Impact of Station GNSS Antenna Phase Centre Calibrations on Satellite Orbits and Station Coordinates: Preliminary Results

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Abstract

The electromagnetic phase centre of a Global Navigation Satellite System (GNSS) antenna does not coincide with the physical one and depends on the azimuth and elevation of the incoming signals. To improve processing results, the International GNSS Service has developed antenna phase centre corrections (PCC), which include models for constant and variable biases, i.e. phase centre offsets and phase centre variations. By assuming that the small differences in PCCs between antenna/radome combinations of the same type/model are negligible, so called type-mean PCCs have been generated and, for practical reasons, have been widely applied.

The type-mean PCCs are averaged corrections, which are composed from several individual PCCs. Contrary to the general assumption, individual PCCs may sometimes be significantly different for antennas of the same type and it can be argued, that the use of type-mean instead of individual calibrations may degrade GNSS-derived products, such as satellite orbits and station coordinates. Furthermore, through simple geometric considerations it can be shown that inaccuracies in the PCCs may propagate into time series of GNSS solutions and may contribute some power at the orbital frequencies and their harmonics.

In this study we assess the impact of the applied antenna PCCs on satellite orbits and station coordinates. As the availability of individual PCCs for GNSS stations is very limited, we analyzed a global network with stations mainly located in Europe. We used 10 years of GPS data in our processing. Despite the limitations imposed by the poor network geometry, we observed improvements in orbit overlaps at day boundaries when individual antenna PCCs were used compared to the respective type-mean solutions. Additionally, we analyzed the impact of the applied PCCs on Precise Point Positioning (PPP) station coordinates using our computed orbits. Our preliminary results showed that out of two PPP runs, the one with individual PCCs and respective orbit set reduced the noise in solutions compared to the other PPP run. We conclude that the use of individual PCCs is advantageous for derived GNSS products, as improvements are observed both in the estimated satellite orbits and station coordinate time series.

Introduction

Continuous efforts by the International GNSS Service (IGS) in refining the applied models and processing algorithms have resulted in outstanding quality of the produced GNSS solutions. The latter are employed in the construction of the International Terrestrial Reference Frames (ITRF), which are based on the GNSS, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Doppler Orbitography Integrated by Satellite (DORIS) solutions. Although GNSS, as a technique for ITRF determinations has some weaknesses (e.g., in its contribution to the origin and scale), it is essential for establishing the links between the other techniques, geographic density, accurate polar motion tracking and providing real-time access to the ITRF. Despite sophisticated methods and models involved in GNSS, these are being constantly improved, resulting in the reduction of scatter in the derived products.

Among others, the IGS uses type-mean phase centre correction (PCC) models for antennas to adjust phase biases caused by interactions between electromagnetic wave and media. Due to the small deviations of the PCCs for individual antennas or antenna/radome combinations from each other within ranges of the same model, type-mean PCCs are widely employed. However, due to these imperfections, the use of the latter instead of individual PCCs may also degrade the GNSS-derived products.

The aim of this study:

To assess the impact of changes in applied PCC models on satellite orbits and station coordinates by processing a network of stations using two sets of PCCs: the IGS type-mean and individual corrections.

Antenna phase centre corrections

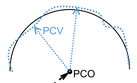


Figure [1] Antenna Phase Centre Offset (PCO) and Phase Centre Variations (PCV)

The electromagnetic phase centre of an antenna does not coincide with the physical one and depends on azimuth and elevation of incoming signal.

- PCC, defined as PCO+PCV, is different for each antenna.
- The IGS type-mean PCCs are average models based on a certain number of individually calibrated antennas.
- Outcome: actual PCCs of individual antennas may deviate from the type-mean models, affecting derived solutions.
- Furthermore, the PCCs may be altered after antennas are installed due to, e.g., electromagnetic coupling between antennas and monuments, etc.

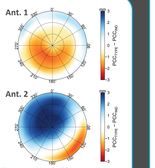


Figure [2] Differences between type-mean and individual PCCs for two geodetic type antennas of the same model

Observation Network

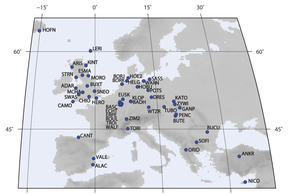


Figure [3] Network of stations used for orbit determination and consecutive PPP processing. 2 sites in North America and 1 site in South Georgia are not shown

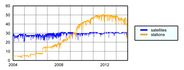


Figure [4] Number of observed satellites and stations used for orbit determination

Due to the small number of stations with individually calibrated antennas, we used mainly stations located in Europe and added 2 sites in North America and one on South Georgia Island. The employed stations take part in the EPN[1], GeoNet[2], SPSLux[3] and the IGS network[4].

To summarize:

- 55 stations, 75 antenna/radome combinations (due to, e.g., replacements)
- 10 years of data (2004-2013)

[1] EUREF Permanent Network (EPN)
[2] Operated by the British Isles continuous GNSS Facility (BIGF)
[3] Operated by Administration du Cadastre et de la Topographie, Luxembourg
[4] Operated by Natural Resources Canada (NRCan)

Methodology

To validate our processing sequence we first produced a set of orbits and clocks using the IGb08 core network complemented by the stations with individual antenna PCCs. This preliminary orbit determination run was performed using the IGS type-mean antenna PCCs. During this first step, satellite positions, satellite and station clock biases and tropospheric delays were estimated, while station coordinates were tightly constrained to those defined in the IGb08 reference frame. Later, the clock and tropoospheric delay estimates were imported into consecutive steps to reduce the number of estimated parameters and, therefore, to constrain the solutions.

In all processing the observation data were down-sampled to 300 s. Only the GPS data were used. Broadcast ephemeris were used as a priori satellite orbits.

To validate the orbit determination sequence, the estimated orbits were compared to the IGS final solutions. The average combined RMS between the computed and the IGS final orbits for the period 2004-2013 was 19.1 mm.

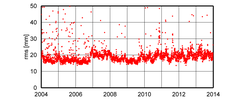


Figure [5] Combined RMS of the differences between the IGS final satellite orbits and those computed in the preparative orbit determination run.

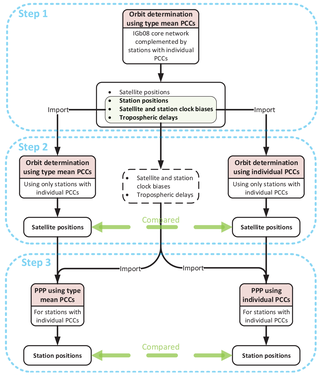


Figure [6] Schematic description of the experiment. Three steps show the way to assess the impact of changes in the applied antenna PCCs on satellite orbits and station coordinates.

- Validation of the orbit determination sequence
- Estimation of a consistent set of clock products and tropospheric delays using type-mean antenna PCCs and global observation network.
- Orbit determination runs using only stations with individual PCCs, but applying first type -mean and then individual antenna PCCs
- Clocks and tropospheric delays are fixed
- Assessment of the computed orbits based on orbit overlaps at day boundaries
- PPP runs with type-mean and individual antenna PCCs using respective orbit sets
- Clocks and tropospheric delays are fixed
- Assessment of the computed station coordinates

Impact on satellite orbits

Similar to Griffiths and Ray (2013), our orbit quality assessment was based on the orbit overlaps at day boundaries. Analogous to the IGS products, we produced daily orbital solutions, but as the processing was performed at 300 s intervals, our orbits have a higher sampling rate compared to the IGS final orbits and ranged from 00h00m until 23h55m.

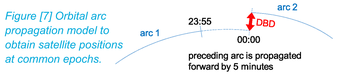


Figure [7] Orbital arc propagation model to obtain satellite positions at common epochs.

- Preceding arc propagation by 5 minutes forward.
- Day boundary differences (DBD) at 00h00m are computed and split into radial, along- and cross-track components

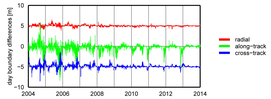


Figure [8] An example of the DBDs (PRN10) obtained using only stations with individual antenna PCCs. Radial and cross-track components are shifted.

Due to a rather small network of stations with a distribution far from being optimal for orbit determination (i.e., less than 10 stations in 2004-2006 and all in Europe) the estimated DBDs could reach several meters.

- Identical settings were used to produce two sets of orbits: employing the IGS type-mean and individual antenna PCCs.
- DBDs computed.
- For each satellite and each orbital component Lomb-Scargle periodograms were computed and those for respective components were combined. In order to allow more contribution from less noisy time series, each time series was weighted according to the inverse of the variance.
  The above was performed separately for the "type-mean" and "individual" scenarios.

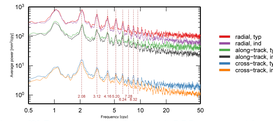


Figure [9] Power spectra of the orbit DBD computed for 2004-2013 using only stations with individual antenna PCCs, while clocks, tropospheric delays and stations coordinates were kept fixed. Radial and cross-track components are shifted.

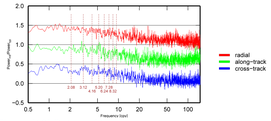


Figure [10] Ratios of the power at respective frequencies in the "individual" and "type-mean" orbit determination runs. Radial and cross-track components are shifted by +0.5 and -0.5, respectively

Outcome:

- The analyzed DBD time series obtained with individual antenna PCCs are less noisy compared to those obtained with type-mean PCCs across the entire frequency range considered (0.5<f<150 cpy)
- Average power reduction at high frequencies (100<f<150 cpy) was 44%, 36% and 43% for radial, along- and cross-track components, respectively.
- As the attenuation factor for draconitic frequencies (1.04×n cpy, n=1, 2, 3…) was similar to the neighboring frequencies, no conclusion at this point can be made on contribution of antenna PCC errors to draconitic signals observed in the GPS-derived time series.

Impact on station coordinates

The obtained satellite orbits and clocks were also used for PPP processing, Figure 6, step 3. The station coordinate time series (CTS) obtained separately in the "type-mean" and "individual" scenarios were analyzed and compared.

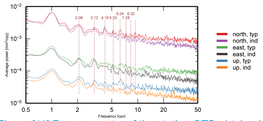


Figure [11] Power spectra of the station CTS obtained applying type-mean and individual antenna PCCs and respective orbits, while clocks and tropospheric delays were kept fixed. North and up components are shifted.

- According to results of the spectral analysis, the CTS obtained with individual PCCs are less noisy compared to those obtained with type-mean PCCs.
- On average, power at high frequencies (100<f<150 cpy) was reduced by 40%, 52% and 54% for the north, east and up coordinate components, respectively.

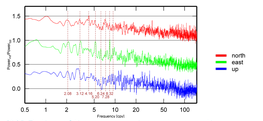


Figure [12] Ratios of the power values at respective frequencies in the "individual" and "type-mean" PPP runs. North and up components are shifted by +0.5 and -0.5, respectively

Orbital frequencies and harmonics

Although the quality of the orbits produced using the network of stations shown in Figure 3 may not be optimal to assess contribution of antenna PCC modelling errors to draconitic signals seen by, e.g., Griffiths and Ray (2013)and Collilieux et al. (2011), we still present comparison of power values at draconitic frequencies observed in our solutions.

Table [1] Numerical values [mm²] of the GPS orbit DBD power spectra at harmonics of 1.04 cpy. Percentages indicate corresponding improvement with respect to the "type-mean" solution.

Component	Sol.	1.04		2.08		3.12		4.16		5.20		6.24		7.28		8.32		9.36	
Radial	typ	81.00		79.17		57.12		49.14		39.59		30.94		23.56		22.99		19.62	
Radial	ind	78.47	3%	74.25	6%	52.76	8%	40.88	17%	36.35	8%	27.20	12%	20.06	15%	20.53	10%	16.11	18%
Along-track	typ	317.72		251.16		172.81		133.58		111.70		150.99		103.31		86.86		73.40	
Along-track	ind	279.20	12%	228.85	9%	162.11	6%	126.93	5%	104.72	6%	108.97	28%	81.69	21%	55.28	36%	63.97	13%
Cross-track	typ	87.57		158.67		87.38		68.00		56.39		51.26		37.31		48.01		35.38	
Cross-track	ind	81.38	7%	130.48	18%	76.93	12%	55.51	18%	49.73	12%	45.25	12%	29.47	21%	33.63	30%	29.66	16%

Table [2] Numerical values [×10^{-4} mm²] of station PPP CTS power spectra at harmonics of 1.04 cpy. Percentages indicate corresponding improvement with respect to the "type-mean" solution.

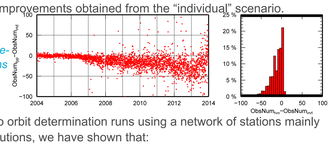
Component	Sol.	1.04		2.08		3.12		4.16		5.20		6.24		7.28		8.32		9.36	
North	typ	6.26		2.73		2.23		2.24		1.81		1.90		1.46		1.35		1.55	
North	ind	6.23	0%	2.50	8%	2.05	8%	2.25	0%	1.55	14%	1.40	26%	1.34	9%	1.11	16%	1.15	26%
East	typ	5.62		2.52		2.37		1.70		1.43		1.48		1.41		1.08		1.12	
East	ind	4.80	15%	2.40	5%	2.28	4%	1.35	21%	1.39	3%	1.20	19%	1.08	23%	1.03	2%	0.88	21%
Up	typ	11.21		6.66		5.25		4.63		4.33		5.03		3.33		3.44		2.67	
Up	ind	9.49	15%	5.72	14%	3.91	24%	3.39	27%	3.11	28%	2.88	44%	2.32	30%	2.47	28%	2.16	19%

Thus, average improvement for the lower draconitic frequencies in our orbit solutions reached 11%, 15% and 16% for radial, along- and cross-track components, respectively. At the same time, the draconitics in our PPP CTS were reduced by 12%, 13% and 25% for the north, east and up components, respectively.

Discussion and conclusion

Besides the effects on the draconitics, the results also suggest that the employed PCCs have a positive effect on the number of observations retained during processing. During the iterations of the least squares adjustment noisier observations are rejected until the user-defined criteria are fulfilled. For our orbit determination runs we noticed higher number of rejected observations when type-mean PCCs were used than for the individual PCCs. The additional observations should have a positive effect on the orbit computation and may be responsible for improvements obtained from the "individual" scenario.

Figure [13] Difference between the total numbers of accepted observations in the "type-mean" and "individual" orbit determination runs and corresponding histogram.



Based on this preliminary analysis of two orbit determination runs using a network of stations mainly located in Europe and consecutive PPP solutions, we have shown that:

- Deviations of individual from type-mean PCCs do not necessarily average out as is widely assumed, but may propagate into computed satellite orbits and derived PPP solutions either directly or indirectly.
- PPP solutions produced with individual antenna PCCs and corresponding orbits show reduced scatter compared to the noisier "type-mean" solutions.
- The clock biases and tropospheric delays were fixed to preliminary computed values using type-mean PCCs. To which degree this may have affected the results needs to be further investigated. Both biases and delay estimates may potentially be improved once estimated using individual PCCs.

Acknowledgments

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