Extension of the GPS satellite antenna patterns to nadir angles beyond 14°

A. Jäggi[1], F. Dilssner[2], R. Schmid[3], R. Dach[1], T. Springer[2], H. Bock[1], P. Steigenberger[2], S. Lutz[1]

[1] *Astronomical Institute, University of Bern, Switzerland*

[2] *Navigation Support Office, European Space Operations Centre, Darmstadt, Germany*

[3] *Institute for Astronomical and Physical Geodesy, Technische Universität München, Germany*

IGS Workshop 2012, 23–27 July 2012

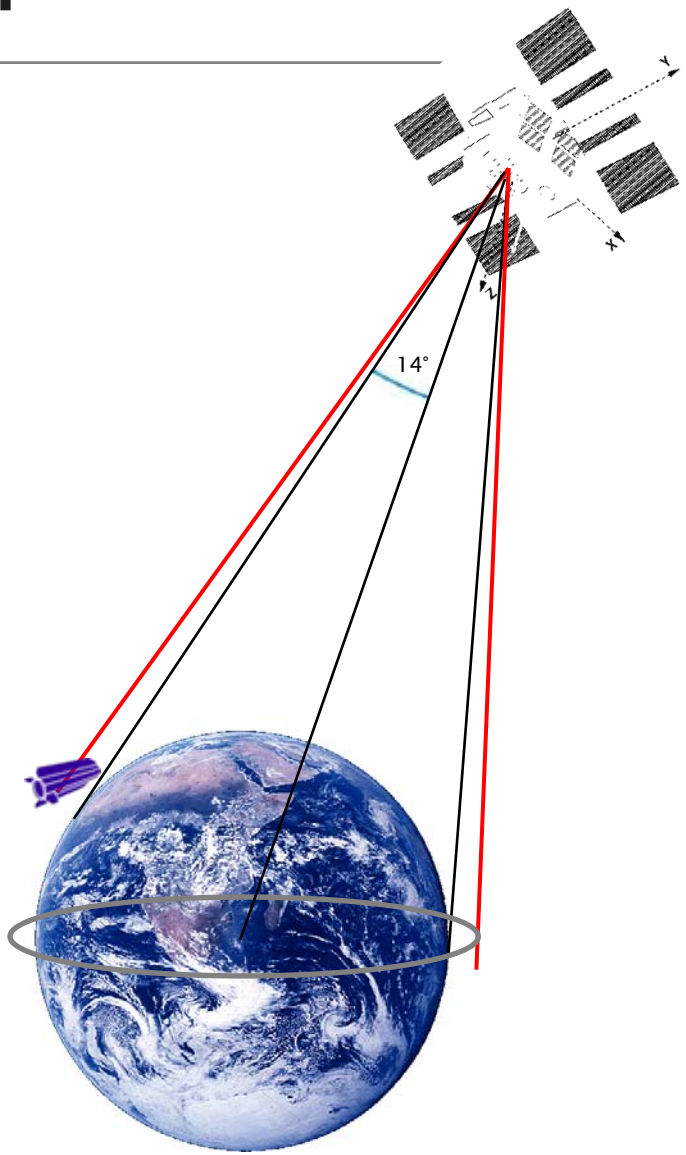
Olsztyn, Poland

Introduction

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

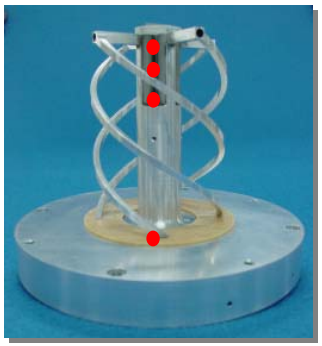
GPS data from Low Earth Orbiters (LEOs) may be used to extend the GPS PCVs to nadir angles <= 17°

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

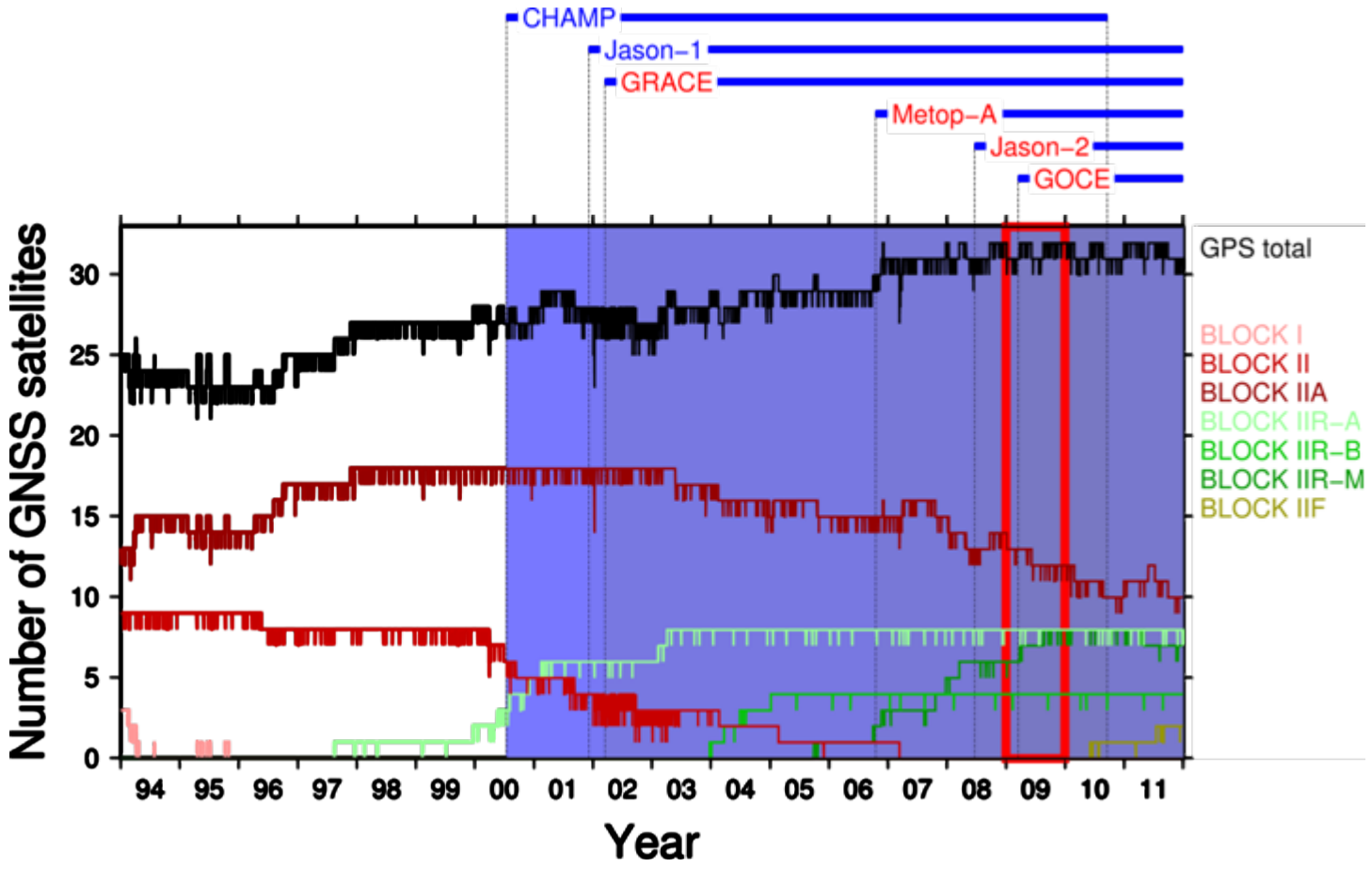


L2 PCO
L1 PCO
LC PCO

antenna reference point



Evolution of active GPS constellation



- **Increasing number of LEOs equipped with geodetic-grade receivers in recent years**

Input Data & Products

- **LEO GPS data**, undifferenced ionosphere-free (Jason-2, GRACE-A/B, GOCE, MetOp-A from 2009; Jason-2 from second half of 2011 for Block IIF satellites)
- **GPS orbits and clock corrections** from the CODE reprocessing, introduced as known (consistent with PCOs & PCVs from igs08.atx)
- **LEO orbits** from AIUB relying on the CODE reprocessed products, introduced as known (not based on empirical PCVs)
- **GPS PCOs and GPS PCVs** from igs08.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)

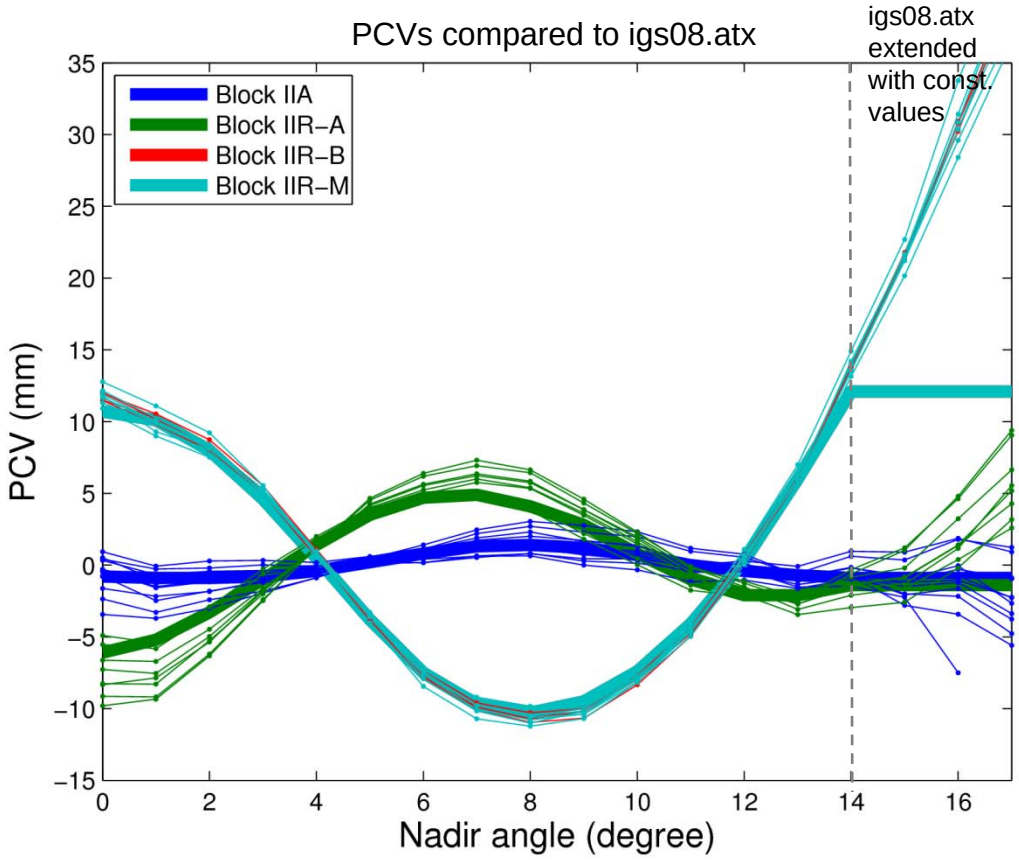
Estimated parameters & constraints

- **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 to solve for the PCVs.

LEO-only solution

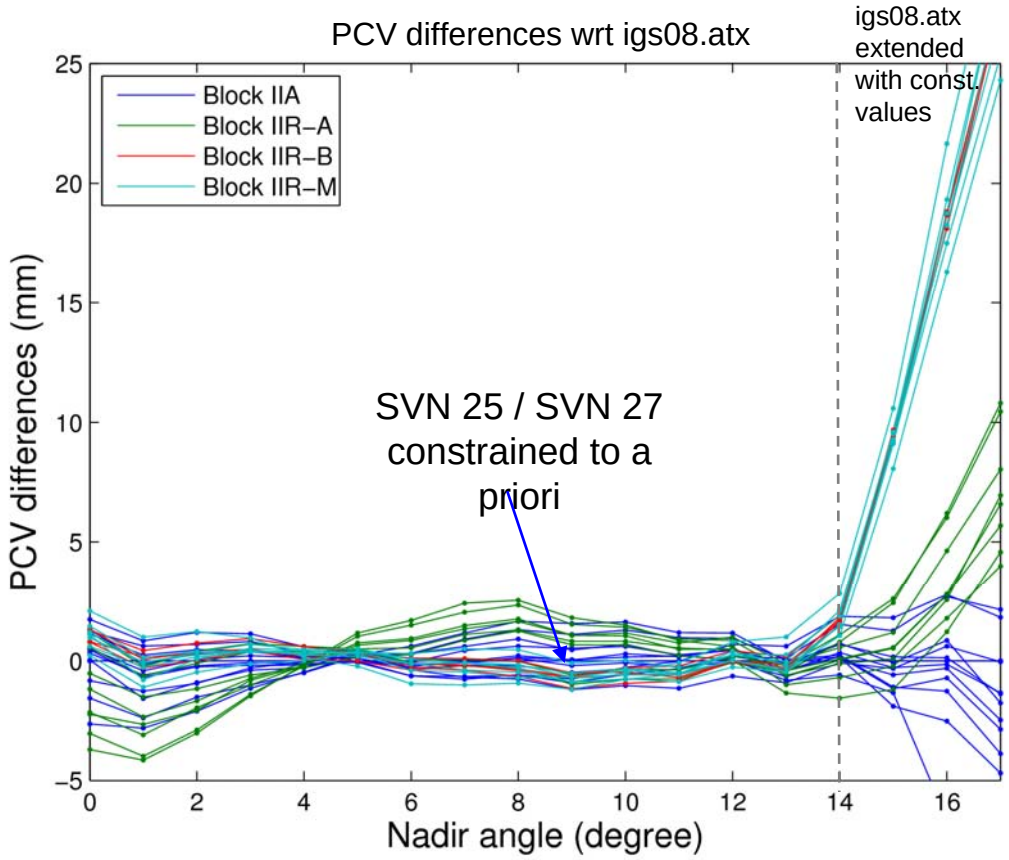


Data used:

Jason-2
MetOp-A
GRACE-A
GRACE-B
GOCE

- **Large differences wrt a priori PCVs beyond 14° (constant extension)**

LEO-only solution

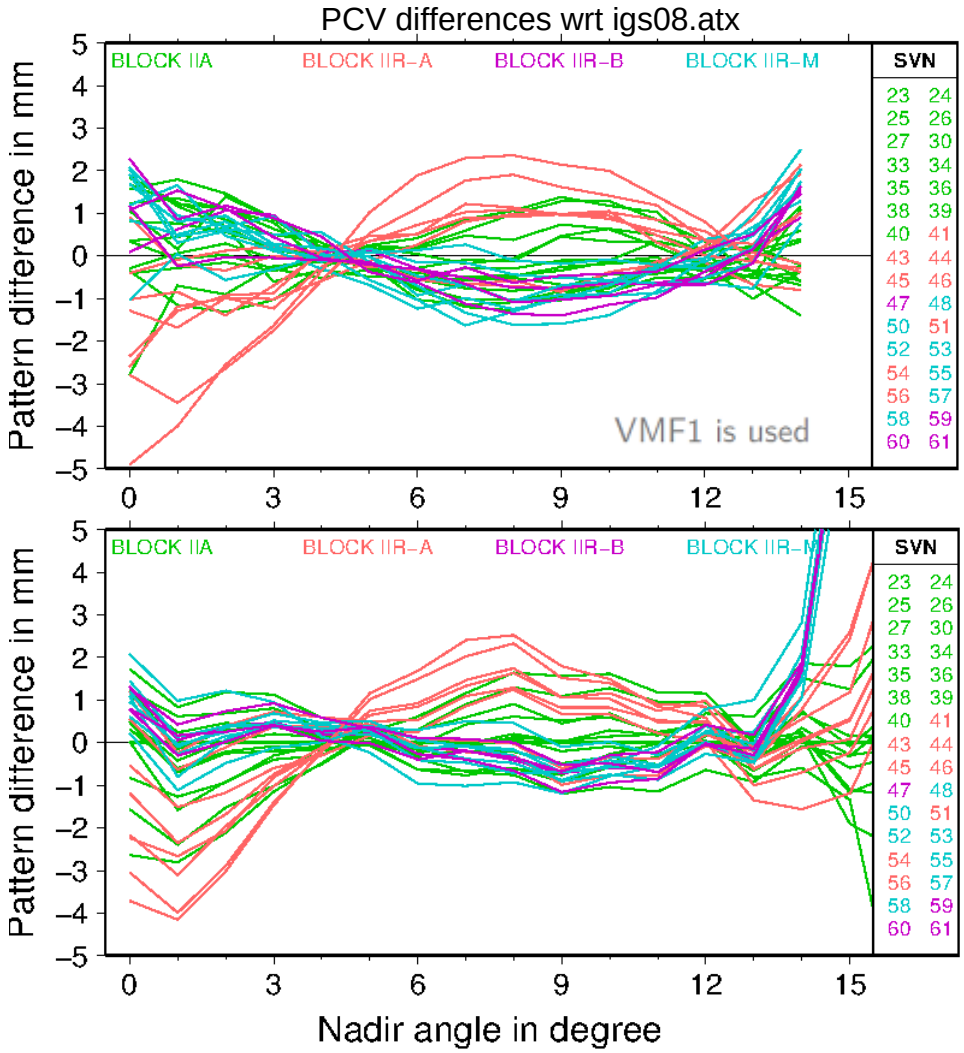


Data used:

Jason-2
MetOp-A
GRACE-A
GRACE-B
GOCE

- **Differences of 2-3 mm wrt block-specific values of igs08.atx below 14°**

Solution comparison

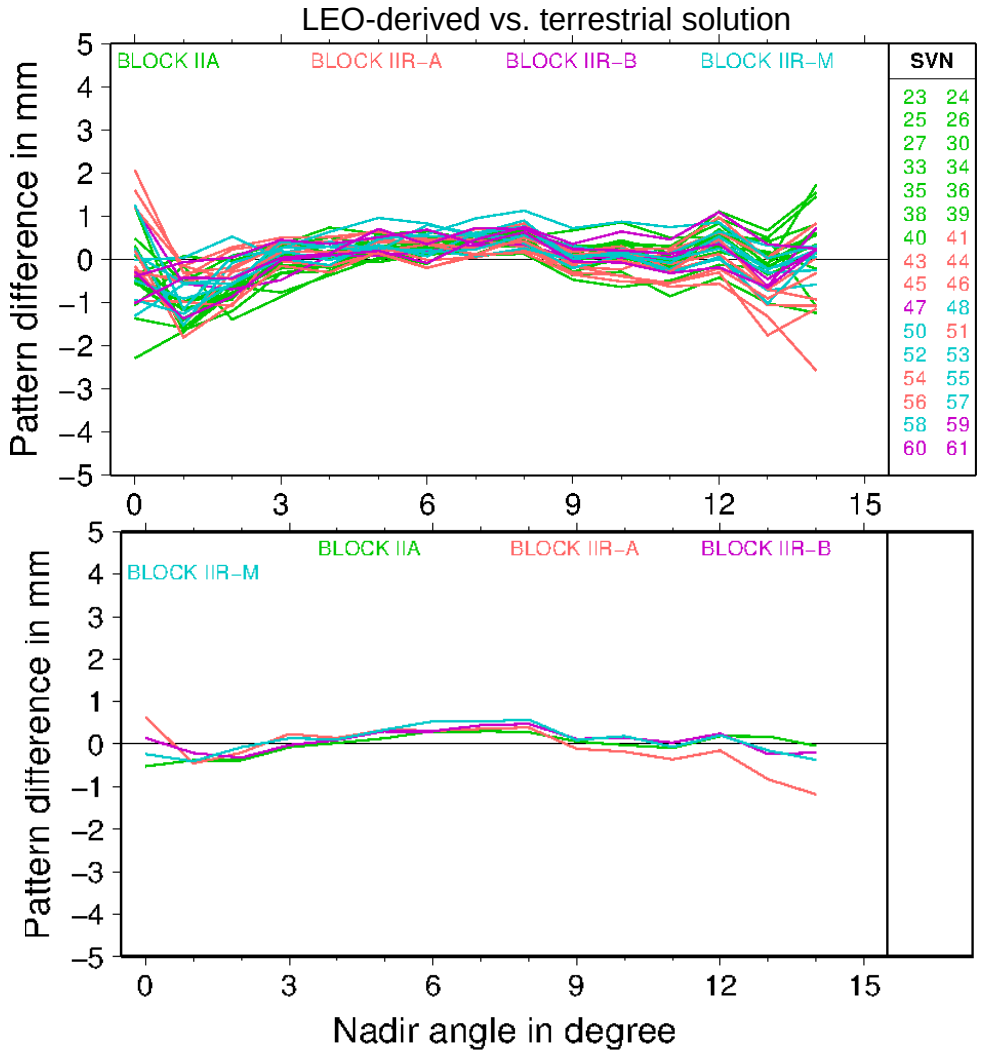


Terrestrial data

LEO data

- **Both solutions detect similar differences to the block-specific model igs08.atx**

Solution comparison



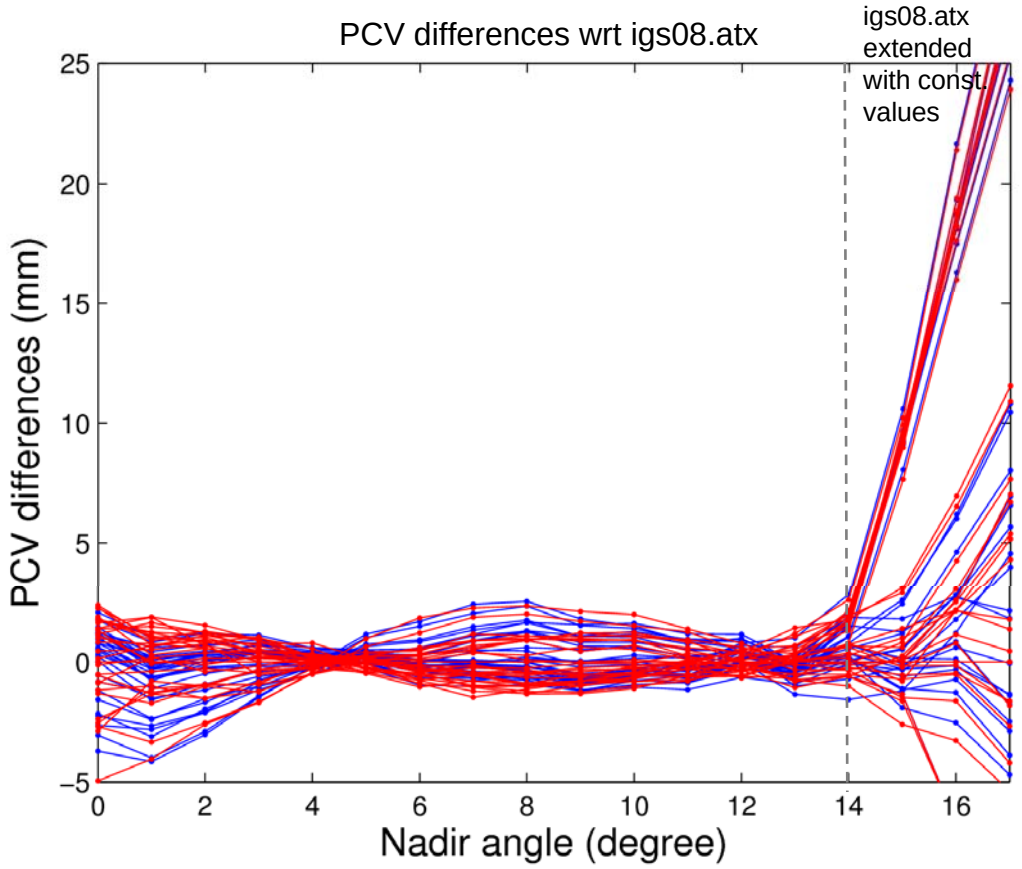
Satellite-specific

Block-specific

- **Excellent agreement between block-specific solutions below 14°**

Combined solution

- **by stacking normal equations (NEQs) from the LEO-only solution and the terrestrial solution**



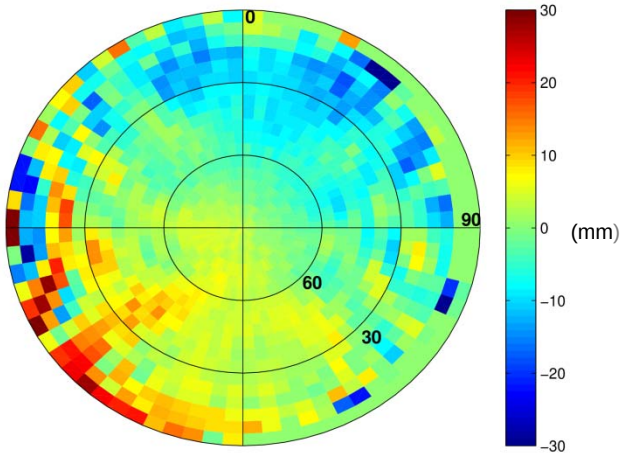
NEQs used:

LEO-NEQs only

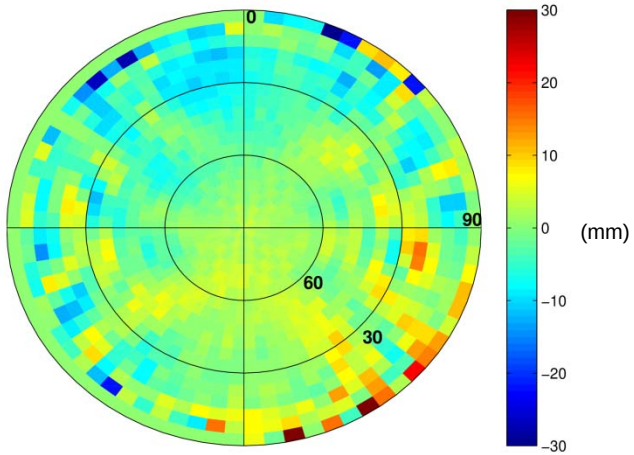
Combination of LEO- & terrestrial-NEQs

- **Combination mainly improves the estimates for low nadir angles**

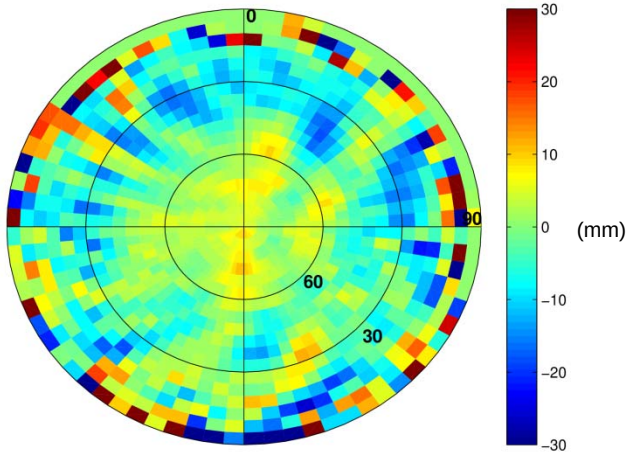
LEO PCVs estimated together with GPS PCVs



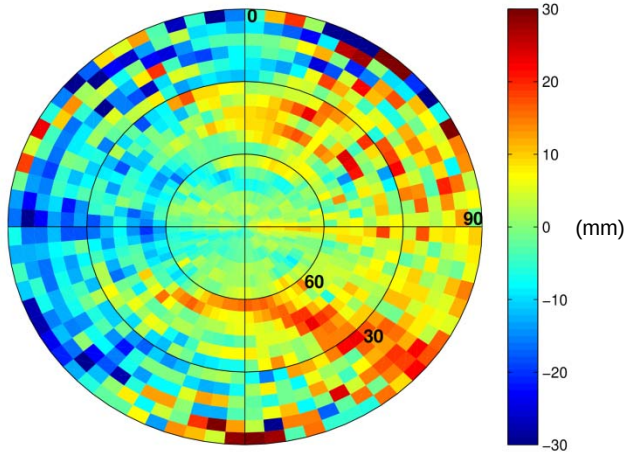
GRACE-A



GRACE-B



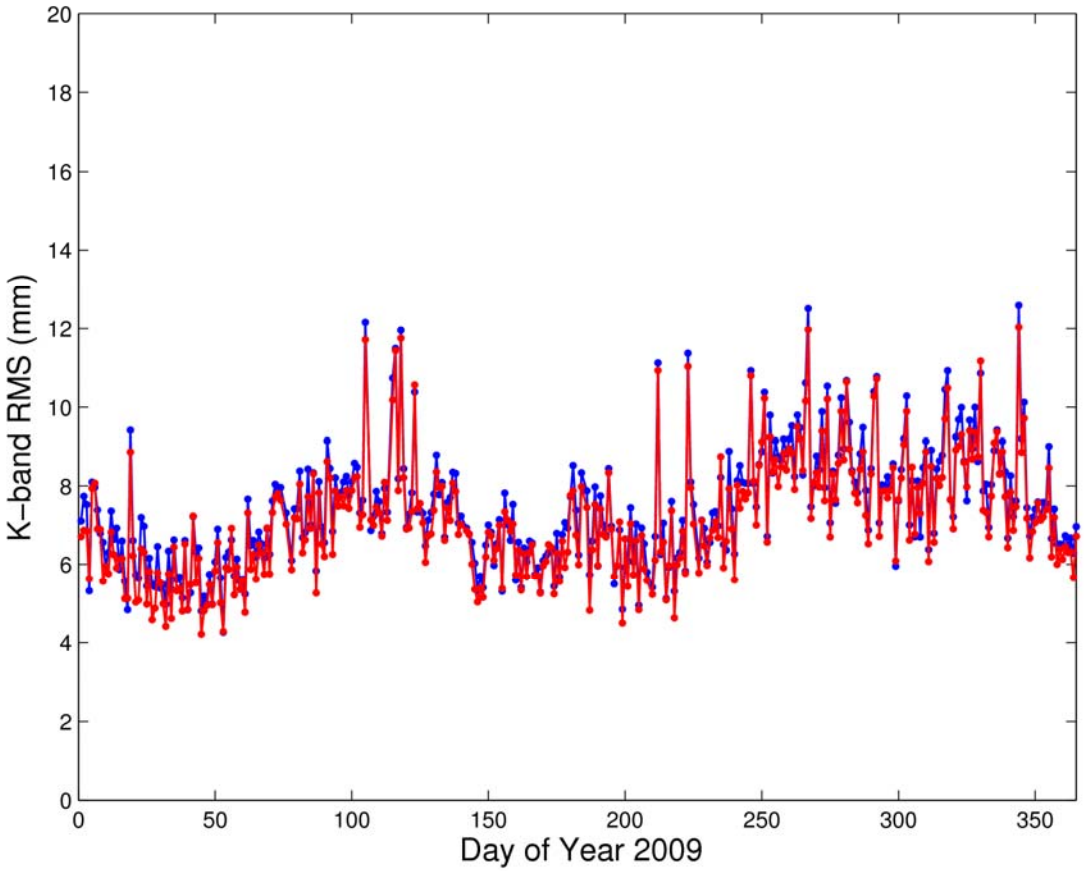
Jason-2



GOCE

Impact on LEO POD

- **GRACE orbit validation by independent K-band data**



PCVs used:

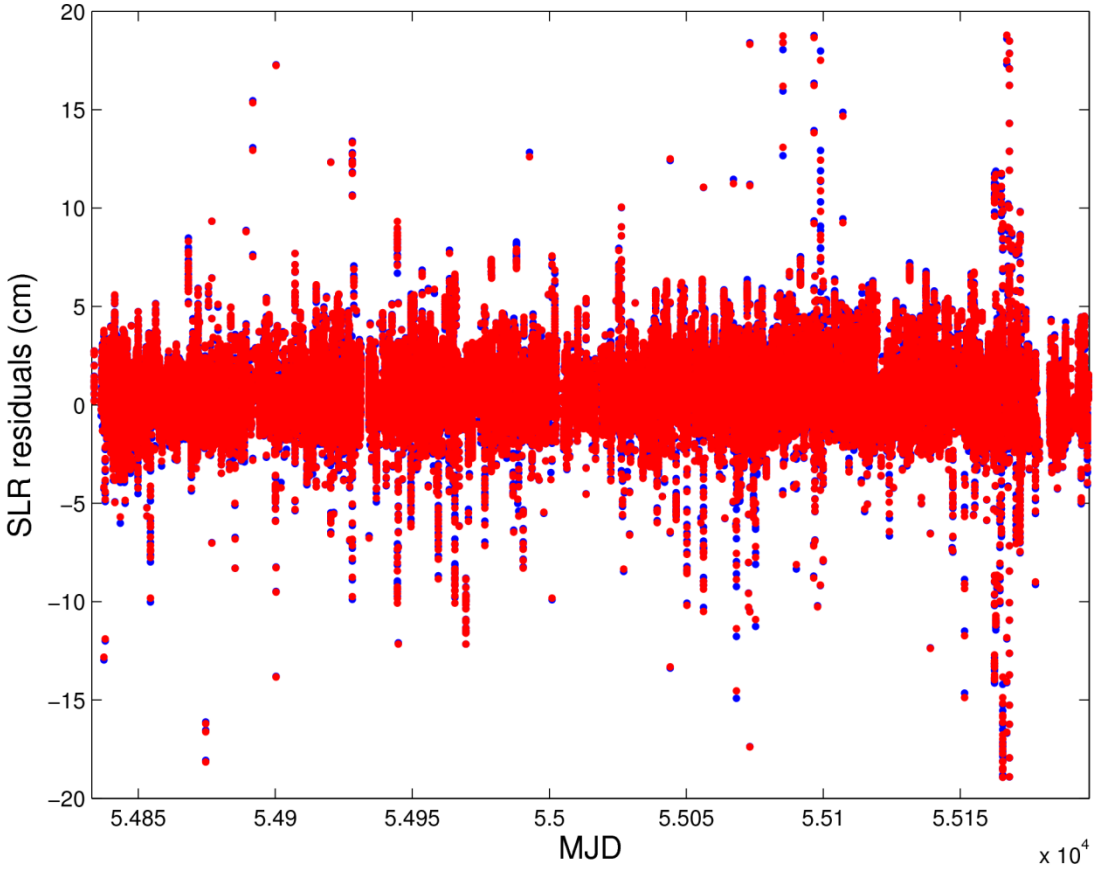
LEO: GRACE A&B
GPS: igs08.atx

LEO: GRACE A&B
GPS: extended

- **Small improvement from 7.4 to 7.1 mm K-band range RMS**

Impact on LEO POD

- **GRACE orbit validation by independent SLR data**



PCVs used:

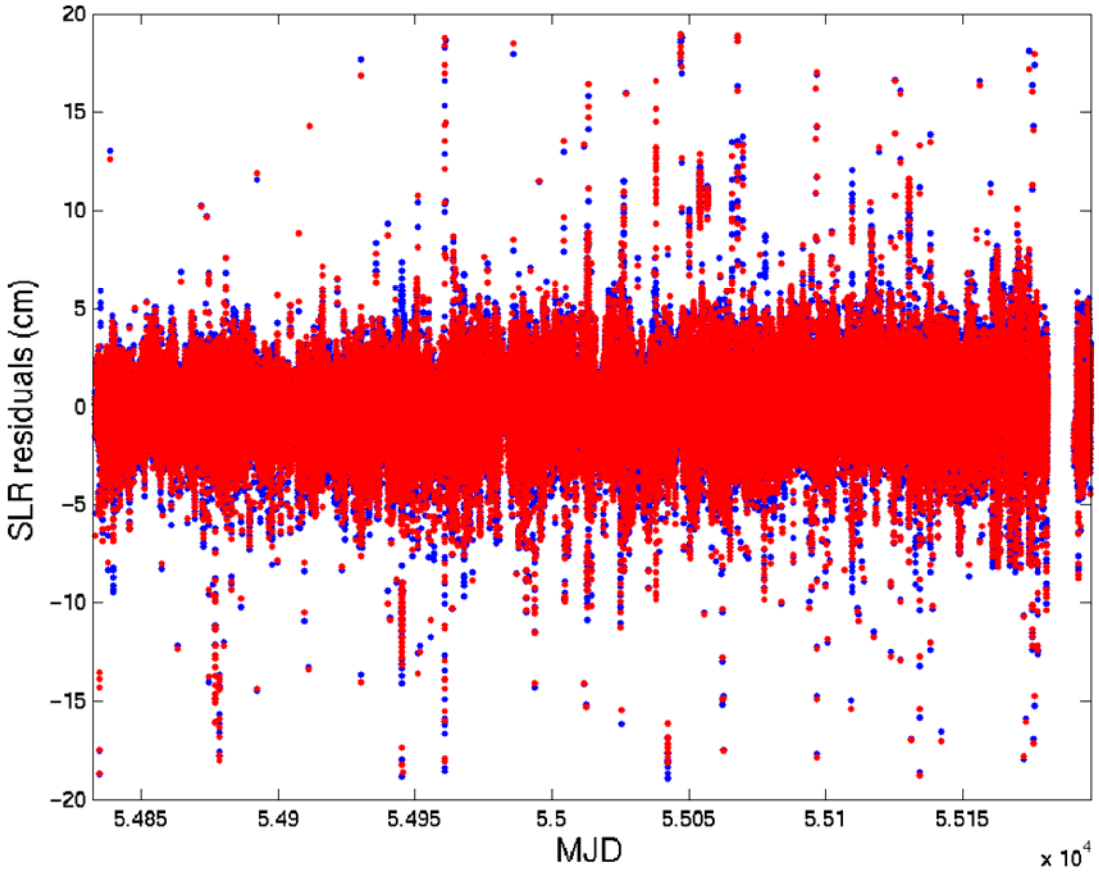
LEO: GRACE A&B
GPS: igs08.atx

LEO: GRACE A&B
GPS: extended

- **Almost no improvement from 1.85 to 1.84 cm SLR RMS**

Impact on LEO POD

- **Jason-2 SLR validation (higher altitude, larger impact expected)**



PCVs used:

LEO: Jason-2
GPS: igs08.atx

LEO: Jason-2
GPS: extended

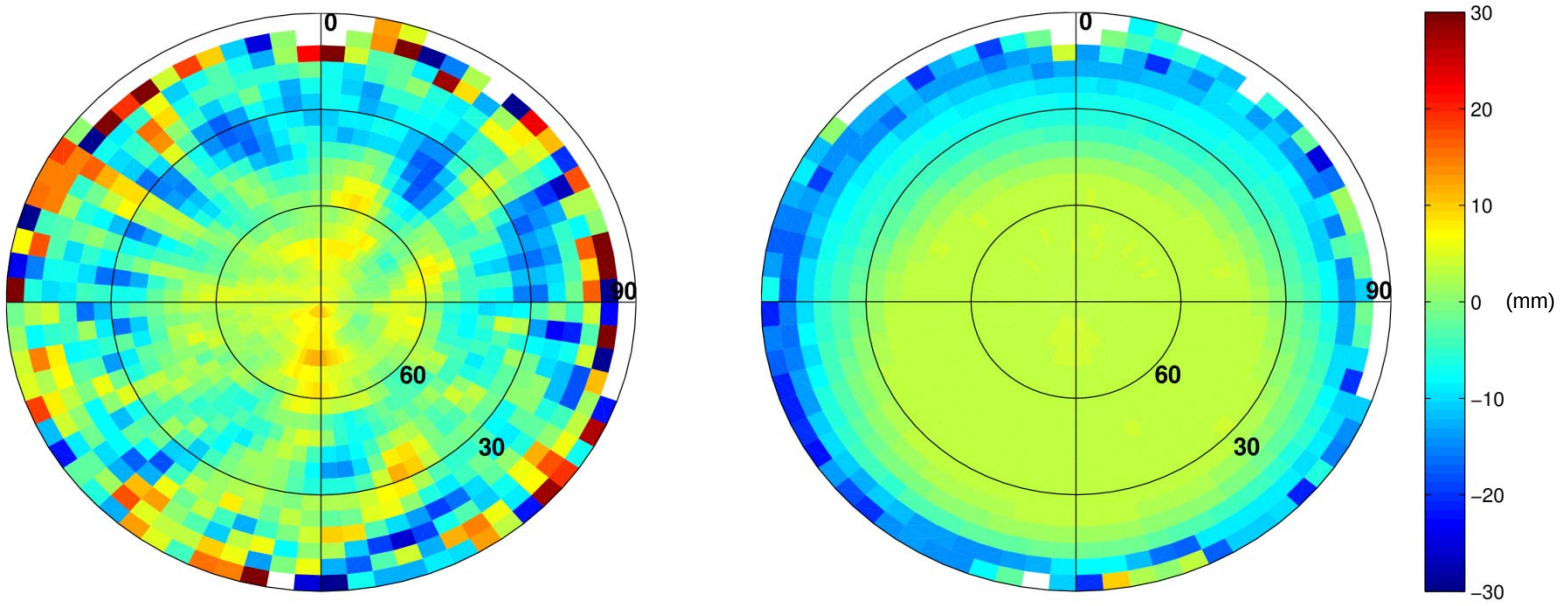
- **Slightly larger (but still only small) improvement from 1.77 to 1.71 cm SLR RMS**

Impact on LEO POD

- **Why only such a small impact?**

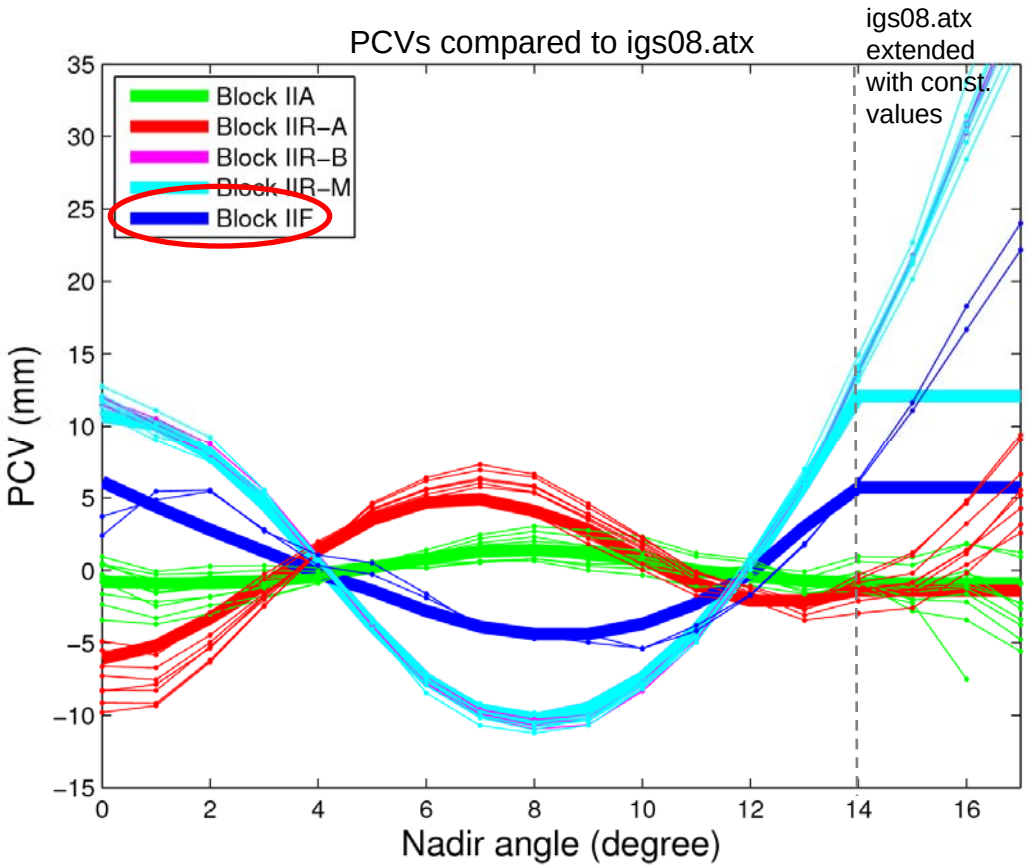
LEO PCVs (GPS extended)

Differences:



- **LEO PCVs may absorb systematic effects at low elevations to a large extent → orbit solutions of good quality may still be obtained, even if GPS PCVs are not properly modeled by an extension beyond 14°**

Construction of the proposed extension

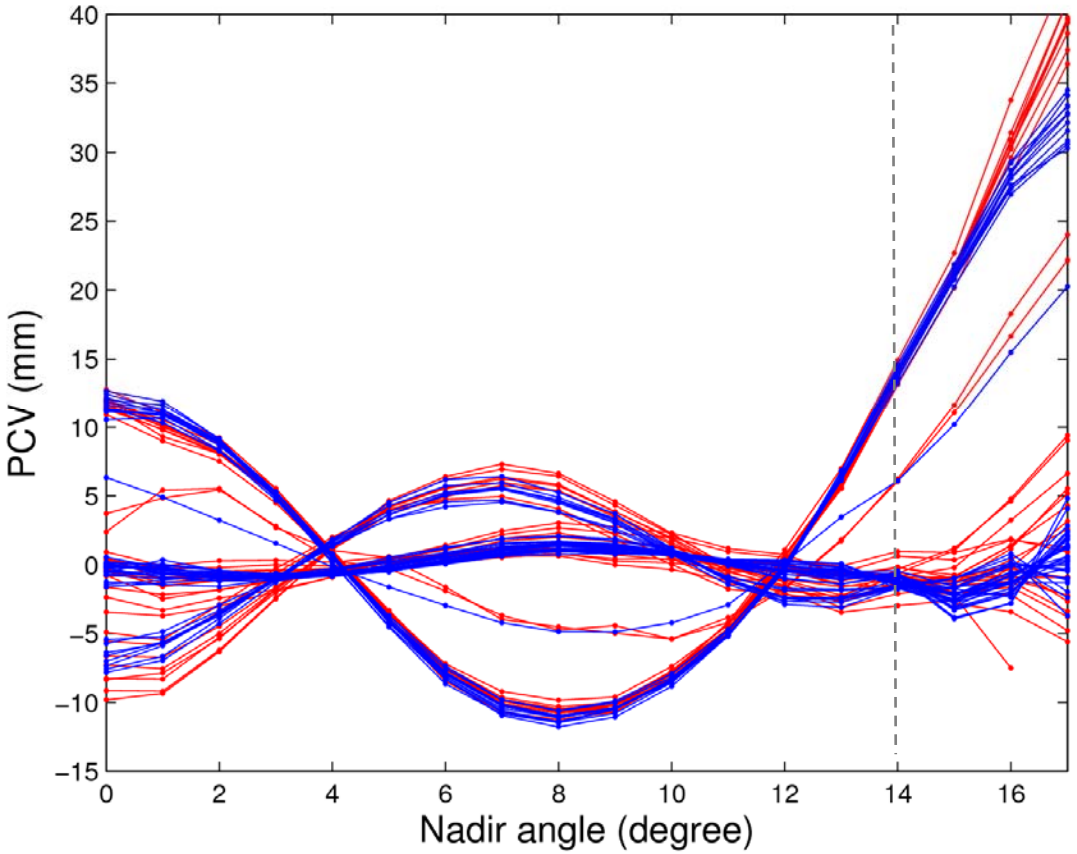


Data used:

Jason-2
MetOp-A
GRACE-A
GRACE-B
GOCE

- **Presented AIUB LEO-only solution is the basis, data from 2011 are used for IIF's**
- **Block IIF PCVs for SVNs 62, 63 are rather weakly determined (half a year of data)**

Comparison with combined ESOC solution



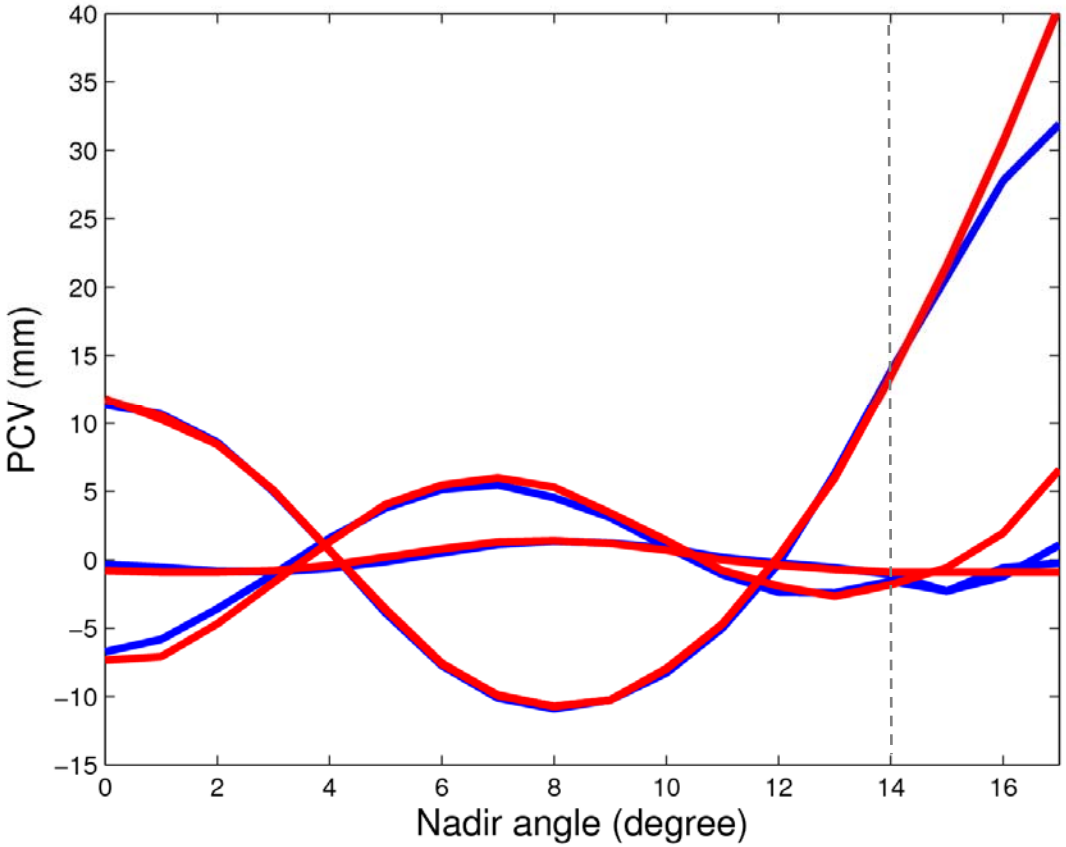
ESOC:
Combination of LEO and terrestrial data

AIUB:
LEO-only data

- **Comparison with ESOC solution shows a very good agreement below 14°**
- **Scatter for AIUB (LEO-only) solution is generally larger at low nadir angles**

Comparison with combined ESOC solution

Solution strategies are unfortunately too different to allow for a meaningful combination



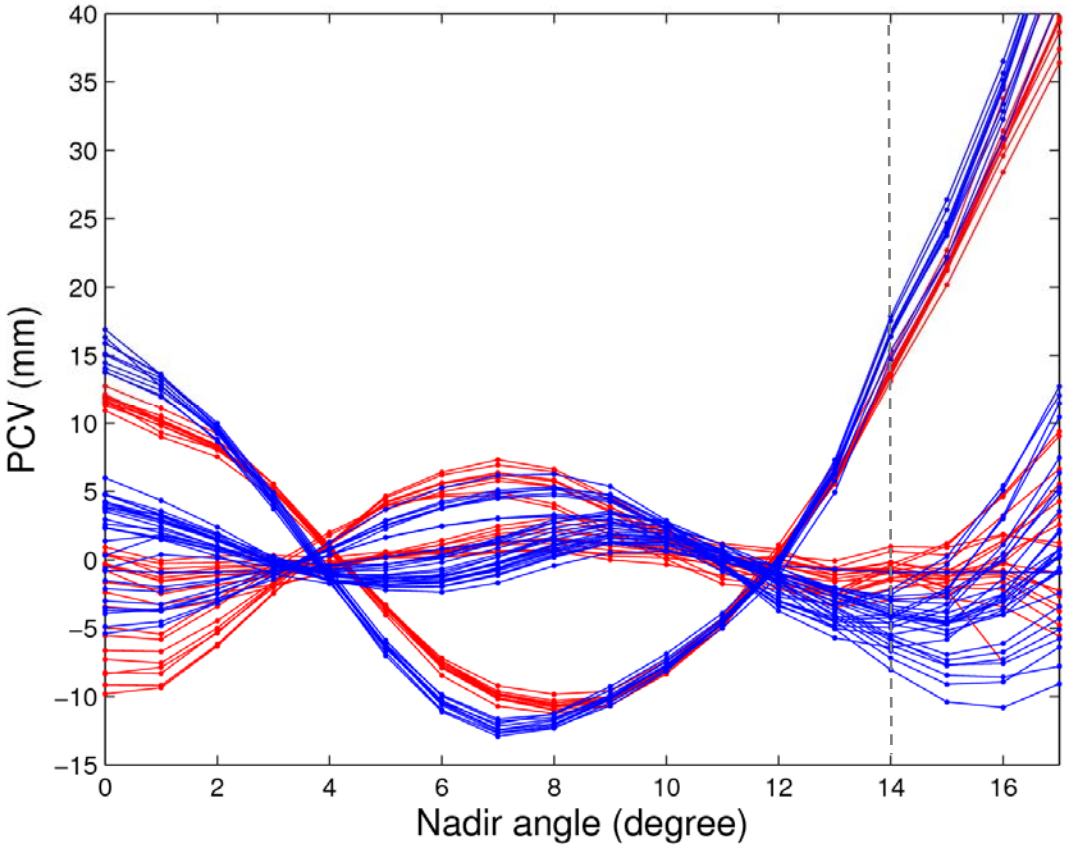
ESOC:
Combination of LEO and terrestrial data

AIUB:
LEO-only data

- **Block-specific comparison with ESOC shows an excellent agreement below 14°**
- **AIUB LEO-only approach seems to be well suited to derive PCV values**

Comparison with LEO-only ESOC solution

Solution strategies are comparable, but differences prevent a meaningful combination

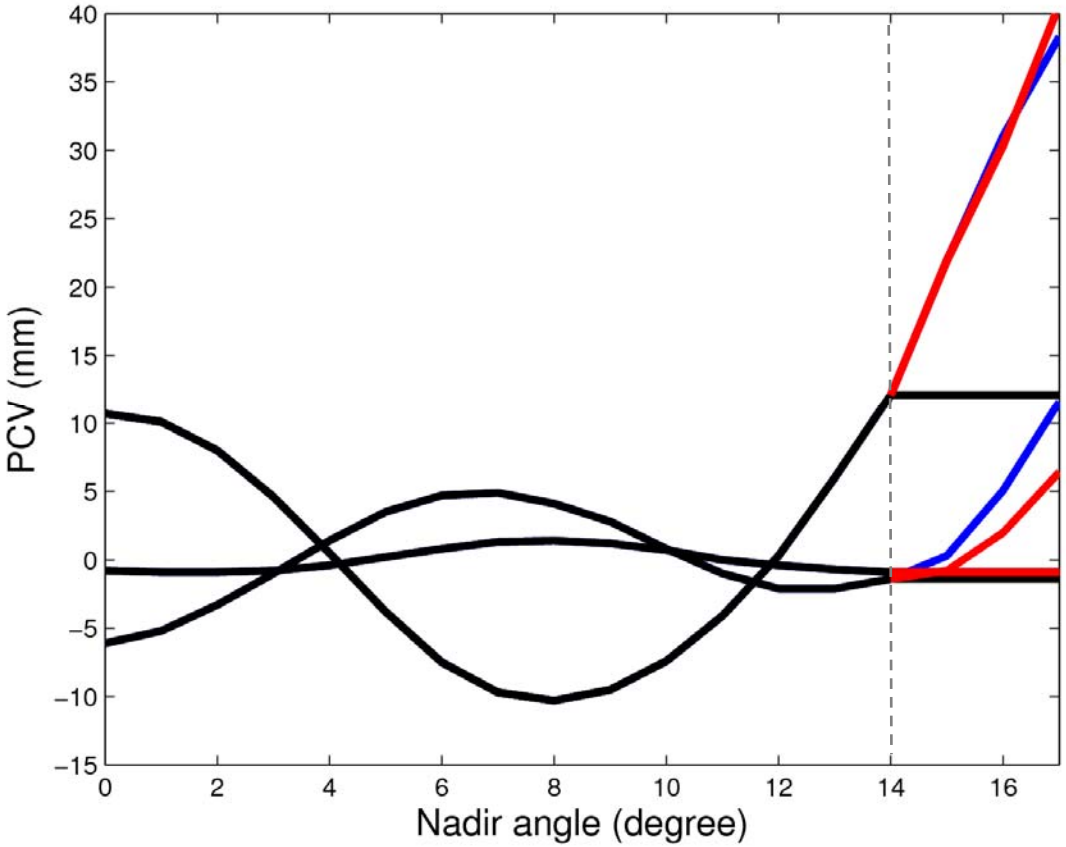


ESOC:
LEO-only data
(Jason-1)

AIUB:
LEO-only data

- **Comparison with ESOC LEO-only solution is considerably worse for all nadir angles**
- **Scatter is similar for both solutions**

Proposed extension for igs08.atx



ESOC:
LEO-only data
(Jason-1)

AIUB:
LEO-only data

- **Block-specific comparison with ESOC shows an acceptable agreement when fixing nadir angles below 14° to igs08.atx (apart for Block IIR-A satellites)**

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 wrt igs08.atx, the agreement is about 2-3 mm below 14°
- Satellite-specific GPS PCVs show a very good agreement of about 1 mm with estimates from terrestrial data
- Block-specific values show an excellent agreement of better than 1 mm with estimates from terrestrial data
- Block-specific values could be used to extend igs08.atx PCVs beyond 14° and to keep the values below 14° unchanged, no impact on terrestrial applications is expected