Antenna phase centre calibration effects on sub-daily and daily position estimates

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Abstract

In recent years, the number of absolutely calibrated GNSS antenna/radome combinations used within the global IGS network and other networks, for example, the EUREF Permanent Network (EPN), has increased considerably. Due to a number of reasons, including the fact that the individual calibrations for an antenna/radome combination show fairly consistent phase centre offsets and variations across all combinations of the same type of antenna and radome, the geodetic community currently employs averaged ("type mean") rather than individual calibrations in high-accuracy GNSS data processing. As the individual calibrations for a specific antenna/radome combination do deviate from the type mean calibration, it needs to be investigated, if the use of individual rather than type mean calibrations could provide a significant improvement for geodetic and geophysical applications.

In this study we investigate the effect of using type mean and individual antenna/radome combination calibrations on the position estimates. We do this by analysis of position differences between precise point positioning (PPP) solutions employing both calibration models. Using four weeks of GPS observations we show that time series of sub-daily position differences contain periodic variations and systematic biases at the millimetre to centimetre levels. Using GPS observations, ranging from one to nine years, we show that for the time series of daily position differences the periodic variations seem less pronounced but the biases remain and are of similar magnitude to those in the sub-daily position differences. In general our preliminary results suggest that both sub-daily and daily position estimates are affected by the differences between the type mean and individual antenna/radome combination calibrations and require further investigation.

Introduction

The electromagnetic centre of a GNSS antenna does not coincide with the physical one, therefore for high precision applications antenna phase centre models are employed. These models include antenna Phase Centre Offset (PCO) and Phase Centre Variations (PCV), which are unique for each individual combination of antenna and radome. While PCO contains a constant part of a model, PCVs accommodate azimuth and elevation delay dependency of an antenna (Figure 1). For brevity a combination of PCO and PCV will be denoted as PCV hereinafter.

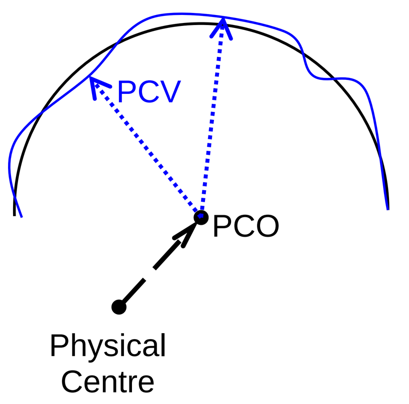

Figure [1] Antenna Phase Centre Offset (PCO) and Phase Centre Variations (PCV)

The geodetic community employs PCVs classified into groups by antenna calibration method: chamber, robot, field, copied and converted [Rothacher and Schmid, 2011]. While the first three groups result from direct calibration of an antenna/radome combination, the copied and converted PCVs are formed with reference to other (known) models. PCVs, as applied by the global GNSS community, are a result of averaging of individual calibrations of the same type of antenna and radome. This suggests that averaged PCVs may introduce additional noise in coordinate time series (CTS) of the same nature, as observed at stations without calibrations.

We have examined 191 stations for antenna/radome calibration, out of which 91 stations form the IGS08 core network and 100 stations are recommended substitutions. Our statistics, presented in Table 1, are based on the most recent SINEX file (igs.snx) and the latest ATX file (igs08_1685.atx), available at ftp://igscb.jpl.nasa.gov/igscb/station/general.

According to these data up to 21% of stations do not have calibrations, although their use is required for the homogeneity of global coverage (Figure 2).

Table [1] Antenna/radome calibration statistics of the IGS core network with suggested substitutions. Absolute number of stations is given in brackets.

Calibration method	Robot	Field	Copied	Converted	No calibration
IGS core network (91 stations)	67% (61)	8% (7)	4% (4)	0% (0)	21% (19)
IGS core network with substitutions (191 stations)	63% (119)	8% (16)	10% (19)	1% (2)	18% (35)

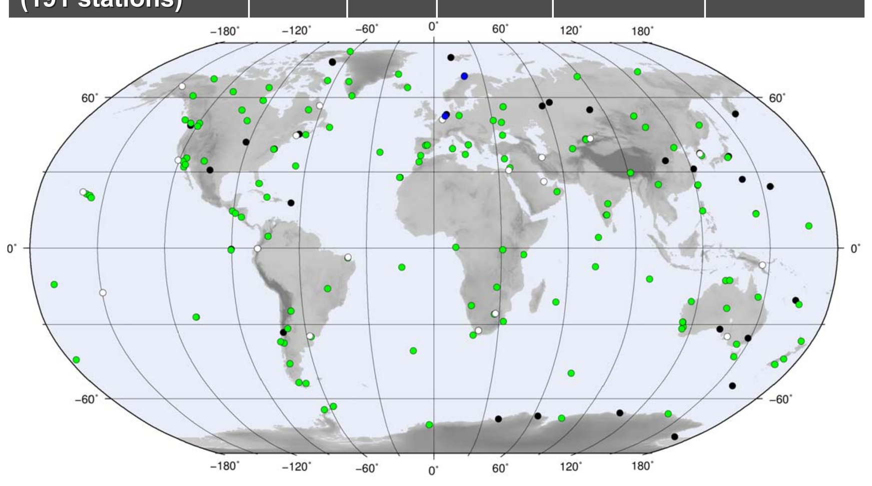

Figure [2] The IGS core network with substitution stations, having absolute antenna/radome calibrations (robot or field) — green, copied calibrations — white, converted — blue and no calibration — black, respectively

In this study we demonstrate the difference in Precise Point Positioning (PPP) solutions obtained using individual and averaged PCVs.

Our research is based on a number of antenna/radome combinations, employed within the IGS network, the EUREF Permanent Network (EPN), and several local networks: Service de Positionnement par Satellites (Satellite Positioning Service of Luxembourg — SPSLux), GeoNet, run by Ordnance Survey of Great Britain (OSGB) and two stations operated by the University of Nottingham (UNOTT). The list of antenna/radome combinations with corresponding network affiliation is presented in Table 2.

Table [2] Antenna/radome combinations, included in daily statistics with corresponding network affiliation.

Antenna/radome combination	Networks	# of examined stations	# of antennas used to produce type mean calibration
AOAD_M/T NONE	EPN, IGS	2	2
LEIAR25 LEIT	GeoNet	11	5
LEIAR25.R3 LEIT	SPSLux	6	5
LEIAR25.R4 LEIT	EPN	1	5
LEIAT504GG LEIS	EPN, IGS	8	78
LEIAT504GG SCIT	UNOTT	2	- (converted)
TPSCR3_GGD CONE	EPN, IGS	7	159
TRM29659.00 NONE	EPN	2	18
TRM29659.00 SNOW	EPN	1	2
TRM41249.00 NONE	EPN	1	42
TRM55971.00 NONE	EPN, IGS	1	58
TRM55971.00 TZGD	EPN	1	8

Our sub-daily results originate from processing four consecutive weeks (GPS weeks 1669-1672) of GPS observation data of the SPSLux network, all six stations of which are equipped with Leica AR25.R3 LEIT antennas. For these stations the kinematic PPP solutions were computed at 15 minutes intervals, which corresponds to the intervals of the IGS final orbit and clock products, employed in processing.

Our daily results are based on processing GPS observation data from 43 stations, having more than 365 daily measurements between 2002 and 2012.

The IGS final products were used throughout this study.

The aim of this study:

To investigate the effect on sub-daily and daily positioning when switching from type mean to individual antenna/radome calibrations.

Methodology

For each of the 43 stations, using the Bernese GPS Software ver. 5.0 [Dach et al. 2007], we performed two parallel PPP runs, keeping all processing options identical, except the antenna/radome calibrations.

Processing stages included:

- a PPP run using the type mean antenna/radome calibration;
- a PPP run using the individual antenna/radome calibration;
- Computation of the difference CTS.

Because all error sources are identical in both PPP runs, differences in the final solutions are only affected by variations in the antenna/radome calibrations.

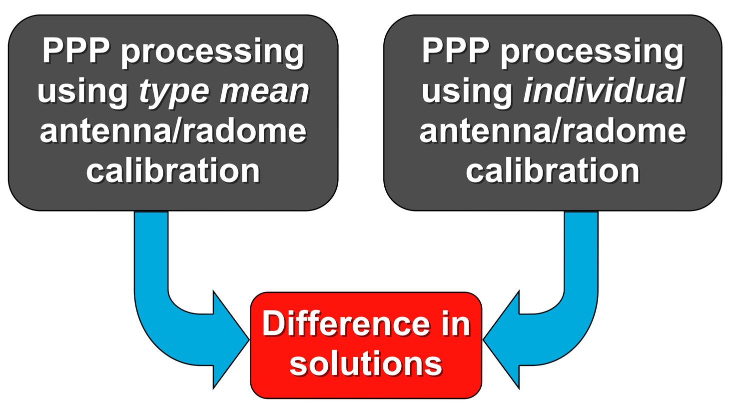

Figure [3] Methodology of this study.

In order to identify periodic signals in daily position differences, we computed a Lomb-Scargle periodogram for each station and then stacked the individual power spectra.

Results—Sub-daily

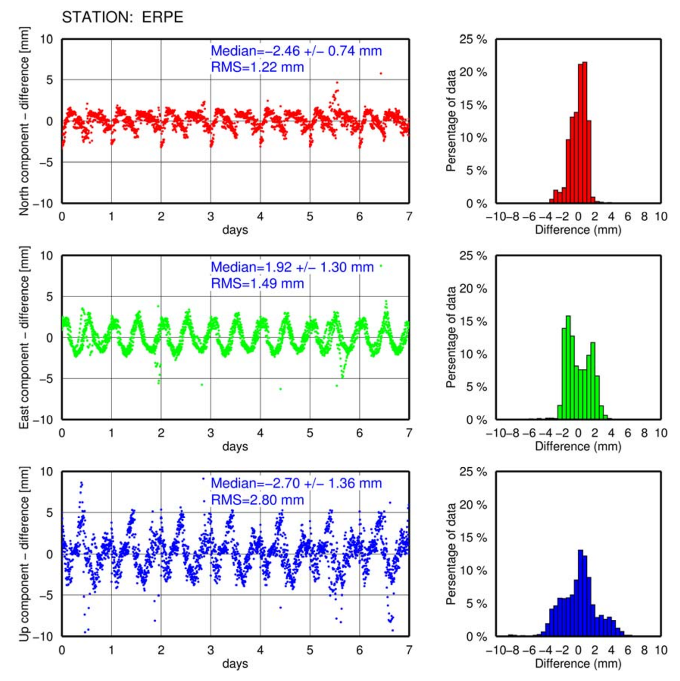

Figure [4] Station ERPE (SPSLux). GPS weeks 1669-1672 stacked over each other. Differences in kinematic 15 minutes PPP solutions, using individual and type mean PCVs, and corresponding histograms for the North (red), East (green) and Up (blue) components.

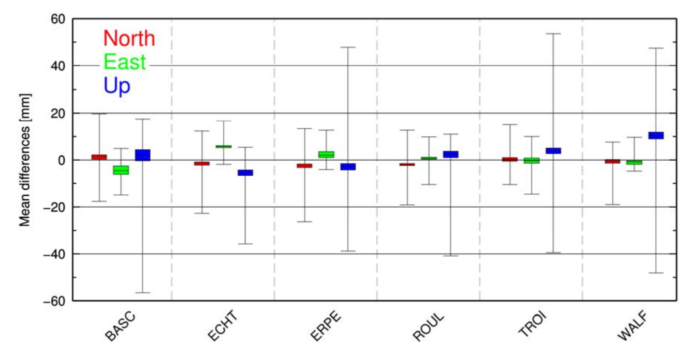

Figure [5] Box-and-Whisker diagrams for the SPSLux network, reflecting the differences in PPP solutions between the individual and type mean PCVs during GPS weeks 1669-1672.

The analysis of the differences in sub-daily kinematic PPP solutions, obtained using individual and type mean antenna/radome calibrations has revealed the following:

- All six stations exhibit constant biases up to 10 mm in all three components;
- Variations in coordinate differences have periods close to 24 hours (Figure 4) which corresponds to the orbital period of the GPS satellites or one sidereal day;
- Position differences experience rapid changes and even jumps within short time periods.

Table 3 summarizes the statistics on the significance of biases, discovered in the SPSLux network, originating from the imperfections in the antenna/radome calibrations.

Table [3] Summary statistics on biases, introduced by type mean PCVs in the SPSLux network.

	Number of stations having biases within		
	1σ conf. lev.	2σ conf. lev.	3σ conf. lev.
North	3	1	0
East	3	2	1
Up	3	2	1

Although for the examined stations the 1-, 2- and 3-quartiles of the differences, enclosed into the coloured boxes in Figure 5, are concentrated around zero, the minimum and maximum values have much larger spread, especially for the Up component.

Results—Daily

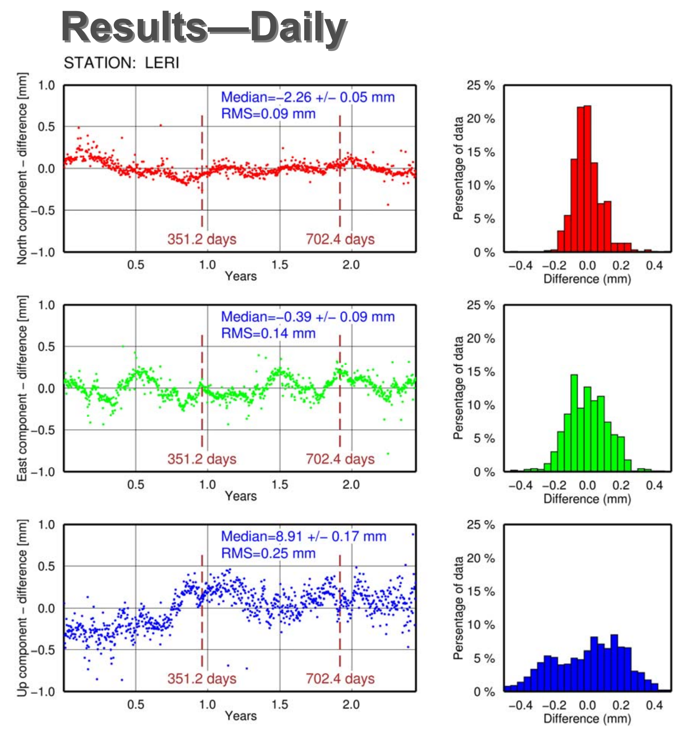

Figure [6] Station LERI (GeoNet). Period from 2009.7 to 2012.2. Differences in daily PPP solutions, using individual and type mean PCVs, and corresponding histograms for the North (red), East (green) and Up (blue) components.

Because most of the stations, having individual antenna/radome combination calibrations, were installed in the recent years, 50% of datasets in this study are between 2 and 4 years long. To a degree, this limited our investigations and results.

Nevertheless, after analysing differences in daily PPP coordinates of 43 antenna/radome combinations, using individual and type mean calibrations, we observed the following:

- Across all examined combinations of the same type of antenna and radome, variations of the systematic biases in PPP solutions reach 17 mm (Figure 7);
- Imperfections in antenna/radome calibrations introduce periodic variations in the difference CTS (Figure 6). The frequencies of these variations coincide with the harmonics of the GPS draconitic year (Figure 8).

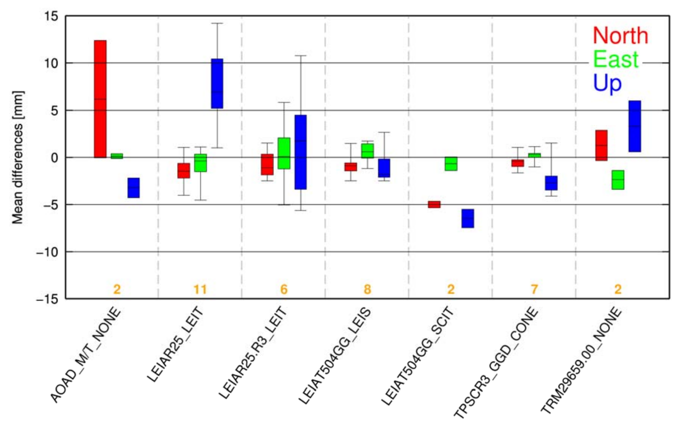

Figure [7] Mean differences for various antenna/radome combinations. Orange numbers at the bottom of the graph indicate the number of the investigated antenna/radome combinations.

Periodic variations in position residuals, having frequencies of the GPS draconitic year (~351.2 days) and its harmonics, were discussed in previous studies [e.g. Ray et al. 2007], where their relation to GPS satellites orbit and clock modelling errors was suggested. The results in this study indicate that some of these model deficiencies, resulting in the above periodic variations, may be related to inaccuracies in the employed PCVs.

Stacked periodograms for the difference CTS of examined stations demonstrate common frequencies in all three components (Figure 8). Spikes are observed at frequencies 2.08, 3.12, 4.16, 5.20, 6.24, 7.28 and 8.32 cycles per year (cpy), being more pronounced in the East component.

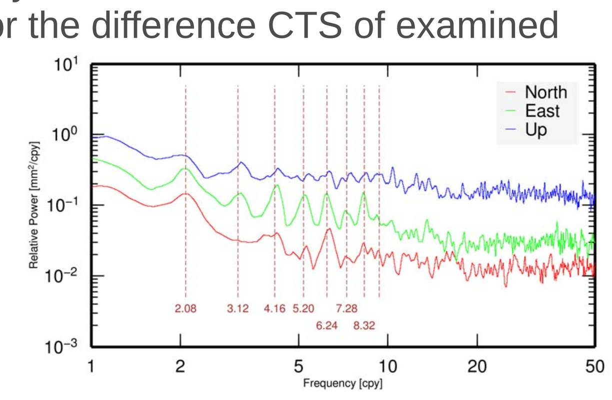

Figure [8] Stacked periodograms for the difference time series of 43 investigated antenna/radome combinations, having more than 365 daily measurements between 2002 and 2012.

The North component undergoes fewer periodic variations, nevertheless, frequencies at 2.08 and 6.24 cpy are still notable. The high noise level in the Up component results in a flatter periodogram, leaving noticeable frequencies only close to 2.08, 3.12 and 4.16 cpy.

Conclusions

In both daily and sub-daily analysis imperfections in employed antenna/radome calibrations lead to:

- systematic biases and
- periodic variations in the coordinate time series.

- The periodic variations in the difference time series of the sub-daily coordinate estimates correspond to the orbital periods of the GPS satellites.
- The difference in the daily coordinate estimates exhibits variations with periods close to the GPS draconitic year and its harmonics.

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