# Comparison of GPS Antenna Calibration Models and Their Effects in Determination of Precipitable Water Vapors

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### Abstract

To get accurate positions of GPS antennas, one should apply phase center variations (PCV) corrections in the data processing. Until recently, relative calibrations, originally proposed by National Geodetic Survey of United States, were the international standard. However, in late 2006, International GNSS Service will switch to absolute calibration methods. In this study, we compared the position differences caused by different PCV models, and their effects on the calculations of Precipitable Water Vapor (PWV) in the atmosphere. Data from ~40 permanent GPS stations in Korea were processed and we found that the vertical position differences reach up to 5 cm, depending on the model selected. Also the PWV values varied quite significantly: the maximum bias in the computed PWV values was ~4 mm.

**Keywords:** GPS, Global Positioning System, Phase Center, Water Vapor, PWV.

## 1. Introduction

Global Positioning System (GPS) has been widely accepted as an enabling technology in survey and geodesy, and the situation is similar in Korea. As the application areas of GPS expand, many of them require highly accurate positioning capability, sometimes in real-time. Especially, state-of-the-art technologies such as Real-Time Kinematic (RTK), Network RTK, and Virtual Reference System (VRS) allow one to get the centimeter-level precision in real-time surveys. To achieve this level of accuracy and precision, one has to consider all the sophisticated force and measurement models (Hatanaka et al., 2001).

Phase center variations (PCV) can cause positioning errors of several centimeters in the vertical direction, and one cannot ignore these errors in RTK. The reason is because one has to fix the integer ambiguity at each epoch, and several centimeters of positioning error from PCV should make the fixing very difficult. In the case of GPS meteorology, an accuracy of a few millimeters is required in determining Precipitable Water Vapor (PWV). In PWV calculations, a vertical positioning error of 2 cm translates into ~3 mm PWV error (Bevis, et al., 1992).

In late 2006, the new International Terrestrial Reference Frame (ITRF) 2005 will replace the ITRF 2000. Right after the new reference frame release, International GNSS Service (IGS) is planning to adapt an absolute PCV calibration model as the international standard (IGS Mail, 2006). Until now, the Korean geodetic community has been using relative PCV calibration models. Thus, one has to analyze the impact of implementing a new calibration model and take necessary steps to minimize the impact and confusion which might be caused by the change.

In this paper, we introduce the theory and concept of PCV calibrations, and then analyze the position and PWV differences caused by implementing different PCV models in GPS data processing.

## 2. Theory and Concept of PCV

In this section, explanations about Antenna Reference Point (ARP) and PCV are given. In addition, international standards of PCV calibration methods are presented.

### 2.1 ARP and PCV

ARP is the reference point for a GPS antenna, and it is usually located in the bottom part of the antenna. The three-dimensional coordinates of a GPS antenna obtained through GPS data processing refer to the ARP. But the actual location where the antenna receives GPS signals is not the ARP, but a phase center. Usually they think the geometric center of the antenna is the phase center, but it is not true. Rather, the phase center varies depending on the direction (azimuth and elevation angles) of the line-of-sight between the antenna and the satellite. These variations of a phase center are called PCV and they are different for L1 and L2 signals. The mean values of the PCV are called phase center mean offsets. Figure 1 shows the locations of the ARP and L1/L2 mean offsets for the TRM29659.00 antenna.

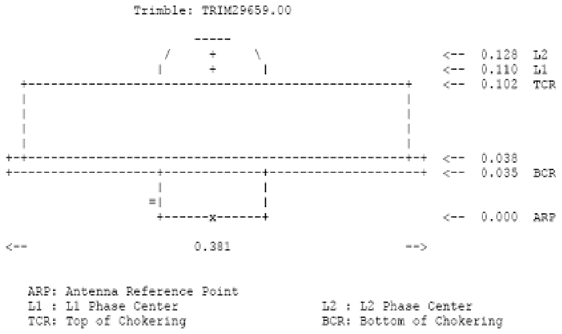

Figure 1. The ARP and L1/L2 phase center mean offsets for TRM29659.00.

Figure 2 depicts the relative geometry of the ARP and phase center mean offsets. The location of the phase center mean offset is usually given in the north, east, and up (NEU) directions relative to the ARP. The PCV is a function of azimuth and elevation angles, but it varies more significantly with the elevation angle than the azimuth angle. Thus the calibration tables are generally given as a function of elevation angles.

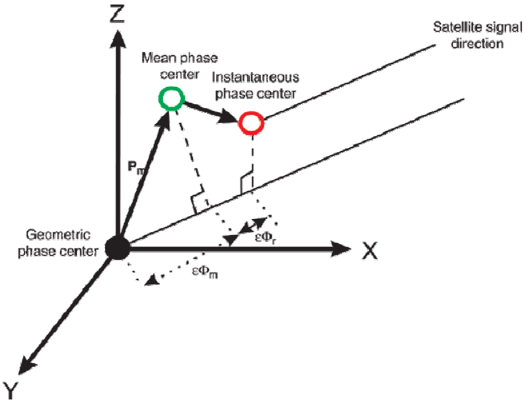

Figure 2. The ARP, phase center mean offset, and PCV (Mader and Czopek, 2002).

In Korea, they have about 80 permanent GPS stations, being operated by several governmental agencies and research institutes. Several types of GPS antennas are being used at those sites, but most of them are TRM29659.00 and TRM33429.00+GP. In this study, we investigated only those two popular types used by National Geography Information Institute (NGII) and Ministry of Government Administration and Home Affairs (MOGAHA). NGII and MOGAHA are operating 14 and 30 sites, respectively.

## 2.2 PCV Calibration Methods

GPS research groups have suggested several methods for PCV calibration, but there are only two methods that are internationally acknowledged. One is the relative calibration by National Geodetic Survey (NGS), which was adapted by IGS in 1996. The other is an absolute calibration developed by University of Hannover and Geo++ in Germany. The absolute calibration will be announced as an international standard in late 2006.

### *Relative Calibration*

The relative calibration is conducted at the NGS Corbin Facility (refer to Figure 3). Two concrete pillars of 1.5 meters height are separated by ~5 meters. The ground is grass and the nearest building is a one-story building about 21 meters away (Mader, 1999). This environment of a grassy ground and no-nearby-buildings is one of the best ones for multipath reduction. On one of the two pillars is located the AOAD/M_T antenna, which is considered to be free from PCV errors. The antenna to be calibrated will be installed at the other pillar. The positions of the pillars are known very accurately from other surveys. Then, the positions of the two antennas are estimated from L1 and L2 observations and the residuals from the known coordinates are regarded as the effects of PCV. A fourth-order polynomial is fitted to the residuals to produce the PCV calibration table as a function of elevation angles. The tropospheric and ionospheric errors are assumed negligible because the distance between the two antennas is only 5 meters.

The problem with relative calibration arises from the fact that it assumes that the reference antenna AOAD/M_T is free from PCV. The neglected PCV of the reference antenna will propagate into the test antenna's PCV. In addition, relative calibrations do not provide the calibration values under the elevation angle of 10 degrees. Also, the facility's environment is not perfectly free from multipath errors. For these reasons the idea of absolute calibration came along.

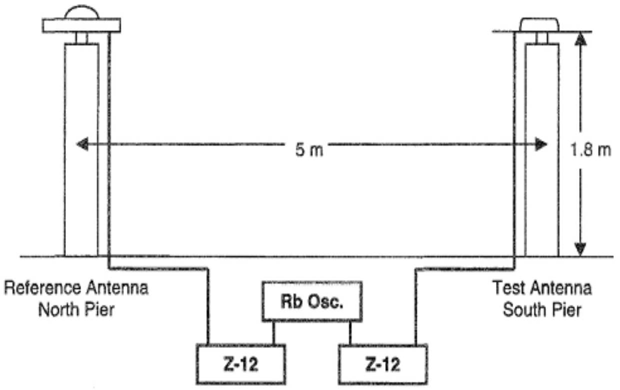

Figure 3. The relative calibration test at the NGS Corbin Facility (Mader, 1999).

### *Absolute Calibration*

The absolute calibration methods were developed by the University of Hannover and Geo++ in the late 1990's (Wübbena et al., 2000). Absolute calibrations are produced using the robot arm, the test antenna being attached at the end of the arm (refer to Figure 4). The robot arm tilts and rotates the antenna and collect measurements in every possible combination of azimuth and elevation angles. The multipath effects are eliminated by the formula in Seeber et al. (1998).

Figure 4. The robot arm for absolute calibration.

The major advantage of absolute calibration is the fact that it can compute calibration values even for elevation angles under 10° and that it catches the small variations in the azimuth angles. As in the relative calibration, absolute calibration provides calibration tables for L1 and L2 signals separately.

## 3. Comparison of PCV Calibrations

As described earlier, most of the permanent GPS stations in Korea are equipped with TRM29659.00 and TRM33429.00+GP. The position differences caused by different PCV calibration models were evaluated through GPS data processing. The GPS data were processed using GIPSY-OASIS II developed by Jet Propulsion Laboratory (Webb and Zumberge, 1997). The standard precise point positioning techniques were employed (Zumberge et al., 1997). All the processing procedures and parameters were unchanged except for PCV models. Thus the choice of PCV models should be the only cause of the resulting position and PWV differences. In this comparison, the relative model chosen is the NGS one (Mader, 1999) and the absolute model is igs05_1365.atx (IGS Mail, 2006).

Four different test cases were designed as in Table 1. T1 and T2 cases consider the phase center mean offset only, so the variations are ignored. T3 and T4 consider both the mean offsets and variations. Currently either T1 or T3 calibration is the standard procedure in the Korean geodetic community.

The data from 14 NGII and 30 MOGAHA sites were used in the analysis. The data spans 10 days; July 19 through 28, 2003. The data sampling was 30 seconds and 24-hour data were processed to get daily coordinates. The daily three-dimensional positions were obtained in the ITRF2000, and then transformed into the local NEU (North-East-Up) frame.

Table 1. PCV calibration methods

| Test Scheme | Mean Offset | PCV |
|---|---|---|
| T1 | Relative | × |
| T2 | Absolute | × |
| T3 | Relative | Relative |
| T4 | Absolute | Absolute |

## 4. Results and Discussion

Figure 5 shows the histogram of the position differences due to different PCV models for 14 NGII sites, and Figure 6 for 30 MOGAHA sites. T1-T3 and T2-T4 depict the cases where the only difference is the presence/absence of the PCV calibration. T3-T4 is for the absolute calibration and therefore the change of the coordinates is due to the PCV. T1-T4 is the difference between the most fundamental relative calibration method considering only relative mean offsets and the most advanced absolute calibration considering both the mean offsets and the PCV. Because the Korean geodetic community employs either T1 or T3 methods, T1-T4 and T3-T4 in Figures 5-6 should be of primary interest when the community switches to T4 in late 2006.

The average values of position differences in Figures 5 and 6 are listed in Table 2. The mean values are slightly different for NGII and MOGAHA sites, and the reason is because their antenna types are not the same.

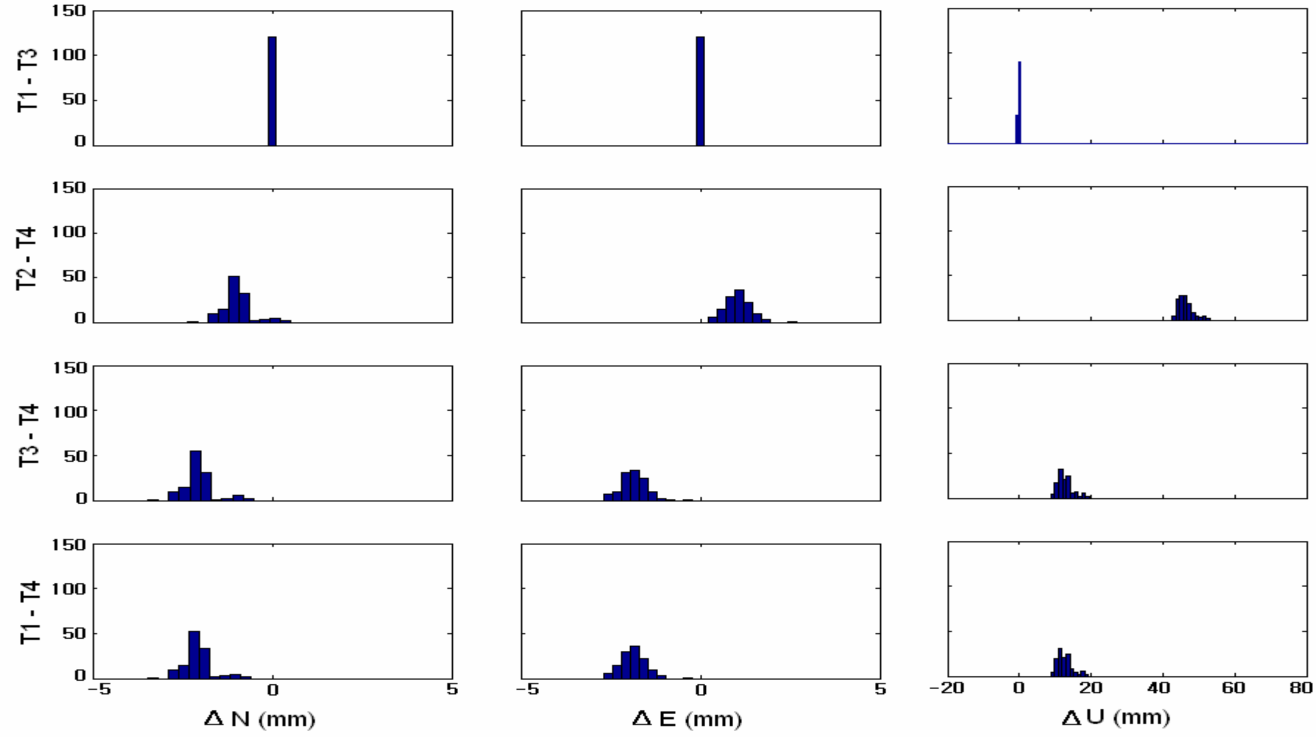

Figure 5. The histogram of position differences (NGII).

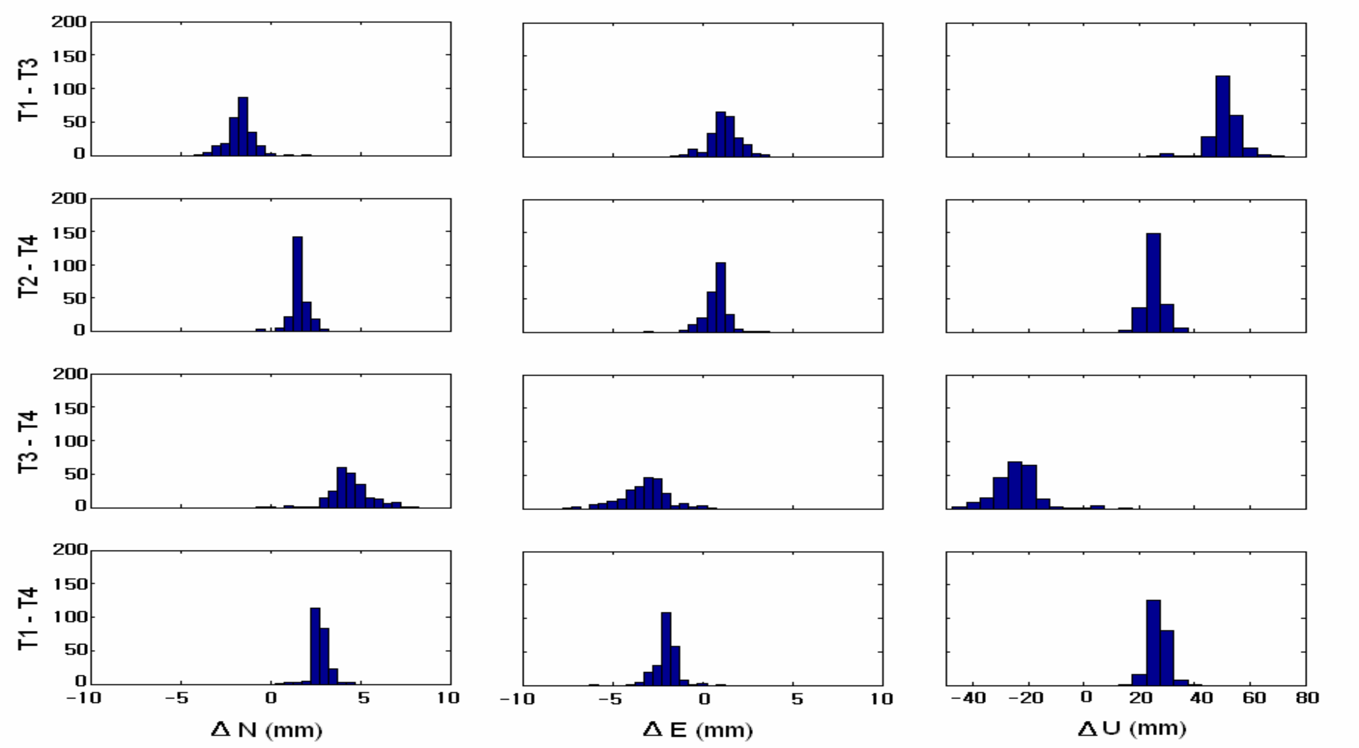

Figure 6. The histogram of position differences (MOGAHA).

Table 2. Average values of position differences.

| | NGII | | | MOGAHA | | |
|---|---|---|---|---|---|---|
| | ΔN (mm) | ΔE (mm) | ΔU (mm) | ΔN (mm) | ΔE (mm) | ΔU (mm) |
| T1-T3 | 0.0 | 0.0 | -0.2 | -1.7 | 1.2 | 51.0 |
| T2-T4 | -0.9 | 1.0 | 46.4 | 1.6 | 0.8 | 25.3 |
| T3-T4 | -2.0 | -1.9 | 12.8 | 4.5 | -3.2 | -24.2 |
| T1-T4 | -2.0 | -1.9 | 12.6 | 2.8 | -2.0 | 26.7 |

To analyze the impact of PCV models on the calculated PWV values, we did choose one site each from the NGII and MOGAHA GPS network. SEOS is the NGII site located in Seosan, and the YANP is the MOGAHA station in Yangpyeong. We processed only one day of data (July 19, 2003) and evaluated T1-T4 and T3-T4 cases. Figure 7 shows the differences in PWV; the blue solid line is for T3-T4 and the red dotted line for T1-T4. For visual comparison, the scales on the y-axis in the two figures were set to be equal.

SEOS shows very similar trends for the two cases and the RMS values are 2.6 mm for both T1-T4 and T3-T4. However, the differences for YANP are quite dissimilar: the RMS values for T3-T4 and T1-T4 are 4.0 and 0.8 mm, respectively. As noted earlier, the accuracy of PWV computation required for GPS meteorology is about 1-2 mm. Thus, for accurate determination of the PWV, a thorough analysis for the observed discrepancy is required.

One of the reasons for the rather large differences observed in the position and PWV estimates can be attributed to in-correct GPS satellite phase center models (Mader and Czopek, 2002). IGS recommends using GPS satellites phase center models along with the ground receiver phase center models (IGS Mail, 2006). Without implementing the appropriate satellite phase center models, the scale of the terrestrial reference frame can suffer from significant biases. However this study did not consider satellite phase center models yet, which we are planning to do in the near future.

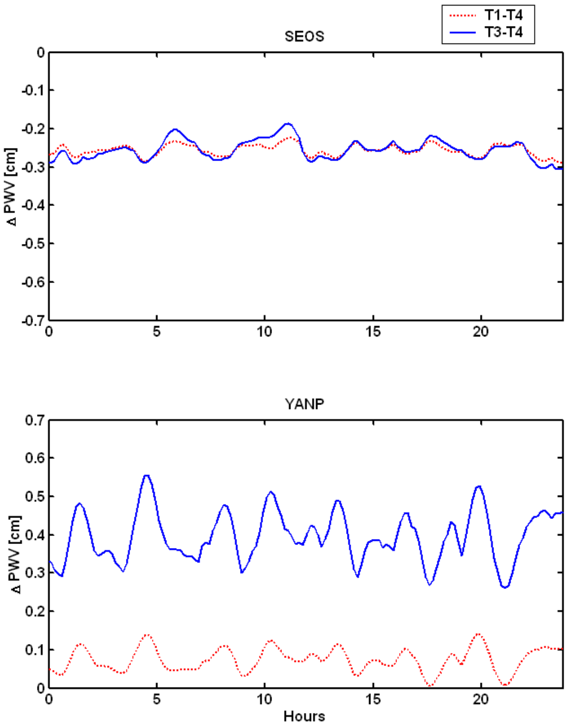

Figure 7. PWV differences for T1-T3 and T1-T4 cases.

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