
**ANTENNA PHASE CENTER VARIATIONS
CORRECTIONS IN PROCESSING
OF GPS OBSERVATIONS WITH USE OF COMMERCIAL
SOFTWARE**

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Key words: GPS antenna, phase center variations, GNSS data processing.

A b s t r a c t

It is well known that magnitude of antenna phase center variations (PCV) can reach several centimeters. Unfortunately part of commercial GPS post-processing software does not include corrections related to antenna PCV. This paper presents a proposal of a subroutine which introduces PCV corrections to code and phase observations basing on ANTEX file and RINEX observations and navigation files. This approach has been tested using GPS data collected at four measurement points. Three different types of antenna were used in observations. Observation processing was done with Ashtech Solutions and TopconTools software. The results of calculations show, that the proposed subroutine can be successfully used in commercial software which does not include such correction algorithms. The subroutine can also serve to verify antenna PCV corrections algorithms in commercial software where there is often no possibility of looking into applied algorithms.

**POPRAWKI DO ZMIENNOŚCI POŁOŻENIA CENTRUM FAZOWEGO ANTENY
W OPRACOWANIU OBSERWACJI GPS OPROGRAMOWANIEM KOMERCYJNYM**

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Słowa kluczowe: antena GPS, zmienność położenia centrum fazowego, opracowanie obserwacji GNSS.

A b s t r a c t

Powszechnie wiadomo, że zmiany położenia centrum fazowego anteny (phase center variations – PCV) mogą osiągać wartość kilkunastu centymetrów. Niestety, część programów komercyjnych do opracowania obserwacji GPS nie zawiera poprawek związanych z PCV. W artykule przedstawiono

propozycję podprogramu, który na podstawie pliku ANTEX oraz obserwacyjnych i nawigacyjnych plików RINEX wprowadza poprawki PCV do obserwacji kodowych i fazowych. Podejście zostało przetestowane na podstawie danych GPS zebranych w czterech punktach pomiarowych. W pomiarach wykorzystano trzy różne typy anten. Obserwacje opracowano z wykorzystaniem programu Ashtech Solutions i TopconTools. Wyniki obliczeń dowodzą, że proponowany podprogram może być skutecznie wykorzystany jako uzupełnienie programu firmowego nie mającego takich poprawek. Podprogram może również służyć do weryfikacji zastosowanych poprawek PCV w programach komercyjnych, w których często brakuje wglądu w zastosowane algorytmy.

Introduction

A fundamental role of GPS antenna is filtering, amplification and changing electromagnetic waves sent from satellites to electric current, which can be transmitted through electronic systems of the receiver. The electrical antenna phase center is the point in space where GPS signal is received. The actual location where the signal is received, however, varies depending on the direction of the incoming GPS signal. For practical needs a mean position of the electrical antenna phase center (MPC) is determined. The height above the physical network point, at which the antenna is situated, is usually measured to the antenna reference point (ARP). The IGS has defined the ARP as the intersection of antenna's vertical axis of symmetry with the bottom of the antenna. The antenna phase center offset (PCO) is defined as the difference between the ARP and the MPC. When comparing the electrical antenna phase center of an individual measurement with the mean electrical antenna phase center, a deviation arises. These deviations are referred to as antenna phase center variations (PCV). A review of the antenna phase center variations problem can be found e.g. in BRAUN et al. 1993, GEIGER 1998, HOFMANN-WELLENHOF et al. 2008, ROCKEN 1992, SCHMID et al. 2005, SCHMITZ et al. 2002, SCHUPLER, CLARK 1991.

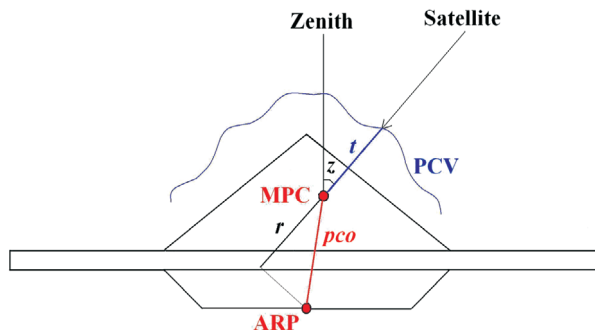


Fig. 1. Diagram of the ARP, MPC and PCV location

Spatial relations between ARP, MPC and PCV points are determined in the calibration process. Three major methods are presently used to determine variations of the phase center for GPS receiver antennas and create their models:

- relative field calibrations,
- anechoic chamber measurements,
- absolute field calibrations.

In relative field calibrations PCO and PCV of one antenna are determined with respect to another, the reference antenna. Both antennas are set up on very short baseline with accurately known coordinates. The GPS measurements are used to estimate the position of the phase center depending on the elevation (or elevation and azimuth) of the measured satellites.

Anechoic chamber measurements allow the absolute antenna phase center variations obtained by measuring how the phase of an artificial GPS signal is changed when the antenna (put into an anechoic chamber) is rotated and tilted.

Absolute field calibrations are performed using a high precision robot which rotates and tilts the antenna. In the same time the reference antenna is kept fixed.

These methods are described in detail e.g. in FALKO et al. 1998, MADER 1999, ROTHACHER 2001, ROTHACHER, MADER. 1996, WÜBBENA et al. 1997.

Antenna models are produced in several scientific centers. Well-known examples are: US National Geodetic Survey (IGS, 2008) and Geo++GmbH (Geo++, 2008). In NGS are created relative antenna calibrations models, where all antenna offsets and phase center variations are computed with respect to the AOAD/M-T antenna. Absolute NGS antenna calibrations models are created in such a way that the relative antenna offsets and phase center variations that the National Geodetic Survey has computed have been added to the absolute values for AOAD/M-T antenna defined by Geo++. Geo++ antenna calibrations models are created by the automated absolute field calibrations. There are some differences between antenna corrections files created in these two centers. For example in NGS all values are given in mm and in Geo++ in meters. Additionally PCV values in Geo++ file have an opposite sign to values in NGS file.

Antenna phase center variations can have an amplitude of several centimeters. The effect is more crucial in the elevation dependent component although azimuth dependent effects can become important over very long baselines. Ignoring these phase center variations can lead to serious (up to 10 cm) vertical errors (ROTHACHER, MADER 1996, MADER 1999).

In the last years research groups started to realize that not only the receiver, but also the satellite antennae show phase center variations. At the

moment, several IGS analysis centers are working on the generation of best possible satellite antenna correction values (ROTHACHER et al. 2002, SCHMID et al. 2005).

In some commercial post-processing software, the solution to the antenna phase center variations problem is simplified. For example in Ashtech Solutions 1.0 there is no possibility to account for the type of antenna used in measurements (*Magellan...* 1998). In Ashtech Solutions 2.0 there is only the possibility to reduce the antenna phase center offsets, but not the antenna phase center variations (*Thales...* 2002). Only the newest versions of so-called commercial software are equipped with models of antenna phase center variations corrections. An example of that is GNSS Solutions (presently replacing Ashtech Solutions) or Topcon Tools in which the US National Geodetic Survey's absolute antenna calibration models are applied by default from version 6.11 (*Topcon...* 2006). Unfortunately even these software products are not equipped with models of satellite antenna phase centers variations, which is very important when using precise orbit in observation processing. So when we use commercial software to observations processing, particularly for the determination of heights, we should pay particular attention to how the phase center variations problem was solved.

The paper presents a proposal of a subroutine which introduces PCV corrections to code and phase observations. Observations prepared in such way can be then processed with use of any commercial software. Another advantage of presented procedure is the possibility to use antenna calibration files from all scientific centers where they are created. The subroutine also lets to look into every stage of the correction process which is not guaranteed in commercial software.

The subroutine allows correction of observation by using information about the real position of antenna phase center which is a function of direction of incoming GPS signals. This information, obtained as a result of antenna calibration is available, for example, on International GNSS Service website in ANTEX format text files. In any ANTEX file, profiles of antenna are defined by three so-called offsets ("north", "east" and "up") and changes of the antenna phase center position as a function of incoming signal elevation and (at present for some antennas) also as a function of azimuth. These values are given in a five-degree interval: from 0° to 80° (90°) for elevation and from 0° to 360° for azimuth.

The proposed subroutine, written in MATLAB programming language, introduces (Fig. 2) corrections to code and phase observations basing on the antenna phase center positions and RINEX observation and navigation files. The satellites coordinates on observational epoch are calculated in the first stage. Then, elevation and azimuth of each satellite are calculated using

satellites positions data and approximate coordinates of the receiver. The next stage is reading the proper data from the antenna phase center position file. These values are then used to calculate the corrections to code and phase observations. The subroutine can make calculations using antenna calibration results from all centers where they are created. The observations can be reduced to MPC and to ARP.

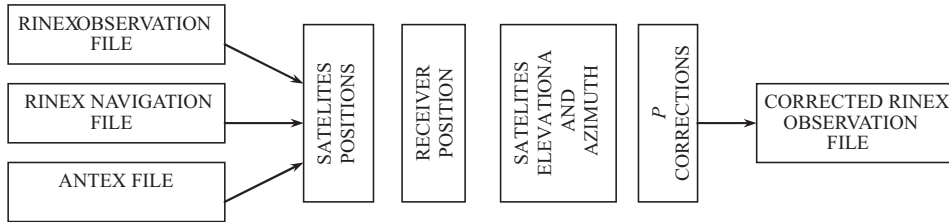


Fig. 2. Diagram of corrected RINEX observation file calculation with use of the proposed subroutine

Corrections to ARP are computed using below formula (Fig. 1):

$$p = r + t = (pco)\cos z + t \quad (1)$$

where:

p – correction to the observation; r – correction of the phase center position as function of pco and elevation of the satellite; t – correction of the phase center position as function of the satellite’s elevation or elevation and azimuth; pco – position of phase center in relation to ARP (“up” offset); z – elevation of the satellite.

In the present version of the subroutine, the estimation of r value is simplified because only the “up” offset is taken under consideration in calculations. Such approximation does not influence the results in an essential way, because comparing to “up” offset, the other two offsets are very small and their values are mostly less than 1mm and do not exceed several millimeters for any antenna. Because the value of t is expressed in five degrees interval, its proper value (for current elevation or elevation and azimuth) is calculated by a well known linear interpolation formula:

$$t = t_1 + (e - e_1) \frac{t_2 - t_1}{e_2 - e_1} \quad (2)$$

where:

t – position of the phase center as a function of current satellite’s elevation or elevation and azimuth (e); t_1, t_2 – values of phase center position for e_1, e_2 satellite’s elevations or elevations and azimuths known from the ANTEX file.

The code observations are directly adjusted with corrections calculated in such way. In order to conduct phase observations, the corrections have to be converted to phase cycles. For L1 frequency, the final value of t is calculated by dividing the result obtained from equation (1) by 0,19029, and for L2 frequency by 0,24421. When observations are reduced to the MPC, correction p simply equals t value interpolated for current satellite's elevation or elevation and azimuth.

For comparison in Bernese GPS Software Version 5.0 (DACH et al. 2007), which is a sophisticated tool meeting highest quality standards for geodetic and further applications using Global Navigation Satellite Systems, antenna phase center variation correction has the following mathematical representation:

$$\Delta\phi(\alpha, z) = \Delta\phi'(\alpha, z) + \Delta r \cdot e \quad (3)$$

where:

$\Delta\phi(\alpha, z)$ – the total phase center correction in direction; α, z , α, z – azimuth and the zenith angle of the satellite line of sight; Δr – the position of the mean antenna phase center with respect to the mechanically defined antenna reference point; e – the unit vector in the direction from the receiver antenna to the satellite; $\Delta\phi'(\alpha, z)$ – the function modeling the phase center variations (two different model functions may be used in the Bernese GPS Software: piece wise linear function or spherical harmonic function).

Similar research was performed by GÓRAL and KUDRYS 2007. Ashant subroutine, described by them, worked with Ashtech binary files (b-files), and made possible to correct observations only in function of elevation of incoming GPS signal. L2 observations were reduced to MPC of L1 frequency, differently than in the subroutine proposed by the author (L1 and L2 observations can be reduced to their MPC or both observations can be reduced to ARP). In following analyses the author proposed also use different, newer versions of software to observations processing and focuses on PCV magnitude calculation and reduction when medium baselines are measured and this causes the necessity to use linear combination of observations in processing.

Methodology of studies

Measurement points

Four points situated between 53°34' and 54°00' north latitude and 20°04' and 20°27' east longitude were selected for test measurements. The longest measured baseline has about 49 km, the shortest – 25 km. The location of

proposed points causes the necessity to use linear combination in observations processing, which causes antenna phase center variations of both frequencies to appear in final results.

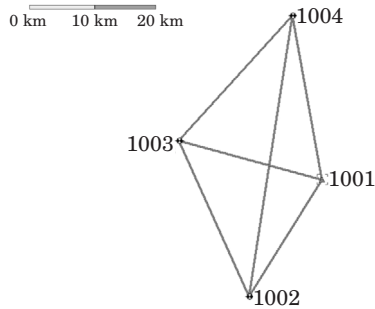


Fig. 3. Diagram of measurement points

Testing hardware and software

Three measurement sessions were conducted on the test points. The GPS observations were made by workers of Institute of Geodesy University of Warmia and Mazury in Olsztyn (research project nr 528-0302-0803). The following GPS parameters were assumed for all measurement sessions: sampling interval 10s, minimum satellite's elevation 15°, time of measurement 4 hours. Following types of antenna, presented on figure 4, were used in the measurements: ASH700228A (session 1 and 2), ASH700718A (session 2 and 3) and AOAD/M_T (session 3).



Fig. 4. Antenna used in measurements: a) ASH700228A, b) ASH700718A, c) AOAD/M_T

ASH700228A and ASH700718A are typical surveying antennas in contrast to AOAD/M_T antenna which is rather geodetic than surveying. The locations of MPC over ARP (“up” offset) for L1 and L2 frequencies for these antennas

are respectively (in millimeters): ASH700228A (61.14; 71.26); ASH700718A (68.54; 55.46); AOAD/M_T (91.24; 120.06).

Figure 5 presents comparison of the elevation dependent phase center variations for antennas used in session 2 and 3 – it is visible that they have completely different profiles.

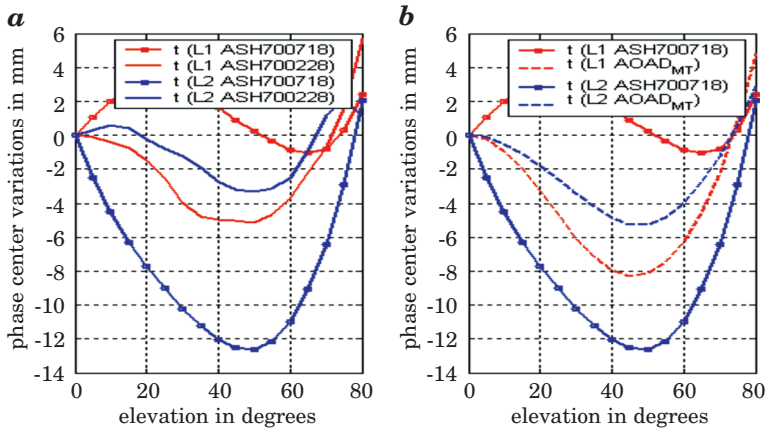


Fig. 5. Elevation dependent phase center variations: a) for antenna pair ASH700228A and ASH700718A; b) for antenna pair AOAD/M_T and ASH700718A

The aim of this paper was proposing a subroutine which, using the results of antenna phase center variation calibrations, can prepare GPS observations for processing with software which is not equipped with proper correction algorithms. An example of such software is Ashtech Solutions 1.0, which does not give any possibility of antenna type selection (*Magellan...* 1998). Topcon Tools 6.11 software was also chosen for observation processing. Topcon Tools software from version 6.11 uses the US National Geodetic Survey's absolute antenna calibration models and therefore can be used for verification of received results. The software selected assured verification of usefulness of the proposed subroutine on one hand and control of correctness of his calculations on the other.

Both chosen software types are examples of so-called commercial software. The operator has only little influence on the choice of processing options – for example processing frequency, troposphere model or ambiguity resolution strategy are beyond possibilities of selection. Automatic selection of processing frequency in chosen software looks as follows:

- 0-10 km baselines processing is L1 and L2,
- 10-30 km baselines processing is L1&L2c (ionosphere-free combination),
- 30-400 km baselines processing is wide lane.

Because using linear combination of observations causes antenna phase center variations for both frequencies to appear in final results, and processing frequency is beyond possibilities of own selection, suitable distant points locations were proposed for the measurements. The length of baselines between 25 km and 49 km causes the selection of processing frequency using linear combination.

Analysis of processing results

The GPS observations for all sessions were corrected by proposed subroutine with use of `igs_05.atx` file, which contains values of absolute elevation and azimuth dependent antenna phase center variations. Then, the corrected and the uncorrected observations were processed with two selected examples of commercial software (Ashtech Solutions 1.0 and Topcon Tools 6.11).

Point 1001 situated in Olsztyn (ASH700228A antenna on first session and ASH700718A antenna on second and third sessions), with coordinates appointed in reference to IGS LAMA station, was chosen as the reference station. Post-processing was done in the following variants:

- processing of uncorrected observations (without antenna phase center variation corrections) using Ashtech Solutions software (**AS without corrections**),
- processing of corrected observations (with antenna phase center variation corrections introduced using the proposed subroutine) using Ashtech Solutions software (**AS subroutine corrections**),
- processing uncorrected observations (without antenna phase center variation corrections) using Topcon Tools software (**TT without corrections**),
- processing corrected observations (with antenna phase center variation corrections introduced using the proposed subroutine) using Topcon Tools software (**TT subroutine corrections**),
- processing corrected observations (with use antenna phase center variation corrections available in the software) using Topcon Tools software (**TT software corrections**). Ellipsoidal heights calculated in such way were considered in further comparisons as true.

Third and fourth variants were possible because in Topcon Tools software there is an option of processing observations without using any antenna model (option “none” in the window of antenna model selection).

The ellipsoidal heights of measurement points obtained for all post-processing variants were compared on figure 6.

When the same type of antenna as on the reference station (session 1 for all points and session 2 and 3 for 1004 point) was placed on the measured point,

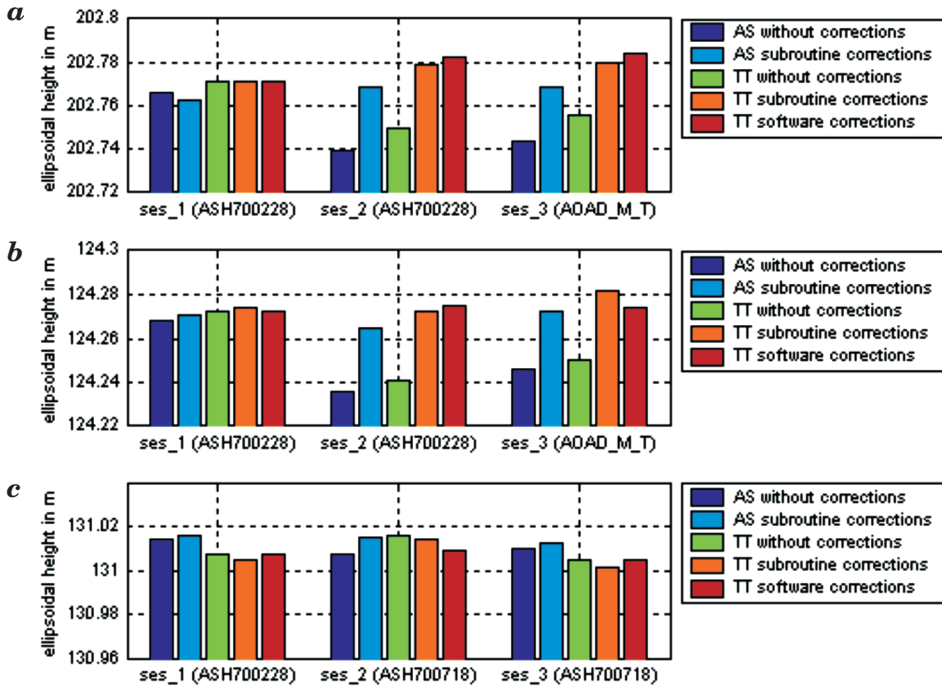


Fig. 6. Ellipsoidal height obtained for measurement points depending on the used software and used or no the antenna calibration file: a) for 1002 point; b) for 1003 point; c) for 1004 point (in brackets type of antenna used in respective sessions)

heights from all processing variants were consistent with 10 mm accuracy. Processing medium baseline, with the same type of antenna on both ends, without using PCV corrections, does not influence the results because systematic error is reduced in differential elaboration. When there was a different type of antenna on the measured point than on the reference station (session 2 and 3 for 1002 and 1003 points) it was clear that observations processing without the PCV corrections caused systematic error of about 2–3 cm. The error magnitudes are similar for antennas ASH700228A and AOAD/M_T surely because the both antennas have very similar phase center variation characteristics (Fig. 5). The heights, obtained from observations processing with use of the PCV corrections method proposed by author and with use of antenna phase center variation corrections available in Topcon Tools software, are consistent with 6mm accuracy.

In addition, preliminary analysis has been carried out concerning the effects of adoption absolute or relative antenna calibration file on height appointment. The calculations were performed again using two commercial software (Ashtech Solutions 1.0 – **AS**, Topcon Tools 6.11 – **TT**). Before

processing, GPS observations has been corrected through proposed by the author subroutine using developed by NGS (the most accessible) relative and absolute antenna calibration models. The results of these calculations are shown in Figure 7.

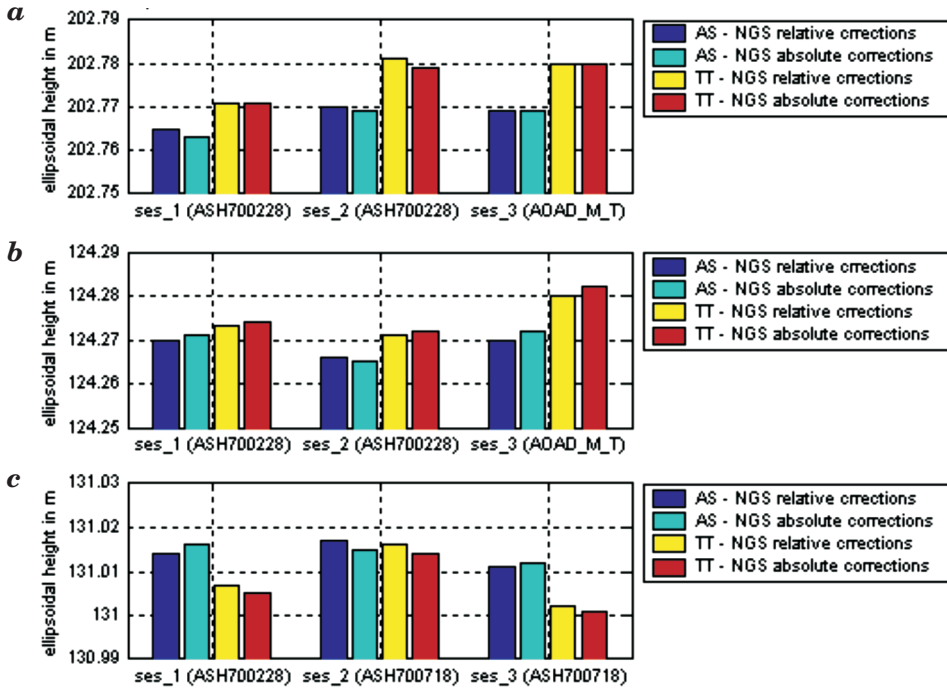


Fig. 7. Ellipsoidal height obtained for measurement points depending on the used software and the type of antenna calibration file: a) for 1002 point; b) for 1003 point; c) for 1004 point (in brackets the type of antenna used in respective sessions)

The height difference between the solution using NGS absolute and relative antenna calibration file, for the same software, in any of the cases did not exceed 2 mm. In the proposed study the use of absolute or relative antenna calibration model no effect the height appointment. Such results are not surprising because NGS absolute calibration model was created by adding the relative antenna offsets and phase center variations that the National Geodetic Survey has computed to the absolute values for AOAD/M_T antenna and all processing, presented in paper, were done with broadcast orbit.

Maybe more interesting results could give similar analyses conducted with use GPS observations on short baselines in short sessions with precise orbits and more antenna calibration models.

Conclusions

Analyses were done using GPS data collected at four measurement points with distances between them ranging from 25 km to 49 km. Such long baselines cause the necessity of conducting suitably long observational sessions. In nearest future the author plans to conduct similar analyses performed using GPS observations on short baselines in short sessions. The author also plans some modifications of the subroutine. In future the subroutine will allow corrections of observations taking satellites antenna PCV into account.

Moved analyses confirmed that the PCV problem cannot be disregarded in surveying measurement – seemingly very similar surveying antennas (ASH700228A and ASH700718A) have significantly different PCV characteristics. Using those antennas in measurements and then processing observations without PCV corrections causes a systematic vertical error of several centimeters. The results presented in this paper also show that the subroutine proposed by the author can be used in commercial software which is not equipped with PCV correction algorithms.

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References

- Ashtech Solutions Tutorial*. Printed in USA. 1998. Magellan Corporation Ashtech Precision Products.
- Ashtech Solutions User's Guide*. Printed in USA. 2002. Thales Navigation.
- BRAUN J., ROCKEN C., MEERTENS C.M., JOHANSON J. 1993. *GPS antenna mixing and phase center corrections*. Eos Trans. AGU, Fall Meeting Supplement, p. 197.
- DACH R., HUGENTOBLER U., FRIDEZ P., MEINDL M. 2007. *Bernese GPS Software Version 5.0*. Astronomical Institute, University of Bern, p. 327–346.
- FALKO M., SEEBER G., VÖLKSEN CH., WÜBBENA G., SCHMITZ M. 1998. *Results of Absolute Field Calibration of GPS Antenna PCV*. ION GPS-98; Proceedings of the 11th International Technical Meeting of the Satellite Division of the Institute of Navigation, Nashville, TN; UNITED STATES; 15–18 Sept., p. 31–38.
- Geo++ GmbH / GeoService GmbH /. 2008. *Format of Geo++ PCV Antenna File*, <http://www.geopp.de/media/docs/pdf/>
- GEIGER A. 1998. *Modeling of Phase Center Variation and its Influence on GPS Positioning*. GPS-Techniques Applied to Geodesy and Surveying: Proceedings of the International GPS-Workshop Darmstadt, April 10 to 13, Editor: Erwin Groten, Robert Strauß, Lecture Notes in Earth Sciences, 19: 210–222.
- GÓRAL W., KUDREY J. 2007. *Obliczanie poprawek uwzględniających wpływ charakterystyk anten w pomiarach fazowych GPS*. Geomatics and Environmental Engineering, 1(1/1): 133–139.
- HOFMANN-WELLENHOF B., LICHTENEGGER H., WASLE E. 2008. *GNSS – Global Navigation Satellite Systems*, Springer-Verlag Wien, Austria.
- IGS Working Group. 2008. *IGS antenna files*. <ftp://igsceb.jpl.nasa.gov/pub/station/genereal/antenna-README.pdf>
- Instrukcja Techniczna G-2. 2001. *Szczegółowa pozioma i wysokościowa osnowa geodezyjna i przeliczanie współrzędnych między układami*. Główny Urząd Geodezji i kartografii, Warszawa.

- MADER G.L. 1999. *GPS Antenna Calibration at the National Geodetic Survey*. Journal of Geodesy, 3(1).
- ROTHACHER M. 2001. *Comparison of Absolute and Relative Antenna Phase Center Variations*. GPS Solutions, 4(4): 55-60
- ROTHACHER M., MADER G. 1996. *Combination of antenna phase center offsets and variation: antenna calibration set IGS-01*, anonymous ftp ubeclu.unibe.ch, June.
- ROCKEN C. 1992. *GPS antenna mixing problems*. UNAVACO Memo, November 12.
- SCHUPLER B., CLARK T.A. 1991. *How different antennas affect The GPS observables*. GPS World November/December.
- SCHMID R., ROTHACHER M., THALLER D., STEIGENBERGER P. 2005. *Absolute phase center corrections of satellite and receiver antennas*. GPS Solutions, 9(4).
- SCHMITZ M., WÜBBENA G., BOETTCHER G. 2002. *Tests of phase center variations of various GPS antennas, and some results*. GPS Solutions, 6: 18-27.
- Topcon Tools User's Guide*. 2006. Topcon Positioning Systems Inc, May.
- WÜBBENA G., MENGE F., SCHMITZ M., SEEBER G., VÖLKSEN CH. 1997. *A New Approach for Field Calibration of Absolute Antenna Phase Center Variations*. Presented at ION GPS-96, Kansas City, Missouri.