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On adequate Comparisons of Antenna Phase Center Variations

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Introduction

Currently, 5 calibration institutions including the Institut für Erdmessung (IfE) contribute to the IGS ANTEX. Different approaches like field calibrations and anechoic chamber measurements are in use, thus **an adequate comparison concept** is necessary.

In this contribution we name PCC the phase center correction which is traditionally given by the 3×1 phase center offset (**PCO**) vector and the gridded phase center variations (PCV) expressed in an antenna body frame

$$PCC(\phi,\,\theta) = -\mathbf{s}^T\mathbf{PCO} + PCV(\phi,\,\theta) + r, \tag{1}$$

with ϕ, θ the horizontal and vertical angle in the antenna body frame, $\mathbf{s}$ the line-of-sight unit vector, r is a constant offset that cannot be determined. The PCV are generally estimated by spherical harmonics (SH) of polynomials and then gridded.

Issues of PCC determination

1) The determination of PCC has one degree of freedom The problem is rank deficient of one, cf. parameter r in Eq.(1). Neither chamber nor robot calibration in the field can determine *absolute* PCC. In fact, in the network analyzer the overall delay is not known at the ps level. Since GNSS are one-way ranging systems, by definition only pseudo-ranges and not absolute ranges can be determined in the field. Constant parts are thus absorbed by receiver clock offset and float ambiguities or eliminated by forming single or time differences.

Consequently, during the PCC determination, this **one degree of freedom must be fixed by minimum constraints**. Typical examples are $PCV(\phi, 90) = 0$, or $PCV(\phi, 0) = 0$ or $\int_{\theta_1}^{\theta_2} PCV(\phi,\theta)d\phi d\theta = 0$. As a result, **only the shape of the pattern can be determined** but arbitrary and constant values can be added to all PCV, cf. Fig. 1 (2). Note:

- Applying more than minimum constraints will deform the pattern.
- Degrees-of-freedoms in the multi-frequency or multi-GNSS cases to be checked carefully.

2) PCC parametrization and 3) PCO separation is numerically difficult In general, a spherical harmonics expansion or a polynomial fit is used for the determination of the PCC. However, only data in a hemisphere or slightly more is given which leads to strong correlations between the PCC coefficients and a weak determination, [Kersten and Schön, 2010]. Consequently, various stabilization strategies are used: additional constraints, normal equation regularization, process noise for KF approaches or multi-step-strategy. Only few information are publicly available how the calibration institutions solve this issues. However, these processing options influences the obtained patterns.

4) Consistent set of PCO and PCV is essential Traditionally, PCC are separated somehow arbitrarily and a PCO and PCV, published in the ANTEX format. As reported by (e.g. [Rothacher et al., 1995], [Menge, 2003]) PCO and PCV can be transformed in a consistent way:

$$PCC(\phi,\,\theta) = \mathbf{s}^T\mathbf{PCO_1} + PCV_1(\phi,\,\theta) + r_1, \tag{2}$$

$$= \mathbf{s}^T\mathbf{PCO_2} + \underbrace{PCV_1(\phi,\,\theta) + \mathbf{s}^T(\mathbf{PCO_1} - \mathbf{PCO_2})}_{} + r_2 \tag{3}$$

$$= \mathbf{s}^T\mathbf{PCO_2} + PCV_2(\phi,\,\theta) + r_2, \tag{4}$$

if the same datum is required $r_2 = r_1 - \Delta h$ (5).

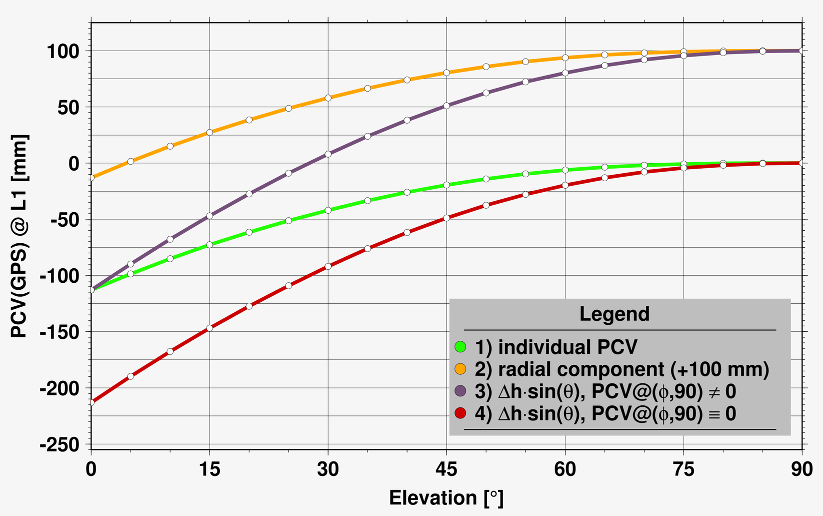


Figure 1: Allowed PCV transformations illustrated for the elevation dependent pattern.

Allowed PCV transformations illustrated for the elevation dependent pattern:

1. Original pattern.
2. Variation of the offset r, cf. Eq. (3).
3. Change of the offset, Eq. (3-4).
4. Transforming (3) to original datum ($PCV(\phi, 90^\circ) = 0$)

Proposal for a comparison strategy

1. The PCV and PCO should be considered together in a consistent way, cf. Eq. (1).
2. The PCC of each antenna to be compared should be transformed on an arbitrarily chosen, but common PCO using Eq. (3).
3. The rank defect of the PCC should be removed in a identical way, e.g. by applying $PCV(\phi, 90) = 0$. However this is only allowed if the original patterns have minimum constraint datum.
4. The resulting PCV can be compared e.g. by forming difference patterns (ΔPCV).
5. Since the comparison in the observation domain may be misleading (see below) also **the impact on all estimated parameters** should be analyzed, i.e. on coordinates, clock errors, tropospheric parameters and ambiguities.

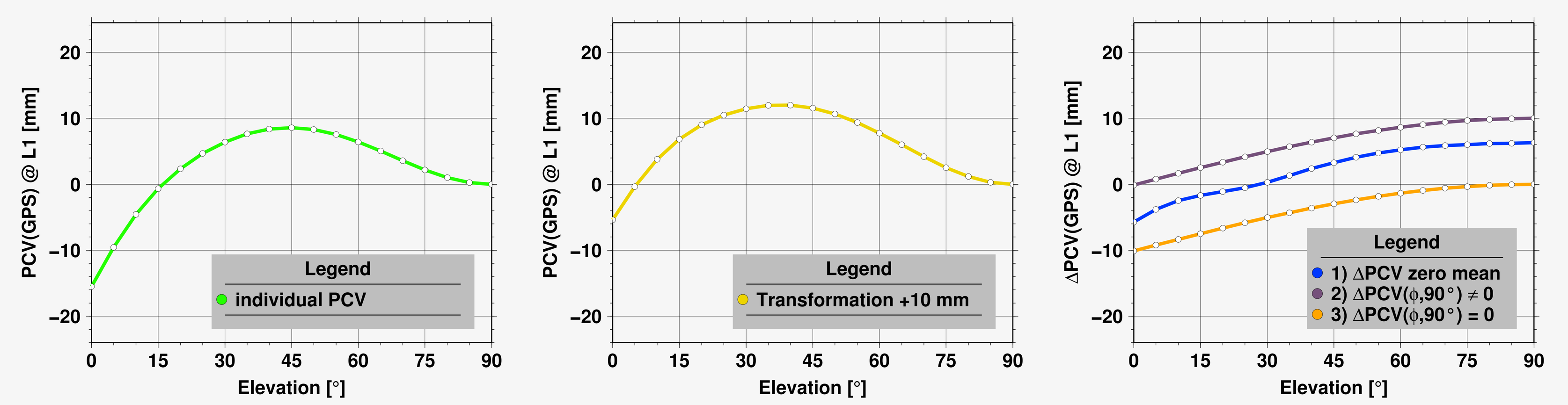
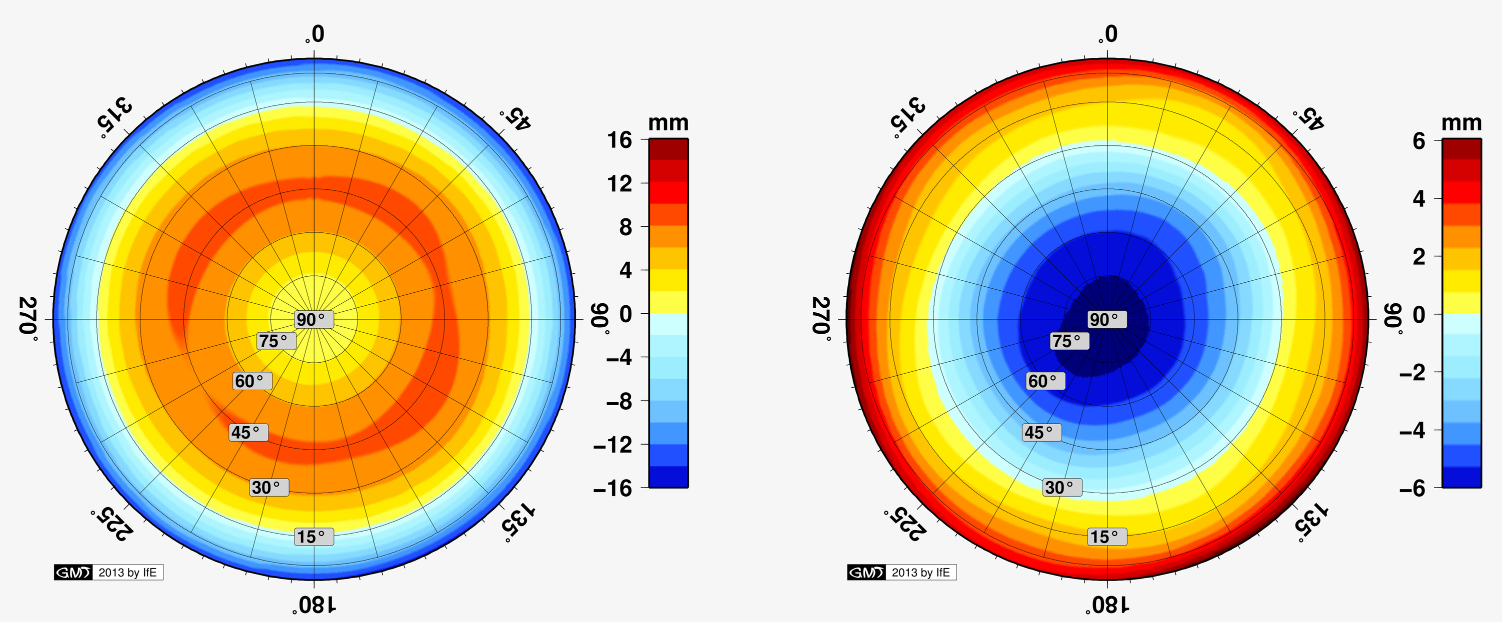


Figure 2: Examples for PCV patterns of a LEIAT504GG NONE antenna in (a-b) and difference pattern (c) with allowed transformations (i.e. (1): zero mean datum, (2): common but arbitrary offset in zenith and (3): datum zenith $\equiv 0$).

Discussion observation domain

- Since PCV are rank deficient (issue 1), also differences of PCV (ΔPCV) are rank deficient.
- Thus, only the form of PCV and ΔPCV pattern can be determined and discussed. Consequently, it is not possible to associate in a unique way a PCV value to a specific elevation, cf. Fig. 1.
- Thresholds for maximum allowed differences between PCV from different calibration institutions or repeated calibrations should be reviewed, taking the datum dependency into account.
- Numerical values should be based on datum independent measures. We propose:
  - the spread $PCV_{max} - PCV_{min}$
  - the RMS of the pattern in zero mean datum which equal the standard deviation of the pattern.
- The impact of PCV variations on the estimated parameters is difficult to assess in general. We propose to analyze the impact of generic ΔPCV patterns, cf. [Geiger, 1988]. In fact, any arbitrary PCV or ΔPCV pattern can be decomposed in generic patterns, cf. next section.

Typical PCV and ΔPCV patterns



(a) original PCV (b) ΔPCV (zero mean datum)

Figure 3: Typical PCV pattern for LEIAT504GG NONE (a) and ΔPCV Pattern with zero mean date (b).

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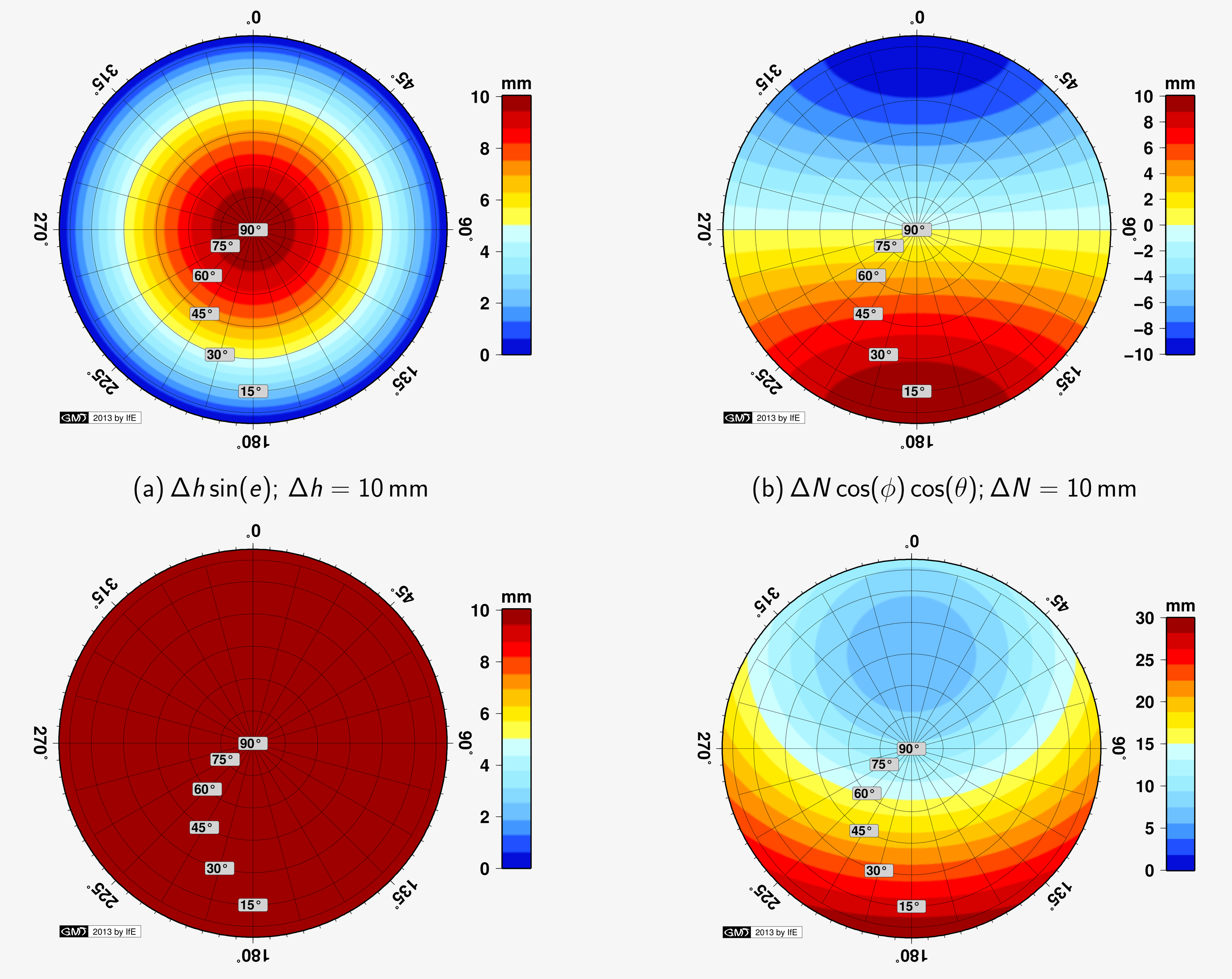
Example of generic PCV patterns



(a) $\Delta h \sin(e)$; $\Delta h = 10$ mm (b) $\Delta N \cos(\phi)\cos(\theta)$; $\Delta N = 10$ mm

(c) $\Delta r = 10$ mm (d) all together

Figure 4: Examples of generic PCV patterns (a) height offset (b) North offset (c) radial offset (d) summation..

Discussion parameter domain - impact of generic PCV patterns

The impact on the parameter domain depends on the GNSS analysis strategy proposed. Here, first results from 24h PPP are shown. For further studies cf. e.g. [Dilßner, 2007], [Menge, 2003] and [Geiger, 1988]. Cross-coupling between parameters is due to the high mathematical correlations and the non-symmetry of the satellite distribution.

PCV pattern / impact	North	East	Up	Clock	Troposphere	Ambiguity
$\Delta\sin(\theta)$	-	-	Δ	$\approx 0.13\Delta$	-	-
$\Delta\cos(\phi-\phi_0)\cos(\theta)$	$\Delta\cos(\phi_0)$	$-\Delta\sin(\phi_0)$	-	$\approx 0.1\Delta$	-	-
Δ	-	-	-	$\approx\Delta$	-	or $\approx\Delta$

Conclusion and Outlook

- The main issues of PCC determination are highlighted
- Subsequently, a comparison strategy is proposed, taking the one degree of freedom in the PCC into account
- Generic PCV patterns are proposed to asses the impact on the parameters
- Due to the high mathematical correlation in the GNSS adjustment, the impact on all parameters must be considered.

Further work will focus on

- Extension of the generic patterns to higher order ($\sin(2\theta), \ldots; \cos(2\phi), \ldots$)
- Consideration of multi-frequency, multi-GNSS cases
- Impact of different analysis concepts and parametrization (PPP or relative positioning, static or kinematic)

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