Antenna Phase Centre Calibration Effects on Position Time-Series: Preliminary Results

D. Sidorov, F.N. Teferle

Geophysics Laboratory, University of Luxembourg, Luxembourg

Contact: dmitry.sidorov@uni.lu

Abstract

Advances in GPS error modelling and the continued effort of re-processing have considerably decreased the scatter in position estimates over the last two decades. The associated reduction of noise in derived position time-series has revealed the presence of previously undetected periodic signals. It has been shown that these signals have frequencies related to the orbits of GPS satellites. A number of potential sources for these periodicities at the draconitic frequency and its harmonics have already been suggested in the literature and include, e.g. errors in the sub-daily tidal models, multipath and unresolved integer ambiguities.

Due to the geometrical relationship between an observation point and an orbiting satellite, deficiencies in the modelling of electromagnetic phase centres of receiving antennas have the potential to also contribute to the discovered periodic signals. The change from relative to absolute type mean antenna/radome calibrations within the international GNSS service (IGS) lead to a significant improvement and the use of individual calibrations could add further refinements to computed solutions. However, at this stage providing individual calibrations for all IGS stations is not feasible. Furthermore, antenna near-field electromagnetic effects might out-weight the benefits of individual calibrations once an antenna is permanently installed.

In this study we investigate the differences between position estimates obtained using individual and type mean antenna/radome calibrations as used by the IGS community. We employ position time-series derived from precise point positioning (PPP) as implemented in two scientific GNSS software packages. Our results suggest that the differences in the employed calibrations propagate directly into the position estimates, affecting both sub-daily and daily results and yielding periodic variations. The sub-daily variations have periods close to half a sidereal day and one sidereal day with amplitudes of up to 10 mm in all position components. The stacked power spectra of the daily difference time-series reveal peaks at the GPS draconitic frequency and its harmonics, having the associated amplitudes of up to 1 mm. Although these results are still preliminary, they confirm that small differences between individual and type mean antenna/radome calibrations propagate into position time series and may be partly responsible for the spurious signals with draconitic frequency and its harmonics.

Introduction

The advances in processing techniques during the last decade as well as the refinement of the applied models have resulted in the outstanding reduction of background noise both in the satellite products and in station position time-series. These improvements enabled more detailed studies of geophysical processes, resulting in further discoveries and revealing processing artifacts. The identification and precise estimation of the latter is essential in confirming geophysical models and, consequently, deeper understanding of the underlying geophysical processes.

Ray et al. (2008) examined the residuals of the GPS position time series, generated in the ITRF2005 combination and discovered periodic signal at 1.04 cpy, followed by 6 overtones. Similar signals were found later in the reprocessed solutions (Collilieux et al.,2011). This has been followed by extensive research (e.g. Griffiths and Ray (2012)), suggesting the following:

- Errors in tidal models:
  - semidiurnal atmospheric
  - sub-daily EOP
- Unmodeled Earth radiation pressure
- Errors in solar radiation pressure models
- Unresolved ambiguities
- etc.

→ Periodic signals at 1.04 cpy + overtones

The aim of this study:

To assess the contribution of the errors in the applied antenna/radome phase centre calibrations to the existing GPS draconitic harmonics.

Antenna Calibrations

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 an antenna Phase Centre Offset (PCO) and Phase Centre Variations (PCV), which are unique for each individual combination of antenna and radome. While PCO contains the constant part of the 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.

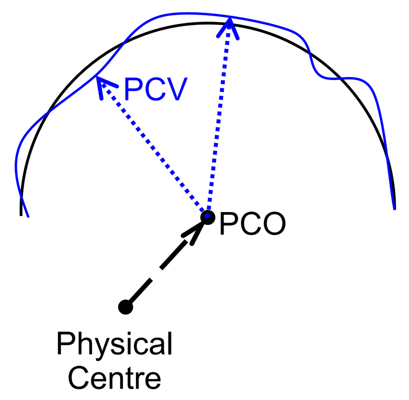

Figure [1] Antenna Phase Centre Offset (PCO) and Phase Centre Variations (PCV)

The existing calibration procedures require mounting the antenna on a robot. Considering that the on-site calibration is not possible yet, the calibration of the already installed stations would inevitably result in discontinuities in the time-series. However, due to 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.

Breaking the common belief that the PCVs of the individual antennas do not deviate much from the type mean model, Figure 2 shows the differences for two LEIAR25.R3 LEIT antennas, which are installed in Luxembourg, within the national real-time kinematic (RTK) network SPSLux. The individual PCV models, produced by Geo++, are available for the stations within the SPSLux. Although the major deviations between the PCV models are below 10° elevation, even at high elevation angles the PCV models exhibit deviations by ± 1mm. This suggests that for two antennas of the same type, using the type mean antenna calibration, the estimated parameters will deviate from their true values differently, leading to the antenna-specific errors.

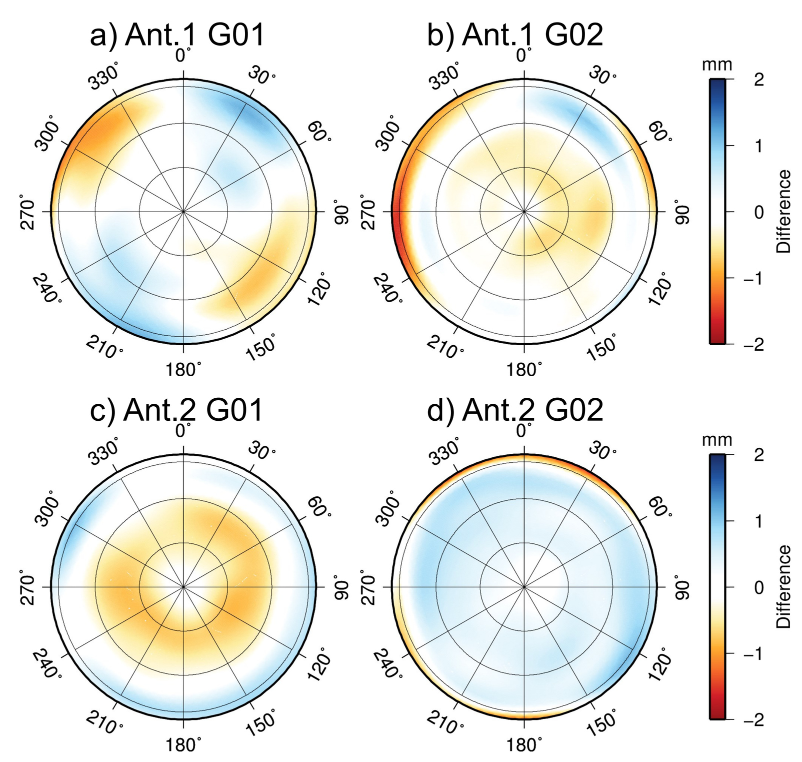

Figure [2] The skyplots of the differences between the type mean PCV and two PCVs of individually calibrated LEIAR25.R3 LEIT for the GPS frequencies G01 (a) and (c), and G02 (b) and (d), respectively.

Methodology

For each of the 54 sites mostly located in Europe, using two scientific software packages:

- the Bernese GNSS Software ver. 5.2 (BSW)
- the NAvigation Package for Earth Observation Satellites ver. 3.3.1 (NAPEOS)

we performed two parallel PPP runs, keeping all processing options identical, except the antenna/ radome calibrations.

Processing stages included (Figure 3):

- a PPP run using the type mean PCV;
- a PPP run using the individual PCV, feeding the tropospheric estimates from the "type mean" run;
- Computation of the difference CTS.

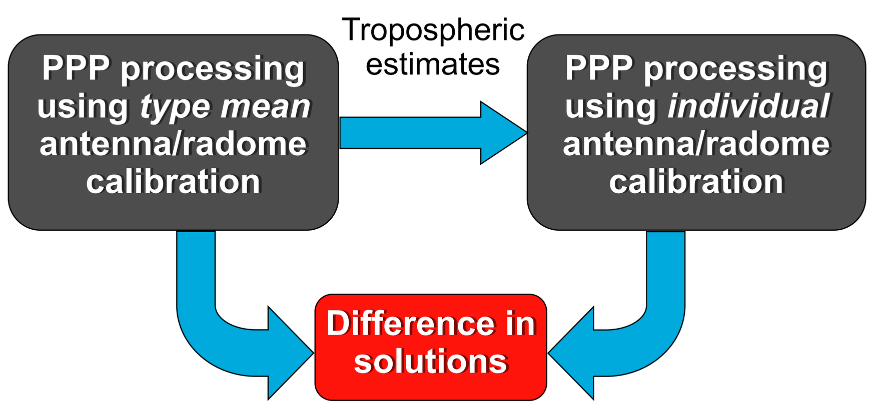

Figure [3] Methodology of this study.

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.

Results—Sub-daily

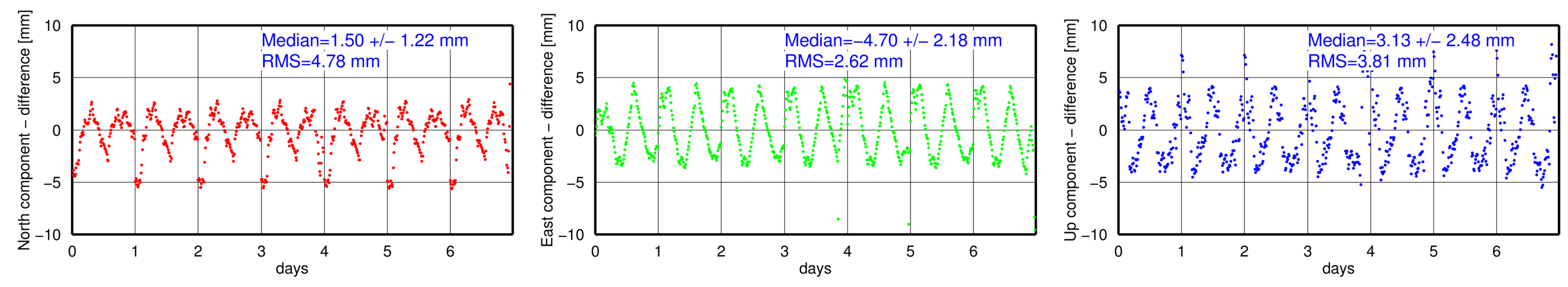

Figure [4] The differences in the 15 minutes pseudo-kinematic PPP solutions for the North (red), East (green) and Up (blue) components over 1 week (GPS week 1667) for the station equipped with LEIAR25.R3 LEIT (Figure 2 a and b), using individual and type mean PCVs.

The pseudo-kinematic 15 minutes PPP solutions for 1 week (GPS week 1667) were obtained for 6 stations of the SPSLux network. The differences of the solutions (Figure 4), applying the type mean and the individual antenna/radome calibrations, reveal the following:

- The processed stations exhibit constant biases up to 10 mm in all three components;
- Position differences experience rapid changes within short time periods;
- Variations in coordinate differences have periods close to 11 hours 58 minutes, which corresponds to the orbital period of the GPS satellites or the half sidereal day;
- The ~11h58m periodic signal, being the result of the PCV errors, represents an unmodeled periodic station displacement, possibly resulting in aliased longer wavelength signals (Stewart et al., 2005).
- All sites may experience similar behavior, if imperfections in the antenna/radome models exist.

Results—Daily

For our daily results we used both the BSW ver. 5.2 and NAPEOS ver. 3.3.1 to guarantee that the observed effects are not software related. After obtaining identical results for several sites, we performed further processing using NAPEOS. Table 1 includes a list of all investigated antenna/ radome combinations.

Table [1] Antenna/radome combinations, included in the daily PPP processing.

Antenna/radome combination	# of examined stations	Antenna/radome combination	# of examined stations	Antenna/radome combination	# of examined stations
AOAD/M T/NONE	2	LEIAT504/SCIT	2	TRM33429.20+GP/NONE	2
JAV RINGANT G3T/NONE	1	LEIAT504GG/LEIS	7	TRM41249.00/NONE	2
LEIAR25/LEIT	13	NOV750.R4/NONE	2	TRM41249.00/TZGD	1
LEIAR25.R3/LEIT	14	TPSCR.G3/TPSH	1	TRM55971.00/NONE	1
LEIAR25.R3/NONE	1	TPSCR3 GGD/CONE	7	TRM55971.00/TZGD	4
LEIAR25.R4/LEIT	5	TRM29659.00/NONE	2	TRM59800.00/NONE	1
LEIAT504/LEIS	1	TRM29659.00/SNOW	2		

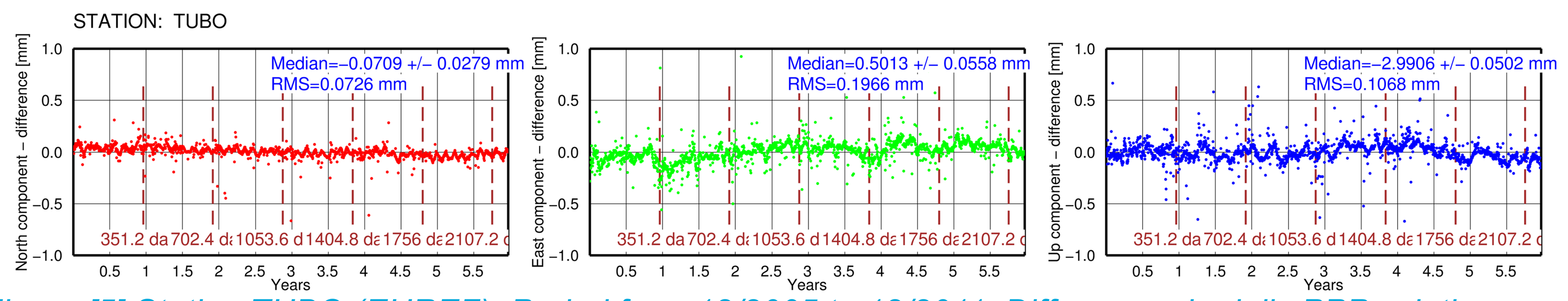

Figure [5] Station TUBO (EUREF). Period from 12/2005 to 12/2011. Differences in daily PPP solutions, using individual and type mean PCVs, for the North (red), East (green) and Up (blue) components.

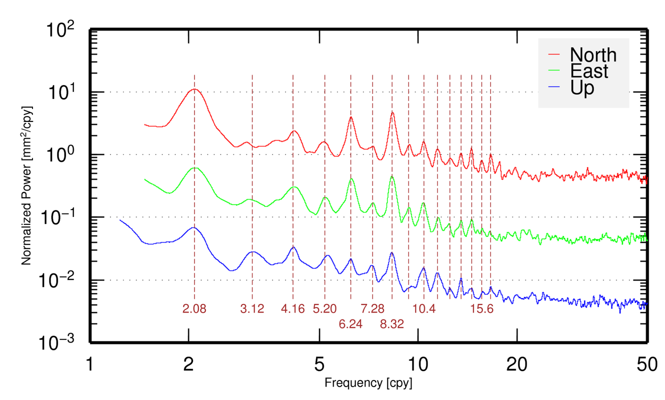

Figure [6] Stacked power spectra for the difference time series of 71 investigated antenna/radome combinations, having more than 365 daily observations between 2002 and 2012. For clarity the curves for the North and East components are shifted.

Figure 5 shows the time series of the differences in the PPP solutions for station TUBO (EUREF) using two PCVs (the type mean and the individual), suggesting the following:

- In addition to biases in solutions periodic variations may exist in all coordinate components;
- Slight modifications in the applied PCV model may lead to the change of the site velocity, or long-term periodic signal (as observed on Figure 5 North and East)

To identify the common periodic signals in daily position differences, we computed the Lomb-Scargle periodogram for each station and after normalizing it to 1mm^2 variance we stacked the obtained individual power spectra. The analysis of the results on Figure 6 leads to the following conclusions:

- The periodic signals are identified at frequencies, matching the overtones of the GPS draconitic year (1.04×n cpy, where n=2, 3, 4, …), consequently, the imperfections in the applied antenna/ radome PCVs do contribute to the draconitic harmonics observed in the GPS coordinate time series;
- Considering that the electromagnetic coupling between the antenna and the monument may significantly change the PCV, the observed effect may be further increased.
- The observed draconitic signatures may be reduced if the ambiguity fixing is performed.

Conclusions

The imperfections in the applied antenna/radome calibrations result in:

- high frequency sub-daily periodic signals, having periods equal to the GPS orbital repeat;
- a contribution to the power of draconitic signals in the daily position time series.
- The electromagnetic coupling between the antenna and the monument may further contribute to the observed effects due to deviations from the applied antenna phase centre model (e.g. King et al. (2012)).

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