Impact of Antenna Phase Center Models: From Observation to Parameter Domain

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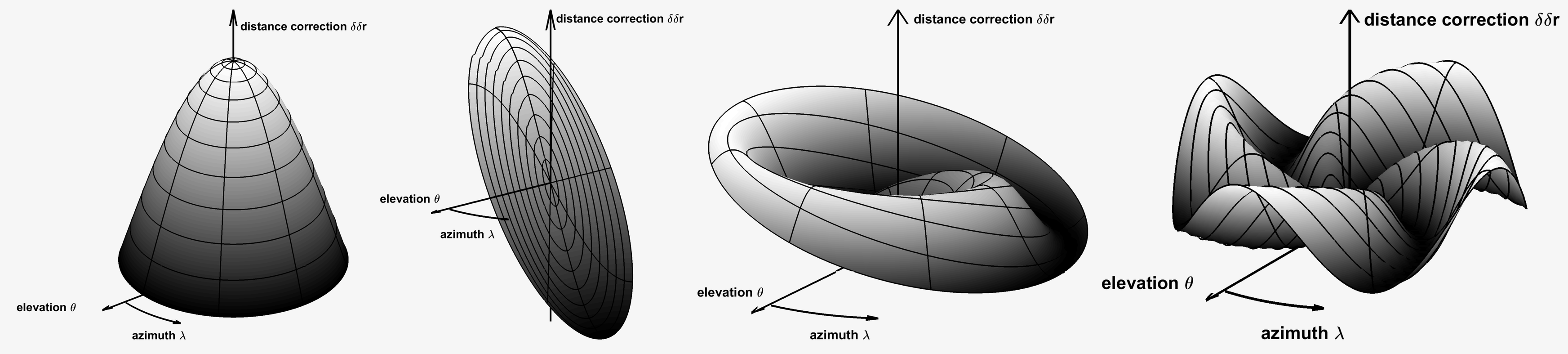
Abstract

Several contributions and papers discuss the impact of the variability of receiver antenna calibration models on the coordinate or parameter domain, respectively. This can only be a first approximation since complex interactions depending on the processing philosophy, propagates carrier phase center variations (PCVs) differently to the parameters, so that unexpected discrepancies on the parameter domain can occur and have to be analyzed consequently.
This approach categorize the impact of carrier phase center corrections (PCCs) on all geodetic parameters and is based on improved simulation methods with generic patterns initially investigated by [Geiger, 1988] and [Santerre, 1991].
The propagation of error functions for several generic antenna models is investigated, [Hiemer et al., 2015]. Simulations are validated by empirical experiments through adding generic PCC patterns to individual calibrated antennas and computing Precise Point Positioning (PPP) w/o generic patterns. The impact of different software packages are studied therefore, too.

Background - Generic Patterns and Simulations

Generic patterns as investigated by [Geiger, 1988] are used in several configurations to simulate error functions on PCC patterns.



(a) Turnstile (b) Micro-Strip (c) 1-wire helix (d) 4-wire helix

Figure 1: Generic patterns to analyze different impacts of error functions on PCC patterns.

(a) P1:=Turnstile	$\delta\delta\mathbf{r}(\theta,\lambda) = A\cdot cos(\theta)$	A=1 cm
(b) P2:=Micro-Strip	$\delta\delta\mathbf{r}(\theta,\lambda) = A\cdot sin(\theta)\cdot cos(\lambda - a_0)$	A=1 cm
(c) P3:=1-wire helix	$\delta\delta\mathbf{r}(\theta,\lambda) = A\cdot sin(\theta) + D\cdot sin(\theta)\cdot cos(\lambda - 4\theta - 1a_0)$	A=D=0.5 cm
(d) P{4/5}:=4-wire helix	$\delta\delta\mathbf{r}(\theta,\lambda) = A\cdot sin(\theta) + D\cdot sin(\theta)\cdot cos(4\lambda - 4\theta - 4a_0)$	A={0.5 cm/2 cm}, D=0.5 cm

with: A, D: amplitude, $\delta\delta r(\theta,\lambda)$: generic PCCs, θ: elevation angle, λ: azimuth, a_0: north-orientation.

Impact of generic patterns is shown by applying estimation model and obtain unknown parameters:

$$\delta\mathbf{x} = (\mathbf{A^T P A})^{-1}\mathbf{A^T P}\delta\delta\mathbf{r}(\theta,\lambda),$$

whereat: $\delta\mathbf{x}$: unknown parameters, $\mathbf{A}$: design matrix, $\mathbf{P}$: weight matrix.

Analysis is carried out by introducing different amplitudes (A, D) and at least 5 generic patterns (P1-P5) to study the theoretical impact on the unknown parameter vector $\delta\mathbf{x}$. Reference values are indicated by dark gray bars in Figure 3.

Methodology - PPP Analysis

Set-Up (reference station equipment)

- 24 hour data set (incl. sidereal repetition from DOY339-342, 2011), 1 sec sampling, 3° cut off angle, with `LEIAR25.R3 LEIT` antenna and `Javad TRE_G3T` receiver
- Laboratory network at IfE, Leibniz University Hannover (mean geographic latitude of 54°)

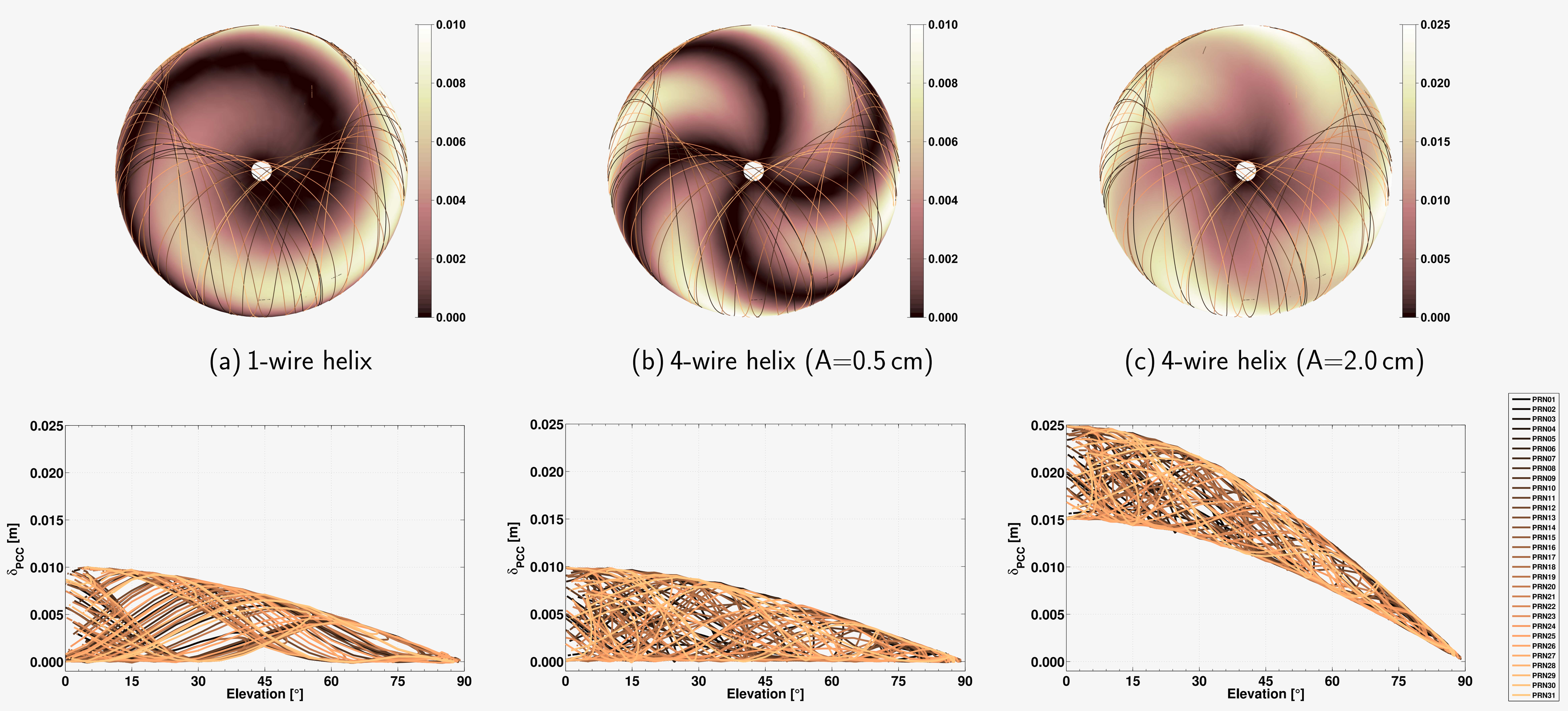
Parameters

- Reference solution determined by PPP with original absolute and individual PCCs.
- Further processing with manipulated PCC patterns (generic patterns on L1/L2, ref. Figure 1).
- Differences of subsequent PPP solutions show impact on coordinate, receiver clock error, tropospheric delay as well as ambiguity parameters.

Software (commercial and open source)

- Software packages used for study: *Bernese GNSS Software 5.2*, *CSRS-PPP (NRCan)*, *GPS Toolkit*, *Matlab GNSS Toolbox V6.0 of IfE* and *RTKLib 2.4.2* (Figure 3 shows results from the first three packages).
- Additionally, Bernese processing with weighted ($cos\,\theta$) and equally weighted ($\mathbf{P} = \mathbf{I}$) observations and different tropospheric mapping functions to study these impacts in detail.

Homogeneity - Sky Distribution



(a) 1-wire helix (b) 4-wire helix (A=0.5 cm) (c) 4-wire helix (A=2.0 cm)

(d) Elevation of 1-wire helix (e) Elevation of 4-wire helix (A=0.5 cm) (f) Elevation of 4-wire helix (A=2.0 cm)

Figure 2: Same satellite sky distribution for different generic patterns show individual satellite paths in patterns (a-c) as well as different corresponding corrections versus elevation (d-f).

Discussion - Impact of Simple Generic Patterns

Turnstile (a) and Micro Strip (b) w.r.t. Figure 3

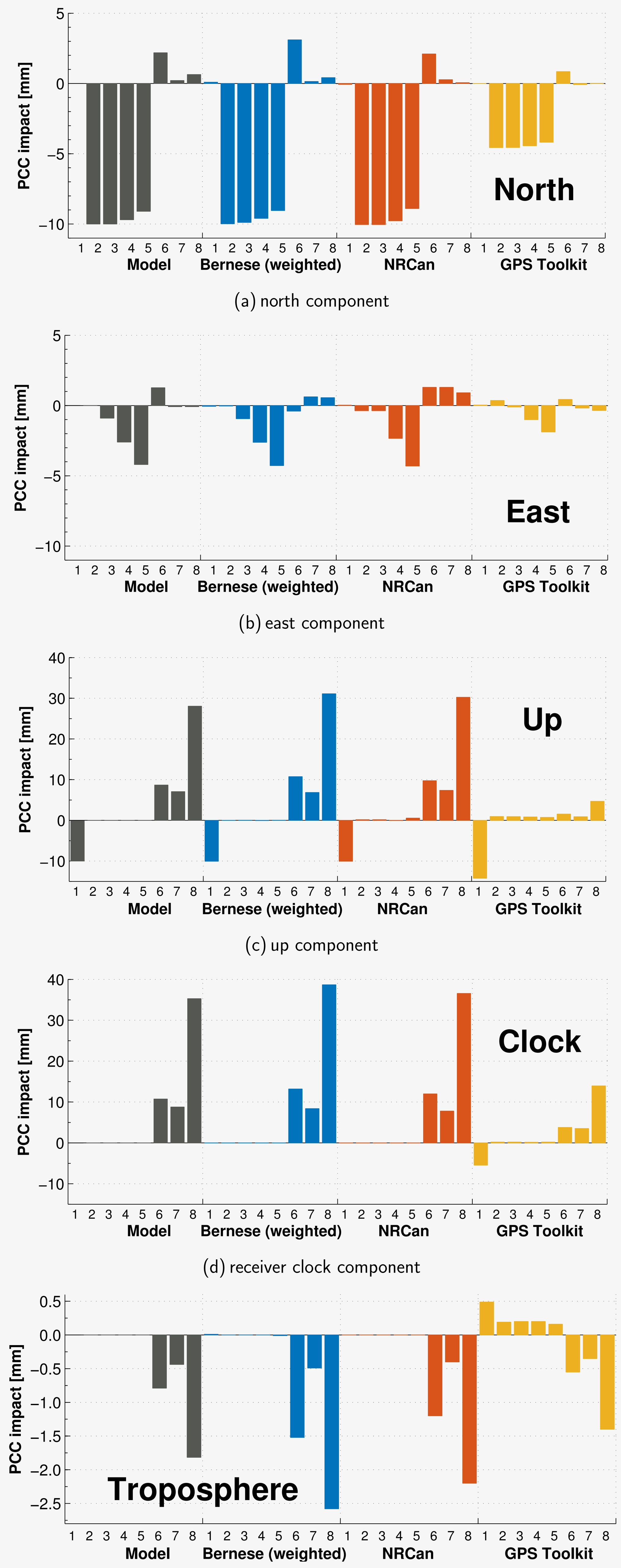
- *Turnstile (a)* (bar 1) only affects the height wheraat *Micro Strip (b)* (bars 2-5) affects the horizontal component only and magnitude in the position equals the amplitude in observation domain.
- All software packages (except GPS Toolkit) agree on sub-mm level w.r.t. to the suggested model.
- Observation weighting shows no impact.

Discussion - Impact of Complex Patterns

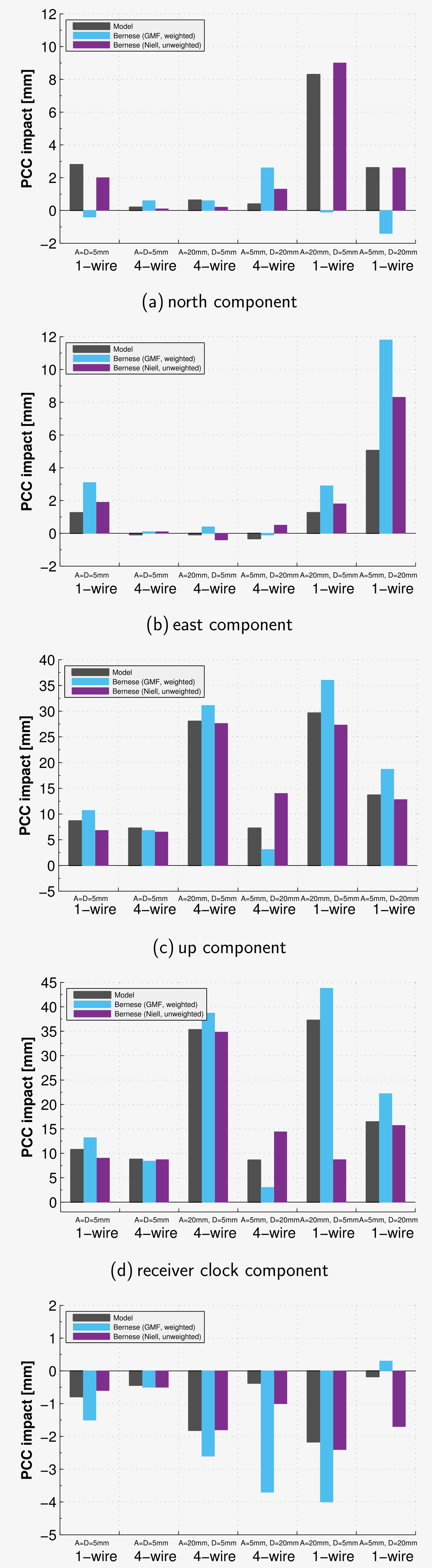
1-wire helix (c) and 4-wire helix (d) w.r.t. Figure 3 and Figure 4

- The patterns of *1-wire helix (c)* and *4-wire helix (d)* affect all parameters (Figure 3, bar 6-8).
- Different software solutions vary at mm-level, but are considerably below the PPP accuracy.
- Elevation weighting increases the magnitude of parameter variations as well as the impact of asymmetries in the satellite sky distribution, for details refer to Figure 4.
- Different patterns change float ambiguities significantly, (not shown here).
- Mean receiver clock parameter mostly affected by variations of up to 39 mm.
- Impact of generic patterns on Up and Clock parameter can reach amplitudes larger than introduced by the pattern itself (e.g.: 10 mm for P3 and P4, 25 mm for P5).

Discussion - Impact of Generic Patterns on Position Domain



(a) north component (b) east component (c) up component (d) receiver clock component (e) troposphere component



(a) north component (b) east component (c) up component (d) receiver clock component (e) troposphere component

Figure 3: Differences between solutions obtained with different software packages. How to read the bars from left to right: (1) *Turnstile*, (2-5) *Micro Strip with orientations a_0 from 0° to 30°*, (6) *1-wire helix*; (7) *4-wire helix*; (8) *4-wire helix with higher amplitude*.

Figure 4: Further exemplary studies with Bernese and 1-wire/4-wire generic patterns with GMF Model and weighted as well as unweighted observations with Niell are shown.

Conclusions - Further Steps

- The theoretical model gives valuable and qualitative information on the impact of PCC pattern on the estimated parameters.
- Overall behavior is predicted very well. However, obtained values are smaller than from observations.
- Study and analyze all estimated parameters; including: *clock*, *troposphere* as well as *ambiguities*.
- Improvements are needed for quantitative comparisons like e.g.:
  - improved model for ambiguity terms (geometrical conditions, initial ambiguity term, Figure 2).
  - extended modeling of the satellite sky distribution (e.g. extended probability density function).

Acknowledgment

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References

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