Institut für Erdmessung

Leibniz Universität Hannover

Applying phase center corrections also to code observables? – A PPP case study

- 28th IUGG General Assembly 2023 -

G01g :: Reference systems and frames

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GNSS receiver antenna uncertainties

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- Calibration facilities: available, independent approaches (chamber, field-robot)
- Receiver antenna calibration values: available for carrier phase (PCC), global and regional
- Multi-GNSS PCCs: available for more and more antennas

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No, far from it!

- Lack of quality measures to validate calibration institutions or approaches
- Open questions regarding the impact of *group delay variations* (code observable, GDV/ CPV)
- Lack of updates for PCC exchange (ANTEX update) and quality measures

Phase Centre Correction requirements

Phase centre corrections (PCC) need to be

- *Accurate* – prerequisite for precise GNSS applications and products
- *Reliable* – value of integrity (differences of *robot* and *chamber*, updates of PCCs)
- *Consistent* – products such as ITRF, orbits, clocks, GNSS IWV require reliable antenna information

Receiver antenna as a bottleneck

- Inconsistencies in GNSS time series (e.g. antenna change, change of LNA)
- Instrumentation (antenna design, surroundings etc.) and interaction (DFG project MAESTRO)
- Location / installation (visibility, geographic location etc.) (Kröger et al., 2022)
- Data processing (methods, cut-off, ambiguity resolution, mapping function etc.)

Kröger et al. (2022). *How Do Different Phase Center Correction Values Impact GNSS Reference Frame Stations?*, **IAG REFAG 2022**

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Same is valid for code phase variations [group delay variations] (CPV /GDV)

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Requirement: We need tools for a sound verification of antenna information!

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Effects due to change of updates in ANTEX type-mean files

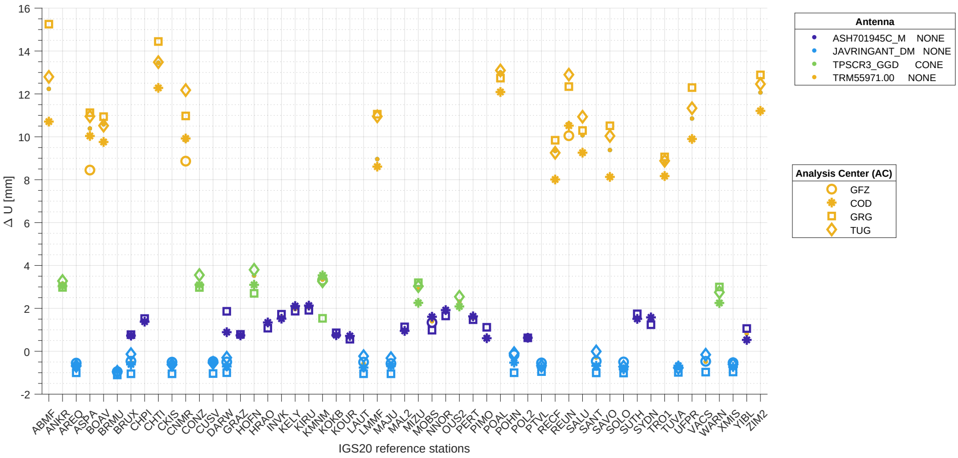
Reported effects on IGS20 reference coordinates (IGSR3.atx to IGS20.atx update)

- PCC-update of four antenna types affects 53 IGS reference stations
- Study the effect to assess uncertainty and derive statistical boundaries
- Check for displacements and variability on parameter doamin

Parameters to check for antenna updates and variations in global networks (multi GNSS)

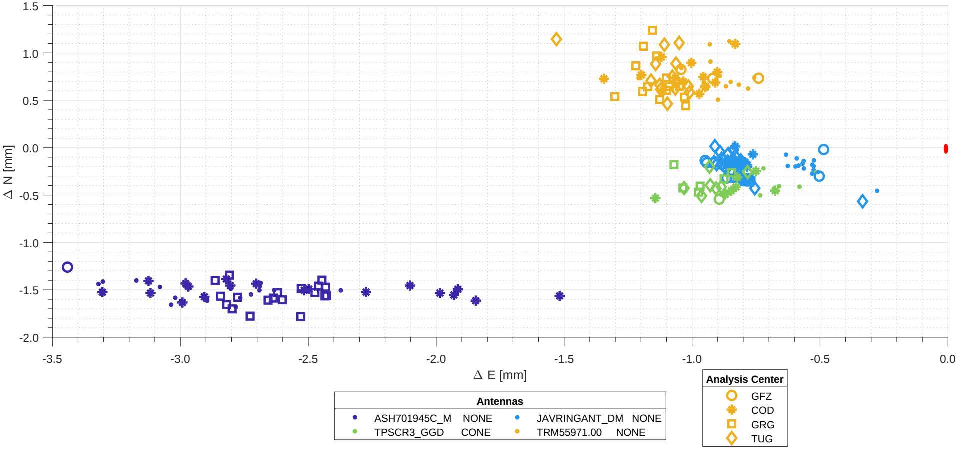
- Each antenna separately processed with PPP time series, data by IGS-IGN (IGS IGN, 2023)
- PPP results provided by different analysis centers (ACs), individual software
- Differences on topocentric position deviation vs. known reference coordinates (N, E, U)

Effects on topocentric Up-component



Data source: IGS IGN, 2023

Effects on topocentric North- and East-component



Data source: IGS IGN, 2023

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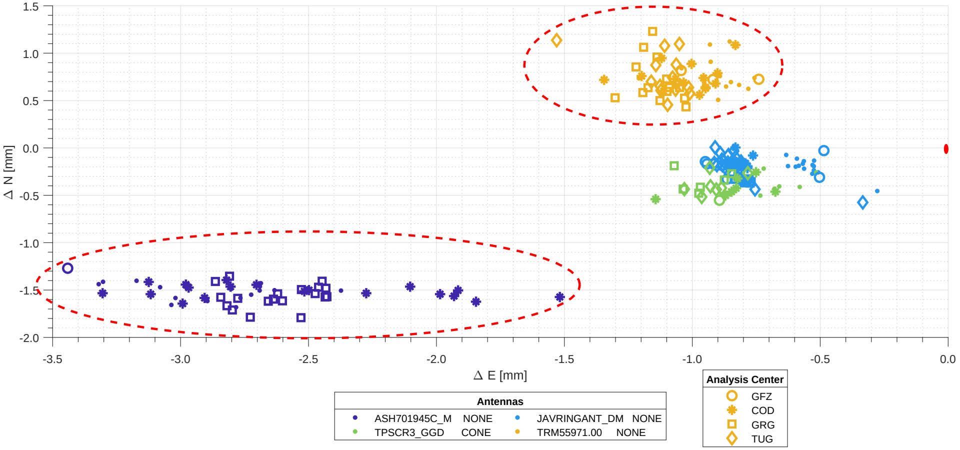

Data source: IGS IGN, 2023

Results on type-mean ANTEX update

Outcome

- Effects on position domain due to ANTEX-updates (multi GNSS) and processing parameters
- North-/East-component: ± 1 mm, deviations with up to of 3–4 mm for ASH701945C_M (NONE)
- Up-component affected by up to +15 mm for TRM55971.00 (NONE)

Important results

- Discontinuities for station specific time-series (geometry) due to PCC updates
- Discontinuities in derived parameters, such as e.g. troposphere, clock (other than geometry)
- Affected precision for PPP *and* network processings (due to linear combinations, multi-GNSS etc.)

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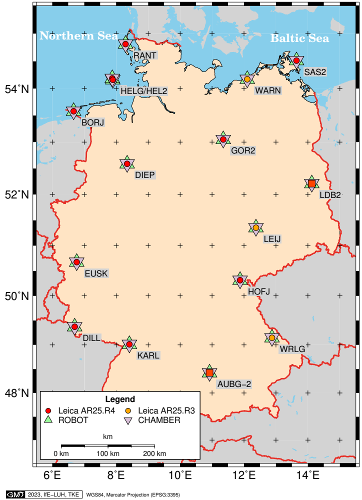
Case study – individual calibration sets from different facilities



Data sets

- Analysed sites (BKG, one ROB) with individual antenna calibrations for methods *robot* and *chamber* (amount: 25 samples)
- Calibrations from Geo++ and Uni Bonn from the years 2010 to 2018
- Main antenna type: LEIAR25.R3/R4 (LEIT/NONE)

Strategy

- Observation domain: PCC comparisons
- Parameter domain: PPP, analyse PCC uncertainties
- CPV/GDV: assess effect of code/carrier phase consistency

Comparison strategies – scalar metrics

Differences of PCC (simplified approach)

- Differences in azimuth and elevation
- Differences in elevation only
- Loss to comprehensive information for both cases

Scalar measures (extended approach)

- Standard deviation: quadratic deviation between PCC sets: $\sigma_{\Delta PCC}$
- Range: maximum range between the PCC sets: $r_{\Delta PCC} = (max(\Delta PCC) - min(\Delta PCC))$
- Spread: maximum in range: $s_{\Delta PCC} = (r_{PCC_j} - r_{PCC_i})$
- Correlation coefficient: overall similarity between two patterns (Pearson correlation coefficient)

Kersten et al. (2022), *J Geod* **96**, 48, doi: 10.1007/s00190-022-01635-8

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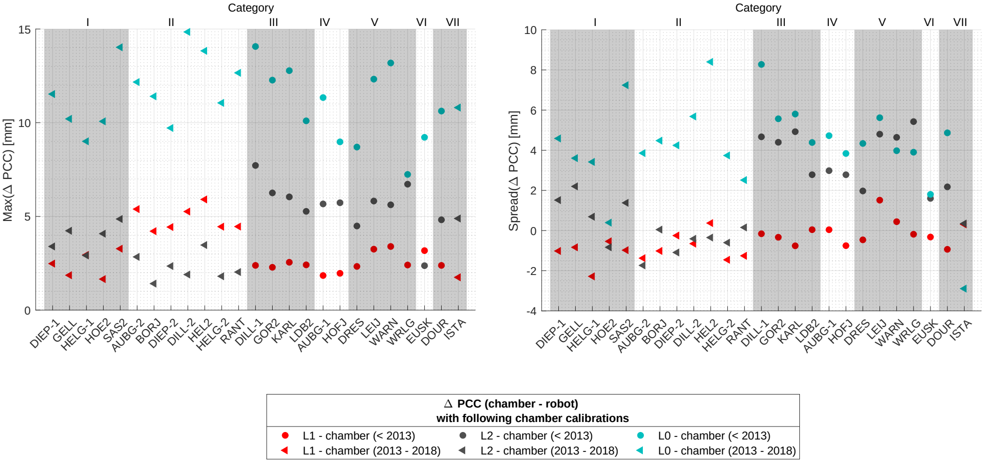
Comparison strategies – scalar quality metrics for ∆PCC between robot and chamber



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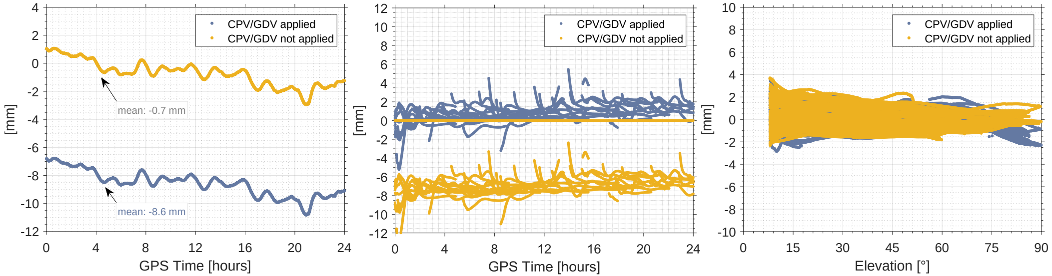
Impact of PCC on estimated parameters – PPP approach (code and carrier phase)

GNSS-Site Lindenberg (LDB2, DEU, indiv. PCC chamber versus robot)



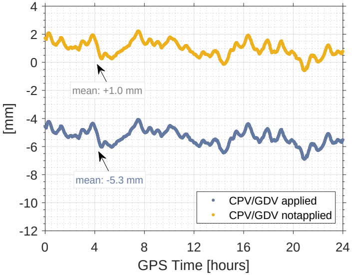
(a) differential receiver clock error **(b)** differential float-ambiguity **(c)** differential post-fit residuals (code)

Outcome

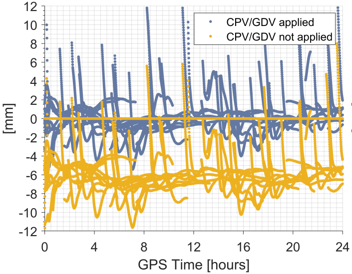
- Value of differential receiver clock error and differential ambiguity swaps
- Differential PCO offset reveals inconsistency of carrier phase and code

Impact of PCC on estimated parameters – PPP approach (code and carrier phase)

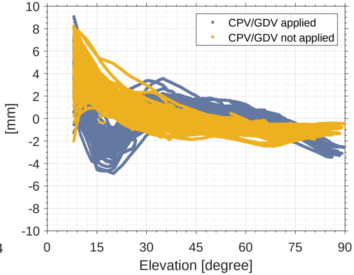
GNSS-Site Augsburg (AUBG, DEU, indiv. PCC chamber versus robot)



(a) differential receiver clock error



(b) differential float-ambiguity



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Next steps in receiver antenna calibration

Current status

- Variations due to *hardware* (antenna, receiver etc.), *software* (processing software) and *processing concepts* (double differenced vs. undifferenced approach)
- Multi-GNSS calibration values not always available
- Usability of individual vs. type mean calibrations (station & network operators, analysis centres)

Initiation of ring calibration and validation campaign

- Assess quality metrics in procedures and facilities
- Coordinated concept of PCC exchange (magnitudes, stability etc.)
- Definition of standards and a rigorous process for consistent comparison of PCC sets

IGS receiver antenna calibration and validation ring campaign (ringCalVal): overview

Procedure

- Start **Sept. 2022**, with focus to finish calibrations in 2023
- Meeting in July/August 2023 to coordinate the evaluation part and concept

Participants

- *Different robots and approaches:* National Geodetic Survey (NGS), Topcon Italy, ETH Zurich, GNSS Research Center Wuhan (GNSS-RC)
- *Same robots – different approaches:* Geo++, Inst. f. Erdmess. (IfE), GeoScience Australia (GSA)
- *Anechoic chamber:* Uni Bonn, German Aerospace Center (DLR) Oberpfaffenhofen

Calibration samples

- Geodetic grade antennas: 4 x choke ring antennas, 1 x Zephyr II, 1 x rover antenna

IGS receiver antenna calibration and validation campaign (ringCalVal): current status

Region	Method	Institution	TPSCR.G5C	TPSG5.A1	JAVRINGANT_DM	TRM57971.00	LEICA25.R3	HXCCGX601A
Australia	robot	GSA - Geoscience Autralia	9	9	1	1	9	9
China	robot	GNSS Research Center of Wuhan University (WHU-GNSSRC)	8	8	3	3	8	1
Europe	chamber	DLR German Aerospace Centre Institute of Communications and Navigation	5	5	9	9	4	8
		Uni Bonn	4	4	8	8	3	7
	robot	Geo++ GmbH	3	3	7	7	2	6
		TOPCON AGRICULTURE S.R.L.	1	1	5	5	5	4
		ETH Zurich	6	6	4	4	6	3
		LUH-IfE	2	2	6	6	1	5
USA	robot	NGS/NOAA	7	7	2	2	7	2

Legend

1:= last stop in rotation

- (pink) antenna(s) not arrived/calibrated
- (orange) antenna(s) under testing/calibration
- (yellow) waiting position for receiving antenna(s) as next
- (green) finished testings/calibration

Summary and conclusions

Summary

- Effect of PCCs on PPP with carrier phase and code divergences shown (IGS & EPN sites)
- Comparison strategy for receiver antennas with dependencies of calibration facilities
- Independent scalar metrics helpful for PCC comparisons

Conclusions

- Reduce the instrumental impact of calibration methods and facilities
- Need for verification strategies for carrier-phase and code calibration sets (consistency)
- IGS ring calibration (IGS ringCalVal) provides further insight into the stability of PCC (and CPV/GDV) sets

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