JOURNAL OF APPLIED ENGINEERING SCIENCES
ISSN: 2247-3769 / e-ISSN: 2284-7197

VOL. 6(19), ISSUE 1/2016
ART.NO. 206, pp. 71-76

THE INFLUENCE OF ZENITH TROPOSPHERIC DELAY ON PPP-RTK

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Received: 02.02.2016 / Accepted: 03.03.2016 / Revised: 20.05.2016 / Available online: 31.05.2016

DOI: 10.1515/jaes-2016-0010

KEY WORDS: PPP-RTK, zenith tropospheric delay, GPT2 model, RMS

ABSTRACT:

The PPP technique is more and more used in different GPS precise application. The PPP precision is related to many factors and the most important are: the number of satellites, the ambiguity resolution, the ability to model the ionospheric and tropospheric delays, solid earth and ocean tides, relativistic effects and antenna phase-center offsets and variations. The article is studying the effect of the zenith tropospheric delay (ZTD) using the GPT2 model and then computing in static mode the ZTD, which is than applied on PPP-RTK method. An analysis on dual frequency ionospheric–free phase combination (LC) and dual frequency ionospheric–free range combination (PC) was made in the first stage and then comparing the two solutions relative to the nominal position. The results revealed the fact that by using the ZTD determined in static mode in the detriment of ZTD from GPT2 model, the results are improving on North, East and Up position components. Also lower RMS was obtain when we used the ZTD from static mode comparative to the GPT2 model.

1. INTRODUCTION

The coordinates of a GPS receiver can be determined by using the absolute positioning technique and relative positioning. The absolute positioning method bears the name of single point positioning (SPP). In this method only one GPS receiver it is used. In the case of relative positioning two GPS receivers are used, from which one is considered to be the reference station. The coordinates of the second GPS receiver are with respect to the reference station. This method is also known as differential positioning technique. The main advantage of this methods is that it is able to cancel the common GPS receiver and satellite clock errors, where the errors introduced by the GPS segment is eliminated by using the precise orbit information (Héroux and Kouba 2001). The main drawback of this method is that we have to use at least two GPS receivers at the same time and the distance between the two receivers shouldn't be too long due to the fact that is recommended that the observations to be approximately from the same satellites.

The International GNSS Service (IGS)(Dow, Neilan, and Rizos 2009) and other organization made available and free of charge the precise orbits and satellite clock correction to improve the accuracy of the GPS determination especially when they are used in single point positioning method. The method that uses this correction and many others together with the un-differenced pseudorange and carrier phase measurements in the estimation process takes the name of Precise Point Positioning technique (Zumberge et al. 1997). In the PPP method we are able to obtain centimeter and even millimeter accuracy and thus we can used it in a large number of applications: navigation, geodynamics (S Nistor and Buda 2016), atmospheric water vapor determination (S Nistor and Buda 2015) and many other application (Li, Li, and Gao 2015).

The accuracy of the PPP method is strongly related to the observation time span of the GPS receivers (Grinter and Janssen 2012) (Dawidowicz and Krzan 2014). By using the ionospheric correction from, e.g., Global Ionospheric Maps (Øvstedal 2002) we are able to obtain a position accuracy at a level of a few decimeters after 15 minutes by using a single

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GPS receiver (Banville et al. 2014). If the ionospheric correction are absent, by using the dual frequency ionospheric–free phase combination (LC) and dual frequency ionospheric–free range combination (PC), the PPP method can obtain centimeter level accuracy but it is required a longer observation time span – at least one hour (Banville et al. 2014).

In the last years several scientist proposed different methods for integer ambiguity resolution for PPP method for which a critical review was presented by (Teunissen and Khodabandeh 2015). Like the RTK method, the PPP-RTK aims at obtaining centimeter level accuracy by resolving the phase ambiguity in the single receiver observation by using the satellite phase and code biases (Ge et al. 2007) (Collins et al. 2010) (Geng et al. 2011) (Odijk et al. 2016). The necessary corrections are determined in a global or regional reference GPS network. To obtain reliable estimates integer ambiguity needs to be resolved (S Nistor and Buda 2015). Also a certain verification principles it is recommended to be applied to test the quality of the data (Suba and Suba 2015).

The PPP method it is been widely used in meteorological application due to the fact that there is no need of baseline length constraint and calibration like in the case of relative positioning. The problem arises from the fact that in PPP, the tropospheric estimates are greatly affected by the fractional ambiguity parts. In the case that a successfully ambiguity resolution has been made, the tropospheric estimates are determined more accurately.

2. MATERIALS AND METHODS

In the conventional method the tropospheric zenith wet delay (ZWD) is estimated only instead of the zenith total delay (ZTD). For this approach to work, requires the troposphere zenith hydrostatic delay to be calibrated in advance (Shi and Gao 2014). Different tropospheric models can be applied for the determination of the troposphere zenith hydrostatic delay such as Saastamoinen model(Saastamoinen 1973).

The environment at the observation site is a determining factor for the tropospheric convergence. The integer ambiguity resolution will not lead promptly to the convergence of the tropospheric parameters. After fixing the ambiguity parameters to their integer values, the tropospheric convergence can be speed up, due to the fact that this convergence requires considerable time, for example longer than one hour. The problem arises because the tropospheric residuals delay will degrade other unknown parameters (Shi and Gao 2014).

The equation for total tropospheric delay (ZD) is given by:

$$T = T_{hyd}^{ZD} * m_{hyd} + T_{wet}^{ZD} * m_{wet} \tag{1}$$

where T_{hyd}^{ZD} is the hydrostatic delay which is dependent on the surface pressure. Usually this part of the total tropospheric delay can be estimated at millimeter level. The T_{wet}^{ZD} is the wet delay which is dependent on the distribution of water vapor in the atmosphere; m_{hyd} and m_{wet} are functions that scale the hydrostatic and wet zenith delays to corresponding slant delays.

The tropospheric delay residuals represent the remaining part of the tropospheric delay which is not estimated by the empirical models. In high accuracy GPS applications this residuals can be considered the largest remaining error source. It is recommended longer time spans of the observation for estimating the tropospheric delay residuals due to the fact that over short time spans there is a strong correlation between the partial derivatives of the tropospheric delay and height.

3. NUMERICAL RESULTS AND ANALYSIS

In the experimental part we have studied the influence of the zenith tropospheric delay (ZTD) which was determined by using the GPT2 model and the ZTD computed in static mode for the station BACA, which were applied to PPP-RTK method. The station BACA is part of the EUREF Permanent Network (EPN) and also part of the Romanian Position Determination System (ROMPOS). The computation was done with the help of the Jet Propulsion Laboratory’s (JPL) software GIPSY/OASIS II (Zumberge et al. 1997).

The processing contained the following settings: the type of the processing was done on PPP-RTK mode with an elevation cutoff of 15^0 and the RINEX file contained only GPS data. For ambiguity resolution was used the wide-lane and phase bias information from JPL and the itineration was set to two. Precise ephemeris and clock information was downloaded from JPL site. The interval for processing was set to 300 seconds.

In the first part of the experiment the data was process in static mode to obtain the zenith tropospheric delay. The zenith tropospheric delay was computed in two ways: using the information from GPT2 resulting the zenith dry delay and wet delay. Second the dry and wet delay was computed using the static mode. The dry and wet tropospheric delays resulted by using the GPT2 model, was combined and then the same procedure was applied to the data resulted by using the static mode.

In the second part of the experiment the processing was done in PPP-RTK mode. The zenith tropospheric delay computed by using the GPT2 model was applied on PPP-RTK method and then the zenith tropospheric delay resulted from static mode were used by the estimator. Their influence is analyzed on LC and PC postfit residuals. The results are presented in Figure 1.

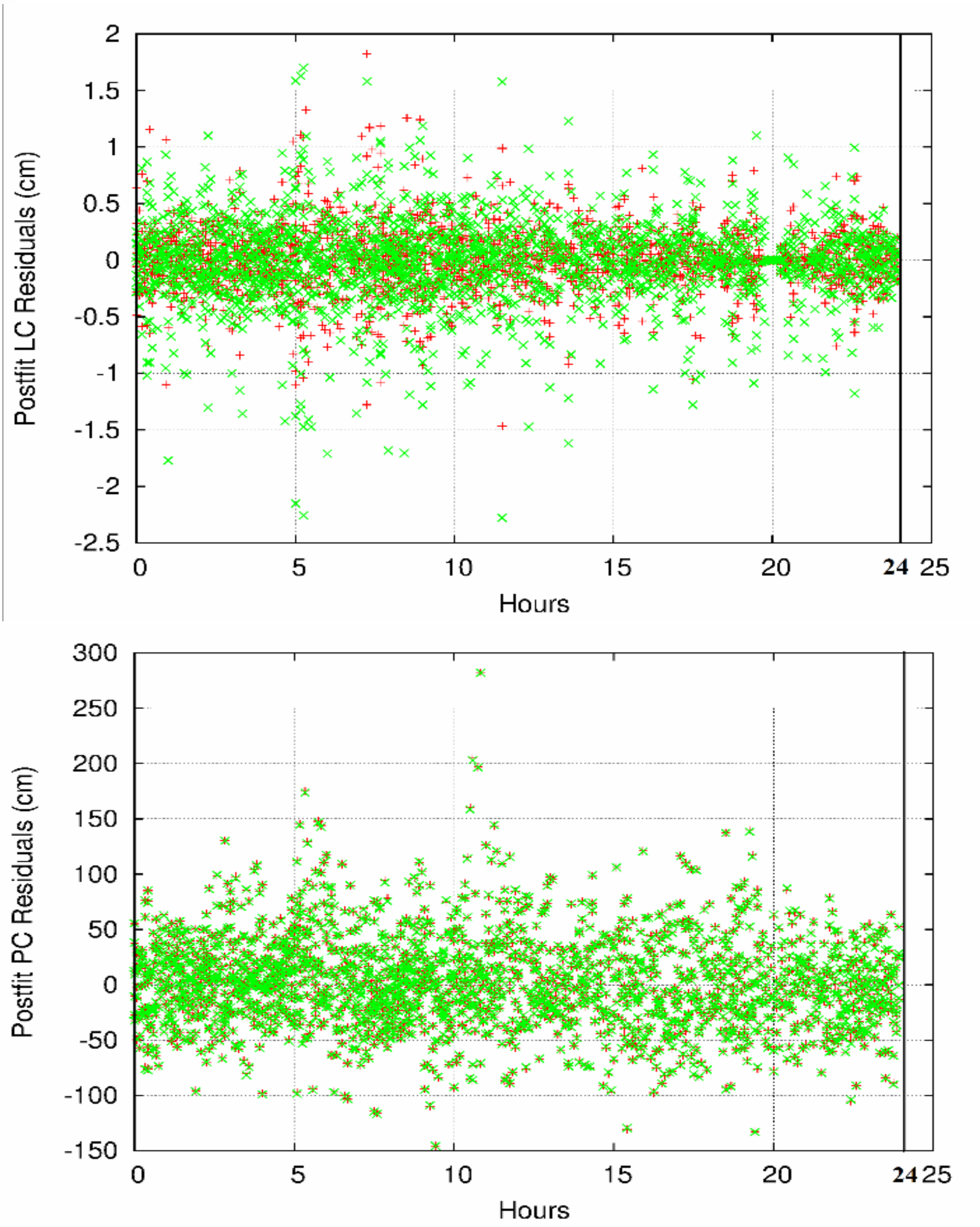

Figure 1. The influence of the ZTD computed using the GPT2 model and static mode on LC and PC postfit residuals

The left part of the plot is presenting the LC postfit residuals and the right part of the plot is presenting the PC postfit residuals. The green points represents the data resulted by using the zenith tropospheric delay from the GPT2 model and the red points represents the data by using the zenith tropospheric delay from the static mode. It can be observed from the plot that by using the static mode for computing the zenith tropospheric delays and applying the information in PPP-RTK the scatter of the LC postfit residuals was improved. The LC postfit residuals for the data in which the ZTD from the static mode were used generated a result of 3.32 mm and in the case were the GPT2 model was employed, the LC postfit residuals was 4.51 mm. In both cases by using the ZTD no outliers were detected for both LC and PC. In the case of LC postfit residuals the scatter is higher in the first half of the day. In the case of PC postfit residuals there is no noticeable differences: in the case that we have used the ZTD resulted from GPT2 model the PC postfit residuals presented a value of 41.388 cm which was lower than in the case that we have used the ZTD from static mode where the PC postfit residuals were 41.436. In this case the higher scatter was in the first half of the day. Although there is a difference by employing the ZTD from the GPT2 mode and the ZTD computed in static mode, the improvement of the LC postfit residuals is 1.18 mm. This is a proof of the advantage created by the ZTD computed in the static mode compared with the ZTD computed by using the GPT2 model. Also the troposphere and clock is more correlated with the position in the PPP-RTK than static and that is way it is recommended to provide nominal ZTD in the PPP-RTK mode.

In the second part of the analysis we have compared the solution in both cases – using the ZTD computed by employing the GPT2 model and ZTD computed in static mode - relative to the nominal position, in which the nominal position were the coordinates taken from the RINEX file. In this part the nominal troposphere – the ZWD and ZHD from the static solution is combined together. The results for North, East and Up component is presented in Figure 2.

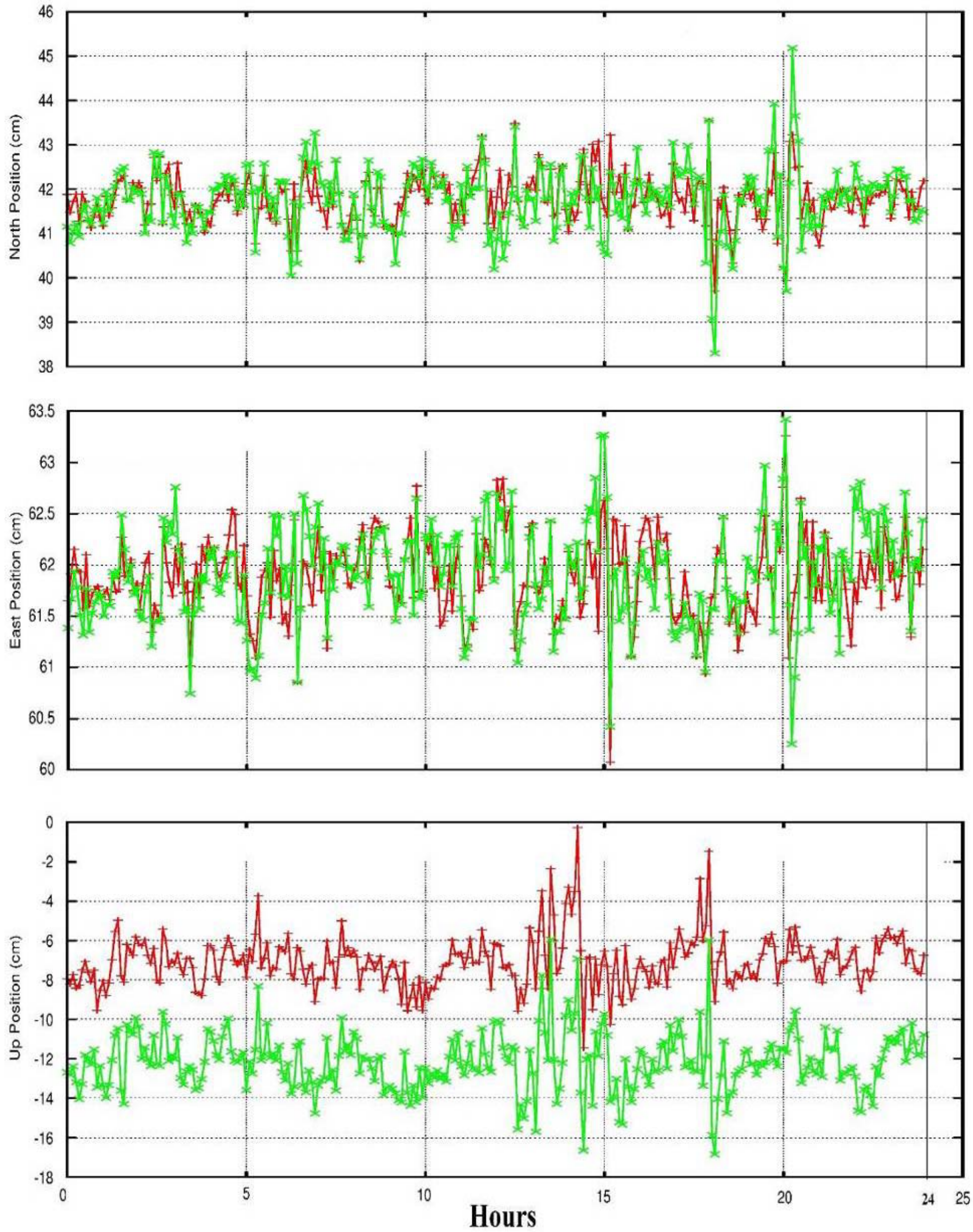

Figure 2. The influence of the ZTD computed using the GPT2 model and static mode on North, East and Up component

The upper part of the plot is presenting the difference on North position between the data resulted by using the data from GPT2 model and the results obtain with the help of the tropospheric delays computed in static mode; the plot form the middle and the lower part, presents the differences for the East respectively Up component. These differences are in centimeters. The green line represents the data resulted by using the zenith tropospheric delay from the GPT2 model and the red line represents the data by using the zenith tropospheric delay from the static mode. In the upper part of the plot it is presented the differences between the North component resulted by using the ZTD from GPT2 model and the ZTD from static mode. The largest difference between the mean and individual values for PPP-RTK when the ZTD from GPT2 was used, in the North component presented 3.41 cm at approx. 18 and 20 hours from the beginning. Only four times the PPP-RTK on the entire 24 hours presented more than 3 cm variation. The highest difference between the mean and individual values for PPP-RTK, when the ZTD from static mode was used, for the North component presented only 2.1 cm at approx. 18 hours from the beginning. It can be seen from the upper part of the plot that the ZTD from static mode has positive impact on the North component, thus creating an improvement of the results. The RMS for the North component was 0.74 cm in case that the ZTD from GPT2 model has be used, where the RMS for the North component were 0.55 cm in case that the ZTD from static mode were used.

The largest difference between the mean and individual values for PPP-RTK when the ZTD from GPT2 was used, for the East component was 1.8 cm at approx. 20 hours from the beginning – middle part of the plot. Only four times the PPP-RTK on the entire 24 hours, presented more than 1.3 cm variation. The highest difference between the mean and individual values PPP-RTK, when the ZTD from static mode was used, for the East component presented 1.8 cm at approx. 15 hours from the beginning. It can be seen from the middle part of the plot that the ZTD from static mode has positive impact on the East component. The RMS for the East component was 0.47 cm in case that the ZTD from GPT2 model has be used, where the RMS for the North component were 0.40 cm in case that the ZTD from static mode has be used. Although the result by using ZTD from static mode presented the same value as by using ZTD from GPT2, this extreme value took place only once on the entire period – the scatter of the data presented a lower value.

The highest difference between the mean and individual values for PPP-RTK when the ZTD from GPT2 was used, in the Up component presented a value of 6.1 cm at approx. 14 hours and also 17 hours from the beginning – bottom plot from Figure 2. Only four times the PPP-RTK on the entire 24 hours presented more than 4.5 cm variation. The highest difference between the mean and individual values for PPP-RTK, when the ZTD from static mode was used, for the Up component presented 6.8 cm at approx. 14 hours from the beginning. It can be seen from the bottom part of the plot that the ZTD from static mode has positive impact on the East component. Only two times the PPP-RTK on the entire 24 hours, presented more than 4.5 cm variation. Although the result by using ZTD from static mode presented a higher value than by using ZTD from GPT2, this extreme value took place only once on the entire period – the scatter of the data presented a lower value. The RMS for the Up component was 1.49 cm in case that the ZTD from GPT2 model has be used, where the RMS for the North component were 1.29 cm in case that the ZTD from static mode has be used. A bias for the Up component can be observed from the plot that has been introduced to a better visual inspection of the data.

It can be seen from Figure 2 that the highest variation of the coordinates for North and East component appeared approx. on the same time, for both ZTD used from GPT2 and static mode. For the Up component the variation for the results generated by using the ZTD from GPT2 model presented the highest variation as in the case where the ZTD from static mode were employed in the computation – approx. 14 hours from the beginning. It can be seen that the variation for the Up component tends to be same on for both ZTD – from GPT2 and static mode.

4. CONCLUSIONS

The main idea of this article is to test the influence of the ZTD from GPT2 model and ZTD computed from static mode on PPP-RTK method. Their influences are first analyzed on dual frequency ionospheric–free phase combination (LC) and dual frequency ionospheric–free range combination (PC). The difference of LC postfit residuals were 1.18 mm and on PC postfit residuals the difference were 0.048 cm. The effect of the troposphere delay on the North, East and Up component using the ZTD computed by the GPT2 model and static mode was also investigated. The results presented an improvement of the RMS in the case that the ZTD computed by using the static mode was applied on PPP-RTK technique. The RMS for the North component was 0.55 cm, for East component 0.40 cm and for the Up component the RMS presented a value of 1.29 cm.

The improvement of the accuracy on all three components recommends that in the estimation process of PPP-RTK, nominal tropospheric delay should be provided.

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