Performance of Real-time Tropospheric Delay Using Low-cost GNSS Receivers and Antennas with PCV Corrections

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Introduction

- Low-cost GNSS receivers can be a potential solution to densify the existing network for GNSS Meteorology, especially **water vapor monitoring** applications.
- **Low-cost antennas without known PCVs**, such as u-blox ANN antenna, are commonly combined use with low-cost receivers, degrading their estimated ZTD solutions.
- Thus, the impacts of PCV corrections on ZTD should be considered, especially for **real-time ZTD estimation** from low-cost GNSS.

Data and Methodology

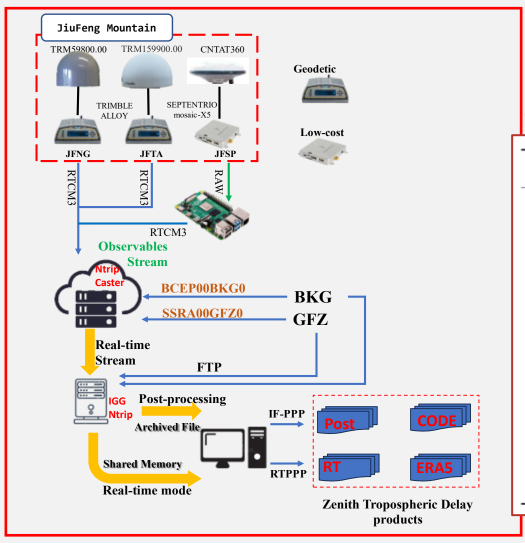


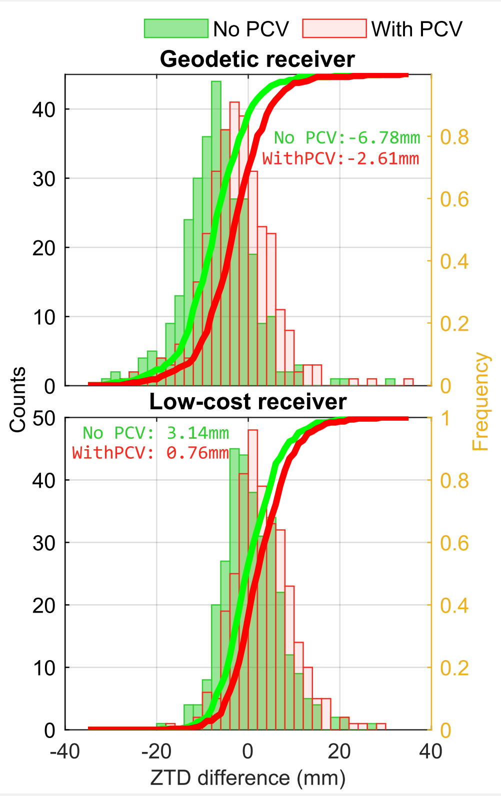
Figure 1 Real-time and postprocessing fow chart of ZTD calculation using low-cost and geodetic GNSS receivers based on real-time stream.

Table 1 Processing strategies used in PPP software.

Items	Strategies: Postprocessing mode	Strategies: Real-time mode
Observations	GPS/BDS-3 raw pseudorange and phase observables	
Frequency usage	L1/L2 for GPS and B1I/B3I for BDS-3	
orbit and clock	GFZ final products	SSRA00GFZ0
Sampling rate	30 s	1 s
Ambiguities	Float	
Estimator	Kalman filter (smooth)	Kalman filter (forwards)
Weighing strategy	A priori precisions of 0.003 and 0.6 m for the phases and codes in the zenith direction. $\sigma=\sigma_0\sqrt{1+4\cos^8 e}$ (Hadas et al. 2020)	
Elevation cut-off angle	5°	
Phase center variation	igs14.atx	
Ionospheric delay	Estimated as white noise	
Station coordinates	Estimated as constant	
Zenith wet delay	Estimated as random-walk noise (10^{-8} m^2/s)	
Tropospheric gradients	Estimated every 24 h	
Mapping function	GMF	GMF

Results

Impacts of PCV corrections



Geodetic setups typically feature pre-calibrated antenna PCVs, while low-cost antennas often lack this calibration information.

After applying the PCVs, the mean bias of ZTD differences is reduced by **around 70%** against the CODE final product, and low-cost estimates achieve a mean of **0.8 mm**.

ZTDs from low-cost receivers with PCV corrected can have better quality.

Figure 2 The cumulative distribution of differenced ZTD (mm) of JFTA (geodetic) and JFSP (low-cost) against CODE, respectively. The antenna on JFTA is TRM159900.00, while the antenna of JFSP is AT360

Results

Real-time ZTDs accuracy

Low-cost GNSS setup also has the potential to provide high-quality ZTD in real-time and be used for water vapor monitoring**.**

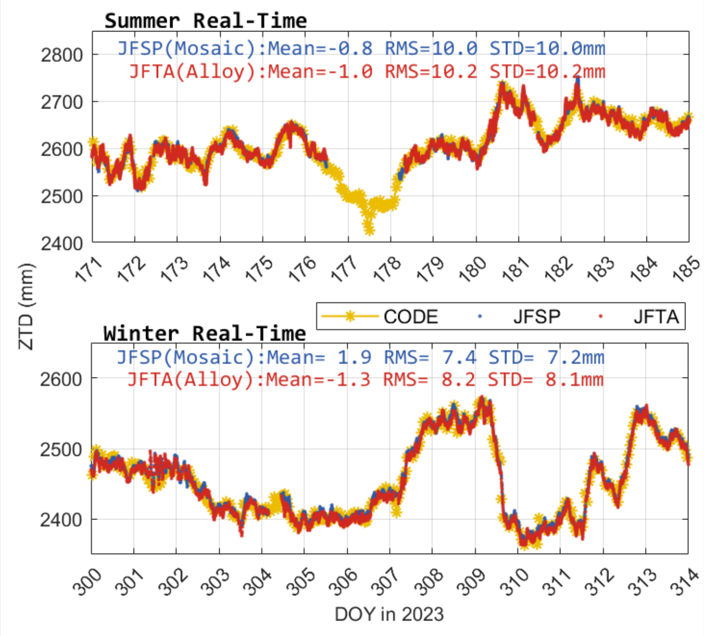


Figure 3 The real-time GNSS-ZTDs estimated at stations JFSP (low-cost setup) and JFTA (geodetic setup) in summer and winter campaigns. The CODE final ZTD products (JFNG) are presented as references.

Real-time ZTDs of low-cost setup during a heavy rainfall

A severe rain event that exceeds **30 mm/hour** could be detected by high-updating rate GNSS-ZTDs with low-cost receivers.

- **consistent with the CODE**
- **usable to densify the network**

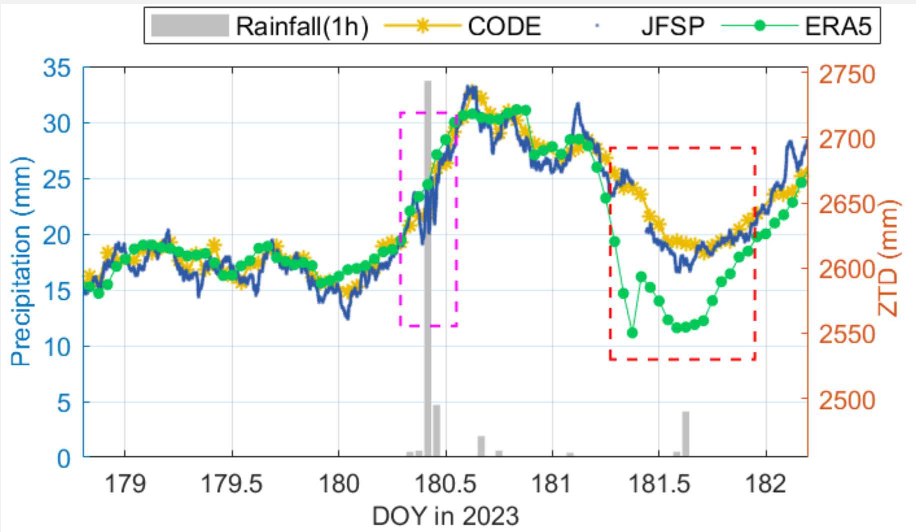


Figure 4 Time series of ionosphere delay derived from smartphone GNSS data.

Conclusion

- Neglecting PCVs results in obvious biases in ZTD estimates. After correction, low-cost GNSS devices achieve accuracies of 6.2 mm (in winter) and 7.5 mm (in summer) in post-processing.
- Real-time ZTDs with a mean RMS of 7-11 mm are achieved using low-cost devices, showing comparable results with a geodetic equipment.
- Low-cost devices have the potential to capture high-rate ZTD in a heavy rain event and densify existing GNSS networks.

Reference

1. Li, L., Zhang, H., Yuan, Y. et al. On the real-time tropospheric delay estimates using low-cost GNSS receivers and antennas. GPS Solut 28, 119 (2024). https://doi.org/10.1007/s10291-024-01655-1.