ESTIMATION TROPOSPHERE DELAY FOR GBAS REFERENCE STATIONS

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Summary. Results of research concerning to determination parameter of troposphere delay for GBAS (Ground Base Augmentation System) reference stations are presented in this paper. The parameter of troposphere delay was designated using PPP method in CSRS-PPP and magicPPP softwares. This paper presents and compares results of Zenith Total Delay as a parameter of troposphere delay. The mean difference of ZTD parameter between CSRS-PPP and magicPPP solution amounts to: 7.7 mm for REF1 reference station, -23.6 mm for VirA reference station, -29.5 mm for VirB reference station, respectively.

Key words: GBAS system, troposphere delay, GPS, PPP method

1. INTRODUCTION

Since a few years the Precise Point Positioning (PPP) method has been implemented in kinematic positioning in area of air navigation. The aircraft position in air navigation can be modeled with high accuracy using PPP method. The typical accuracy of aircraft coordinates is higher than 0.1 m after few minutes of kinematic test. The PPP method also guarantee to determine another products of GNSS satellite positioning, such as: ambiguity parameter for each satellite, receiver clock bias, Zenith Wet Delay (ZWD) as a component of troposphere delay[1].

The total troposphere delay parameter is designated by Zenith Total Delay (ZTD) in PPP method. The Zenith Total Delay parameter is a function of Zenith Hydrostatic Delay (ZHD) and Zenith Wet Delay[2]. The Zenith Total Delay parameter can also included the horizontal gradients in direction to North and East, G_N and G_E terms respectively[3]. The Zenith Hydrostatic Delay component is usually determined using empirical models of troposphere delay. The Zenith Hydrostatic Delay parameter is designated based on surface meteorological data (e. g. temperature and pressure)[4]. The term of Zenith Wet Delay is estimated as a random walk process in stochastic model of PPP method[5].

In this paper, the Zenith Total Delay parameter is estimated for GBAS reference stations. The Zenith Total Delay parameter was calculated as a sum of ZHD deterministic term and ZWD stochastic

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[2] Kleijer F.: Troposphere modeling and filtering for precise GPS leveling, Ph.D. thesis, Delft University of Technology, ISBN 90-6132-284-7, 2004.

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term. The computation was conducted for REF1, VirA and VirB reference stations in research experiment. The article was divided into 5 sections: introduction, methodology of research, research experiment, results and discussion, conclusions.

2. METHODOLOGY OF RESEARCH

The observation model of PPP method is based on „Ionosphere-Free" linear combination as below[6,7,8]:

$$\begin{aligned} P_3 &= \alpha \cdot P_1 + \beta \cdot P_2 = d + c \cdot (dtr - dts) + \mathrm{Re}l + Trop + MP_3 + \varepsilon_{P3} \\ L_3 &= \alpha \cdot L_1 + \beta \cdot L_2 = d + c \cdot (dtr - dts) + \mathrm{Re}l + Trop + B_3 + \delta_{wu} + ML_3 + \varepsilon_{L3} \end{aligned} \quad (1)$$

where:

P_3 - „Ionosphere-Free" linear combination for code measurements in GNSS system,
L_3 - „Ionosphere-Free" linear combination for phase measurements in GNSS system,
P_1, P_2 - code observations in GNSS system,
L_1, L_2 - phase observations in GNSS system,
α = 2.546 (e.g. in GPS system),
β = -1.546 (e.g. in GPS system),
$d = \sqrt{(x - X_S)^2 + (y - Y_S)^2 + (z - Z_S)^2}$,
d - geometric distance between satellite and receiver,
(x, y, z) - receiver coordinates in geocentric frame,
(X_S, Y_S, Z_S) – satellite coordinates in geocentric frame,
c - speed of light,
dtr - receiver clock bias,
dts - satellite clock bias,
Rel - relativistic effect,
Trop - troposphere delay,
B_3 - ambiguity term,
δ_{wu} - phase wind-up,
MP_3 - multipath effect for code measurements,
ϵ_{P3} - measurement noise for code observations,
ML_3 - multipath effect for phase measurements,
ϵ_{L3} - measurement noise for phase observations.

The troposphere delay term in equation (1) can be expressed as below:

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[6] Krasuski K., Jafernik H.: Zastosowanie obserwacji GLONASS w eksperymencie lotniczym w Mielcu, Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska, nr 2, str. 83-88, DOI: 10.5604/20830157.1201323, 2016.

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$$Trop = SHD + SWD \tag{2}$$

where:

SHD - Slant Hydrostatic Delay,
SWD - Slant Wet Delay.

The SHD and SWD parameters are described using mathematic formula in equation (3):

$$\begin{aligned} SHD &= mf_{HYD} \cdot ZHD \\ SWD &= mf_{WET} \cdot ZWD \end{aligned} \tag{3}$$

where:

mf_{HYD} - mapping function for ZHD term,
ZHD - Zenith Hydrostatic Delay,
mf_{WET} - mapping function for ZWD term,
ZWD - Zenith Wet Delay.

The total value of troposphere delay on zenith direction is called as a Zenith Total Delay (ZTD) and calculated in equation (4):

$$ZTD = ZHD + ZWD \tag{4}$$

The total number of unknown parameters from equation (1) equals to:

- 3 parameters corresponded to coordinates of reference station,
- 1 parameter as a receiver clock bias,
- 1 parameter as a Zenith Wet Delay,
- ambiguity term is estimated for all satellites in each measurement epoch.

The unknown parameters in equation (1) are modeled in stochastic processing in PPP method as follows:

- coordinates of reference station are estimated using random walk process,
- receiver clock is estimated using white noise process,
- Zenith Wet Delay is estimated using random walk process,
- ambiguity parameter is estimated using random walk process.

3. THE RESEARCH EXPERIMENT

The Zenith Total Delay parameter was estimated for 3 reference stations of GBAS augmentation system, e. g. REF1, VirA and VirB. The localization of reference stations was presented into Figure 1.

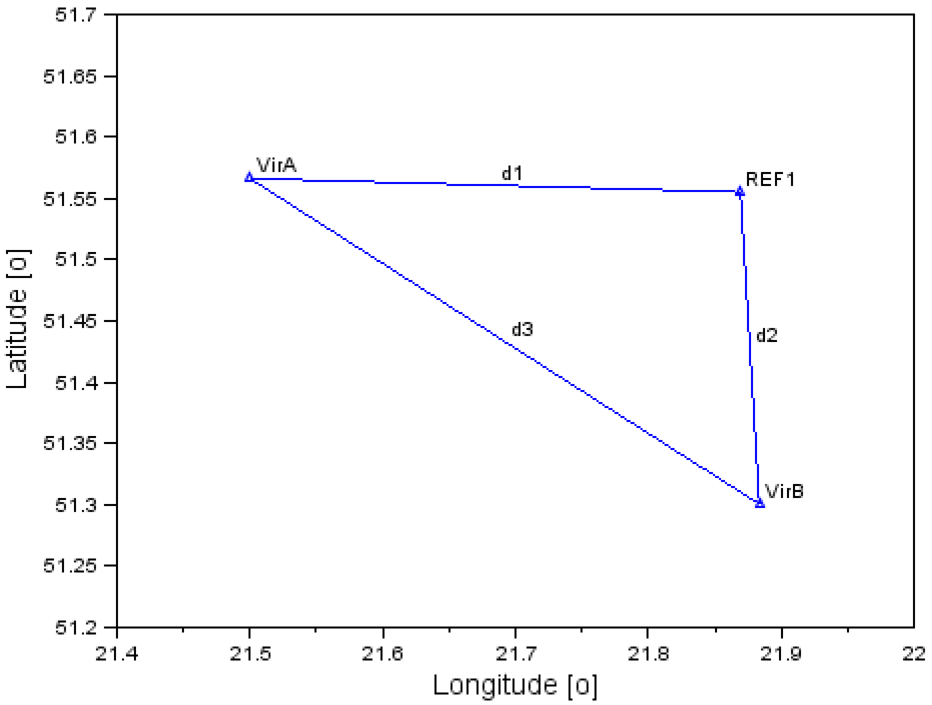

Figure 1 The localization of reference stations in GBAS augmentation system

The length distance between reference stations equals to:

- 25.616 km between REF1 and VirA (distance d1),
- 22.253 km between REF1 and VirB (distance d2),
- 35.338 km between VirA and VirB (distance d3).

The dual-frequency receiver was installed in each reference station as follows[9]:

- the Trimble NETRS was installed at VirA reference station,
- the Trimble NETRS was installed at VirB reference station,
- the Topcon TPS Hiper was installed at REF1 reference station.

The precise coordinates of each reference station were expressed in ETRF'89 geocentric and geodetic frame. The 3 reference stations were utilized during flight test in Dęblin military aerodrome on 1[st] of June 2010. The Cessna 172 airplane position was determinated and accuracy of aircraft coordinates were also designated during the flight test. The reference stations of GBAS augmentation system were applied for recovery of aircraft position using RTK-OTF technique in post-processing mode. The average accuracy of aircraft position in RTK-OTF technique equals up to 3 cm for horizontal coordinates and about 7 cm for vertical plane[10].

[9] Ćwiklak J., Jafernik H.: The monitoring system for aircraft and vehicles of public order services based on GNSS, Annual of Navigation, 16, pp. 15-24, 2010.

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The Zenith Total Delay as a troposphere parameter was calculated for each reference station based on equation (4). The values of Zenith Total Delay term was designated using CSRS-PPP and magicPPP softwares [6] in sample rate of 30 s. The results of Zenith Total Delay term for each reference station were presented into Figure 2, 3 and 4.

4. RESULTS AND DISCUSSION

The Figure 2 presents results of Zenith Total Delay term for REF1 reference station based on CSRS-PPP and magicPPP solutions. The average value of ZTD component from CSRS-PPP software is around 2445 mm, with range between 2390 mm and 2513 mm. The magnitude order of ZTD term from magicPPP solution equals to 2430 mm and 2441 mm, whereas the average value is around 2437 mm. The median value of ZTD parameter equals up to 2438 mm in magicPPP software and 2441 mm in CSRS-PPP software, respectively.

The Figure 3 presents values of ZTD parameter for VirA reference station. The average value of ZTD term from CSRS-PPP software equals 2414 mm, with range between 2362 mm and 2530 m. The mean result of ZTD parameter from magicPPP software equals to 2437 mm, with range between 2434 mm and 2440 m. The median value of ZTD parameter equals up to 2420 mm in CSRS-PPP software and 2437 mm in magicPPP software, respectively.

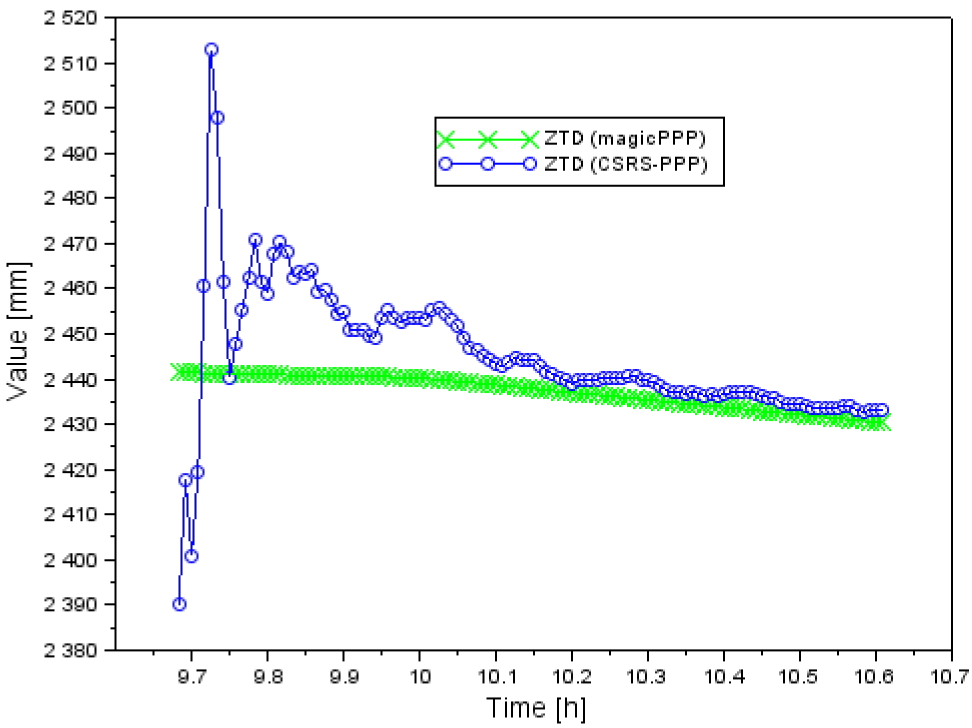

Figure 2 The results of ZTD parameter for REF1 reference station

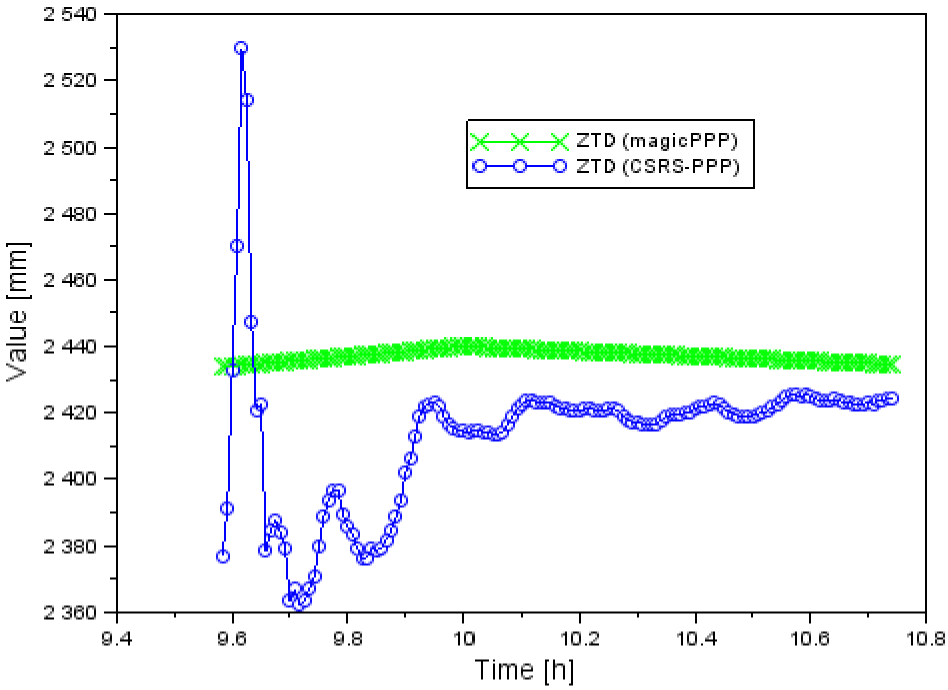

Figure 3 The results of ZTD parameter for VirA reference station

The Figure 4 presents results of ZTD term for VirB reference station. The average value of ZTD parameter in CSRS-PPP solution is about 2407 mm, with range between 2249 mm and 2426 m. The magnitude order of ZTD term in magicPPP solution equals 2428 mm and 2442 mm, whereas the average value is around 2437 mm. The median value of ZTD parameter equals 2420 mm in CSRS-PPP software and 2438 mm in magicPPP software, respectively.

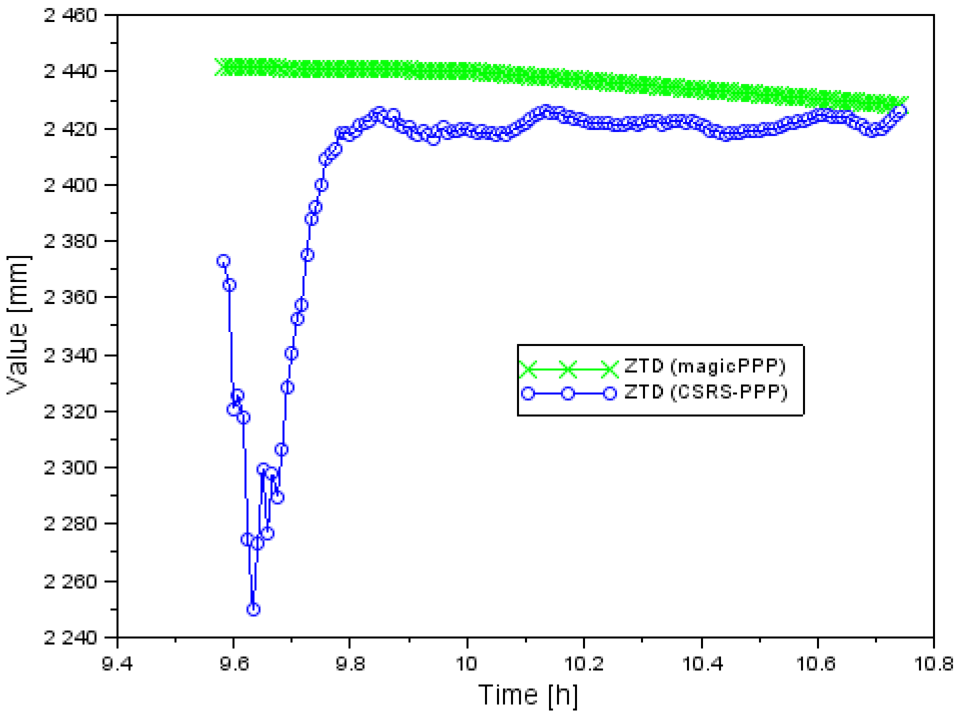

Figure 4 The results of ZTD parameter for VirB reference station

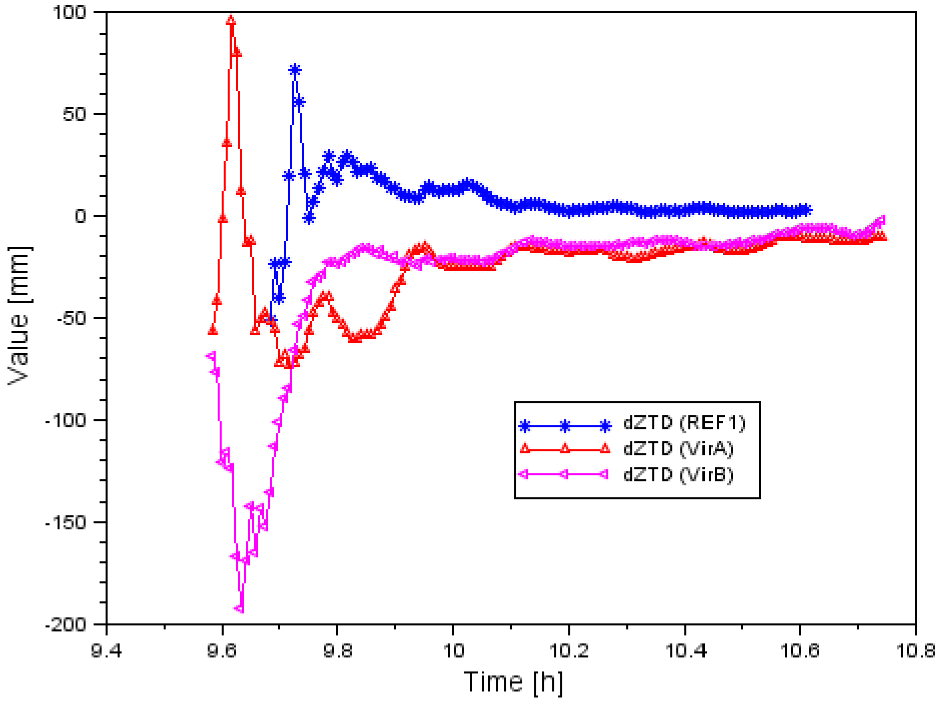

Figure 5 The difference of ZTD parameter for each reference station

The Figure 5 presents difference of ZTD parameter between CSRS-PPP and magicPPP softwares for each reference station. The difference of ZTD term was expressed as follows:

$$dZTD = \begin{cases} ZTD^{REF1}_{CSRS-PPP} - ZTD^{REF1}_{magicPPP} \\ ZTD^{VirA}_{CSRS-PPP} - ZTD^{VirA}_{magicPPP} \\ ZTD^{VirB}_{CSRS-PPP} - ZTD^{VirB}_{magicPPP} \end{cases} \tag{5}$$

where:

$ZTD^{REF1}_{CSRS-PPP}$ - values of ZTD parameter for REF1 reference station based on CSRS-PPP solution,

$ZTD^{REF1}_{magicPPP}$ - values of ZTD parameter for REF1 reference station based on magicPPP solution,

$ZTD^{VirA}_{CSRS-PPP}$ - values of ZTD parameter for VirA reference station based on CSRS-PPP solution,

$ZTD^{VirA}_{magicPPP}$ - values of ZTD parameter for VirA reference station based on magicPPP solution,

$ZTD^{VirB}_{CSRS-PPP}$ - values of ZTD parameter for VirB reference station based on CSRS-PPP solution,

$ZTD^{VirB}_{magicPPP}$ - values of ZTD parameter for VirB reference station based on magicPPP solution.

The mean value of dZTD parameter for REF1 reference station equals up to 7.7 mm, with magnitude order between -51.3 mm and 71.5 mm. The RMS bias of dZTD term for REF1 reference station equals to 13.3 mm. The mean value of dZTD parameter for VirA reference stations equals to -23.6 mm, with magnitude order between -73.9 mm and 95.2 mm. The RMS bias of dZTD term for VirA reference station equals to 22.7 mm. The mean value of dZTD parameter for VirB reference stations equals to -29.5 mm, with range between -192.2 mm and -2.3 mm. The RMS bias of dZTD term for VirB reference station equals to 39.3 mm. The dZTD term has high accuracy for REF1 reference station, whereas the low accuracy is visible for VirB reference station. The RMS bias of dZTD term was improved by 66% for REF1 reference station in contrast to result for VirB reference station.

5. CONCLUSIONS

In this paper the results of Zenith Total Delay for reference stations of GBAS augmentation system are presented. The Zenith Total Delay parameter was estimated for each reference station using CSRS-PPP and magicPPP softwares. In paper the results of ZTD term are compared based on CSRS-PPP and magicPPP solution. The difference of ZTD term between CSRS-PPP and magicPPP solution was also calculated and presented in paper. The RMS bias between CSRS-PPP and magicPPP solution has a high accuracy for results from REF1 reference station. In contrast with it, the low accuracy of RMS bias was designated for results from VirB reference station.

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