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Analysis of the accuracy of zenith tropospheric delay estimates obtained using the Maidantal GNSS data

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In this study, a comparative analysis of the accuracy of zenith tropospheric delay estimates obtained as a result of the post-processing of navigation measurements using the Precise Point Positioning (PPP) method. Tropospheric delays were calculated using MATLAB software and online services CSRS-PPP and Maidantal station. The aim of this paper is to evaluate the kinematic performance and accuracy of the CSRS-PPP online PPP service (operated by The Geodetic Survey Division of Natural Resources Canada) by using Maidantal GNSS station data. In order to evaluate the accuracy of the method in kinematic mode, a test study was carried out at Maidantal, Tashkent in Uzbekistan. GPS data collected by the Maidantal GNSS station were estimated by using an online CSRS-PPP processing service and the coordinates were compared with those of the geodetic receiver. Results are drawn about the expediency of using these software products for the purpose of high-precision estimation of the zenith tropospheric delay. The results also show that the online PPP services perform better than the selected PPP software packages at Maidantal GNSS station.

Keywords: Zenith Tropospheric Delay (ZTD), GNSS, Precise Point Positioning (PPP), Maidantal GNSS station

I. INTRODUCTION

Currently, the number of areas of application of receivers of global navigation satellite systems (GNSS) is increasing, in addition to tasks requiring high position determination accuracies, such as geodesy, navigation, and autonomous control of equipment, navigation data are used to estimate atmospheric parameters [1]. The use of a navigation receiver for atmospheric sounding makes it possible to determine such physical parameters as the integral content of water vapor, pressure, and tropopause height, which in turn are necessary for monitoring the weather and climate change [2, 3].

Another example of the use of a GNSS station, in addition to the tasks associated with determining the location of the consumer, is the integration of the path delay obtained from the navigation receiver with microwave radiometer measurements in order to highly accurately estimate the wet component of the tropospheric delay for altimetry products [4, 5]. One of the most promising methods for the secondary processing of navigation signals, which makes it possible to estimate the value of the zenith tropospheric delay, is the method of high-precision absolute positioning. Due to the growing worldwide interest in this positioning method, mainly due to the possibility of its application in various fields, there are many ready-made algorithms for its implementation, including as online services and applications [6, 7].

This article provides a comparative analysis of the accuracy of zenith tropospheric delay estimates obtained by processing navigation measurements from four ground stations of the international IGS network in three software products: MATLAB, CSRS-PPP and Maidantal GNSS station. In September 2014, a new complex of hydro-meteorological and MTAL GNSS station was installed at Maidantal observatory by GFZ (German Research Centre for Geosciences, Potsdam) in the frame of the CAWa (Water in Central Asia) project [8].

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II. TROPOSPHERIC DELAY

The propagation of a navigation signal in the layers of the atmosphere is affected by the content of electrons in the ionosphere and the density of air in an electrically neutral atmosphere - the troposphere. The influence of the troposphere is described by the total refractive power N:

$$N = 10^6(n-1) \tag{1}$$

The total refractive power of the troposphere can be divided into two main components: hydrostatic N_{dry} and wet N_{wet}, which depend on such metrological parameters as pressure P, temperature T, and partial pressure of water vapor e [8].

$$N = N_{dry} + N_{wet} = k_1\frac{P-e}{T} + k_2\frac{e}{T} + k_3\frac{e}{T^2} \tag{2}$$

where $k_1 = 77.689KhPa^{-1}$, $k_2 = 71.295KhPa^{-1}$ and $k_3 = 375,463K2hPa^{-1}$ are empirically determined coefficients [9]. The troposphere causes a delay to the signal Δ^{PD} which can be expressed as an integral of the total refractivity N along the propagation path s from receiver r to the satellite ω:

$$\Delta^{PD} = 10^{-6}\int_r^{\omega} Nds \tag{3}$$

The tropospheric delay can also be separated in the hydrostatic and the wet component. Therefore, Equation (3) can be written as:

$$\Delta^{PD} = 10^{-6}\int_r^{\omega} N_{dry}ds + 10^{-6}\int_r^{\omega} N_{wet}ds \tag{4}$$

The total tropospheric delay to the satellite-to-receiver path can be displayed in the zenith direction, giving the zenith tropospheric delay ZTD. The transformation of the "slant" component of the tropospheric delay occurs using the mapping function which recalculates depending on the elevation angle of the satellite [10]. The zenith tropospheric delay can also be represented as the sum of the zenith hydrostatic delay (Z_{dry}) and the zenith wet delay (Z_{wet}):

$$ZTD = ZHD + ZWD \tag{5}$$

$$\Delta^{PD} = ZHD \times m_h(E) + ZWD \times m_w(E) \tag{6}$$

where $m_h(E)$ and $m_w(E)$ are the hydrostatic and wet mapping functions depending on the elevation angle. The zenith tropospheric delay (ZTD) can be defined as the integral of the refractive power N in the zenith direction:

$$ZTD = 10^{-6}\int_{h_r}^{\infty} Ndl = 10^{-6}\int_{h_r}^{\infty} N_{dry}dl + 10^{-6}\int_{h_r}^{\infty} N_{wet}dl \tag{7}$$

Equation (7) shows the relationship between zenith tropospheric delay and tropospheric refraction. Since refraction depends on the meteorological conditions along the signal path, the ZTD can depend on these conditions. ZTD is a parameter calculated in the exact point positioning technique.

III. RESULTS AND DISCUSSION

When analyzing the results of the experiment, it was found that the accuracy of zenith tropospheric delays obtained when processing navigation measurements for January 1, 2023, is slightly higher than the accuracy of zenith tropospheric delays obtained using navigation measurements for January 2, 2023. This dependence is observed when using navigation measurements from all ground stations, except for the MTAL GNSS station [11,12]. Similar convergence times are obtained for each station over the examined days. Therefore, for illustration purposes only, the convergence times of the ZTD estimates over the examined MTAL station on January 1,2, 2023 as examples are given in Figure 1.

The concept of using GNSS-PPP to estimate ZTD profiles and components in kinematic mode in sub-optimal signal line-of-sight conditions encountered on mountain roads has been demonstrated, although with slightly lower performance than that of the static case. The approach, however, becomes ineffective when signal obstructions due to a combination of steep slopes and forests along roads degrade observability. In both cases, the absence of long segments of continuous carrier phase measurements caused by signal obstructions affects performance. Estimated discontinuities caused by the latter reach 2.094 to 2.035 m when using the high-grade MTAL GNSS station. Figure 2 illustrates the ZTD time series over the day at the examined MTAL station. As can be seen, station-pertinent ZTD estimates obtained from the various GNSS PPP models exhibit similar behavior, and their values are largely similar.

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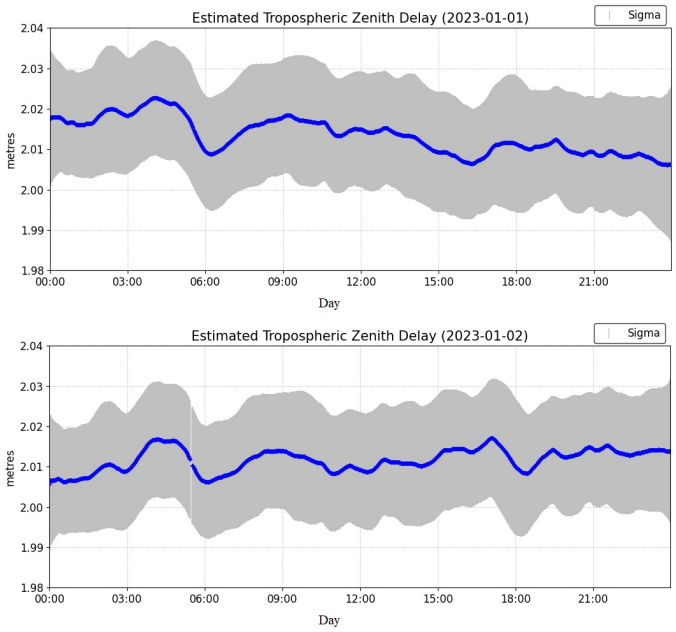


FIG. 1. Convergence time of the ZTD estimates for the examined MTAL GNSS station January 1,2, 2023.

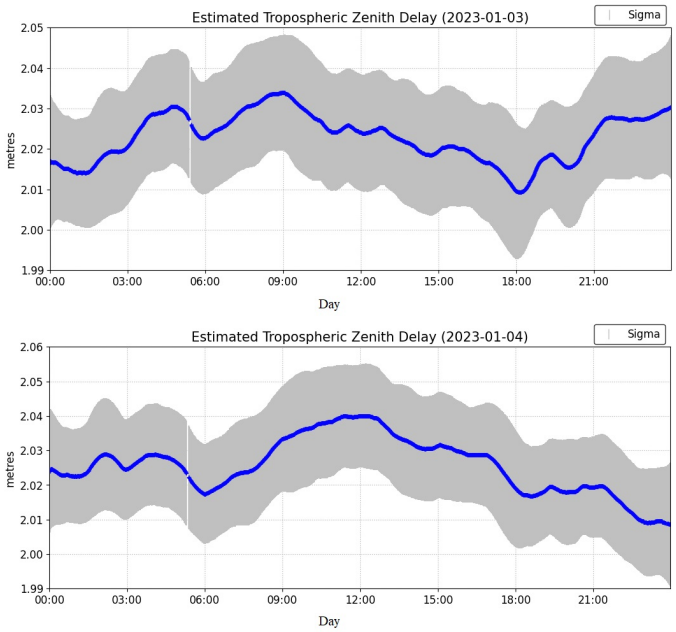


FIG. 2. Convergence time of the ZTD estimates for the examined MTAL GNSS station January 3,4, 2023.

IV. CONCLUSIONS

In conclusion, we have studied the models used to determine the tropospheric delay in the tested software products to make it possible to better estimate its humid component in selected regions at high temperatures and relatively low humidity, or at low or average temperatures and average humidity. For the first time, the zenith tropospheric delay has been estimated above the Maidantal observatory. A comparison with the GFZ algorithm showed that our algorithm estimates the ZTD well enough. A comparison with parallel spectral or water vapor radiometer (WVR) measurements should be performed in order to validate the results. A correlation with atmospheric extinction is being studied. The objective of this paper is to assess the precision of the estimated ZTD using constellation GNSS observations. Constellation GNSS observations from a number of globally distributed

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reference stations spanning a period of four days have been used. PPP solutions have been obtained using constellation GNSS observations. The estimated ZTDs have been obtained as by-products through the GPS PPP solutions.

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