Station calibration in the SWEPOS® GNSS network

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While the performance of positioning services are improved to the benefit of the users, with uncertainties from densified Network RTK networks for construction work approaching the sub-centimetre level also in the vertical, the error sources related to the permanent reference stations (CORS) may soon be limiting factors for further improvement of performance.

Station dependent effects are thus important and limiting factors in high accuracy GNSS positioning. Electrical coupling between the antenna and its near-field environment changes the characteristics of the antenna from what has been determined in e.g. absolute robot or chamber calibration.

Since the initial tests back in 2008, Lantmäteriet together with Chalmers Technical University and SP Technical Research Institute of Sweden has carried out station calibration, in-situ calibration, of its network of permanent reference stations, SWEPOS®. The station calibration intends to determine the electrical centre of the GNSS antenna, as well as the PCV (phase centre variations) when the antenna is installed at a SWEPOS station. One purpose of the calibration is to examine the site-dependent effects on the height determination in SWEREF 99 (the national reference frame). Another purpose is to establish a PCV as a complement to absolute calibrations of the antenna-radome pair.

Figure 1: Station calibration at the SWEPOS site Vänersborg. Photo: Kent Ohlsson, 2015.

Method and principles for the field calibration

- The physical height difference between the monument, and the antennas on tripods are determined using terrestrial methods
- Three reference antennas on tripods allow for gross error detection and some noise reduction
- Five days of continuous observations
- Microwave absorbing material at the reference antennas reduces the effect from multipath (but questionable?)
- Phase residuals in the baseline between the reference antenna on tripod and the CORS are considered to be caused by limitations in the CORS installation
- The concrete pillar monument from 1993, as well as the truss mast monument from 2012 are considered

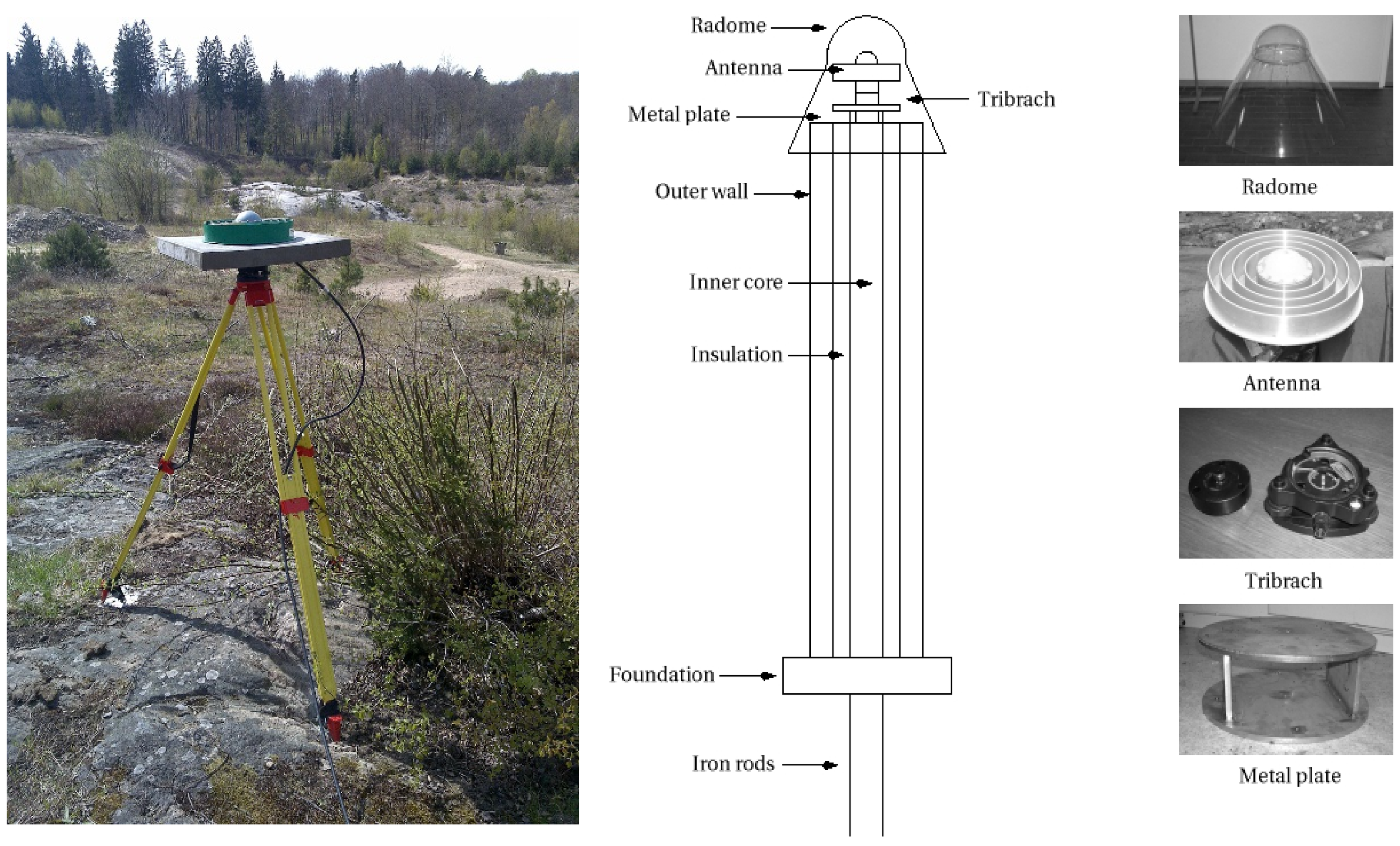

Figure 2: *Left:* The field calibration setup. *Right:* Structure of a concrete pillar foundation in SWEPOS, designed in 1992. The pillar height is ~ 3 m, and is anchored onto crystalline rock. Note the relatively large metal plate used as foundation for the tribrach.

Results – field calibration of nine SWEPOS pillar stations (2009, 2010)

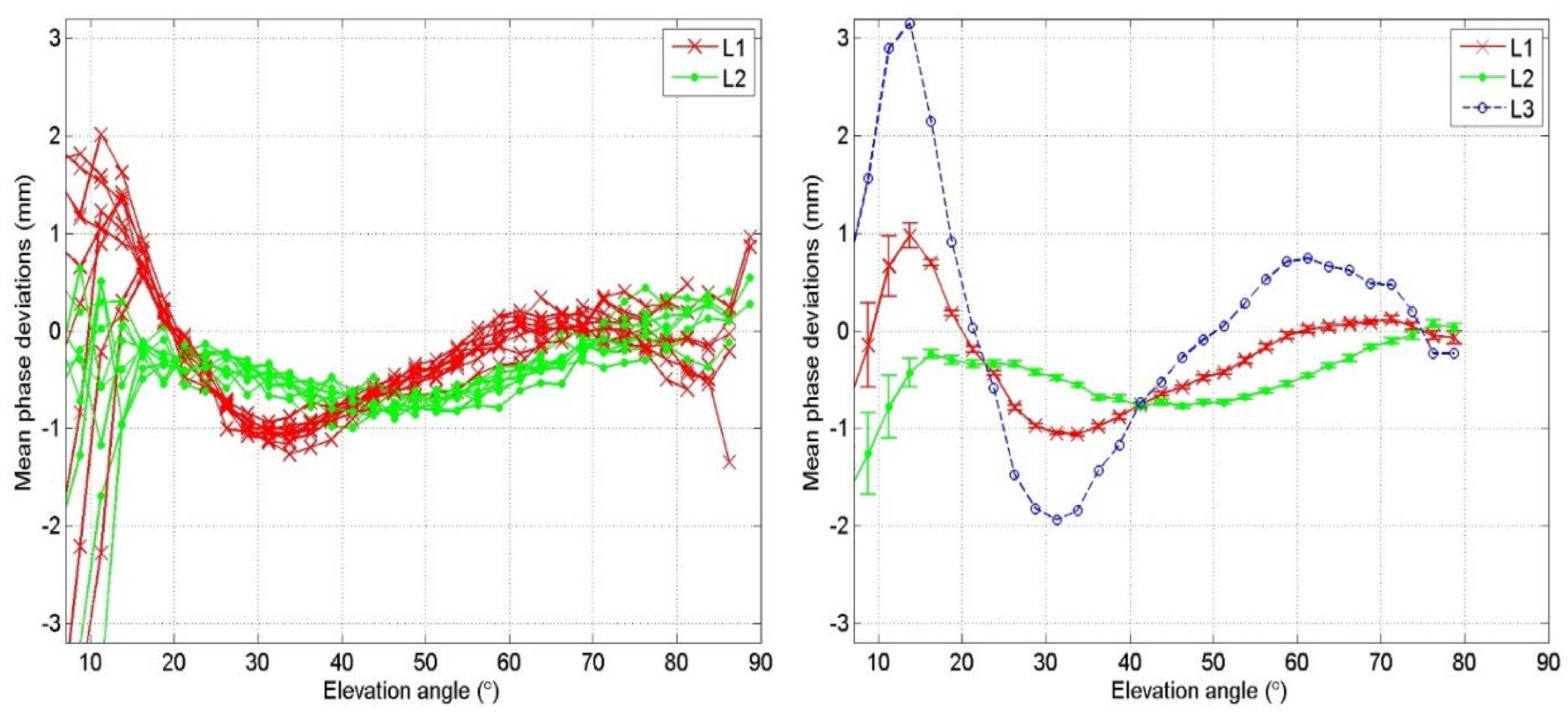

Figure 3. *Left*: Phase deviations of the nine SWEPOS stations investigated. The deviations are formed by sorting the residuals into 2.5° bins and calculate the mean value for each bin. *Right*: Mean of the phase deviations for the nine SWEPOS stations for L1 and L2 based on the data of the graph to the left. An L3 curve (forming the ionosphere free linear combination of L1 and L2 observations) is also included, generated as an "ionosphere free" linear combination of the L1 and L2 curves. Notice the significantly larger amplitude of the L3 curve.

Apply "monument specific" PCV and PCO model and compare

Table 1: Estimated vertical phase center offset (PCO) using original and updated PCO/PCV description file.

Station	Original antenna model		Updated antenna model	
	L1 vertical offset (mm)	L2 vertical offset (mm)	L1 vertical offset (mm)	L2 vertical offset (mm)
Östersund	2.6	3.2	2.2	1.9
Sundsvall	-0.3	0.4	-0.8	-0.9
Leksand	1.5	3.3	0.2	1.4
Karlstad	1.1	1.0	0.7	-0.3
Vänersborg	-0.3	0.9	-0.7	-0.3
Norrköping	-0.3	1.6	-0.7	0.4
Jönköping	-0.6	0.6	-1.0	-0.6
Oskarshamn	0.8	1.8	0.5	0.6
Hässleholm	-0.7	0.4	-1.0	-0.8
Mean	**0.4**	**1.5**	**-0.1**	**0.2**
Std	**1.1**	**1.1**	**1.1**	**1.0**

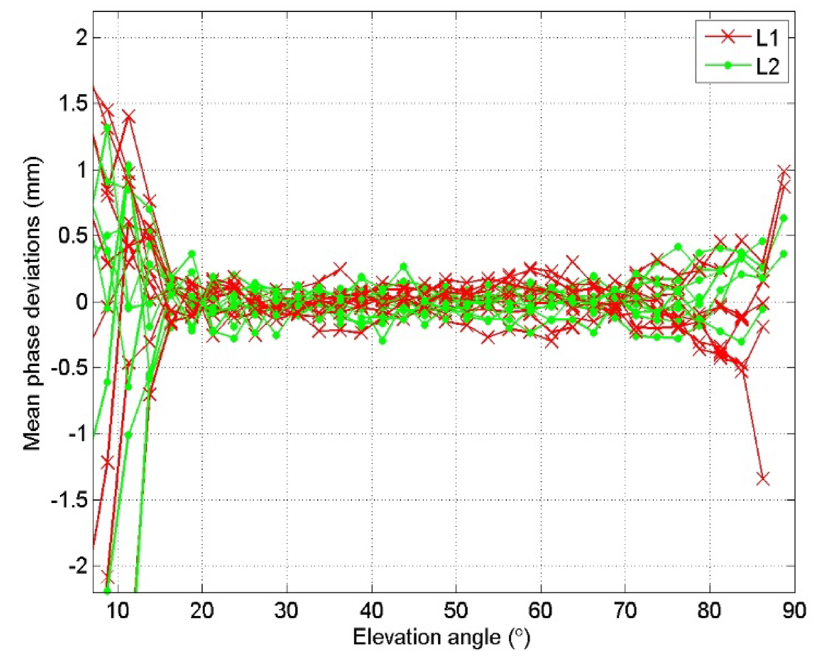

Figure 4: Phase deviations of the nine SWEPOS stations investigated when using the updated PCO/PCV description file for SWEPOS antennas (cf. Figure 3).

Effects when also solving for troposphere

Table 2: Estimated vertical offsets and atmospheric delay difference when using L3 observables with original and updated PCO/PCV description file.
Note the vertical offset at the 1 cm level (-12.1 mm) when using the original antenna model. This is from comparing height difference between the visiting antennas on tripods and the antenna installed on the SWEPOS pillar determined using GPS and terrestrial methods respectively. Explanation is that limitations in the used PCV model are amplified through the mapping function when solving also for tropospheric delay.

Station	Original antenna Model		Updated antenna model	
	Vertical offset (mm)	Atmospheric delay offset (mm)	Vertical offset (mm)	Atmospheric delay offset (mm)
Östersund	-10.4	3.6	2.4	0.1
Sundsvall	-13.6	3.5	-1.4	0.2
Leksand	-9.2	2.4	-1.4	-0.1
Karlstad	-7.0	2.4	4.7	-0.8
Vänersborg	-13.6	3.5	-2.1	0.4
Norrköping	-14.1	3.1	-2.6	0.0
Jönköping	-15.7	4.0	-4.2	0.8
Oskarshamn	-12.3	3.5	-0.8	0.3
Hässleholm	-13.0	3.2	-1.5	0.1
Mean	**-12.1**	**3.2**	**-0.8**	**0.1**
Std	**2.6**	**0.5**	**2.5**	**0.4**

New monuments with LEIAR25.R3 + LEIT installed in 2011

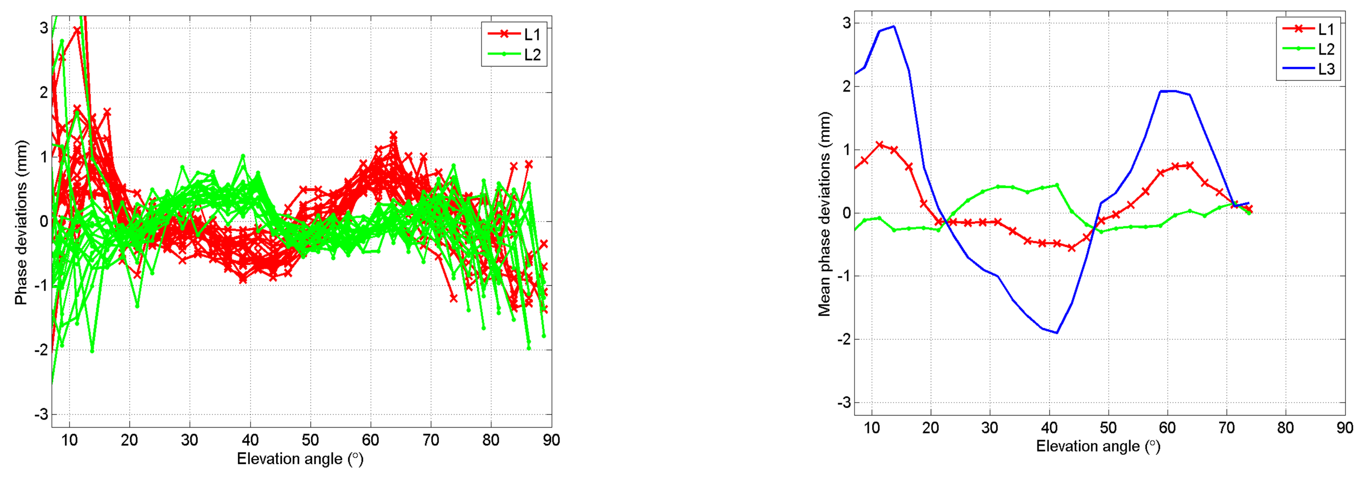

Figure 5: The 19 steel grid masts calibrated using the pillar monuments with the derived PCV/PCO model as reference. *Left*: Phase residuals at the LEIAR25.R3 + LEIT at the new mast monument calibrated relative to the pillar. *Right*: Mean of phase residuals in L1 and L2 from the graph to the left. Also an L3 curve has been included, generated as an "ionosphere free" linear combination of the L1 and L2 curves, in the same way as in Figure 3 (right). Vertical offset from simulated L3t solution: **Mean: -11.5 mm, Std: 5.0 mm (19 sites)**

Checking the models from re-calibration at six sites in 2015

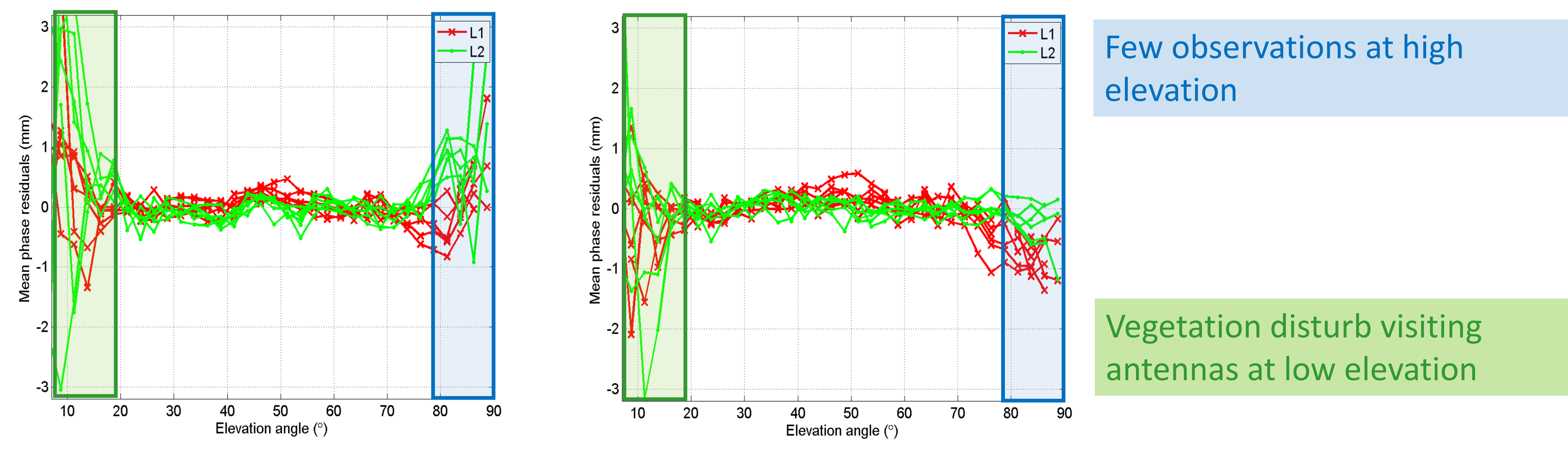

Figure 6: Applying the PCV/PCO models developed in Figure 3 and Figure 5 while analyzing data from a new station calibration campaign at 6 sites in 2015. *Left*: Pillar monuments. Vertical offset in **L3t; Mean:2.3 mm, Std: 3.5 mm.** *Right*: mast monuments. Vertical offset in **L3t**; **Mean: 1.5 mm, Std: 6.9 mm.**

Discussion and summary

- Our real-time users asks for sub-cm uncertainty also in height
- Station dependent effects at CORS is a limiting error source for future developments of GNSS applications
- Individual antenna calibration is not sufficient (PCV/PCO changes when installed on a monument)
- On-site station calibration of GNSS CORS is feasible and the results are presented here
- Microwave absorbing material at the reference antennas reduces the effect from multipath, but needs to be further studied
- Disturbance from vegetation at the visiting antennas is a "growing" problem.
- Lots of details to improve and to develop further

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