On troposphere delay constraining in real-time GNSS Precise Point Positioning

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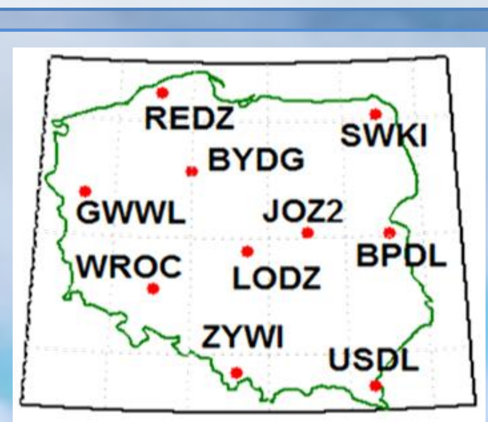
ABSTRACT: On April 1, 2013 IGS launched the real-time service providing products for Precise Point Positioning (PPP). The availability of real-time makes PPP a very powerful technique to process GNSS signals in real-time and opens a new PPP applications opportunities. There are still, however, some limitations of PPP, especially in the kinematic mode. A significant change in satellite geometry is required to efficiently de-correlate troposphere delay, receiver clock offset, and receiver height. This poster is divided into 3 main parts:
1) the results of static and kinematic positioning with GPS only and GPS + GLONASS using real-time products;
2) positioning with the troposphere delay constrained by near real-time ZTD regional model;
3) real-time troposphere delay estimation during challenging conditions.

Real-Time PPP performance

INTRODUCTION AND METHODOLOGY

IGS RTS provides two official streams for GPS and one unofficial stream for combined GPS and GLONAS. The GLONASS products are still of worse quality than GPS products, therefore it was verified, if the use of GLONASS makes benefit to the users.

For 10 Polish EPN stations one day of 1Hz real-time data was processed in 4 configurations simultaneously: static GPS only, static GPS+GLONASS, kinematic GPS only, and kinematic GPS+GLONASS. The real-time coordinates were compared with known IGb08 station coordinates. The analyses concern only residuals obtained after the solution converged below centimeter level for static mode and decimeter level for kinematic mode.



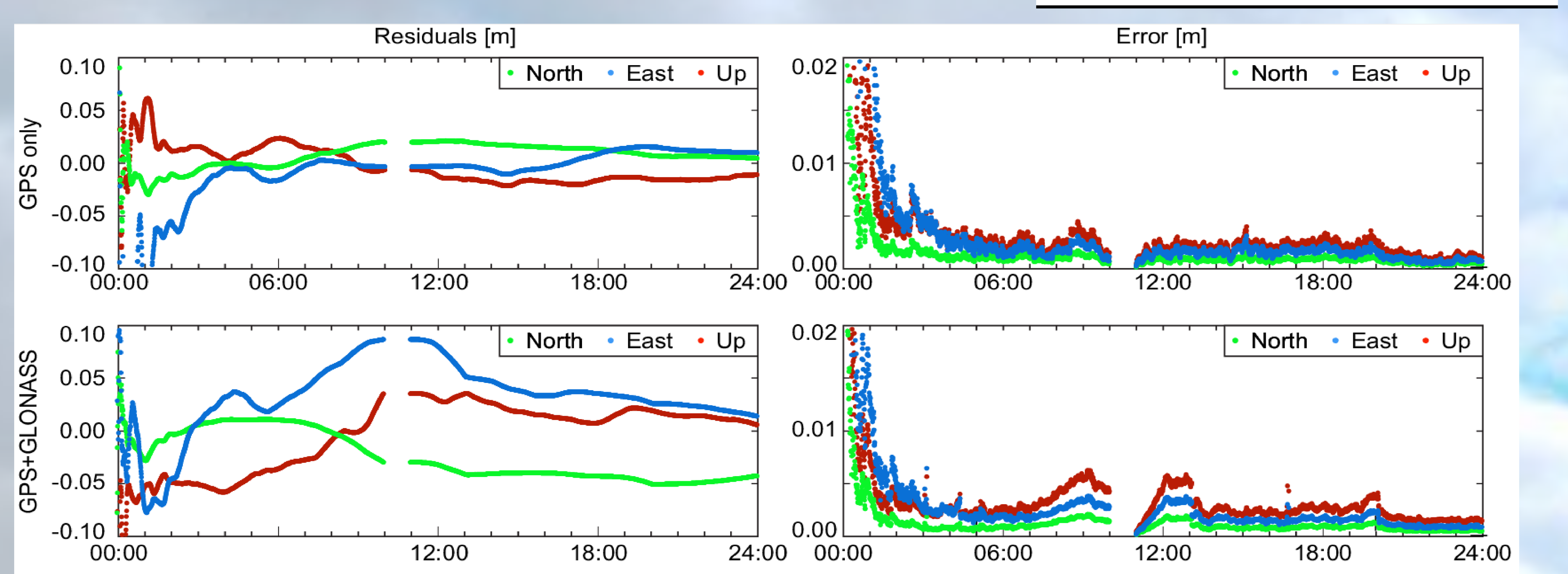
Location of 10 selected EPN stations in Poland used in the experiments

STATIC POSITIONING

The horizontal coordinates were slightly biased if GLONASS satellites were included in the processing. Standard deviations of residuals were significantly smaller in GPS only processing. The estimated error for each component in both solutions were below a few millimeters. For GPS only solution, the solutions converged below 1cm accuracy after about 2 hours, but for GPS+GLONASS solution the convergence time varies from 1 to 6 hours. This confirmed, that the quality of GLONASS products were not yet as high as for GPS.

Mean and standard deviation [m] of coordinate residuals in real-time static PPP

	GPS only		GPS+GLO	
	Mean	Std.Dev.	Mean	Std.Dev.
North	0.005	0.002	0.025	0.013
East	0.007	0.006	0.012	0.018
Up	0.001	0.006	-0.033	0.011



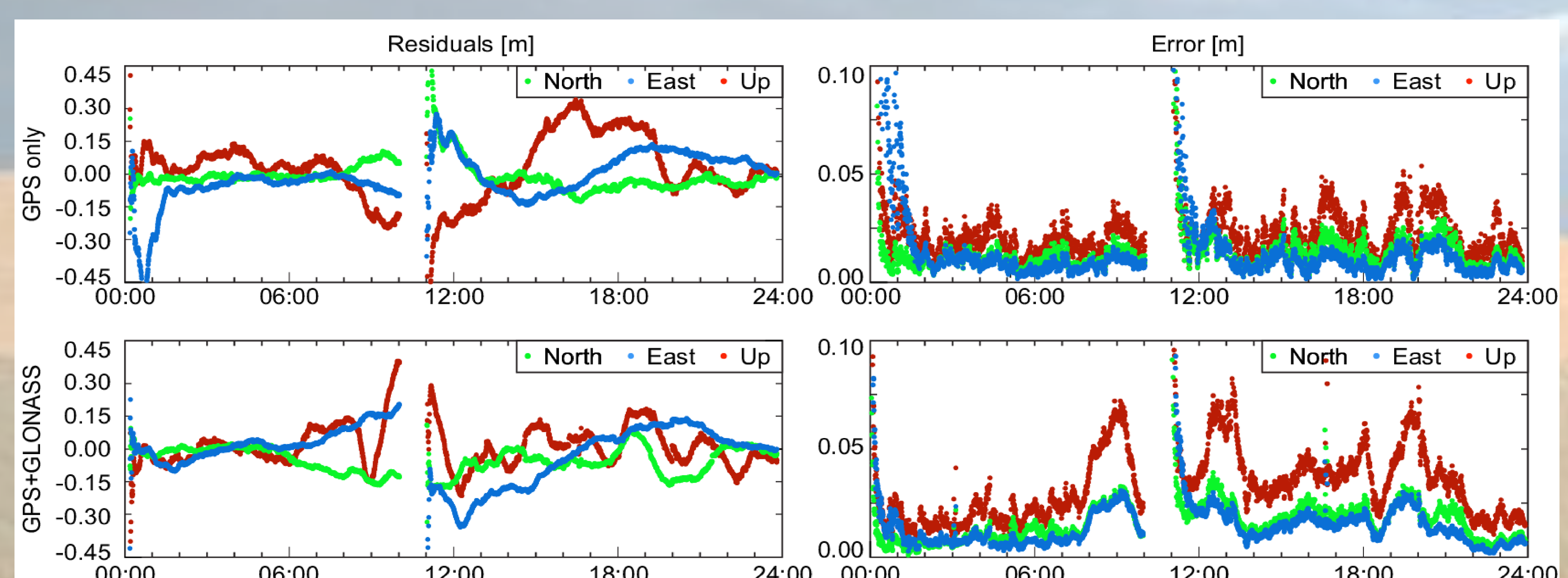
Time series of residuals and estimated errors for GPS only with IGS01 stream (top) and GPS+GLONASS with IGS03 stream (bottom) real-time positioning in static mode for station WROC, DOY 114, 2014

KINEMATIC POSITIONING

The quality of the horizontal coordinates obtained with GPS only and GPS + GLONASS solutions was very similar. For the Up component, the inclusion of GLONASS data resulted in smaller bias and standard deviation. The number and size of extreme residuals was reduced. The average time required for the solution to converge into a decimeter level was 1 hour for GPS only mode and 15 minutes for GPS + GLONASS. Even though the GLONASS products are unofficial, GPS+GLONASS solution is suggested in real-time kinematic PPP.

Mean and standard deviation [m] of coordinate residuals in real-time kinematic PPP

	GPS only		GPS+GLO	
	Mean	Std.Dev.	Mean	Std.Dev.
North	0.007	0.03	0.015	0.035
East	0.004	0.027	0.004	0.032
Up	0.057	0.12	-0.031	0.092



Time series of residuals and estimated errors for GPS only with IGS01 stream (top) and GPS+GLONASS with IGS03 stream (bottom) real-time positioning in kinematic mode for station WROC, DOY 114, 2014

Troposphere delay constraining in real-time kinematic PPP

MOTIVATION

A common procedure in PPP is to have the adjustment model account for the correction of an a priori value of the troposphere delay given at the first epoch of data processing, and have the delay filter updated epoch by epoch. This approach requires some time so that a change in constellation geometry allows to efficiently de-correlate among tropospheric delay, receiver clock error, and height.

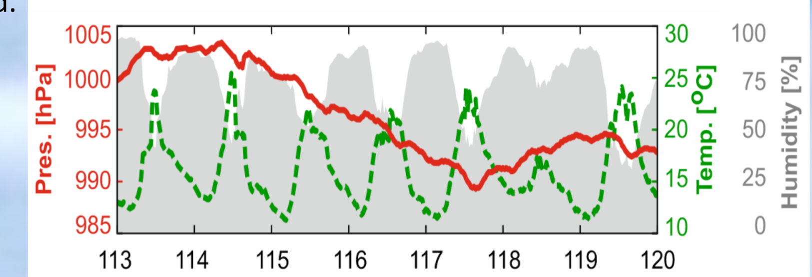
Empirical tropospheric state models and mapping functions are available, however, they may not properly reflect the actual state of the troposphere, especially in severe weather conditions. In this case, it would be more appropriate to make use of a regional troposphere model based on real-time or near-real time (NRT) measurements. In this context, it may be effective to constrain the tropospheric delay using external information coming from NRT analysis of the regional GBAS network.

METHODOLOGY

Near real-time ZTD model developed at WUELS was used to constrain the troposphere delay correction estimates, by including the additional pseudo-observation into a functional model. The standard deviation for the additional equation was set to 10mm, according to the quality of the model. 7 days of 0.1 Hz GPS data from selected Polish EPN stations were processed simultaneously in two approaches: unconstrained and constrained.

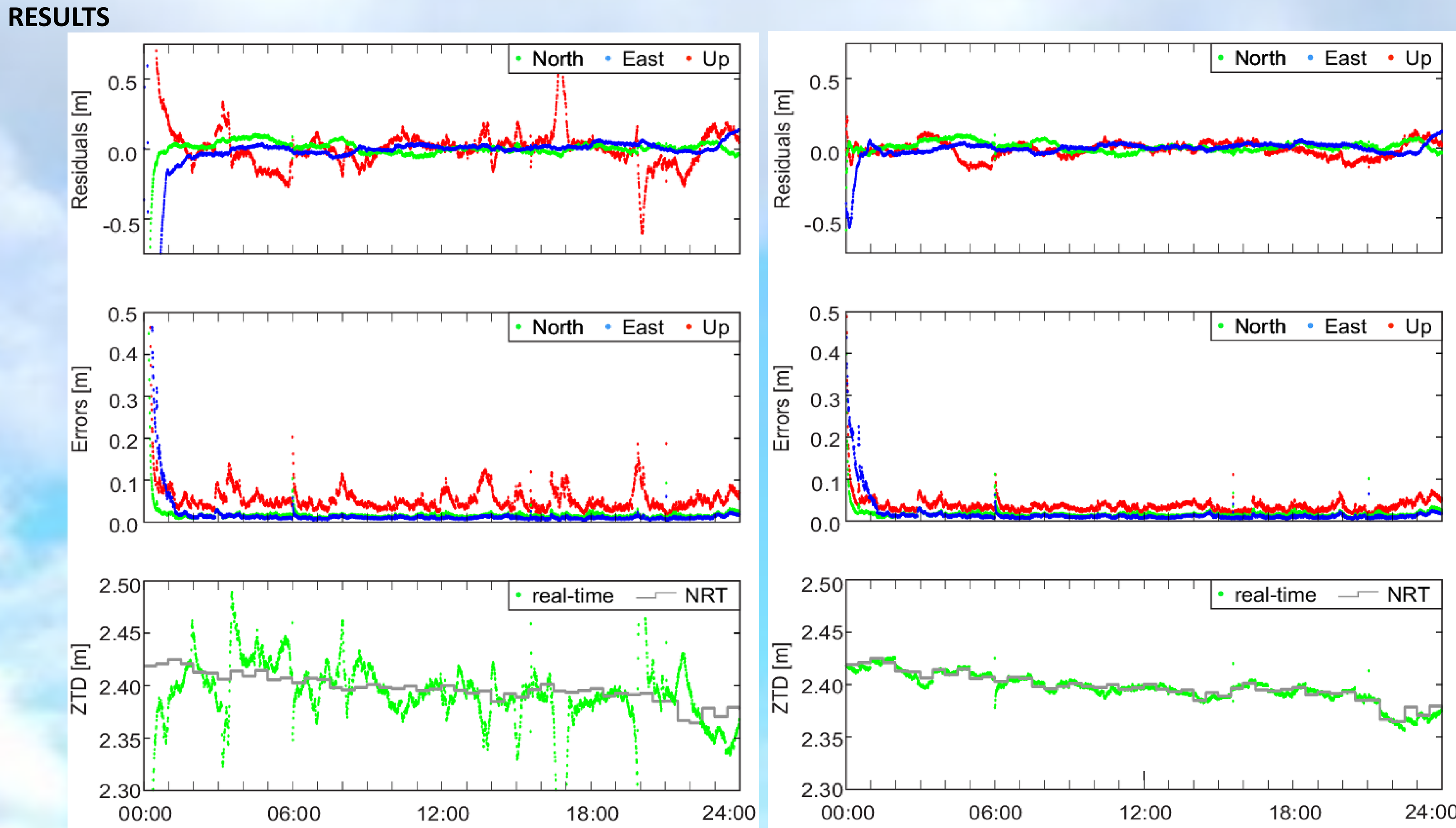
$$\delta ZTD = ZTD^{NRT} - ZTD'$$

where
ZTD^{NRT} - zenith troposphere delay from near-real time regional model;
ZTD' - a priori zenith troposphere delay value;
δZTD - the correction to the a priori zenith troposphere delay value.



Atmospheric conditions at station WROC, DOY 113 – 119, 2014

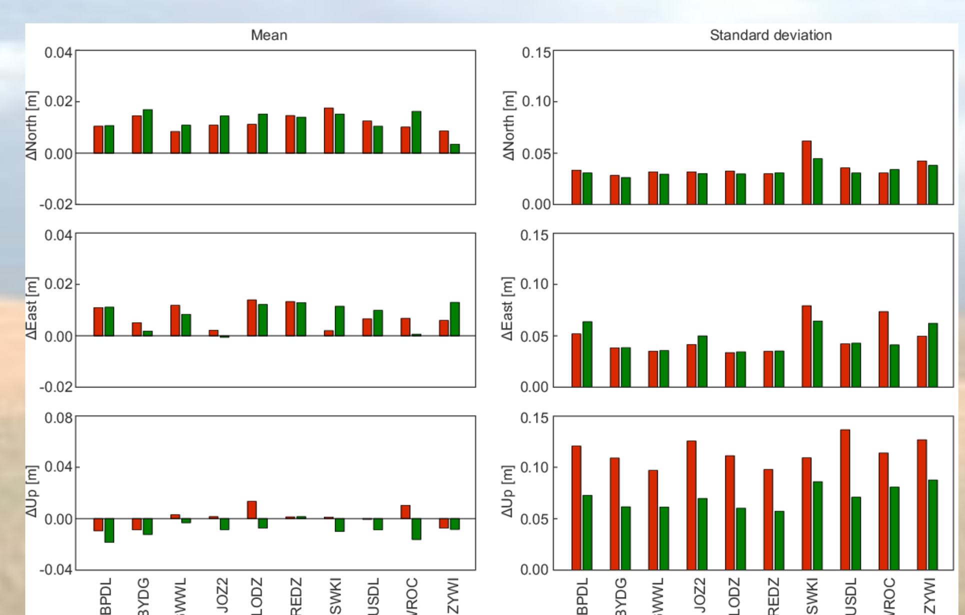
RESULTS



Results of unconstrained (left) and NRT-ZTD constrained (right) kinematic PPP solution for station WROC, DOY 116, 2014

In the unconstrained solution, the Up component was not as well determined, sensitive to the number of satellites, and strongly correlated with estimated ZTD. In extreme cases, the residuals were >0.7m, and the estimated error >20cm. The estimated ZTD differs up to 12 cm from reference NRT ZTD solution. The largest residuals and errors in the Up coordinate occurs, when the estimated ZTD differs the most from the regional ZTD model.

In the constrained solution, all three coordinates are accurate and precise, although the error of the Up (5cm on average) is still slightly larger than for the East and North (2cm on average) components. After the solution has converged, the height residuals do not exceed 20cm, and are smaller than 15cm for 91% of time. From the very beginning of the data processing, the residuals for all three coordinates are much smaller, even though the estimated error is relatively large.



Statistics of residuals for processed EPN stations over DOY 113-119, 2014, using unconstrained (red) and NRT-ZTD constrained (green) approach.

After processing the 7-day long data from 10 Polish EPN stations in PPP kinematic mode in unconstrained and constrained approaches, the mean bias and standard deviation of coordinate residuals, with respect to known EPN coordinates, were calculated. In both approaches the results for the North and East components were very similar. The NRT-ZTD model shifted the height solution by about 1cm and at the same time stabilized the solution over time. The standard deviation for all stations was reduced by up to 40%, from 14cm to 8 cm. The results confirmed the usefulness of near-real time troposphere delay models in real-time PPP kinematic processing because a significant improvement was be noticed in unusual / severe weather conditions.

Estimation of troposphere delay in real-time

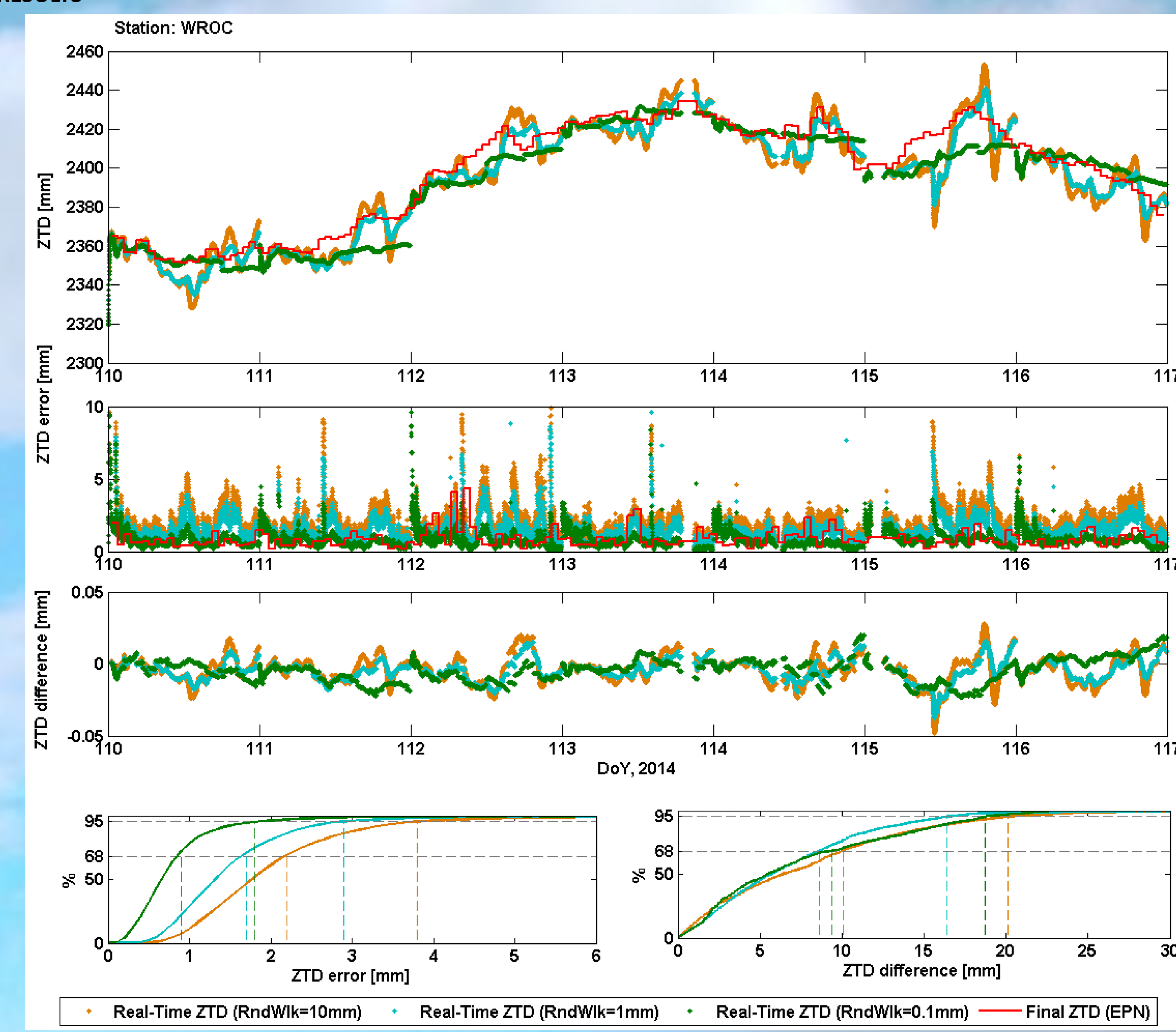
MOTIVATION AND METHODOLOGY

The growing importance of near real-time ZTD estimation for numerical weather prediction models results in some first efforts on real-time ZTD estimation. The accuracy of 6 mm is required in order to assimilate ZTD into numerical weather prediction models.

To evaluate the quality of real-time troposphere delay estimates with GNSS-WARP, a time-limited postprocessing benchmark campaign was analyzed. One-week-long campaigns were processed: GPS data from Polish EPN stations WROC and selected European IGS station, VMF mapping functions, satellites with elevation of 5 degrees or higher. Both campaigns were made under the challenging weather conditions (atmospheric fronts).

Due to the limited software functionality (single station processing only), the processing was done in simulated real-time conditions, using recorded IGS01 / CLK11 stream. ZTD were estimated every 30 seconds and the solution was reinitialized every night at midnight, but such limitations will not occur for the real-time running software.

RESULTS

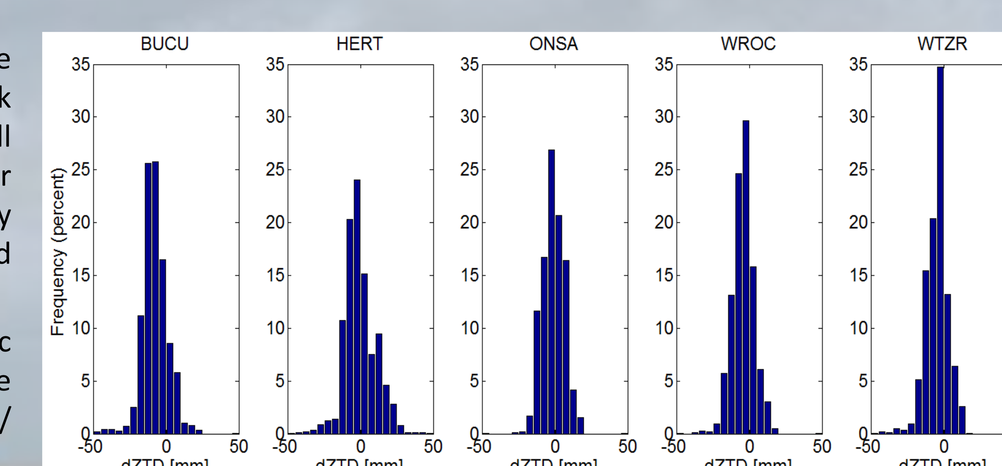


Comparison of real-time ZTD estimates (3 different ZTD stochastic modeling) with EPN final ZTD estimates, station WROC

Station WROC: Real-time ZTD occurred to be very sensitive to stochastic modeling, so different random walk value were investigated. A level of 10 mm provided very noisy ZTD estimates: 95% of residuals were within 20mm and 95% of errors were below 4mm. For random walk set to 1mm both residuals and errors were smaller (95% of residuals were smaller than 16mm, errors smaller than 3 mm). Smaller random walk values resulted in discontinuities of real-time ZTD time series and the residuals with respect to final ZTD increased. In every case, a small bias at the level of -4mm was noticed.

EPN stations: Real-time ZTDs were calculated with different random walk settings. An optimal solutions among all stations were obtained for 5mm/hour random walk. The results were slightly biased (-4 mm to +7 mm) and the standard deviations varies from 7 mm to 12 mm.

Further studies will be related with dynamic ZTD stochastic modeling during real-time processing based on meteorological data / forecast or recent time series analysis.



Histograms of ZTD residuals for selected EPN stations

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