

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

**A. Jäggi¹, F. Dilssner², R. Schmid³,
R. Dach¹, T. Springer², H. Bock¹,
P. Steigenberger³, S. Lutz¹**

¹Astronomical Institute, University of Bern, Switzerland

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

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

IGS Workshop 2012, 23–27 July 2012

Olsztyn, Poland

Introduction

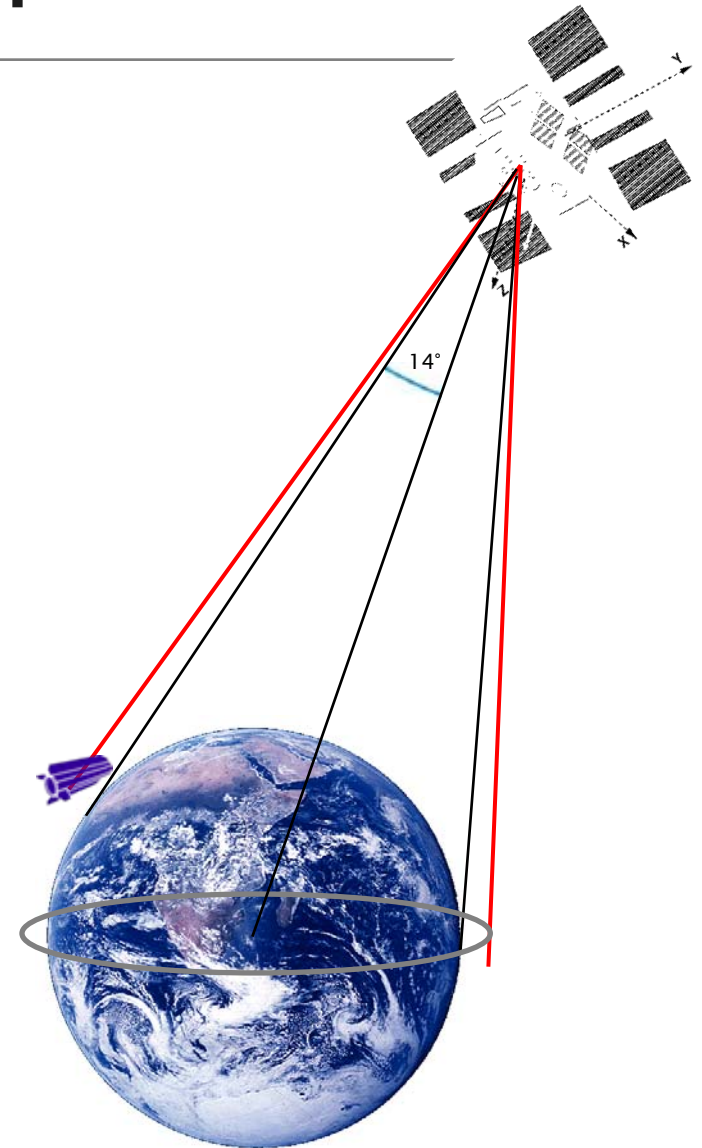
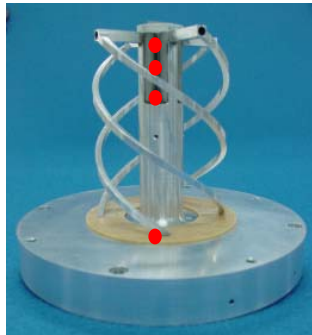
Phase center variations (PCVs) of GPS transmitter antennas, e.g., as provided by the IGS, are restricted to nadir angles $\leq 14^\circ$

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

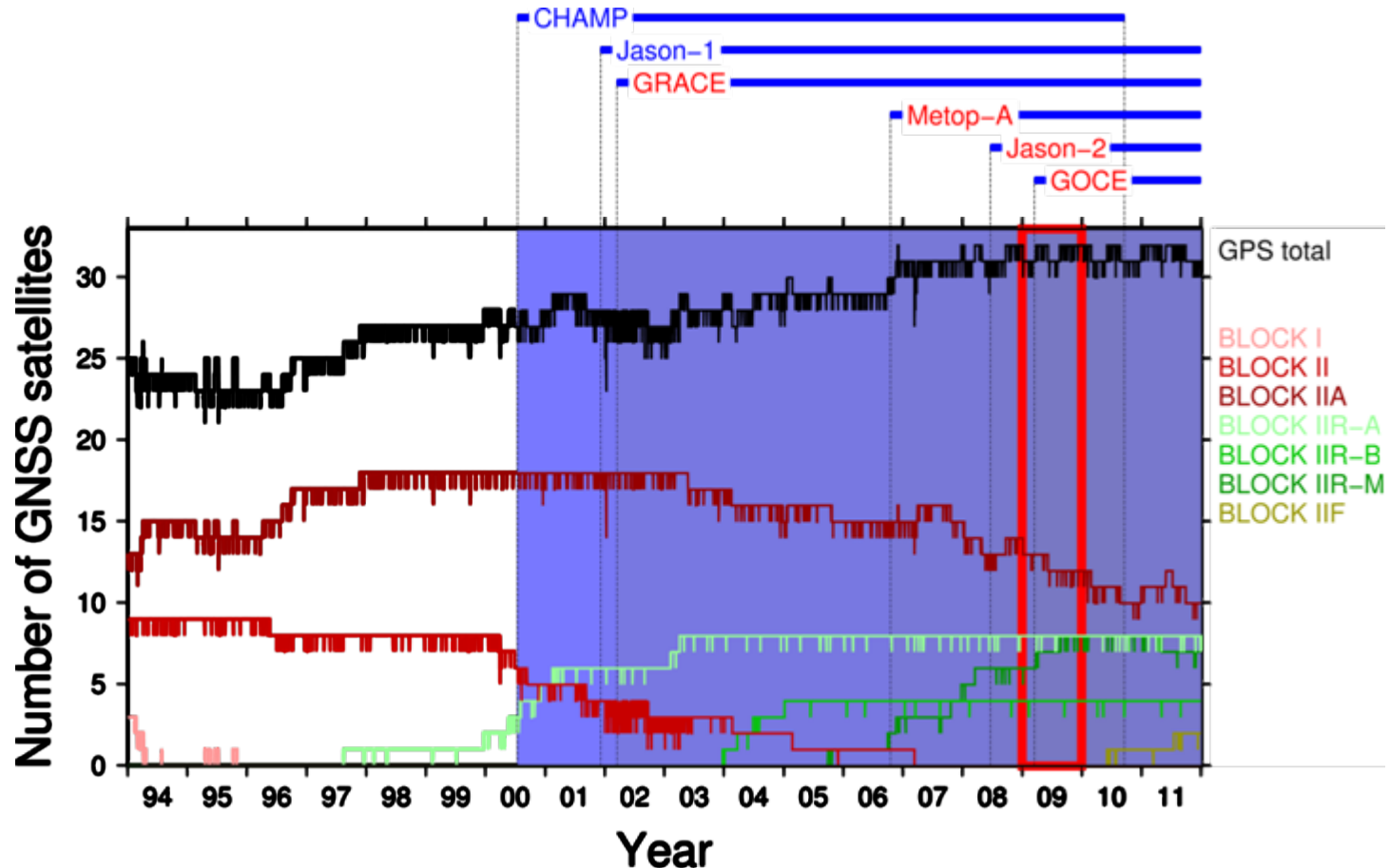
LEO phase center offsets (PCOs) have to be precisely known, LEO PCVs need to be co-estimated

L2 PCO
L1 PCO
LC PCO

antenna
reference
point



Evolution of active GPS constellation



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

Input Data & Products

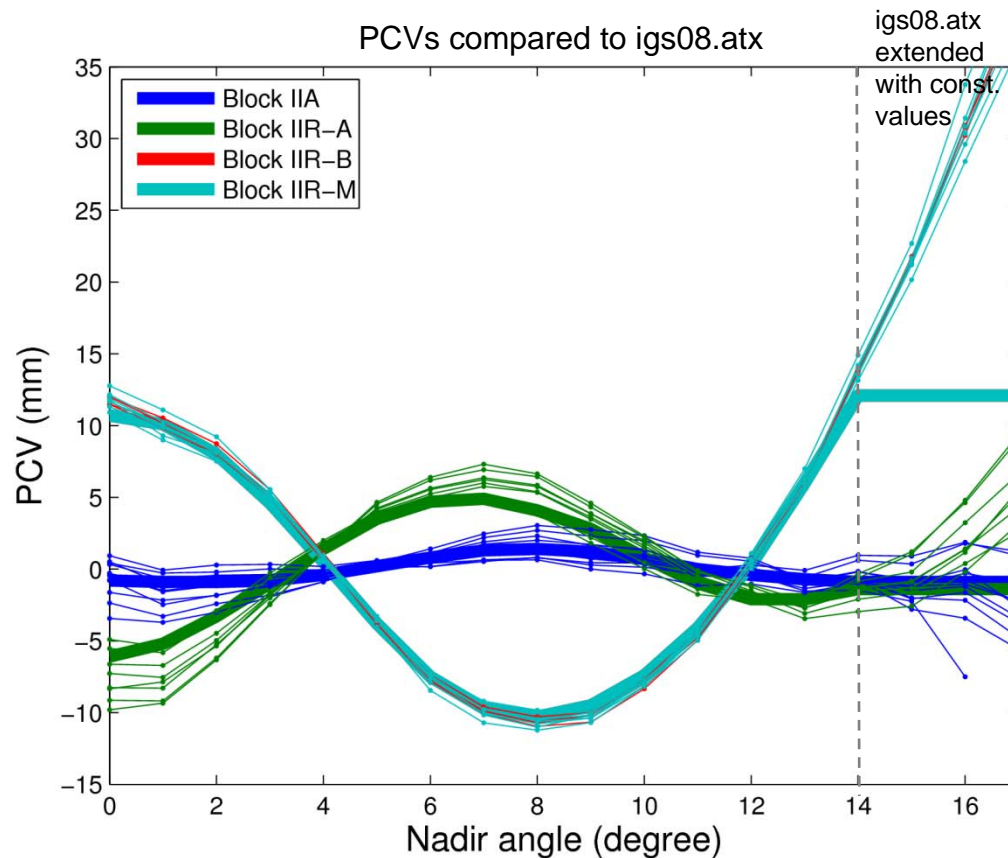
- **LEO GPS data**, undifferenced ionosphere-free (Jason-2, GRACE-A/B, GOCE, MetOp-A from 2009; Jason-2 from second half of 2011 for Block IIF satellites)
- **GPS orbits and clock corrections** from the CODE reprocessing, introduced as known (consistent with PCOs & PCVs from igs08.atx)
- **LEO orbits** 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 $\leq 12^\circ$)
 - 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 to solve for the PCVs.

LEO-only solution

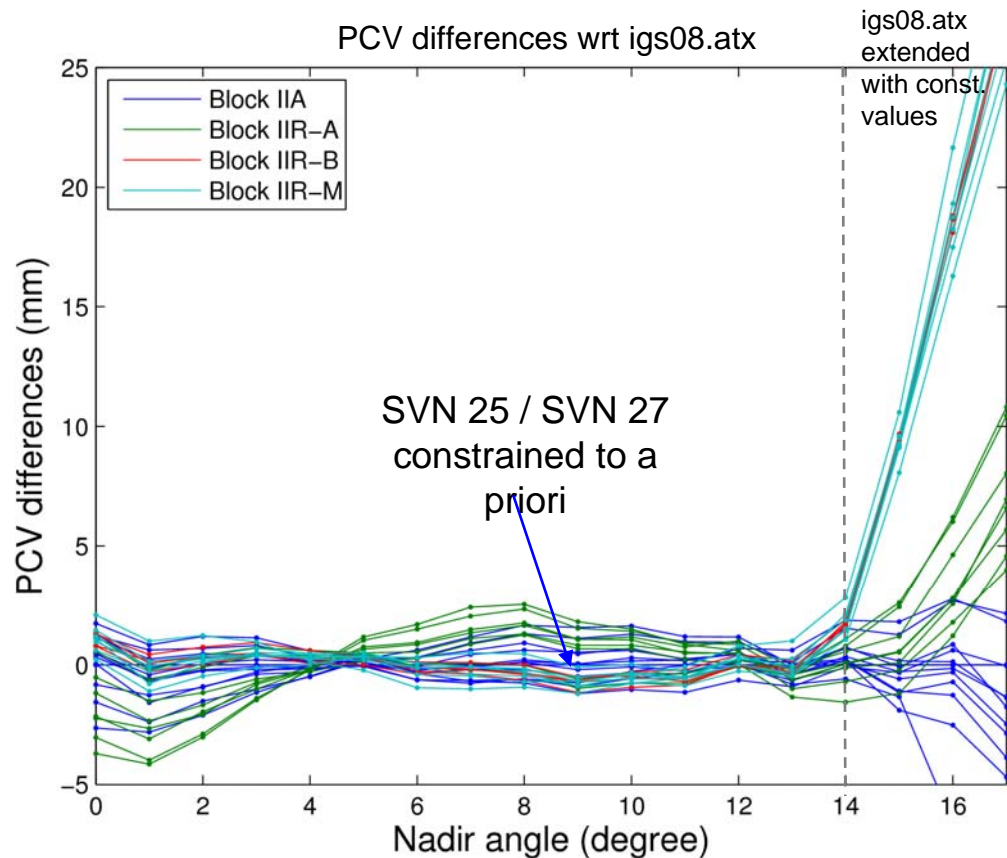


Data used:

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

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

LEO-only solution

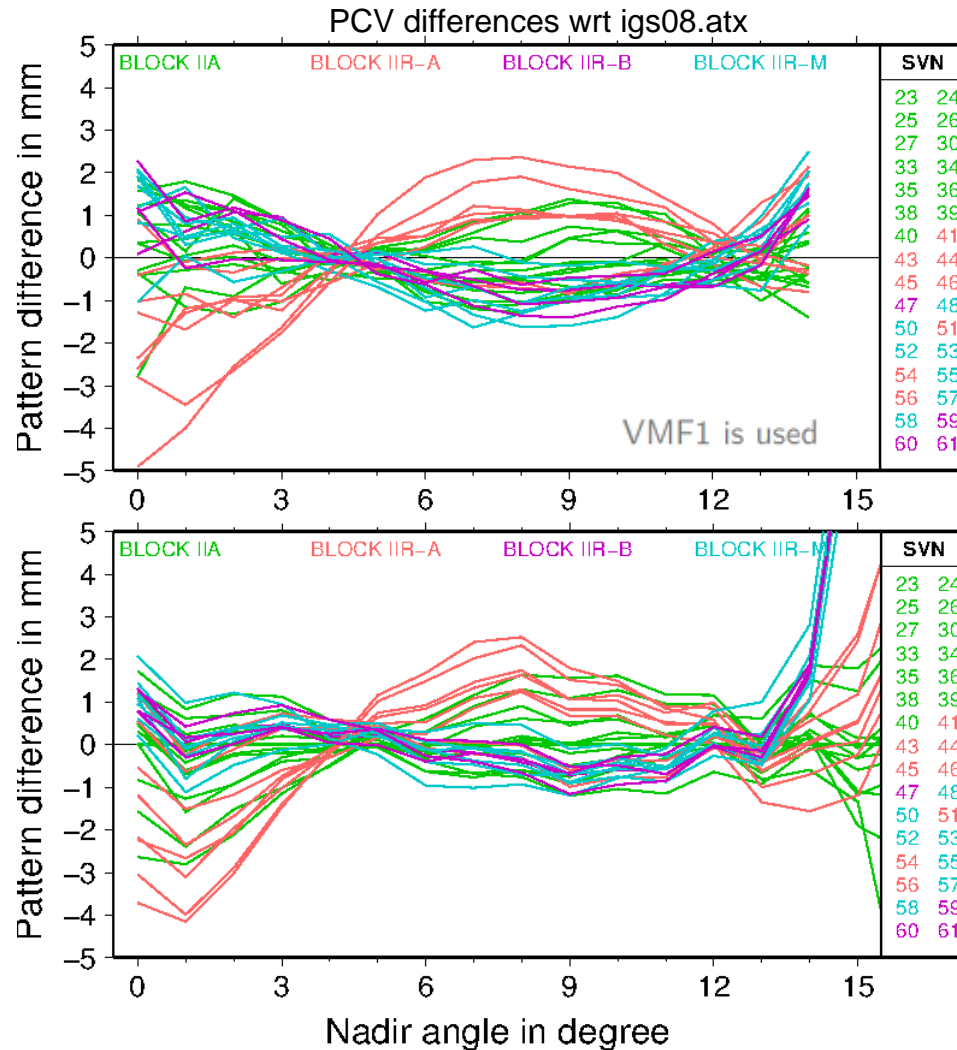


Data used:

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

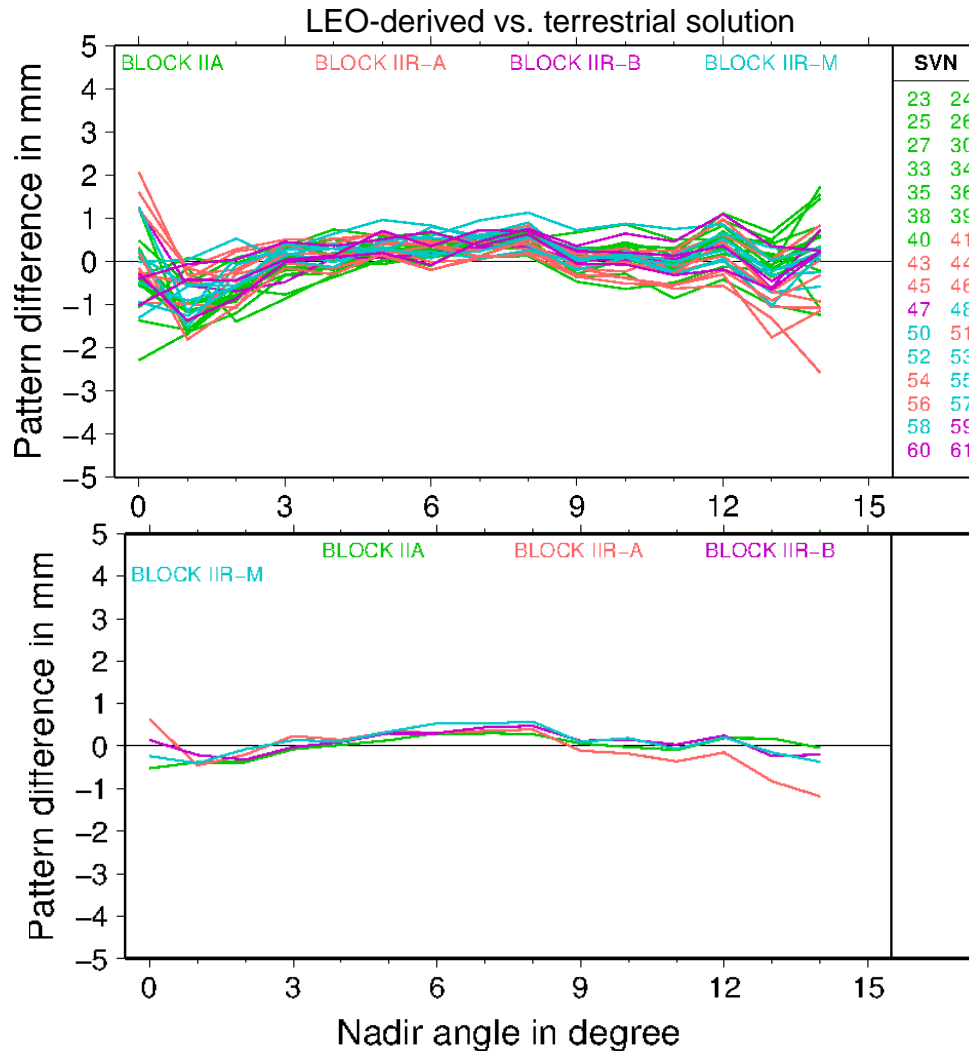


Terrestrial data

LEO data

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

Solution comparison



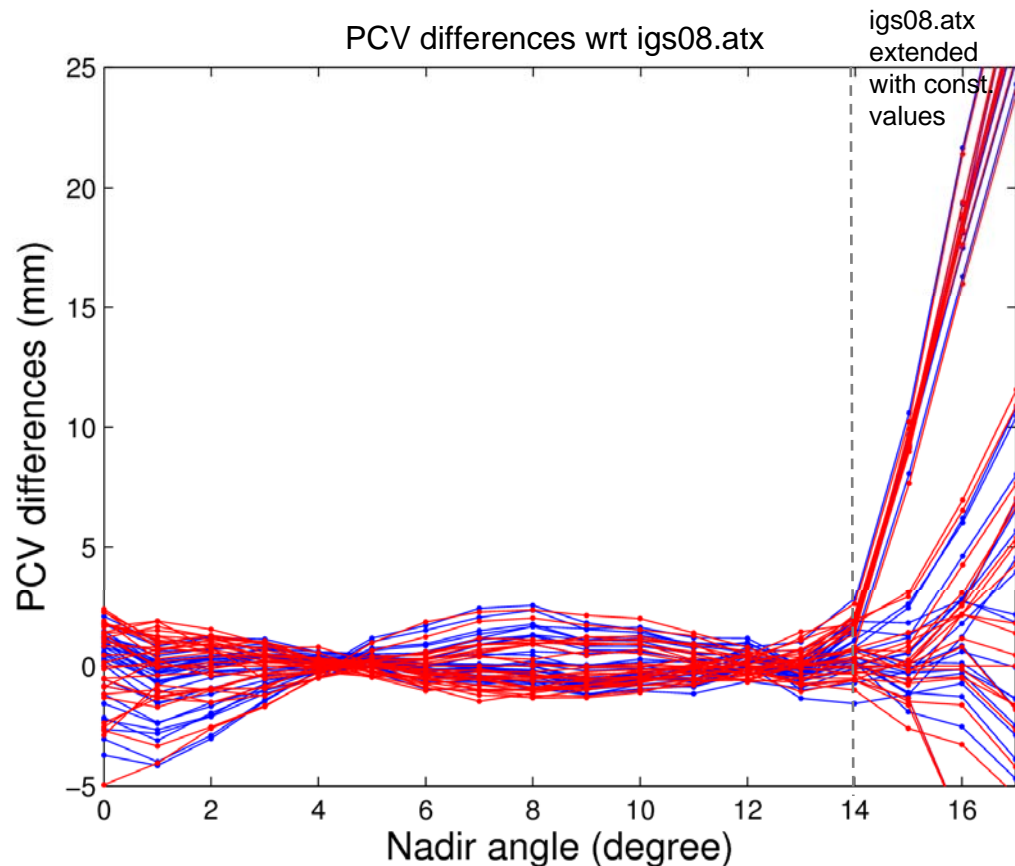
Satellite-specific

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



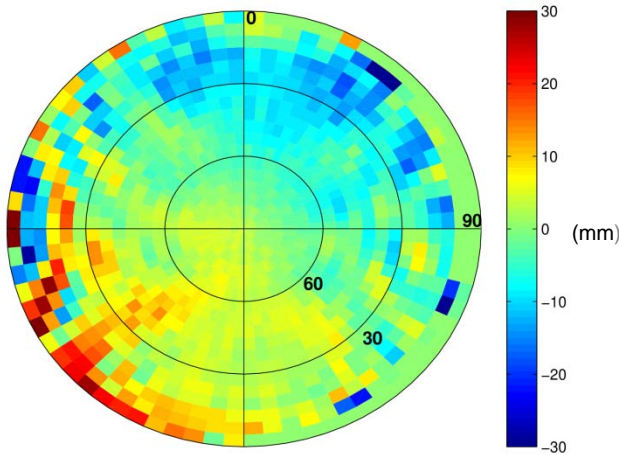
NEQs used:

LEO-NEQs only

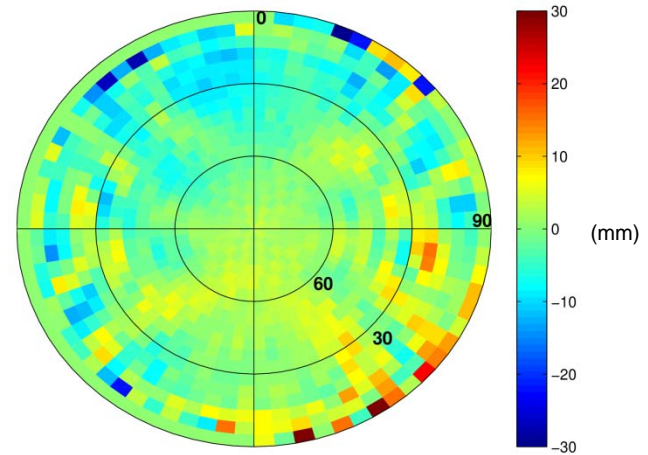
Combination of
LEO- & terrestrial-
NEQs

- Combination mainly improves the estimates for low nadir angles

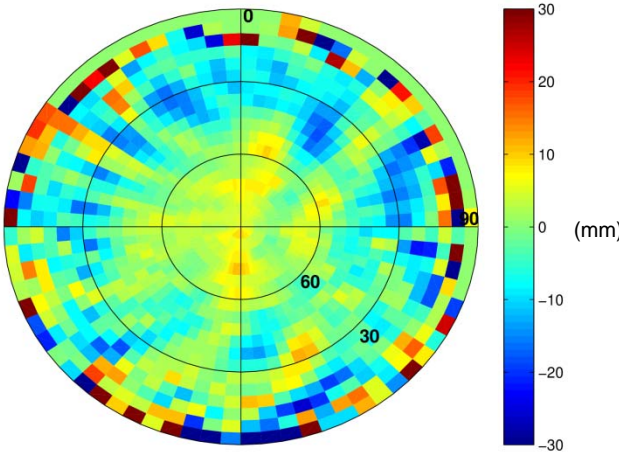
LEO PCVs estimated together with GPS PCVs



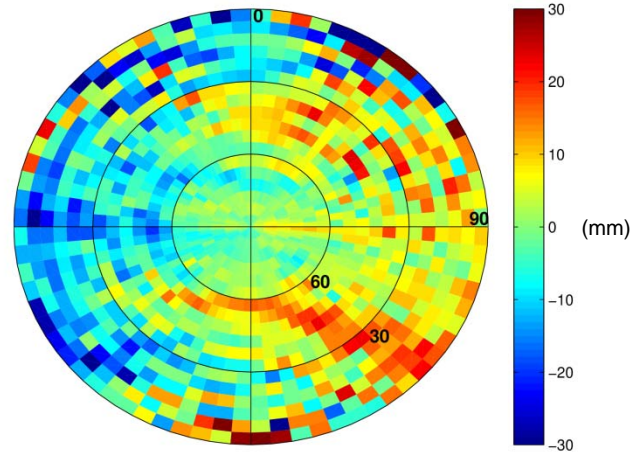
GRACE-A



GRACE-B



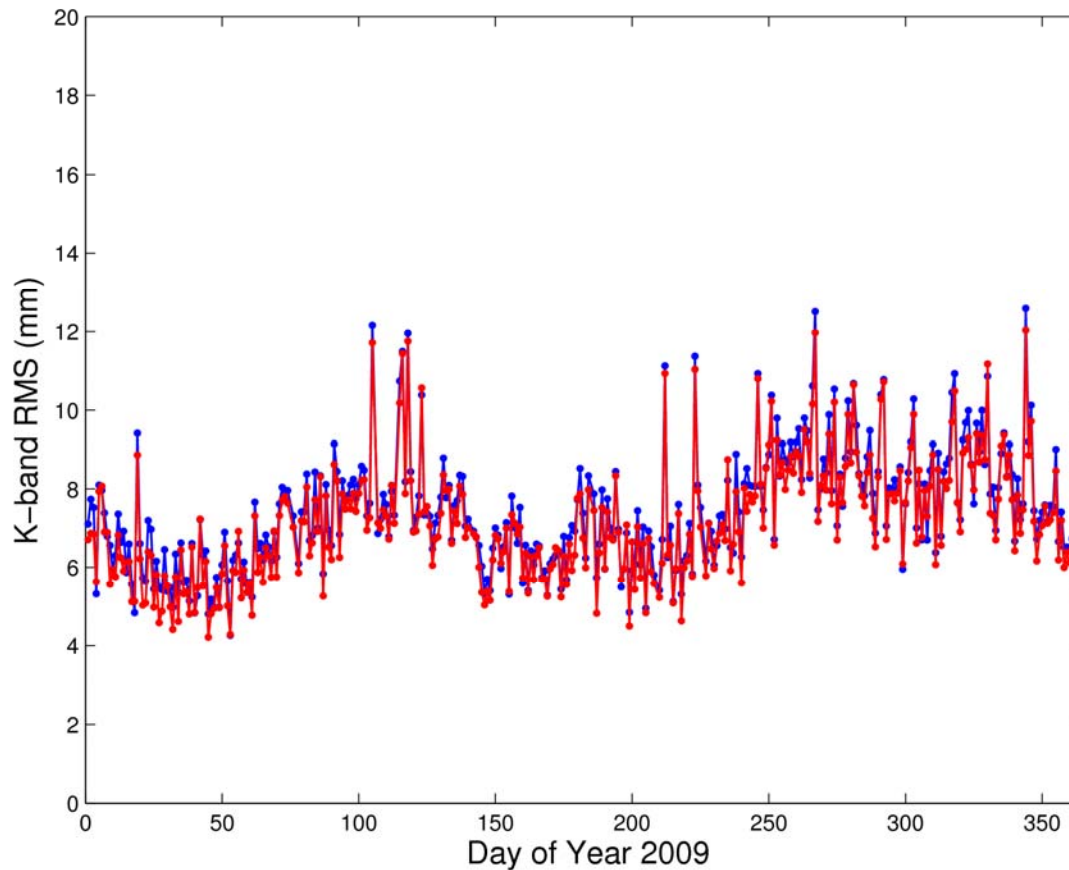
Jason-2



GOCE

Impact on LEO POD

- GRACE orbit validation by independent K-band data



PCVs used:

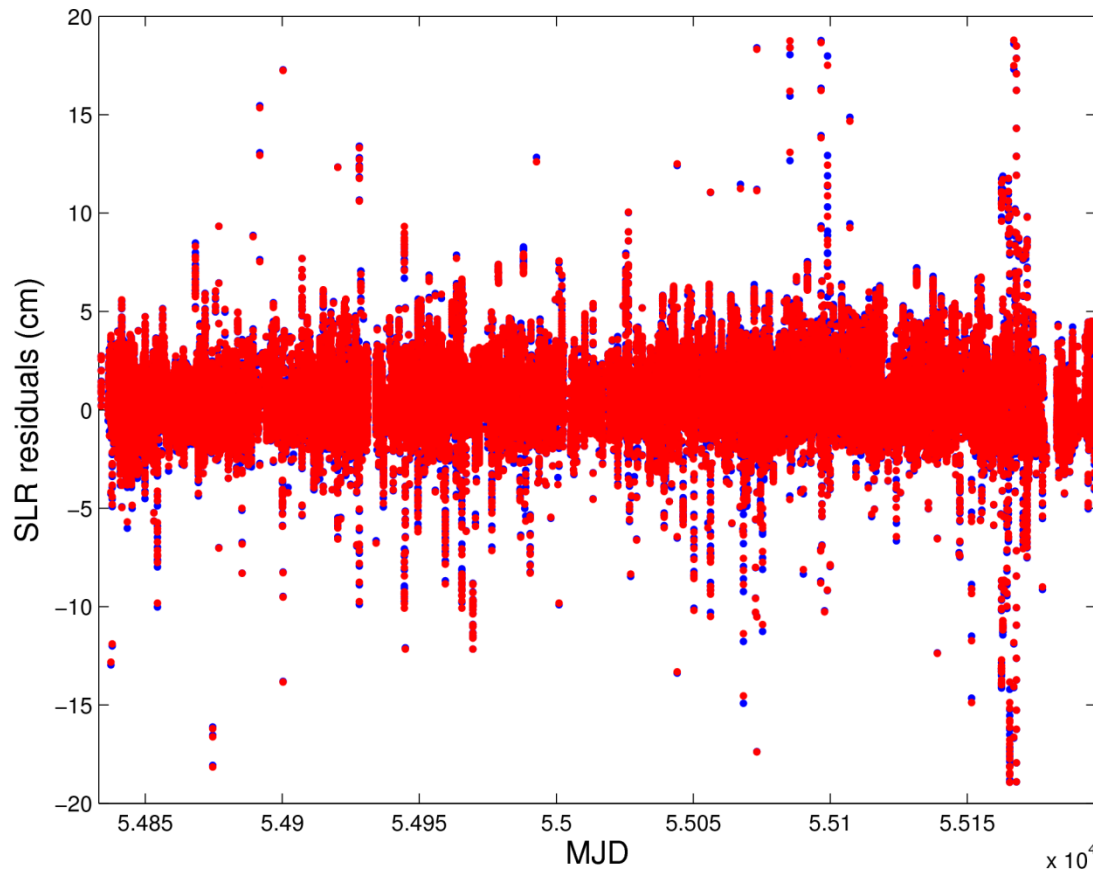
LEO: GRACE A&B
GPS: igs08.atx

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:

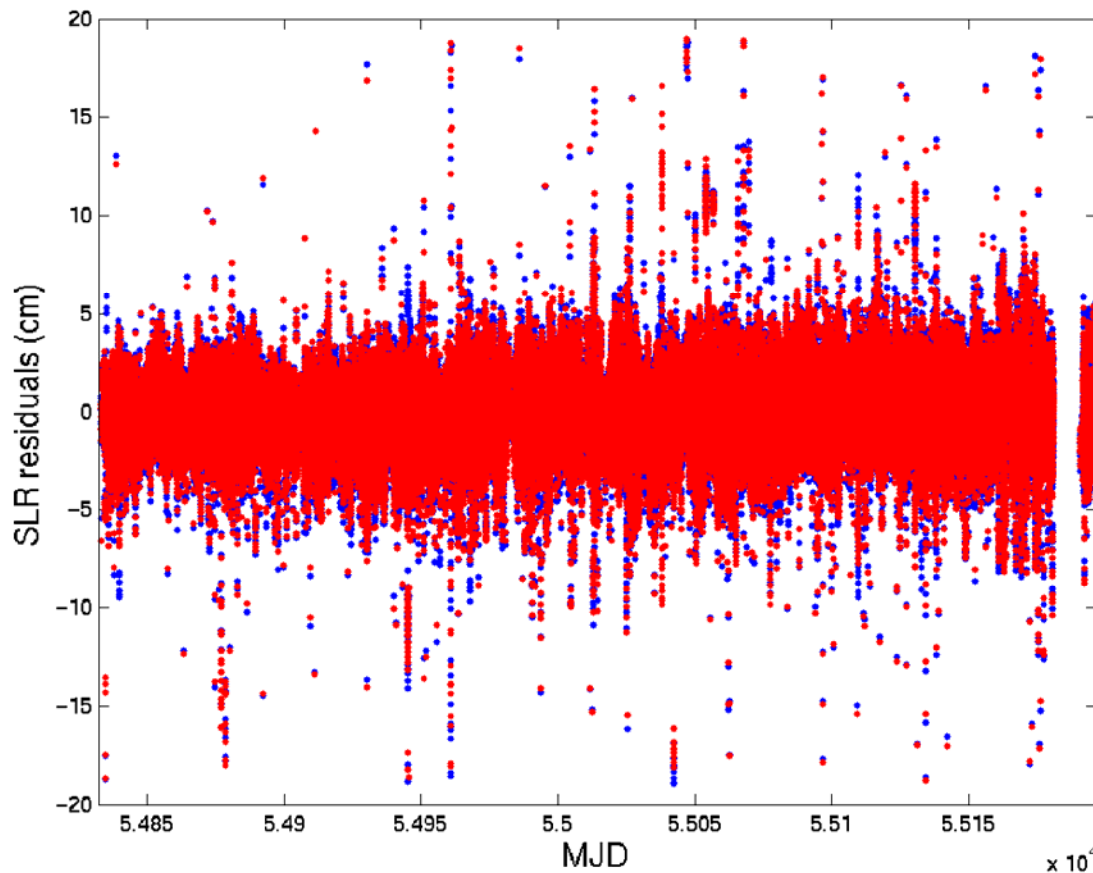
LEO: GRACE A&B
GPS: igs08.atx

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

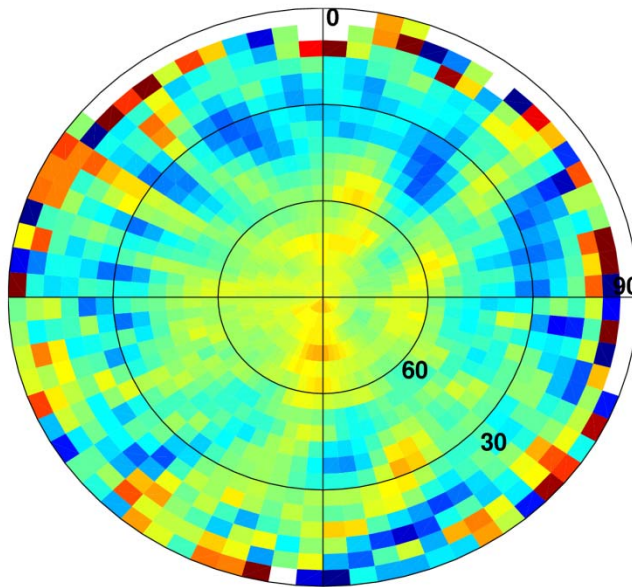
LEO: Jason-2
GPS: extended

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

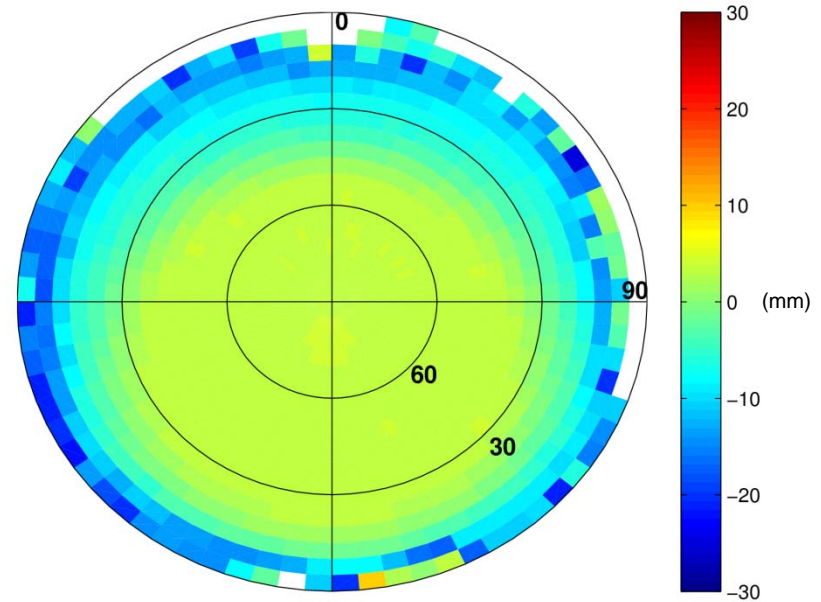
Impact on LEO POD

- Why only such a small impact?

LEO PCVs (GPS extended)

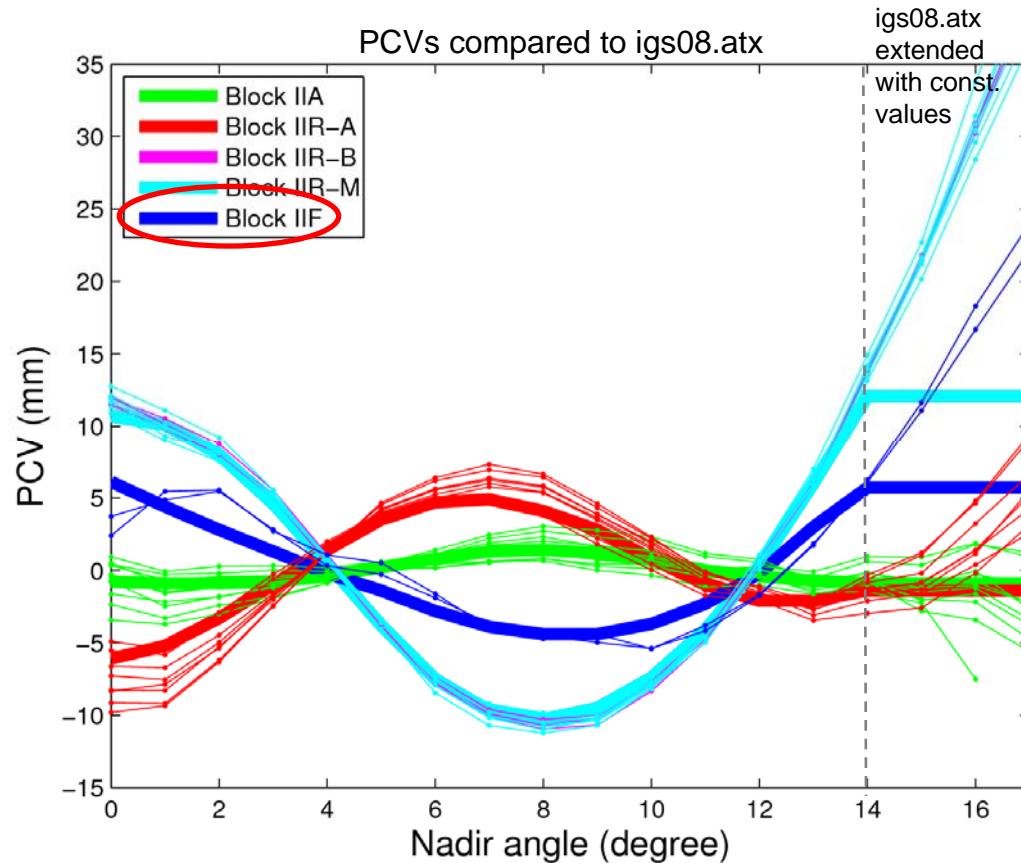


Differences:



- 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

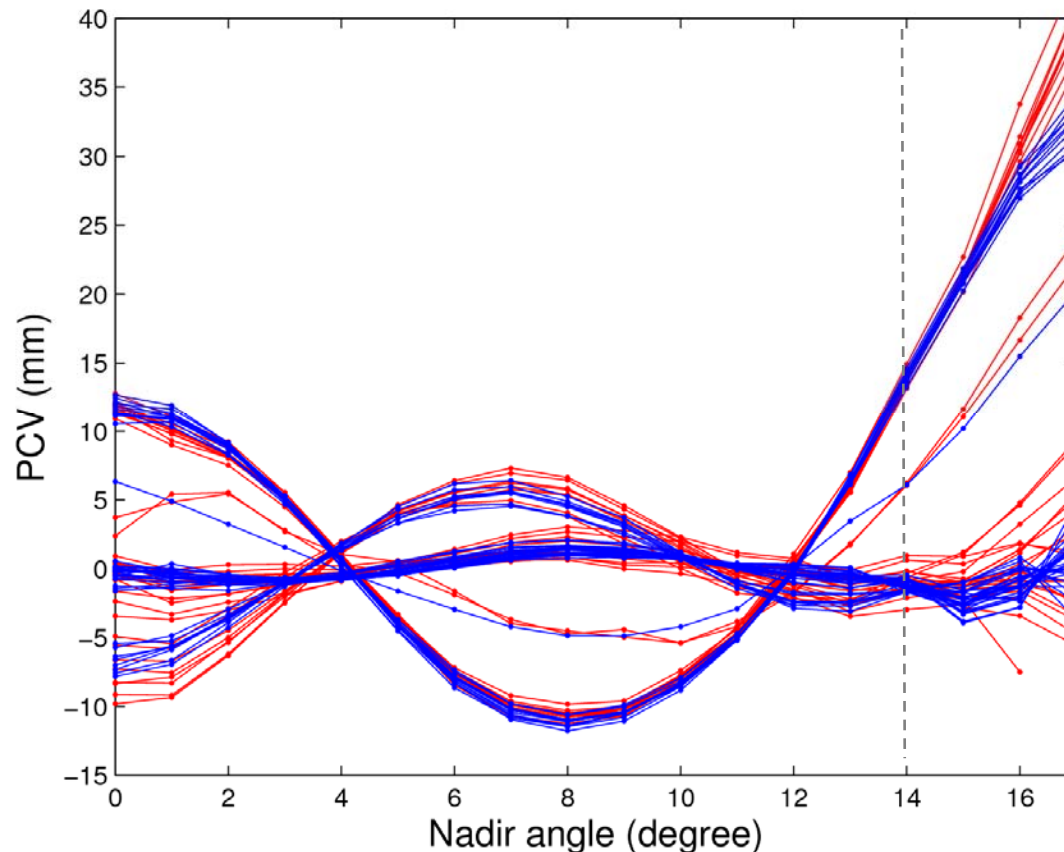


Data used:

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



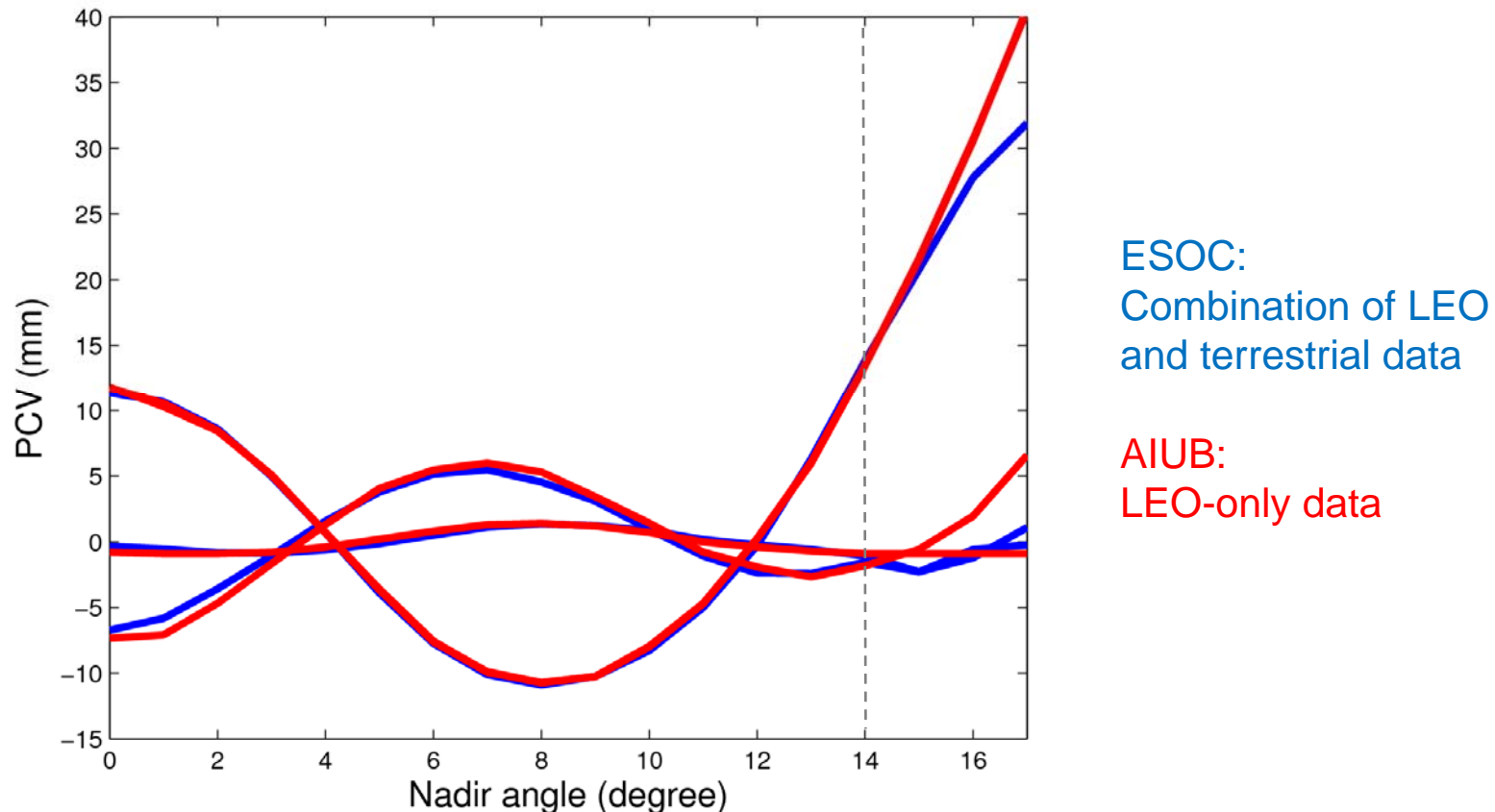
ESOC:
Combination of LEO
and terrestrial data

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

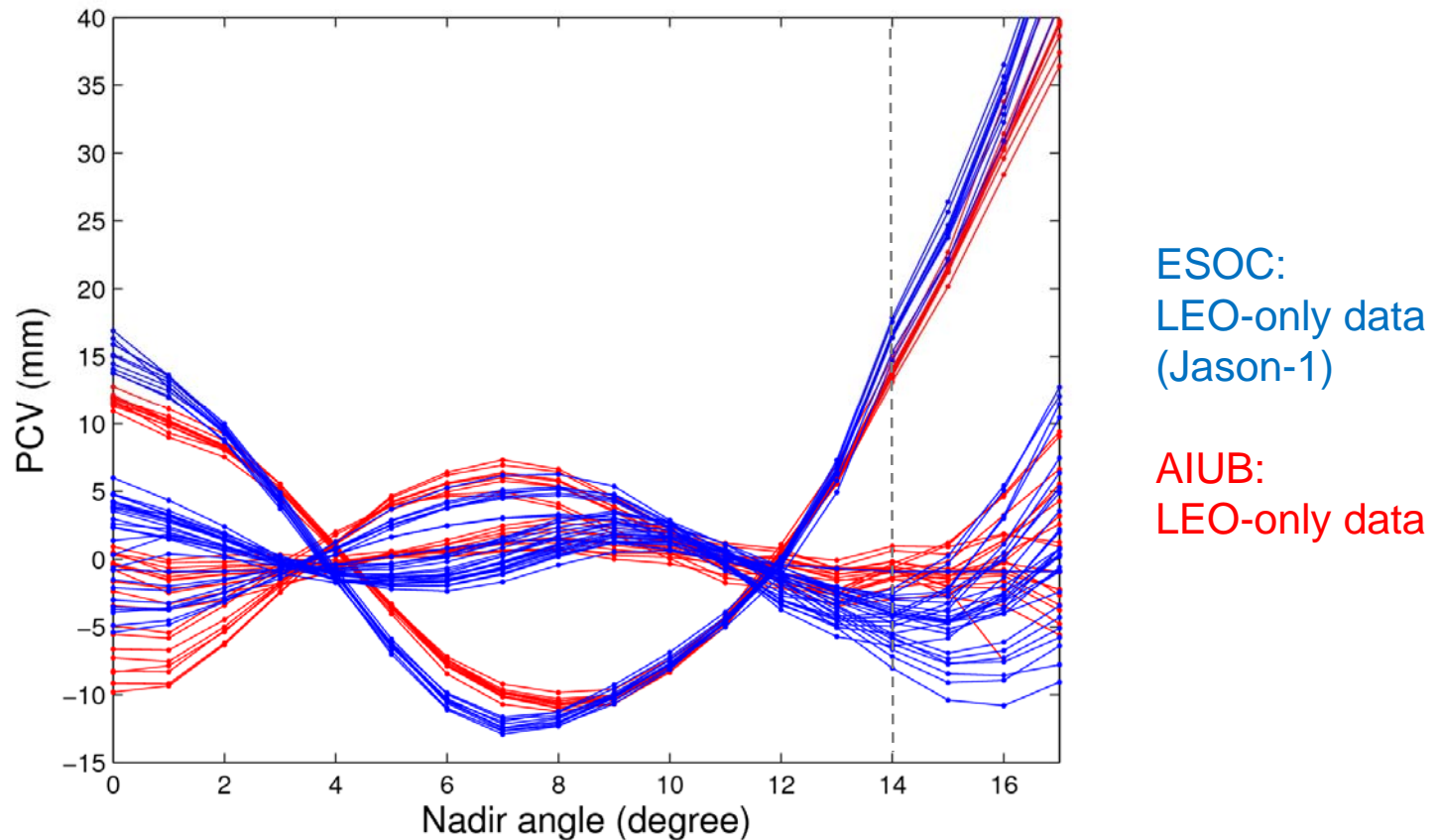
Solution strategies are unfortunately too different to allow for a meaningful combination



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

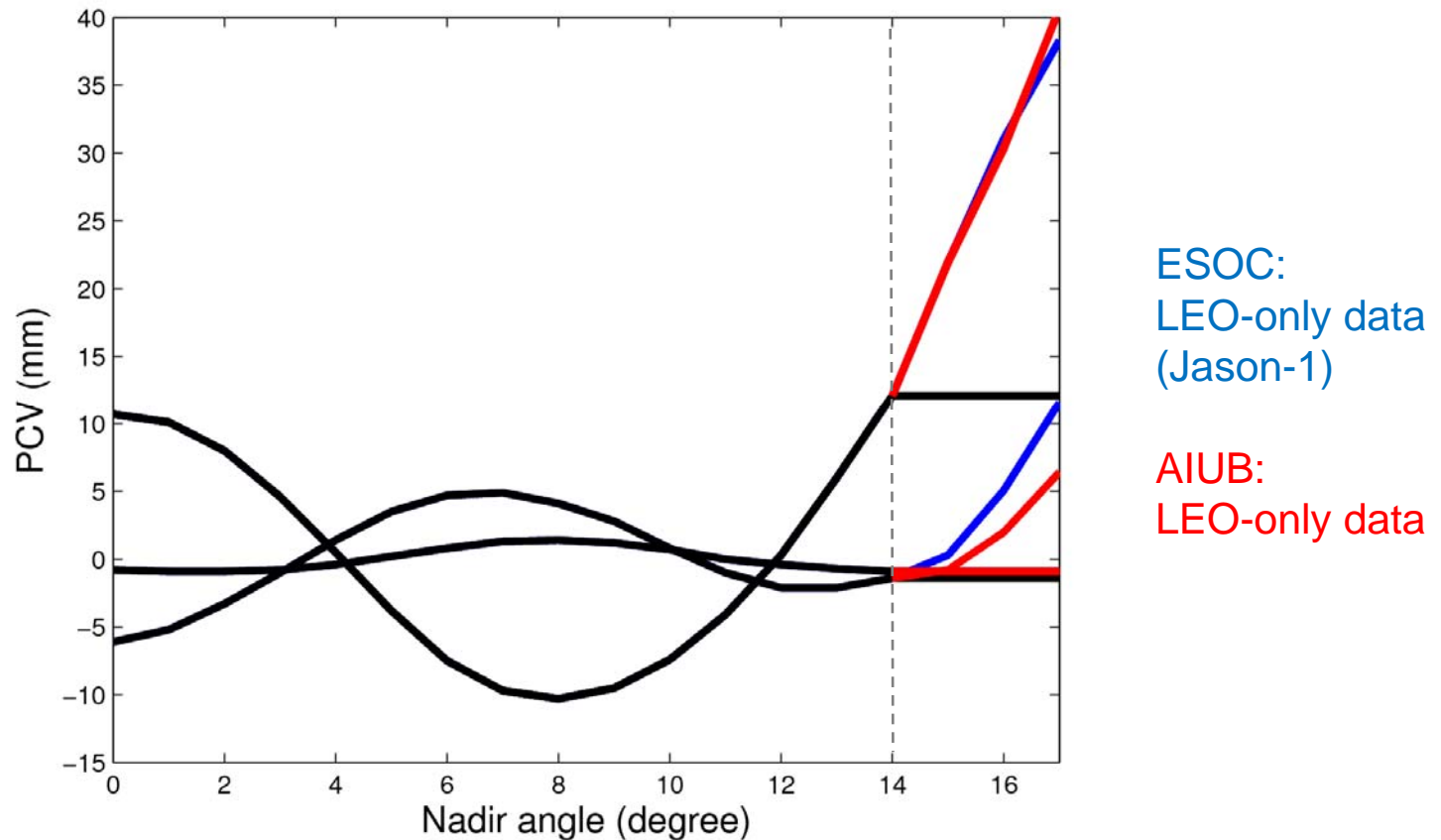
Comparison with LEO-only ESOC solution

Solution strategies are comparable, but differences prevent a meaningful combination



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

Proposed extension for igs08.atx



- **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