Validation of phase center corrections for new GNSS signals obtained with absolute antenna calibration in the field

Yannick Breva, Johannes Kröger, Tobias Kersten and Steffen Schön (#EGU2019-14143)

Institut für Erdmessung | Leibniz Universität Hannover

Introduction

For high accuracy GNSS applications it is necessary to take phase center corrections (PCC) into account. At the moment, PCC from chamber calibrations for various signals are available, however GPS L5 as well as Galileo PCC from field calibrations are still missing. Here, we give details on Institut für Erdmessung (IfE) estimation approach for PCC and the estimated pattern for new signals. These patterns will be validated with a common-clock set up by using receiver-to-receiver-single differences (SD).

Method and estimation approach

To estimate absolute PCC, the IfE robot is used (see Fig. 3).

- Antenna under test is rotated and tilted precisely around specific point (SP) with distance d from antenna reference point (ARP).
- Most effects cancelled out by using:
  - Short baseline ($\sim$ 8 m) and common-clock set up between reference antenna and antenna under test and
  - time differenced single differences (ΔSD).
- Phase-wind up effect has to be modelled as well as the robot pose.
- ΔSD only contains PCC from antenna under test and unmodelled effects/noise ϵ:

$$\Delta SD = \Delta PCC_A^k(t_i, t_{i+1}) + \epsilon(t_i, t_{i+1}) \quad (1)$$

Figure 1: IfE robot for absolute antenna calibration.

Estimation approach by spherical harmonics (eq. 2) with degree 8 and order 8.

$$PCC(\alpha^k, z^k) = \sum_{m=1}^{m_{max}} \sum_{n=0}^{m} \tilde{P}_{mn}\left(\cos(z^k)\right)\left(a_{mn}\cos(n\alpha^k) + b_{mn}\sin(n\alpha^k)\right) \quad (2)$$

- Restricting coefficients to zero, where index sum is uneven.
- Estimated parameters $\hat{a}_{mn}$ and $\hat{b}_{mn}$ are inserted into eq. 2 to calculate the PCC grid.
- Estimation of phase center offset (PCO) from PCC. The residuals indicate the phase center variations (PCV).

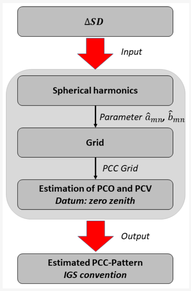

Figure 2: Process of estimation approach.

Estimated PCC-Pattern

Four days of calibration from February 18^{th} to 21^{st} and February 25^{th} to March, 1^{st} 2019 for

- LEIAR25.R3 LEIT, S/N: 8360013 (DOY 56,57,59,60) and
- NOV703GGG.R2 NONE, S/N: 12420040 (DOY 49-52).

Repeatability by consider all possible PCC pattern combinations from different calibration days (Tab. 1) using

- Maximum and average spread[1]($dPCC_{max} - dPCC_{min}$) and
- Maximum and average RMS.

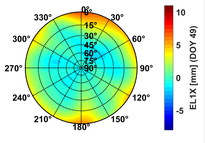

Figure 3: Example of an estimated PCC pattern by using IfE estimation approach for NOV703GGG.R2 None (S/N: 12420040) EL1X.

Table 1: Maximum and average spread and RMS for the two antenna under test for all possible PCC pattern combinations.

	LEIAR25.R3 LEIT [mm]				NOV703GGG.R2 NONE [mm]			
Signal	max spread	max RMS	∅ spread	∅ RMS	max spread	max RMS	∅ spread	∅ RMS
GL1C	3.19	1.43	2.19	0.81	6.83	0.80	4.14	0.58
GL2W	2.91	1.38	2.15	0.77	2.48	0.67	1.69	0.43
GL5X	4.36	2.33	3.58	1.54	6.23	3.75	4.40	1.96
EL1X	2.63	0.84	2.10	0.55	4.09	1.28	3.03	0.82
EL5X	4.17	1.12	2.93	0.77	4.62	1.62	3.16	0.97

Repeatability of estimation

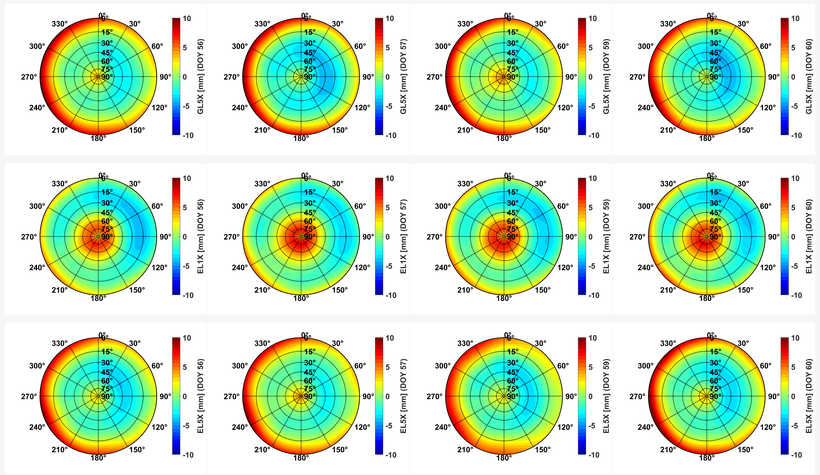

Figure 4: Estimated PCC pattern by using IfE estimation approach for LEIAR25.R3 LEIT (S/N: 8630013). The top row shows PCC pattern for GL5X signal from DOY56 (left) to DOY60 (right). No calibration was done on DOY58. The middle row shows PCC pattern for EL1X and the bottom row for EL5X.

Comparison with IGS and chamber

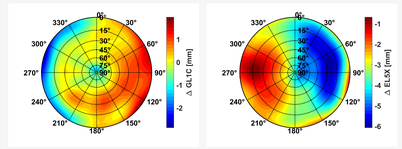

Figure 5: Difference PCC between IfE and IGS for GL1C (left) and between IfE and Bonn for EL5X (right) for LEIAR25.R3 LEIT (S/N: 8630013).

Table 2: Maximum spread and RMS for the comparison between IfE and IGS as well as Bonn for LEIAR25.R3 LEIT (S/N: 8630013).

	IGS [mm]		Bonn [mm]	
Signal	spread	RMS	spread	RMS
GL1C	4.84	0.71	5.46	3.87
GL2W	7.39	1.14	8.21	7.31
GL5X	-	-	4.89	5.01
EL1X	-	-	5.79	4.06
EL5X	-	-	5.39	3.80

- Maximum difference between IfE and IGS occur in low elevation. Overall, a difference is in a range of 1 mm for GL1C visible (Fig. 5 left).
- Difference between IfE (robot) and Bonn (anechoic chamber) shows azimuthal variations especially in east and west directions (Fig. 5 right).

Experimental set-up

- Experimental set-up on the rooftop of the Geodetic Institute Hannover (GIH) (Fig. 6). A common-clock short baseline ($\sim$ 7.5 m) configuration is used to calculate SD.
- Table 3 shows the hardware set-up. The receivers are connected to an external rubidium frequency standard.
- Multi-GNSS signals measurements from February 8^{th} to 10^{th} 2019 (DOY37 - DOY39).
- Precise coordinates are provided from a network solution 2018 with sub-millimeter accuracy.
- For the validation, the SD are related to the SP, which depends on the antenna.

Figure 6: Experimental setup on the rooftop from GIH

Table 3: Hardware setup in the experiment.

Station	Antenna	S/N	Receiver	S/N
MSD5	NOV703GGG.R2 NONE	12420040	JAVAD DELTA TREG3T	081
MSD6	LEIAR25.R3 LEIT	8360013	JAVAD DELTA TREG3T	082

Validation

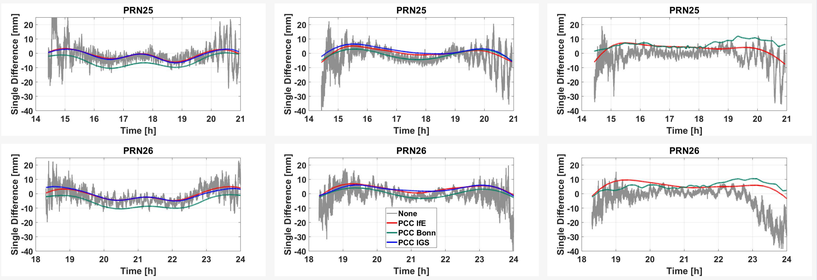

Figure 7: Single Differences (grey) from February 8^{th} with respect to SP, without PCC for GPS satellites PRN25 and PRN26. GL1C (left), GL2W (middle) and GL5X (right) are shown. The red curves indicates the PCC estimated by IfE (robot), the blue curve indicates the IGS type mean PCC (robot) and the green curve are PCC from Bonn (anechoic chamber). Note, that there are no chamber PCC available for NOV703GGG.R2. A similar PCC (LEIAX1202GG) is used instead.

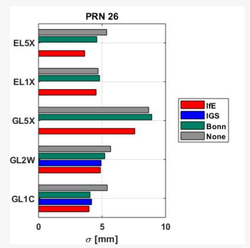

Figure 8: SD without applied PCC (grey) and with applied PCC from IfE (red), IGS (blue) and Bonn (green) for GPS and Galileo satellite PRN26.

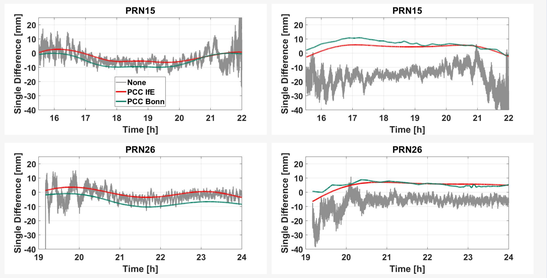

Figure 9: Single Differences from February 8^{th} with respect to SP without PCC for Galileo satellites PRN15 and PRN26. EL1C (left) and EL5X (right) are shown.

- IfE and IGS PCC are similar for GL1C and GL2W and fits very good into the SD.
- Offset between Bonn and IfE/IGS due to different datum definitions (zero mean/zero zenith).
- For L5 frequencies an offset between SD and PCC occur, which is individual for every satellites. Nevertheless, the trend between IfE estimated PCC and the SD are similar.
- The standard deviations from SD without and with PCC shows an improvement if IfE PCC are applied.

Conclusion

- Several calibrations of LEIAR25.R3 LEIT shows a repeatability of the PCC pattern with an average spread of 2–3.5 mm and average RMS of 0.5–1.5 mm for GL5X, EL1X and EL5X.
- A comparison between an estimated IfE PCC pattern with Bonn shows a spread of 4.8–5.8 mm and 3.8–5 mm RMS of for GL5X, EL1X and EL5X.
- GL5X shows the worse repeatability which can be explained in the less number of L5 sending GPS satellites (#12).
- A validation in a common-clock short baseline shows a good fitting of the estimated PCC into the uncorrected SD and has a similar trend to the IGS type mean PCC and chamber PCC from Bonn.

References and Acknowledgement

[1] **Schön, S. and Kersten, T. (2014)**. Comparing antenna phase center corrections: challenges, concepts and perspectives. In: *IGS Analysis Workshop, 23-27 June, 2014, Pasadena, California.*

Antenna calibration data from IGS (method ROBOT & CHAMBER) are available at ftp://igs.org/pub/station/general/igs14.atx

Antenna pattens from University of Bonn (method CHAMBER) published by Europoean Permanent GNSS Network (EPN), available at ftp://epncb.eu/pub/station/general/indiv_calibrations/

Institut für Erdmessung
Schneiderberg 50
D-30167 Hannover

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Yannick Breva, Johannes Kröger
Tobias Kersten, Steffen Schön
www.ife.uni-hannover.de
{breva, kroeger, kersten, schoen}@ife.uni-hannover.de