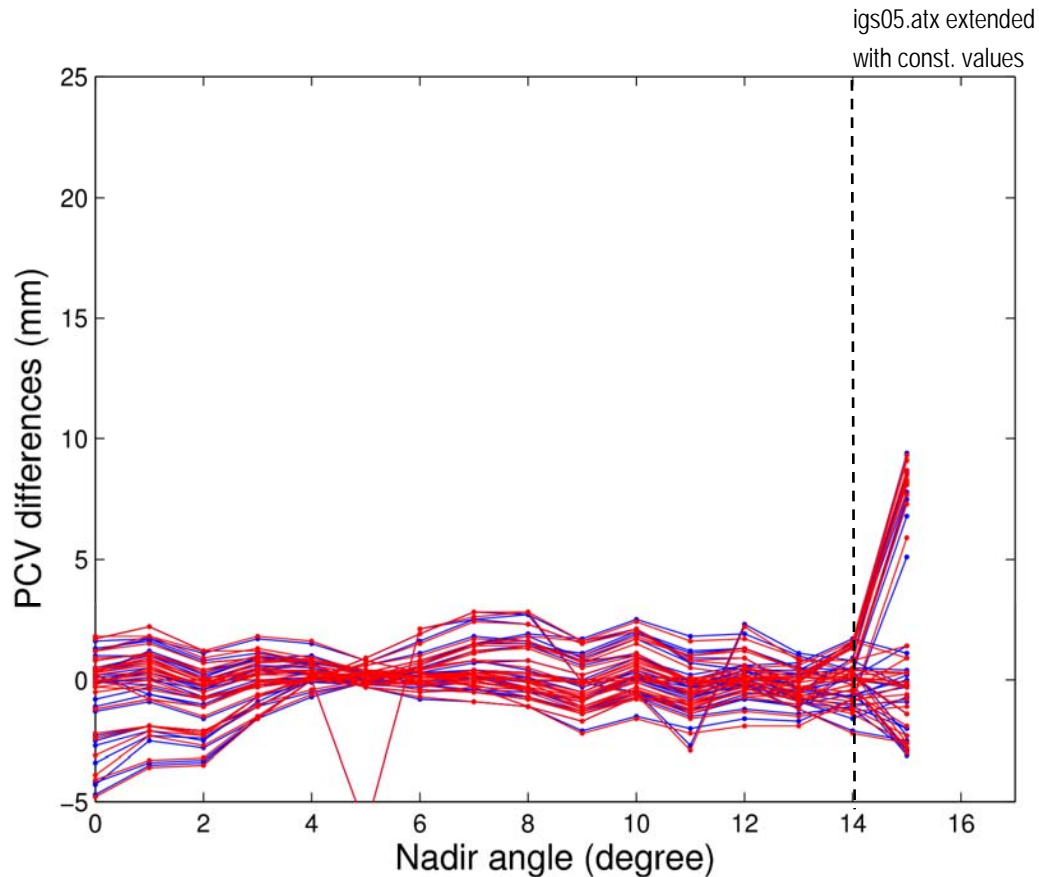


large-scale structures of LEO PCVs show pronounced differences (cross-track shifts)

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  $14^\circ$
- Block-specific values may be generated a posteriori, they show an agreement with igs05.atx of about **1 mm** below  $14^\circ$
- Block-specific values could be used to consistently extend IGS GPS PCVs beyond  $14^\circ$
- For a future re-estimation of GPS PCVs the combination with LEO NEQs should be considered

**Thank you for your attention!**