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Comparing antenna phase center corrections: challenges, concepts and perspectives

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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.
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

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

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 and that defines the datum. The PCV are generally estimated by spherical harmonics (SH) or polynomials and then gridded.

Challenges of PCC determination

1) The determination of PCC has one degree of freedom, i.e. r in Eq.(1) 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:
zero zenith: $PCV(\phi, 90) = 0$,
zero mean: $\int_{\theta_1}^{\theta_2} PCV(\phi,\theta)d\phi d\theta = 0$.
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 for multi-frequency /multi-GNSS have 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 these issues. However, these processing options influence the obtained patterns.

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

$$PCC(\phi,\,\theta) = \mathbf{s}^T\mathbf{PCO_1} + PCV_1(\phi,\,\theta) + r_1, \qquad (2)$$
$$= \mathbf{s}^T\mathbf{PCO_2} + \underline{PCV_1(\phi,\,\theta) + \mathbf{s}^T(\mathbf{PCO_1} - \mathbf{PCO_2})} + r_2 \qquad (3)$$
$$= \mathbf{s}^T\mathbf{PCO_2} + \qquad PCV_2(\phi,\,\theta) + r_2, \qquad (4)$$

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

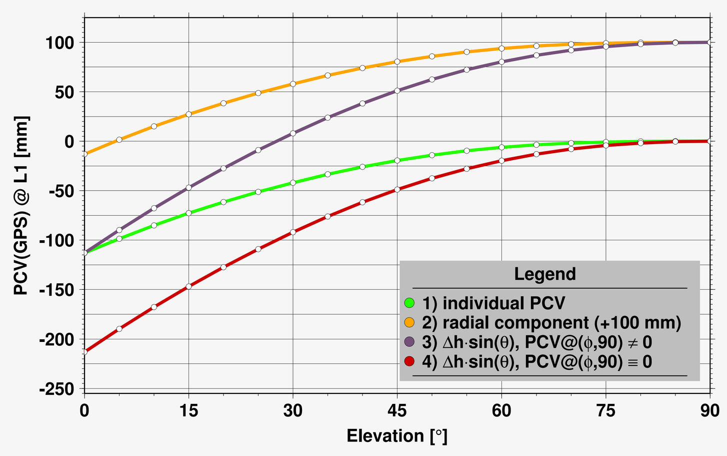


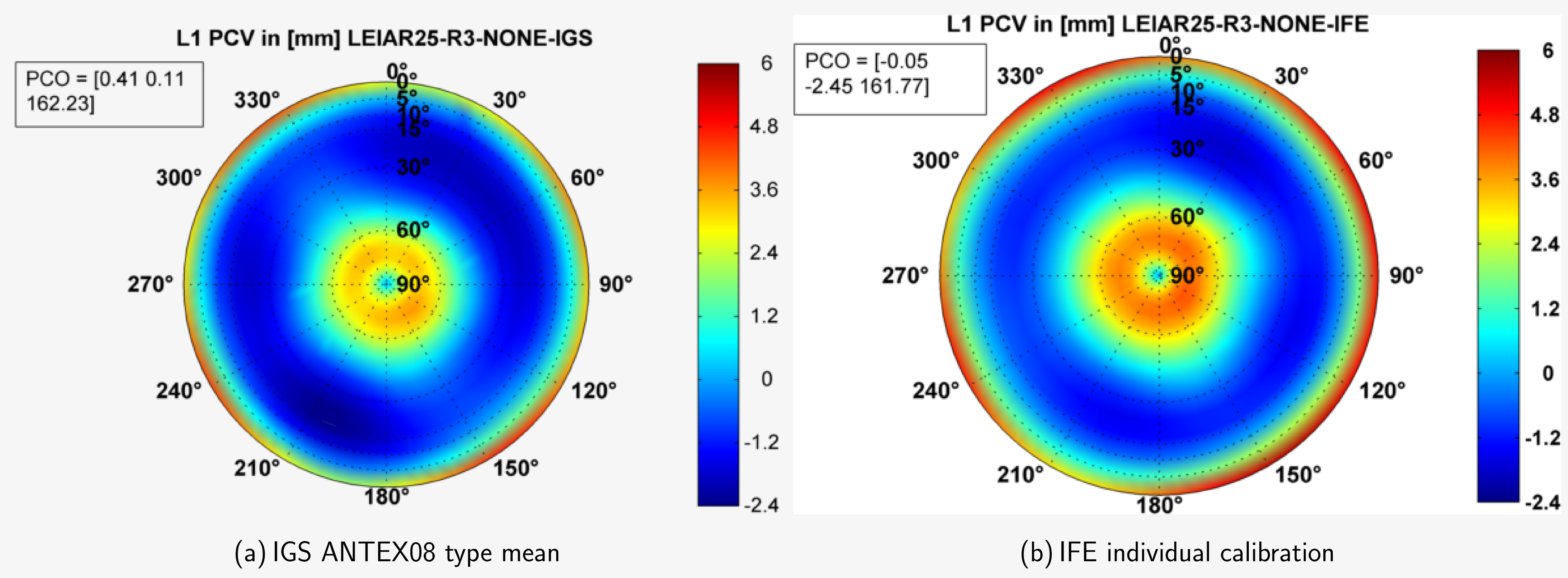
Figure 1 : Allowed PCV transformations

Allowed PCV transformations illustrated for the elevation dependent pattern:

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

Concepts for PCC comparisons

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 solved 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.



(a) IGS ANTEX08 type mean (b) IFE individual calibration

Figure 2 : Exemplary phase center corrections of a AR25.R3 antenna transferred to common PCO of IGS

References

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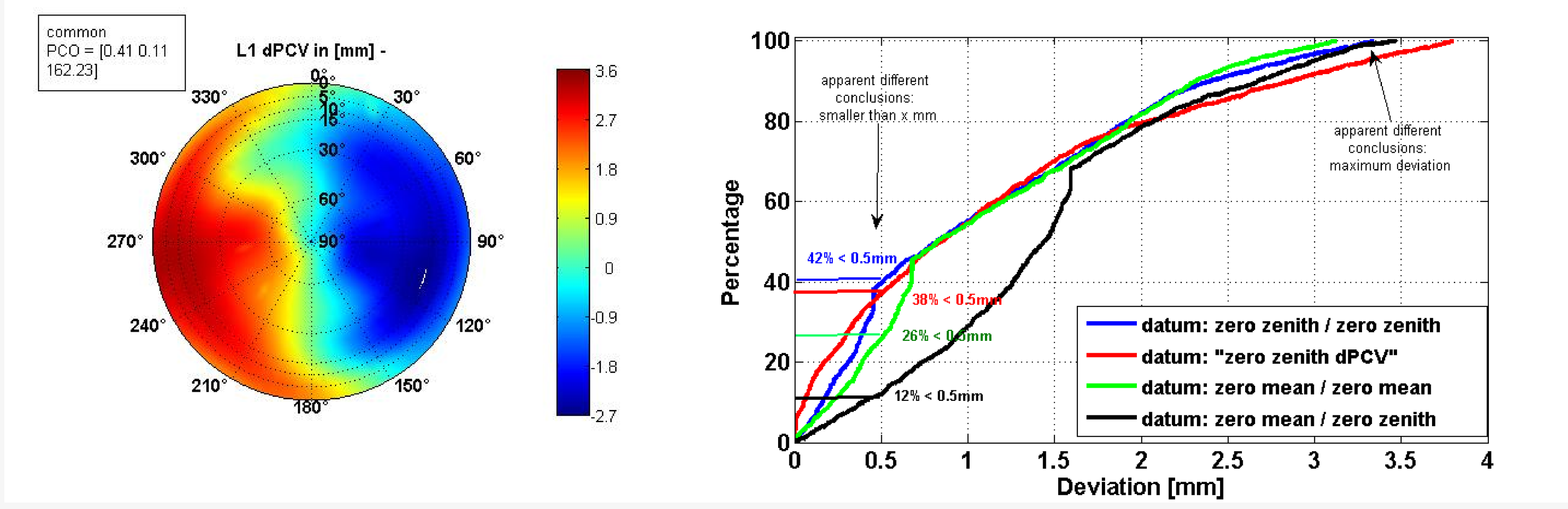
Concepts for a comparison strategy - Observation domain



(a) L1 dPCC in mm (b) cumulative percentage of deviation for different datum

Figure 3 : Comparison of the patterns from Fig.2 underlining the datum dependency

- **Only the form of PCC and dPCC pattern can be determined and discussed**.
  - Consequently, it is not possible to associate in a unique way a PCC value to a specific elevation and azimuth, cf. Fig. 1 and Fig. 3.
  - Thresholds for maximum allowed differences between PCC 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** $dPCC_{max} - dPCC_{min}$ which quantify the maximum deviation between the patterns, cf. Tab. 1 for example values of Fig. 3.
  - the **RMS** of the pattern in zero mean datum which quantify the overall agreement between two patterns.
    Please note: the zero mean datum yields minimum RMS of all datum realizations.

Datum definition	RMS [mm]	spread [mm]
zero zenith / zero zenith	1.40	5.68
"zero zenith dPCV"	1.54	5.68
zero mean / zero mean	1.38	5.68
zero mean / zero zenith	1.65	5.68

Table 1 : scalar quantities

Example of generic PCV patterns

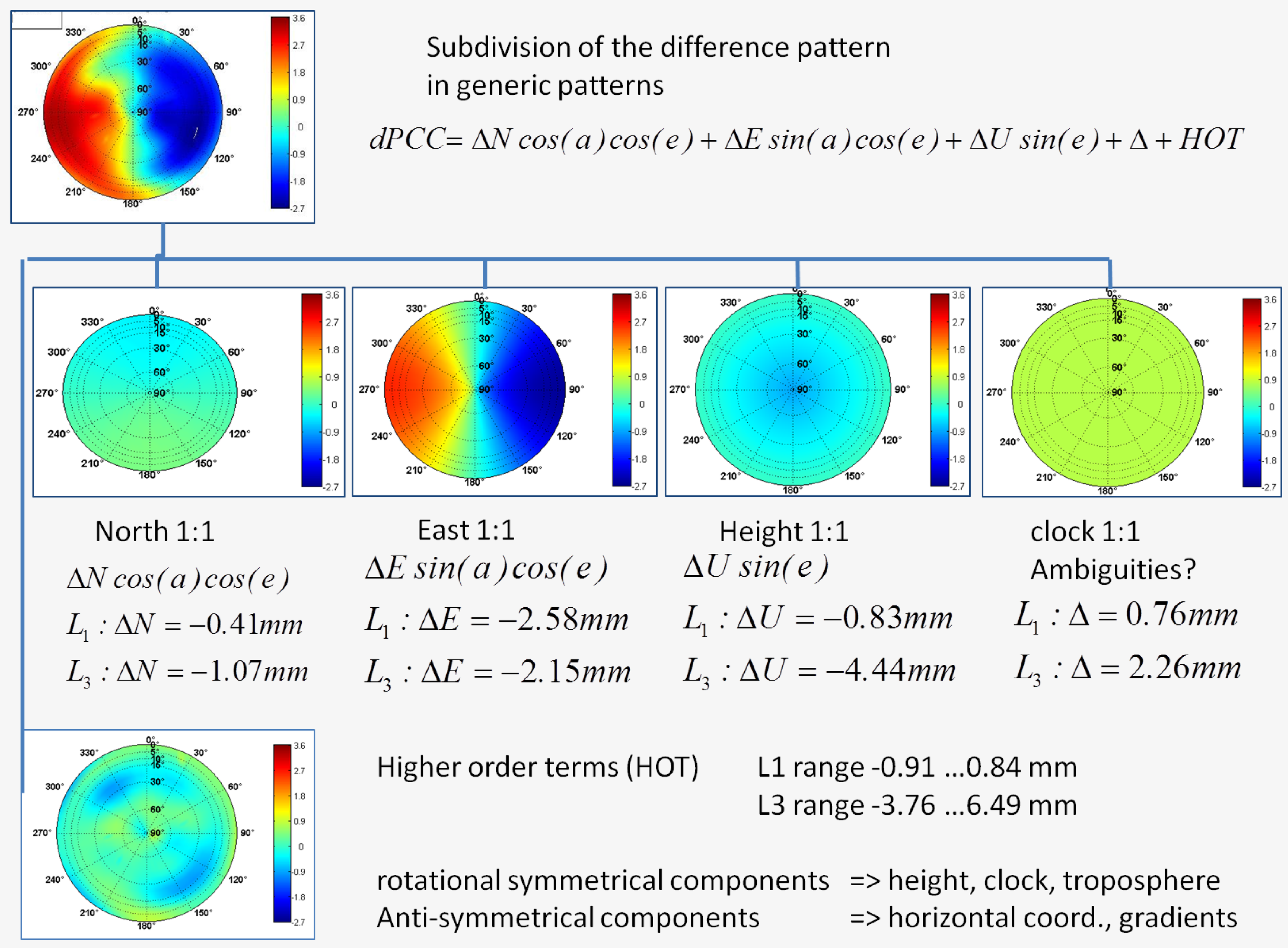
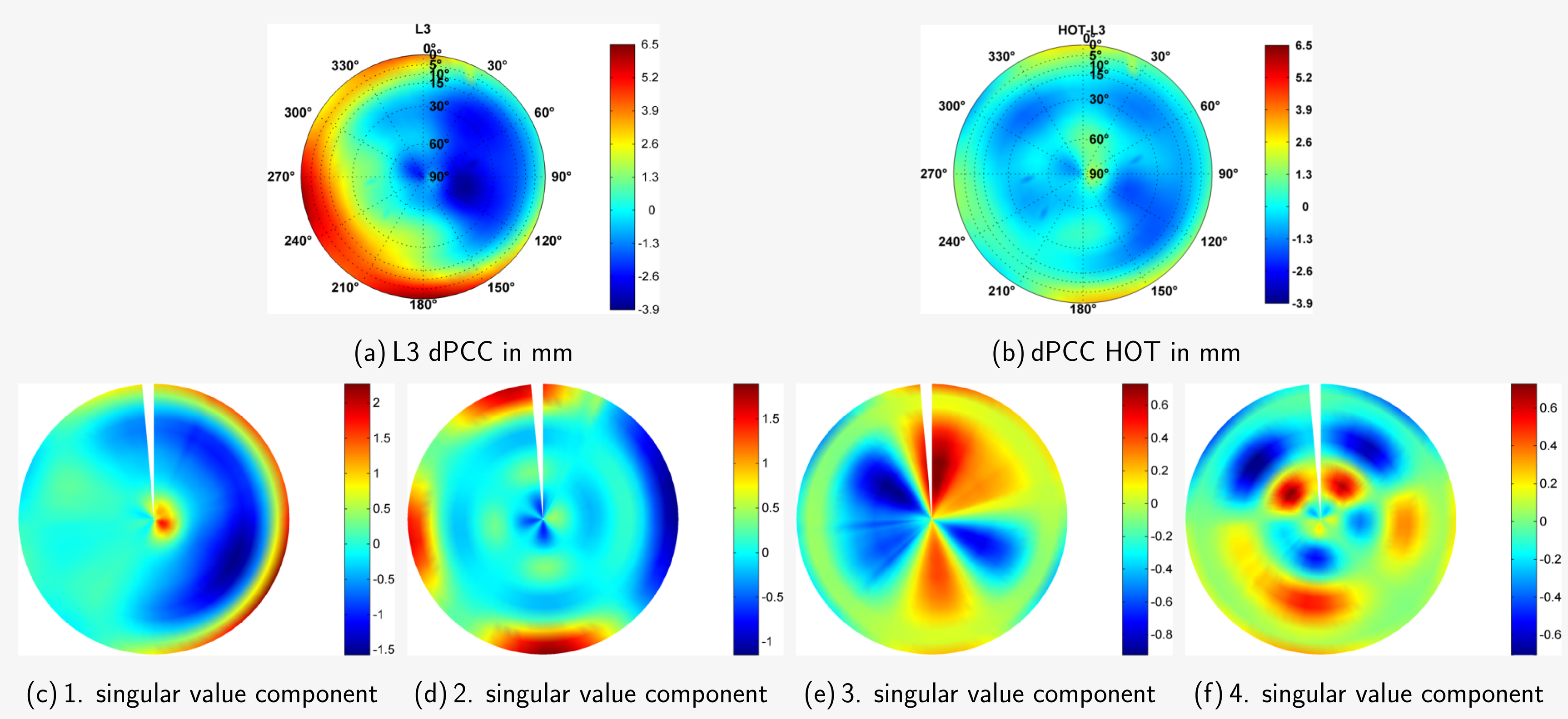


Figure 4 : Examples of dPCC subdivision in generic PCC patterns in order to assess the impact on the parameters, [Geiger, 1988]



(a) L3 dPCC in mm (b) dPCC HOT in mm
(c) 1. singular value component (d) 2. singular value component (e) 3. singular value component (f) 4. singular value component

Figure 5 : Comparison of the AR25.R3 L3 patterns IFE individual - IGS type mean, Subdivision of the HOT by singular value decomposition

Conclusion and Perspectives

- 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.

Current investigations 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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