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Tests of relative vertical offsets for several types of GPS receiver antenna phase centers

Hao Ming[*], *Qin Shanlan*, *Wang Qingliang*, *Wang Jianhua*, *Zhou Lin*

Second Monitoring and Application Center, China Earthquake Administration, Xi'an 710054, China

ARTICLE INFO

Article history:
Received 4 March 2015
Accepted 6 May 2015
Available online 28 August 2015

Keywords:
Global Positioning System (GPS)
Antenna phase center
Phase center variation
Vertical offsets
Horizontal offset
Leveling
Crustal movement
Vertical velocity

ABSTRACT

The correction for antenna phase center is considered in processing Global Positioning System (GPS) data collected from a network of GPS ultra-short baselines. Compared with the leveling measurements, the GPS results show that the relative vertical offsets for the pairs of GPS receiver antenna phase centers still exist, although absolute calibration of the antenna phase center variations (PCVs) has been considered. With respect to the TPS CR.G3 antenna, the relative vertical offset for the LEI AT504 antenna is −8.4 mm, the offset for the ASH701945C_M antenna is 5.5 mm, and those for the ASH700936E_C and ASH701945B_M antennas are approximately between −2 mm and −3 mm. The relative offsets for the same type of antennas are approximately 1 mm. By correcting the absolute PCVs, the existing relative offset becomes negligible for horizontal positioning.

1. Introduction

Global Positioning System (GPS) technology has been used to observe three-dimensional crustal movement. However, due to the errors of atmospheric refraction, GPS satellite and receiver antenna phase center variations (PCVs), and other sources, the vertical positioning precision is only half of the horizontal positioning when GPS is used to monitor crustal movement [1]. When GPS data are processed without correcting for the PCVs, the bias in the relative station height can reach up to 10 cm if different antenna types are mixed [2]. Since Nov. 5, 2006, the absolute values of PCVs have been considered by the international global navigation satellite system service. Therefore, the precision of the GPS vertical component has been improved significantly [3–5].

Since the 1980s, China has established thousands of GPS observations; one station may install different receiver antennas during different surveys, and each station in a network may install different antennas in one survey. All these antennas produce deviations for GPS height measurement [6].

The GPS data collected from ultra-short baselines were processed with absolute calibration of the PCVs. Compared with the leveling measurements, a relative vertical offset for

* *Corresponding author*.
E-mail address: ha_mg@163.com (Hao M.).
Peer review under responsibility of Institute of Seismology, China Earthquake Administration.

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http://dx.doi.org/10.1016/j.geog.2015.04.003

each pair of GPS height was found to still exist even after correcting the PCVs. Hence, the relative vertical offsets for several antenna types often used in the Crustal Movement Observation Network of China (CMONOC I) and the Tectonic and Environmental Observation Network of Mainland China (CMONOC II) were determined to improve the accuracy of crustal vertical rates obtained from the campaign mode of GPS stations.

2. Principle and method

The principle of this experiment involves the comparison of the height difference [6], as shown in Fig. 1.

Two sets of GPS receivers and antennas are installed in two monuments (*A* and *B*) using separate forced-centering apparatus. The geodetic heights of *A* and *B* are H_1 and H_2, respectively, and the heights of the antennas are h_1 and h_2, respectively. H_1 and H_2 can be acquired by processing the GPS data collected from monuments *A* and *B*. The height difference between the two bottom centers of preamplifier (*L*) can be obtained by the leveling measurement. The distance between *A* and *B* is very short; thus, the difference in the geodetic height is equal to *L*, i.e.,

$$L = (H_2 + h_2) - (H_1 + h_1) \quad (1)$$

The PCVs are corrected using the absolute calibration of PCVs when the geodetic height is acquired. The two sides in equation (1) must theoretically be equal to each other.

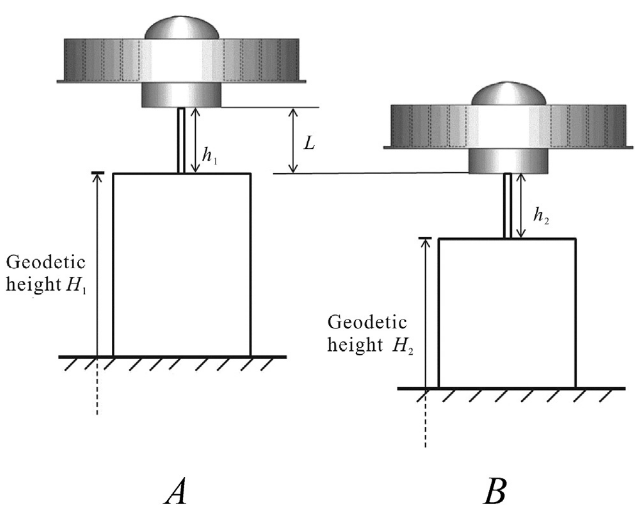


Fig. 1 – Testing principle for the height difference comparison.

However, the results of our experiment indicated that both sides of equation (1) are not equal and show systematic variations. This variation can be expressed as

$$\delta h_{12} = L - (H_2 - H_1) - (h_2 - h_1) \quad (2)$$

which is the relative vertical offset for the GPS antenna phase center.

The ASHTECH, LEICA, and TOPCON antennas, which are often used in CMONOC I and CMONOC II, were installed in the monuments of GPS ultra-short baselines. The experiment was continuously performed over four days and strictly adhered to the “Technical Regulation for Crustal Movement Observation of China.” The installed antennas in the first two days were identical, whereas some of the installed antennas in the last two days were changed to other types.

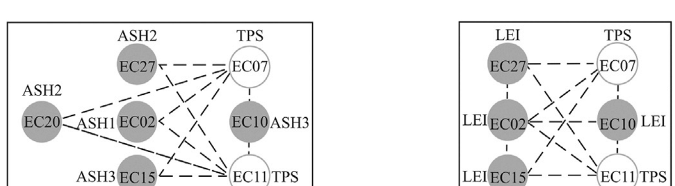
In Fig. 2, ASH1 denotes ASH700936E_C, ASH2 denotes ASH701945B_M, ASH3 denotes ASH701945C_M, TPS denotes TPS CR.G3, and LEI denotes LEI AT504. The TPS CR.G3 antenna has been used in the CMONOC II project since 2011. Therefore, we estimated the relative vertical offsets for the antennas with respect to TPS CR.G3. In the surveys conducted in the first and last two days (Fig. 2a, b, respectively), the baselines of each antenna with respect to the TPS antennas installed on the EC07 and EC11 sites were observed. The baselines between the same types of antennas, such as LEI–LEI and TPS–TPS, were also measured.

3. Results and discussions

The Bernese 5.2 software was used to process the GPS data, and the PCV.I08 model was used to correct the PCVs. Since the lengths of the baselines were very short (3–5 m), the double-difference observations can effectively eliminate the transmission errors from the satellites to the receivers, and the double-difference ambiguities of L_1 and L_2 were directly fixed.

By introducing geodetic height *H* derived from the GPS data, measured antenna height *h*, and the level height differences between the two bottom centers of preamplifier *L* into equation (2), the relative vertical offsets for any two antenna phase centers can be obtained. The results of the relative vertical offset are listed in Table 1 and shown in Fig. 3.

Although the absolute values of the PCVs have been considered in processing the GPS data, vertical offsets still exist between two antennas, as shown in Table 1 and Fig. 3. The offset for the LEI AT504 and TPS CR.G3 antennas is maximum, which reaches up to 8.4 mm. The offsets for the three ASHTECH antenna types are also different. With respect to the TPS CR.G3 antenna, the relative offset for the



a– Antennas installed in the first two days b– Antennas installed in the last two days

Fig. 2 – Installation of the GPS antennas (The dashed lines indicate the pairs of baselines).

Table 1 – Relative vertical offsets for the antenna phase centers (units: mm).

Antennas	Baseline	First day	Second day	Third day	Fourth day	Average
ASH1–TPS	EC02–EC07	−2.3	−3.0	—	—	−2.3
	EC02–EC11	−1.5	−2.2	—	—	
ASH2–TPS	EC20–EC07	−2.4	−2.7	—	—	−3.0
	EC20–EC11	−1.6	−1.9	—	—	
	EC27–EC07	−3.5	−5.1	—	—	
	EC27–EC11	−2.6	−4.3	—	—	
ASH3–TPS	EC10–EC07	6.4	4.9	—	—	5.5
	EC10–EC11	7.3	5.8	—	—	
	EC15–EC07	5.2	3.9	—	—	
	EC15–EC11	6.0	4.7	—	—	
LEI–TPS	EC02–EC07	—	—	−10.7	−8.8	−8.4
	EC02–EC11	—	—	−8.7	−9.4	
	EC10–EC07	—	—	−9.0	−7.4	
	EC10–EC11	—	—	−7.0	−8.0	
	EC15–EC07	—	—	−9.1	−7.6	
	EC15–EC11	—	—	−7.2	−8.2	
	EC27–EC07	—	—	−9.8	−7.7	
	EC27–EC11	—	—	−7.8	−8.2	
LEI–LEI	EC02–EC10	—	—	−1.7	−1.3	−1.3
	EC02–EC15	—	—	−1.6	−1.2	
	EC02–EC27	—	—	−0.9	−1.1	
TPS–TPS	EC07–EC11	−0.8	−0.8	−1.9	0.6	−0.7

Note: "—" means that no measurement was performed on this day.

ASH701945C_M is 5.5 mm, whereas those for the ASH700936E_C and ASH701945B_M are between −2 and −3 mm. The relative vertical offsets for the same type of antennas, such as the LEI AT504 and TPS CR.G3, are the smallest, which is approximately 1 mm [7].

Our results indicate that the vertical offset for LEI AT504 with respect to TPS CR.G3 can reach up to 8.4 mm. Therefore, the horizontal offsets for the different antennas with respect to TPS CR.G3 should be estimated. Unfortunately, we did not perform laser distance measurement in our experiment; thus, we did not have a "real" horizontal distance for comparison. As a result, we computed the differential horizontal distance for the baselines observed in the surveys. The results show that the horizontal offsets for the tested antennas with respect to TPS CR.G3 were not more than 0.5 mm, which is negligible.

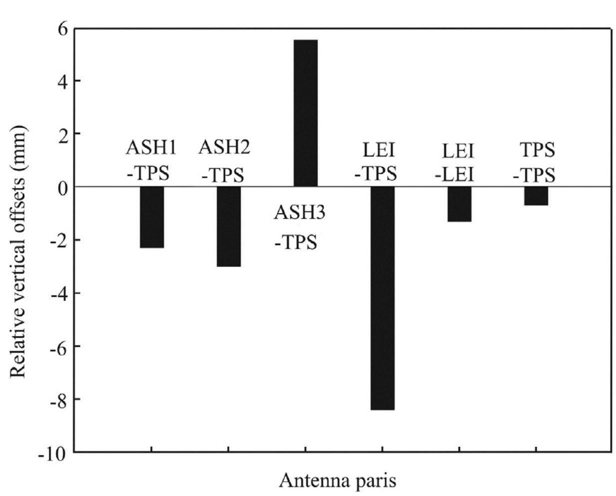


Fig. 3 – Comparison of the relative vertical offsets for the antenna phase centers.

4. Conclusion

According to the results of the five stations, we can draw the conclusion as follows:

By collecting GPS data in a network composed of GPS ultra-short baselines and considering the absolute values of PCVs, we found that relative vertical offsets still exist in several antennas in our experiment. With respect to the TPS CR.G3 antenna, the maximum offset for the LEI AT504 antenna is −8.4 mm, the secondary offset for the ASH701945C_M antenna is 5.5 mm, and the offsets for the ASH700936E_C and ASH701945B_M antennas are between −2 and −3 mm. Even in the ASHTECH antennas, differences of several millimeters exist between ASH701945B_M and ASH701945C_M. The offsets for the same type of antennas are approximately 1 mm. We also calculated the horizontal offsets for the different antennas with respect to TPS CR.G3. The results suggest that by correcting the absolute PCVs in the GPS data processing, the effect of the horizontal offset for horizontal positioning is negligible.

The relative vertical offsets obtained from our experiment can be used to correct the vertical components of a time series of campaign-mode GPS data, thus realizing high precision in crustal vertical movement. On the other hand, we should use the same type of GPS antenna as much as possible in every GPS station in different surveys during high-precision vertical crustal movement monitoring [2,6].

Acknowledgements

This study was supported by the Science for Earthquake Resilience (XH14070Y, XH15064Y) and the China National

Special Fund for Earthquake Scientific Research in Public Interest (201208009). Thanks for helpful comments provided by the reviewers.

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Hao Ming, Senior Engineer at Second Monitoring and Application Center, China Earthquake Administration. He got the doctoral degree of Geophysics from Institute of Geology, China Earthquake Administration in 2012. His research interests mainly focus on GPS and leveling data processing, applications of GPS and leveling in monitoring crustal movement, coseismic slip distribution inversion and mechanisms of postseismic deformation. By using GPS and leveling data, he has obtained the high spatial and long-term crustal vertical movement of eastern margin of Tibetan Plateau; also, he has inferred postseismic deformation mechanisms of the 1990 Mw6.4 Gonghe earthquake by using leveling data.