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Zenith Tropospheric Delay Estimation Using a Low-Cost GNSS

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Abstract

Global Navigation Satellite Systems (GNSS) are widely used in many fields such as surveying, navigation, meteorological studies, and other geomatic applications. Although high-performance GNSS receivers are widely used for GNSS applications, interest in low-cost GNSS receivers has increased in recent years and has become a research point. Many studies are realized to investigate the usability and performance of GNSS receivers with these properties. One of the topics to be investigated due to the ubiquity of low-cost receivers is the Zenith Tropospheric Delay (ZTD). This paper aims to test whether low-cost GNSS receivers can provide tropospheric parameters with close accuracy to high-performance GNSS receivers. For this reason, dual-frequency low-cost u-blox F9P GNSS receivers and CHC P5 geodetic GNSS receivers were chosen in the study. RINEX observation files of 4 days with a data recording interval of 30 seconds were obtained with chosen receivers. These observation files were processed with CSRS-PPP, one of the internet-based PPP services, and tropospheric parameters were estimated for the relevant days. ZTD values obtained from u-blox F9P GNSS receiver and geodetic receiver were examined with a comparative approach.

1. Introduction

Global Navigation Satellite Systems (GNSS) are widely used in many fields such as surveying, navigation, precision agriculture, and meteorological forecasts with relative and absolute positioning methods. These applications are usually carried out using high-precision GNSS receivers to obtain accurate results. However, applications may be limited due to the high cost. Low-cost receivers have several advantages compared to high-cost receivers. These are low power consumption, small size, portability, etc. (Lu et al. 2019).

Low-cost GNSS devices are produced as double-frequency shortly after they start to be produced as single-frequency. Various studies have been conducted to test the ongoing improvements and performance of low-cost GNSS receivers (Hamza et al. 2021; Odolinski and Teunissen 2019; Gill et al. 2017). Especially the positioning and navigation with low-cost receivers (Nie et al. 2020; Yi et al. 2021; Odolinski and Teunissen 2020; Uradziński and Bakuła 2020), structural health monitoring (Xue et al. 2022; Manzini et al. 2022), landslide monitoring (Zuliani et al. 2022), crustal deformation monitoring (Tunini et al. 2022), coastal sea levels measuring (Knight et al. 2020) and many others.

Another parameter that can be used for testing low-cost GNSS receivers is tropospheric zenith delays (ZTD). ZTD is the basic tropospheric parameter used in GNSS data processing. ZTD is composed of two parts: Zenith Hydrostatic Delay (ZHD) and Zenith Wet Delay (ZWD). ZHD is modeled using meteorological data such as surface pressure and temperature. ZHD constitutes 90% of the total delay. ZWD relates to water vapor, which is difficult to model. Therefore, it can change rapidly temporally and spatially. Several studies have been conducted to test the performance of the low-cost GNSS receiver in terms of ZTD. Krietemeyer et al. 2020 evaluated ZTD estimates using precise point positioning (PPP) using a low-cost dual-frequency receiver and antennas of different quality. With their experiments, they concluded that the limiting factor in the low-cost receiver is the quality of the receiving antenna, and it gives high-quality results. Koohzadi et al. 2019, developed several models for the tropospheric delay.

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They tested whether the models were sufficient for low-cost real-time positioning. Stepniak and Paziewski 2022 tested whether low-cost GNSS receivers would provide tropospheric parameters with near accuracy to high-order receivers. They concluded that the difference is about 1.6mm and the two receivers are of comparable accuracy.

Although there have been a few studies on low-cost GNSS and zenith delays, low-cost GNSS is still of great interest for meteorological and atmospheric research. In this study, four days of data were recorded using a dual frequency u-blox F9P GNSS receiver and a geodetic GNSS receiver. We tested whether tropospheric zenith delays obtained with low-cost GNSS receivers provide accuracy and reliability close to tropospheric zenith delays obtained with geodetic GNSS receivers. The results were evaluated in terms of accuracy.

2. Method

Different GNSS receivers were chosen to evaluate the ZTD performance of the low-cost GNSS receiver compared to the high-cost receiver. Thus, u-blox F9P was chosen as low cost and the CHC P5 geodetic GNSS receiver was chosen as high cost. As a low-cost GNSS receiver, the u-blox F9P high-precision GNSS module was used, which provides cm-level accuracy. U-blox F9P is 118-channel multi-band GNSS receiver and capable of monitoring GPS(L1C/A, L2C), GLONASS(L1,L2OF), Galileo (E1B/C, E5b) and BeiDou (B1,B2) signals. The u-blox F9P receiver and the geodetic receiver were placed on an apparatus from the roof of the Engineering Faculty of Necmettin Erbakan University, in Konya. The status of the receivers during data recording is shown in Fig. 1.

Figure 1. Low-cost and geodetic receivers

For both receivers, 4-day (26.08.2022-29.08.2022) and 24-hour observation data were collected. Observation data were collected in clear sky conditions with a sufficient number of satellites and at 10 degrees cut-off angle. GPS+GLONASS (GR) combination was used for the geodetic receiver and u-blox.

3. Results

The 4 days of observation data obtained from 26 August 2022 to 29 August 2022 with u-blox F9P and the geodetic receiver were converted into RINEX format. Then, RINEX data were processed with the online GNSS data processing service CSRS-PPP. The troposphere file, one of the CSRS-PPP outputs contains zenith hydrostatic delay, zenith wet delay, and tropospheric gradient data in 30-sec data record intervals. Using this file, the tropospheric zenith delays obtained at each epoch for both receivers and four days were calculated. Tropospheric zenith delays were obtained from zenith wet delay and zenith hydrostatic delay values. The calculated tropospheric zenith delays are shown in Fig. 2.

The accuracy assessment of the ZTD values obtained with the u-blox F9P receiver was applied by comparing them with the results of the geodetic receiver.

Fig. 3-6 show graphs of ZTD differences between u-blox and geodetic receiver. According to the figures, ZTD differences between the two receivers range from -6.8/1.0 mm, -9.1/-0.5 mm, -7.6/0.8 mm, and -8.8/0.3 mm respectively.

Furthermore, root mean square error (RMSe), absolute maximum and mean values were calculated. The basic statistical values of the differences between the two receivers are given in Table 1.

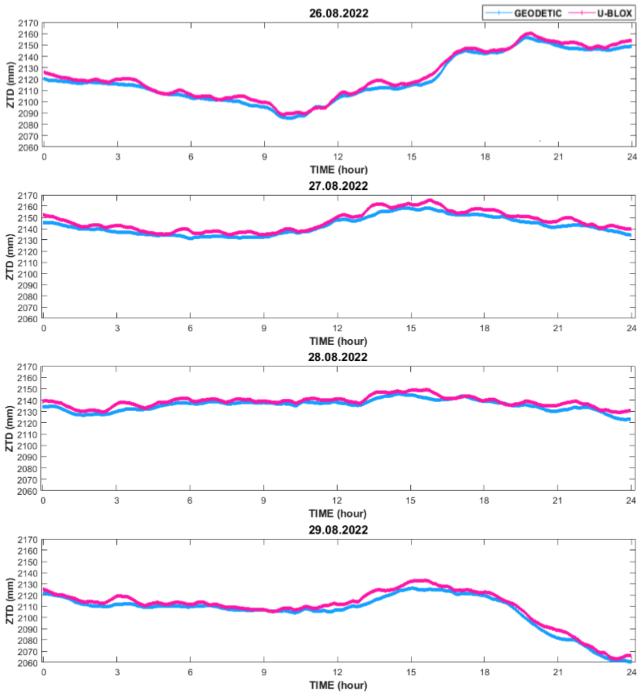

Figure 2. ZTD values of u-blox F9P and geodetic receiver

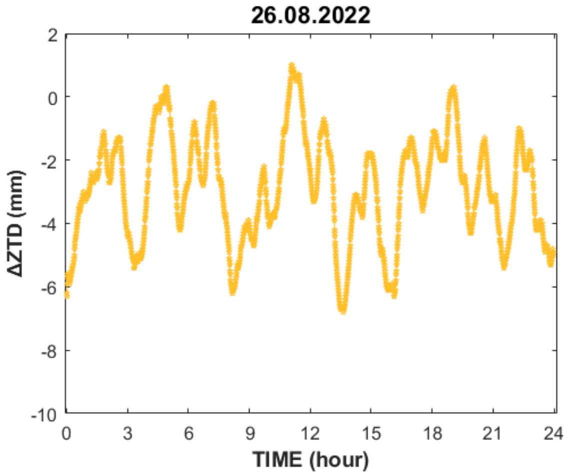

Figure 3. ZTD differences between u-blox F9P and geodetic receiver.

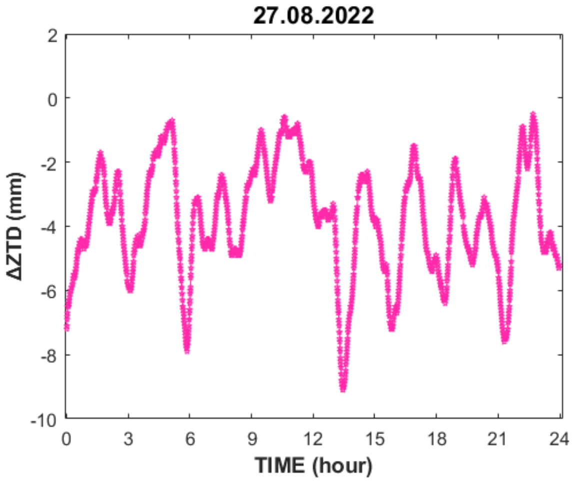

Figure 4. ZTD differences between u-blox F9P and geodetic receiver.

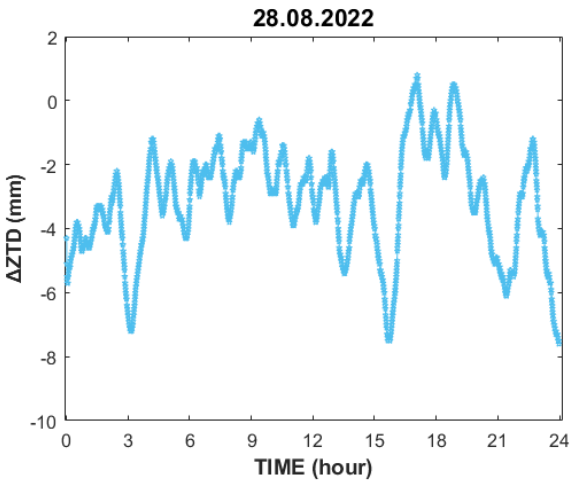

Figure 5. ZTD differences between u-blox F9P and geodetic receiver.

Table 1. The statistical values for ZTD differences between the geodetic and u-blox F9P receiver solutions

Days	RMSe (mm)	Max (abs) (mm)	Mean (mm)
26 Aug 2022	3.34	6.80	-2.88
27 Aug 2022	4.15	9.10	-3.76
28 Aug 2022	3.54	7.60	-3.10
29 Aug 2022	4.00	8.80	-3.47

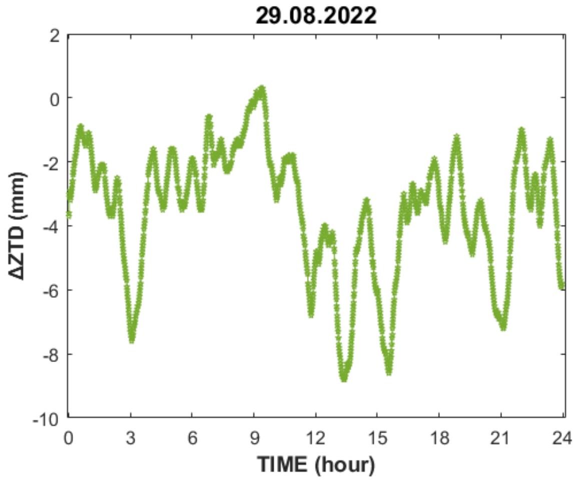

Figure 6. ZTD differences between u-blox F9P and geodetic receiver.

As seen in Table 1, the absolute maximum values of ZTD differences between the two receivers range from 6.80 mm to 9.10 mm. When mean values are analyzed, it is seen that similar findings are obtained. In addition, the lowest RMSe value is 3.34 mm, while the highest RMSe value is 4.15 mm.

4. Conclusion

In this study, the performance of a low-cost GNSS receiver in terms of ZTD prediction was tested by comparing it with a geodetic GNSS receiver. For this purpose, 4-day RINEX observation data with u-blox F9P and geodetic receivers were used. The results showed that the biggest absolute difference between the two receivers is 9.10mm. When the average difference of the four days is examined, it is seen that it varies from -2.88mm to -3.76mm.

By examining all these outcomes, we concluded that the tropospheric parameters derived from the low-cost GNSS receiver can compete with the high-cost GNSS receivers in terms of accuracy.

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