Extension of the GPS satellite antenna patterns beyond 14°

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Introduction

The absolute phase center model igs08.atx adopted by the International GNSS Service (IGS) in 2011 is based on robot calibrations for more than 200 terrestrial GNSS receiver antennas and consistent correction values for the GNSS transmitter antennas estimated from tracking data of the global IGS ground network. As the calibration of the satellite antennas is solely based on terrestrial measurements the estimation of their phase patterns is limited to a nadir angle of 14°. This is not sufficient for the analysis of spaceborne GPS data collected by low Earth orbiting (LEO) satellites that record - depending on the missions' orbital altitude - observations at nadir angles of up to 17°.

We use GPS tracking data from the LEO missions Jason–1/2, MetOp–A, GRACE, and GOCE to extend the IGS satellite antenna patterns to nadir angles beyond 14° using different processing strategies and GNSS software packages (Bernese, NAPEOS). In order to achieve estimates that are consistent with the PCVs currently used within the IGS, GPS satellite orbits and clocks are fixed to reprocessed solutions obtained by adopting the IGS conventional values from igs08.atx. Due to significant near-field multipath effects arising in the LEO spacecraft environment, it is necessary to solve for GPS (nadir–dependent only) and LEO (azimuth– and elevation–dependent) antenna patterns simultaneously. We compare the results obtained with both software packages to prepare a PCV extension proposed for igs08.atx.

AIUB solution: data used

- Undifferenced ionosphere-free GPS data from Jason-2, GRACE-A/B, GOCE, MetOp-A from 2009 (2011 for Block IIF satellites).
- GPS orbits and clock corrections from the CODE reprocessing are introduced as known. They are fully consistent with the phase center offsets (PCOs) and variations (PCVs) from igs08.atx
- LEO orbits from AIUB relying on the CODE reprocessed products are introduced as known. They are not based on empirical PCVs.
- GPS PCOs and PCVs from igs08.atx are used as a priori values for the transmitter antennas. The a priori PCV values are extended beyond 14° with constant values referring to 14°.
- LEO PCOs are introduced as known for the LEO receiver antennas.

AIUB solution: estimated PCV parameters

- PCVs for the LEO receiver antennas are estimated as LEO-specific piecewise linear functions with a 5°x5° resolution. A zero-mean condition is applied to all grid points.
- PCVs for the GPS transmitter antennas are estimated as satellite-specific nadir-dependent piecewise linear functions with a 1° resolution. A zero-mean condition is applied to nadir angles <= 12° and PCVs of two Block IIA satellites are constrained to their a priori values due to the simultaneous estimation of LEO PCVs.

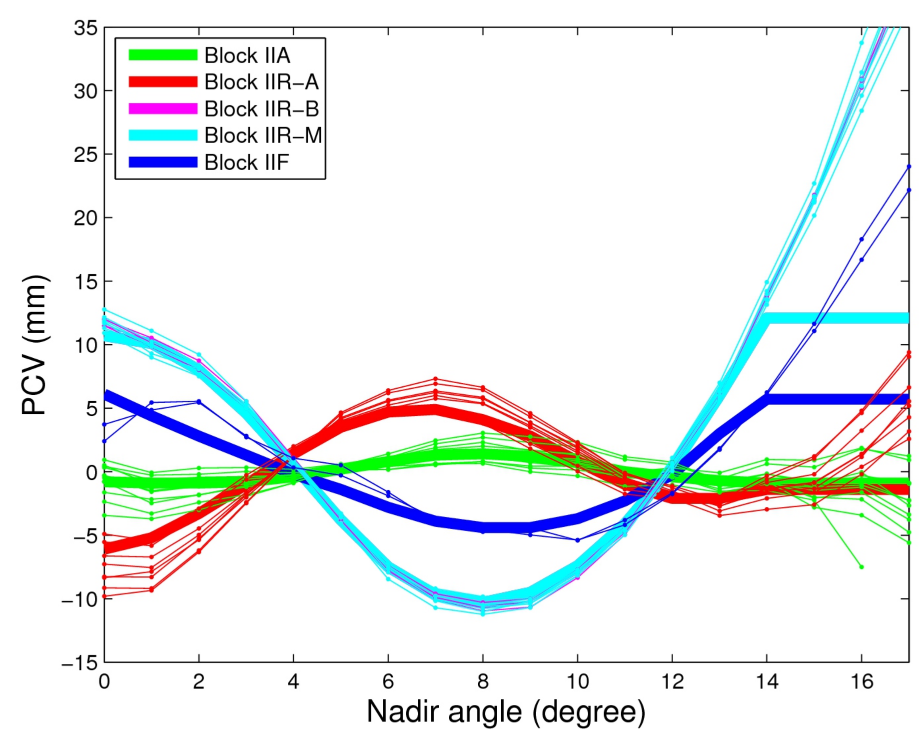

Fig. 1: Estimated satellite-specific PCVs (thin lines) and igs08.atx block-specific values with constant extension beyond 14° (bold lines).

Comparison of the AIUB LEO-only solution with igs08.atx and a terrestrial solution

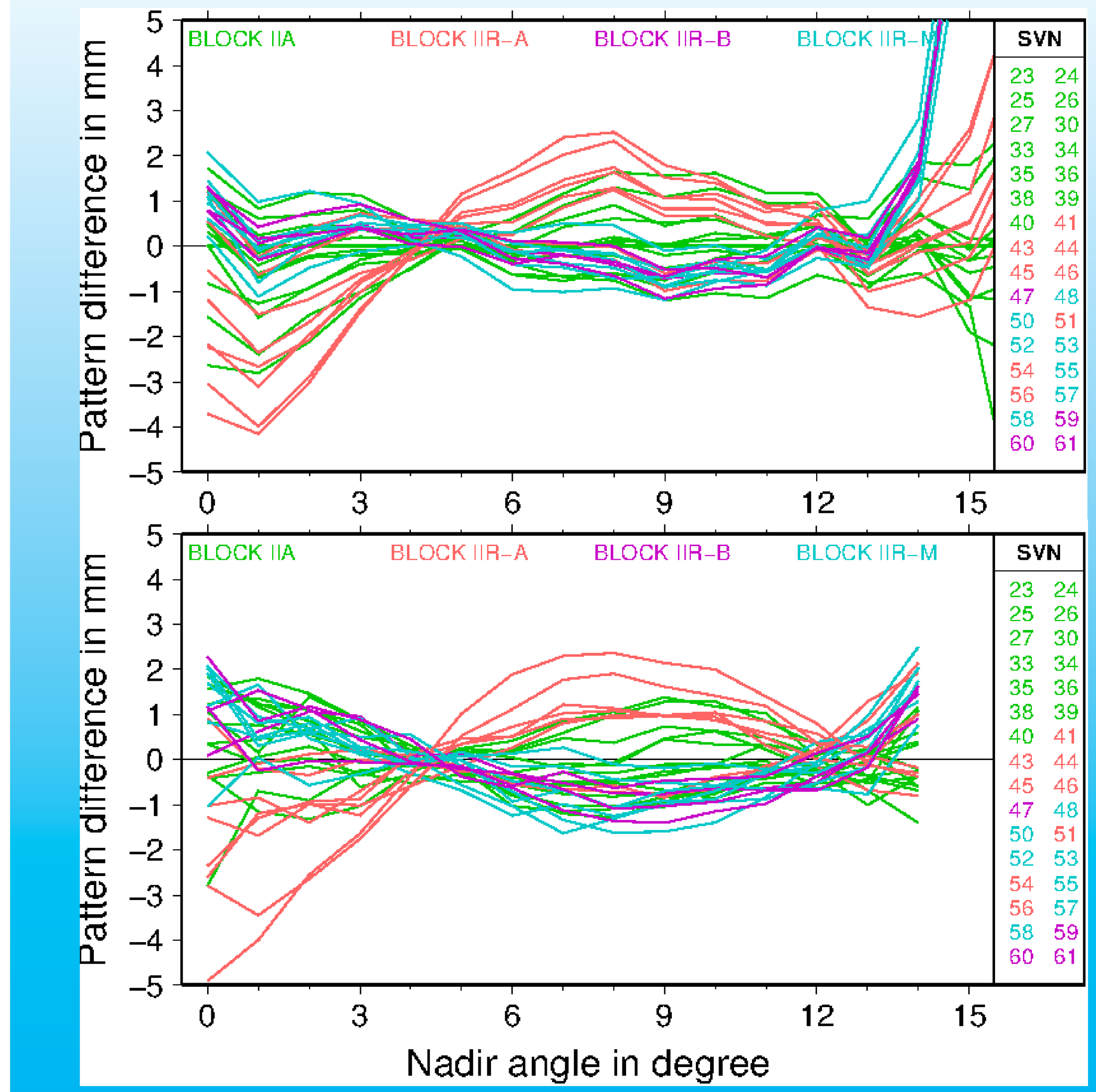

Fig. 2: Estimated PCVs from the AIUB LEO-only solution with respect to igs08.atx (top). An independent solution using GPS data from the IGS ground network (Dach et al., 2011) shows similar differences in the comparison with igs08.atx (bottom).

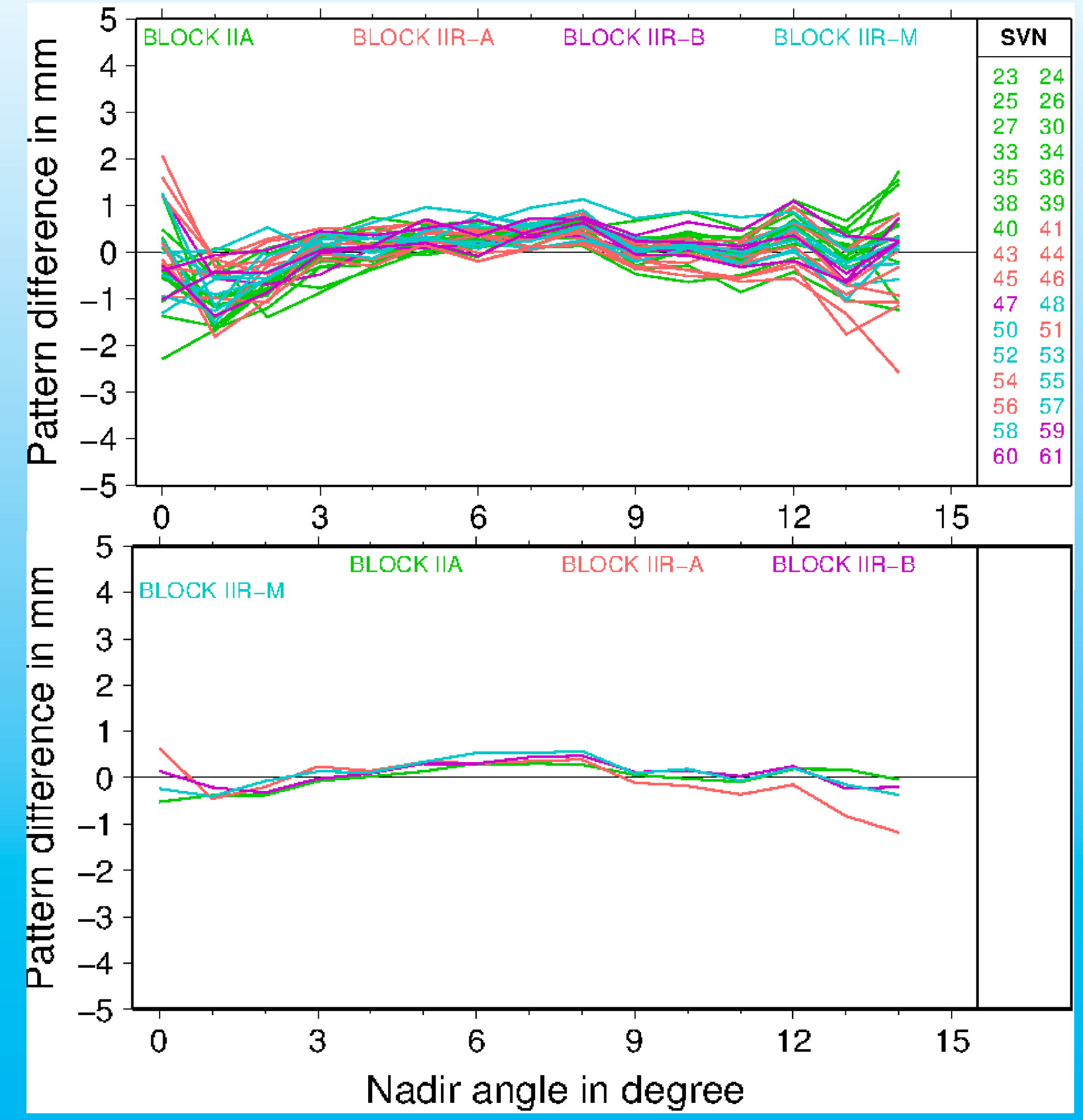

Fig. 3: Differences between the AIUB LEO-only solution and the terrestrial solution (Dach et al, 2011) for satellite-specific (top) and block-specific (bottom) PCVs. The block-specific values agree on the sub-mm level for nadir angles of up to 14°.

Impact of PCV extension on precise orbit determination of GRACE and Jason-2

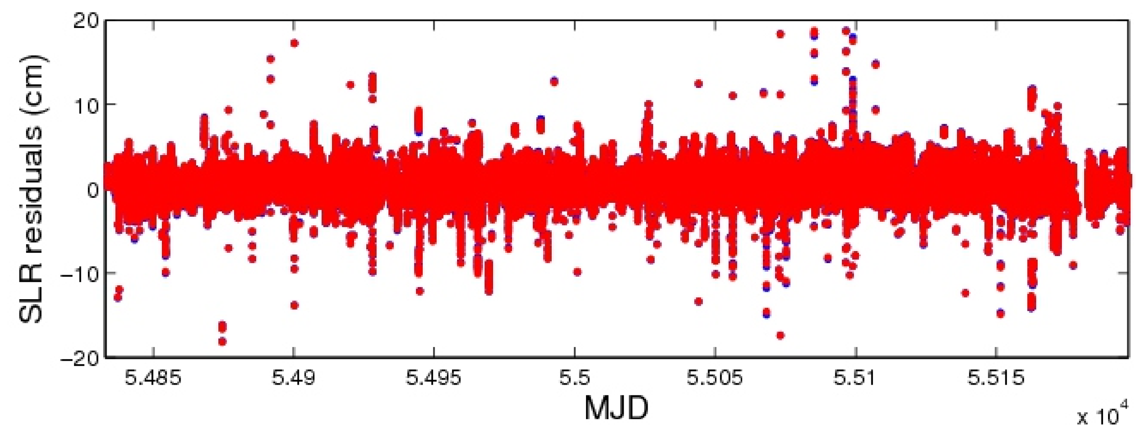

Fig. 4: Independent SLR validation of GRACE precise orbit determination when using PCVs from igs08.atx or from the AIUB LEO-only solution. The SLR RMS just marginally improves from 1.85 to 1.84 cm.

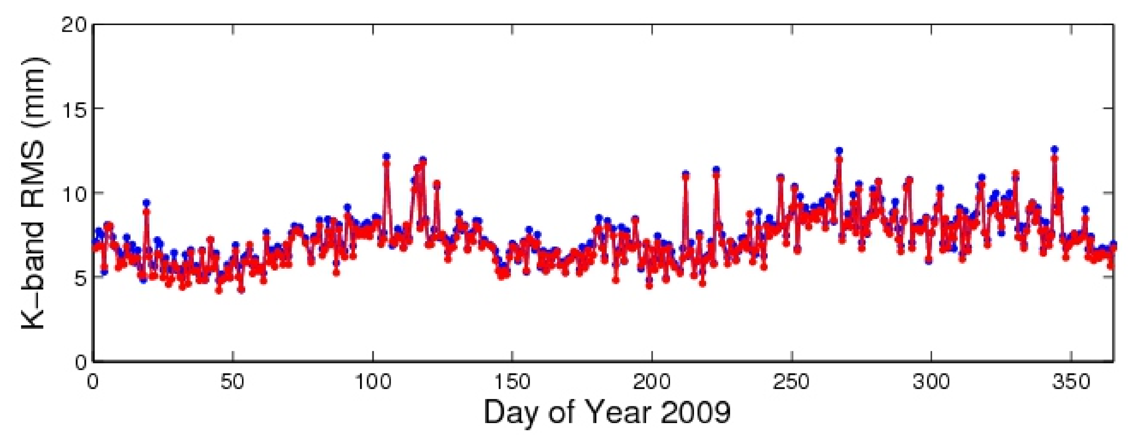

Fig. 5: Independent K-Band validation of GRACE precise orbit determination when using PCVs from igs08.atx or from the AIUB LEO-only solution. A small improvement from 7.4 to 7.1mm K-band range RMS can be seen. Part of the effect is also caused by using satellite-specific instead of block-specific PCVs from igs08.atx.

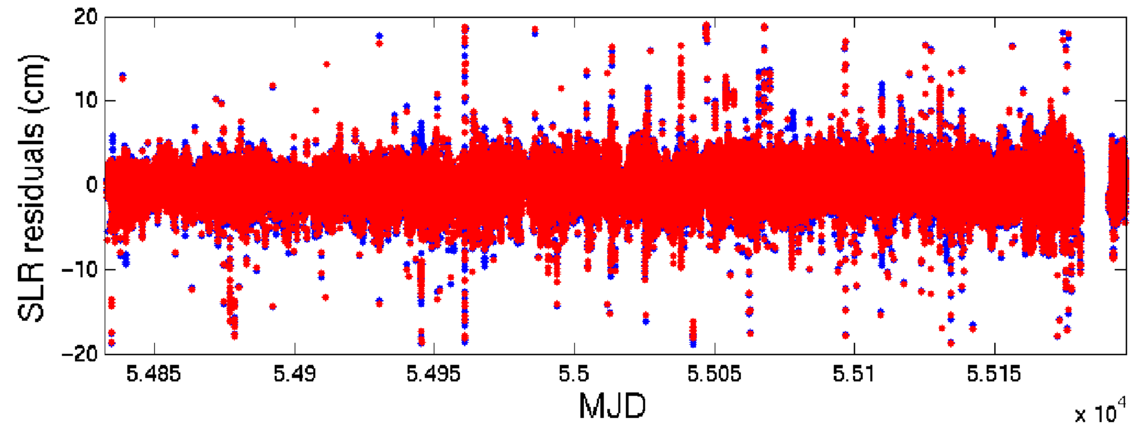

Fig. 6: Independent SLR validation of Jason-2 precise orbit determination when using PCVs from igs08.atx or from the AIUB LEO-only solution. A small improvement from 1.77 to 1.71 cm SLR RMS can be seen .

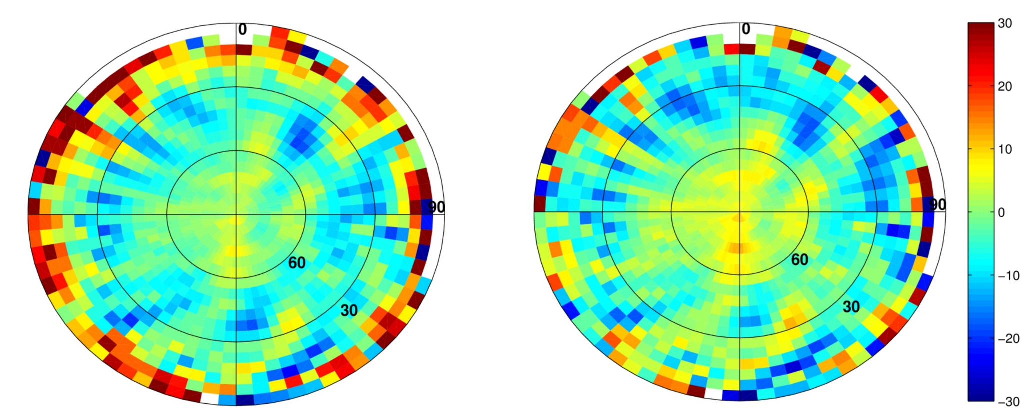

Fig. 7: Jason-2 PCVs (in mm) when using transmitter PCVs from igs08.atx (left) or from the AIUB LEO-only solution (right). The receiver PCVs absorb, to a large extent, systematic effects at low elevations when using the current version of igs08.atx. Thus, the impact of the mismodeling on orbit determination is not very large.

ESOC solution: data used

- Undifferenced ionosphere-free GPS data from Jason-1 (2002-2008).
- GPS orbits and clock corrections from an ESOC-internal GNSS reprocessing campaign are introduced as known. They are fully consistent with the PCOs and PCVs from igs08.atx.
- Jason-1 orbits and clocks are simultaneously estimated together with the PCV parameters in a combined GNSS/SLR adjustment.
- GPS PCOs and PCVs from igs08.atx serve as a priori values for the transmitter antennas. The a priori PCV values are extended beyond 14° with constant values referring to 14°.
- Jason-1 PCOs are introduced as known.

ESOC solution: estimated PCV parameters

- PCVs for the Jason-1 antenna are estimated as a piecewise linear function of the elevation angle with a resolution of 5°. A zero-mean condition is applied to all estimates.
- PCVs for the GPS transmitter antennas are estimated as satellite-specific nadir-dependent piecewise linear functions with a 1° resolution. A zero-mean condition is applied to nadir angles <= 14° and PCVs of two Block IIA satellites are constrained to their a priori values.

Comparison: ESOC and AIUB solution

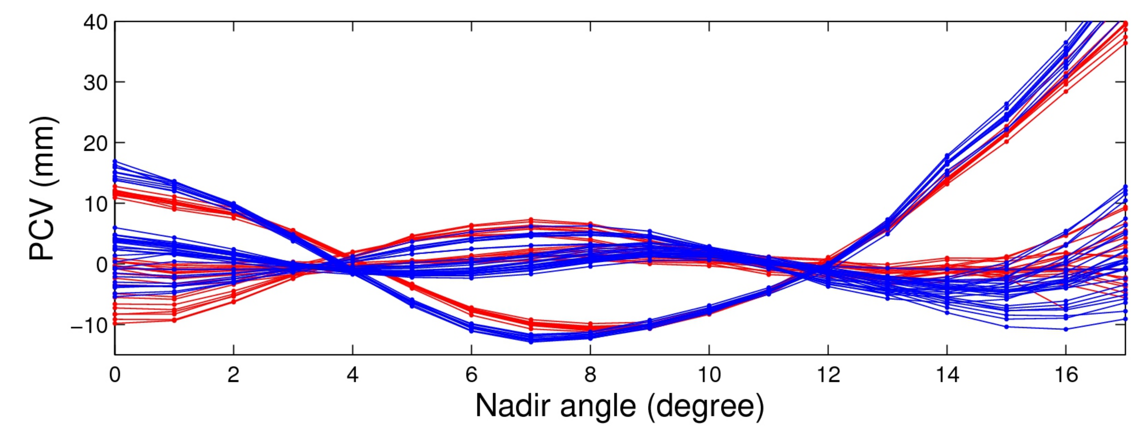

Fig. 8: Estimated satellite-specific PCVs from AIUB and ESOC.

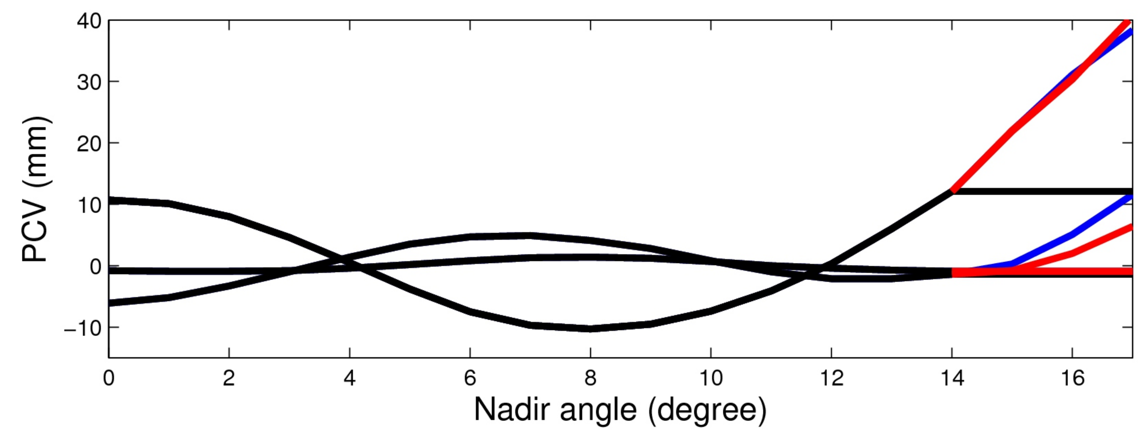

Fig. 9: Estimated block-specific PCVs from AIUB and ESOC with values <= 14° constrained to igs08.atx (black lines). The agreement between the two solutions for the Block IIR-B/M satellites is excellent. Larger discrepancies are present for Block IIR-A satellites.

Conclusions

Two completely independent GPS PCV solutions were computed at AIUB and ESOC from LEO-only GPS data using a similar constraining approach. Discrepancies found between the solutions need to be further investigated. The AIUB PCV solution shows an agreement of about 1 mm with corresponding estimates obtained from terrestrial GPS data, block-specific values agree even better than 1 mm. By constraining the block-specific values <= 14° to igs08.atx values an extension of igs08.atx can be derived, which will be beneficial for spaceborne applications but not affecting terrestrial applications.

References

Dach, R., R. Schmid, M. Schmitz, D. Thaller, S. Schaer, S. Lutz, P. Steigenberger, G. Wübbena G. Beutler (2011): Improved antenna phase center models for GLONASS. GPS Solutions, 15(1), 49-65

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