An Evaluation of Real-Time, Near Real-Time and Post-Processed Zenith Total Delay Estimates

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Abstract

Zenith total delay (ZTD) can be estimated in real-time, near real-time and post-processing modes using existing GPS processing strategies and each mode results in different accuracies for the estimates. The Bundesamtes für Kartographie und Geodäsie Ntrip Client (BNC) can provide ZTD estimates in real-time using precise point positioning (PPP) without integer ambiguity resolution. Recently, the Centre National d'Etudes Spatiales (CNES) has released a modified version of BNC which produces ZTD estimates in real-time with integer-PPP, i.e. PPP with integer ambiguity resolution using their integer-recovery clock and widelane phase bias information. The University of Luxembourg in collaboration with the University of Nottingham operates hourly and sub-hourly near real-time processing systems for estimating ZTD using the Bernese GPS Software v5.0 and double-differenced observations. The IGS Troposphere Working Group produces an official IGS Final Troposphere product using the final satellite orbits and clocks, and Earth orientation parameter products.

In this study, we present a comparison of the ZTD estimates from the various processing systems. We will investigate the accuracies of the ZTD estimates from the real-time and near real-time systems using the official IGS Final Troposphere product and our own post-processed solution. We will also show some results from integer ambiguity resolution in real-time PPP.

Accuracy Assessment of Near Real-Time ZTD Estimates

In this section, we present a comparison of ZTD estimates obtained using the hourly NRT system at the University of Luxembourg (NRT1H) with those obtained from two post-processed solutions i.e. IGS Final Troposphere product[1] and a post-processed solution generated at the University of Luxembourg. The comparisons have been performed for 7 stations from the IGS permanent network and for the time period of 2012-04-02 12:00UTC to 2012-04-09 12:00UTC. Table 1 summarizes the characteristics of the compared solutions.

Table 1: Solutions compared for Near Real-time ZTD assessment

Solution	Clocks, Orbits and ERPs	Mapping Function	Software
Near Real-time	IGS Ultra-rapid	NMF	Bernese 5.0[2]
IGS Final Troposphere product	IGS Final	GMF	Bernese 5.0
Post-Processed Solution	CODE Final	GMF	Bernese 5.0

The IGS Final Troposphere product contains the ZTD estimates in form of 27-Hour long sessions with a sampling interval of 5 minutes. The near real-time system (NRT1H) produces ZTD estimates with an update cycle of 1 hour and sampling rate of 15 minutes. The statistics of the comparison in Table 2 have been computed by taking the common epochs from both datasets. Figure 1 shows the ZTD time series for 4 out of the 7 stations obtained from NRT1H and the IGS Final Troposphere product. The green curves in this figure show the difference in the estimates from two solutions by using the IGS Final Troposphere product as a reference. The comparison yields an overall mean difference of 0.93 ± 3.99 mm with an average RMS of 4.53 mm in ZTD which translates to an error of about 0.75 kg/m² in integrated water vapour (IWV).

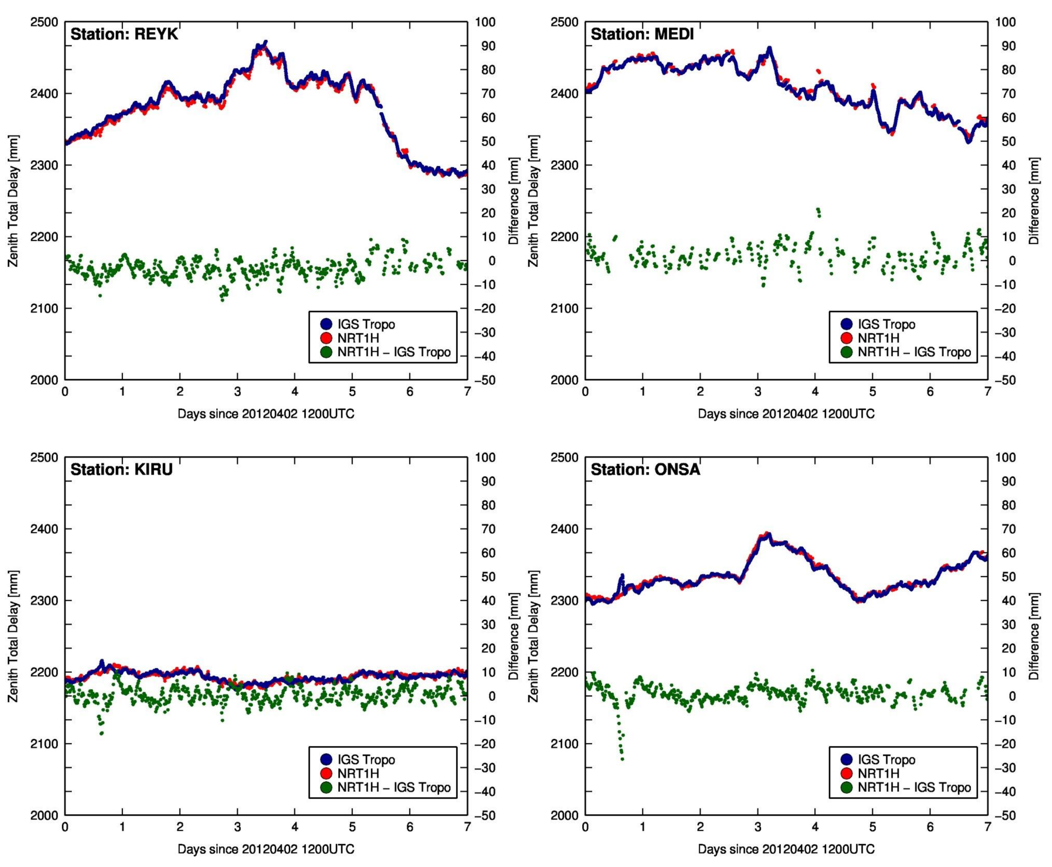

Figure 1: Comparison of ZTD time series obtained from NRT1H and IGS Final Troposphere product for 4 stations for 2012-04-02 12:00UTC to 2012-04-09 12:00UTC (Note the different scales for the estimates and the difference)

Table 2: Statistics for difference between NRT1H and IGS Final Troposphere product

Station	Mean [mm]	SD [mm]	RMS [mm]
ONSA	0.89	3.95	4.05
REYK	-3.42	3.99	5.25
YEBE	2.33	3.75	4.41
MEDI	2.18	4.82	5.29
GOPE	2.98	3.43	4.54
KIRU	0.40	3.55	3.57
CAGL	1.18	4.42	4.57

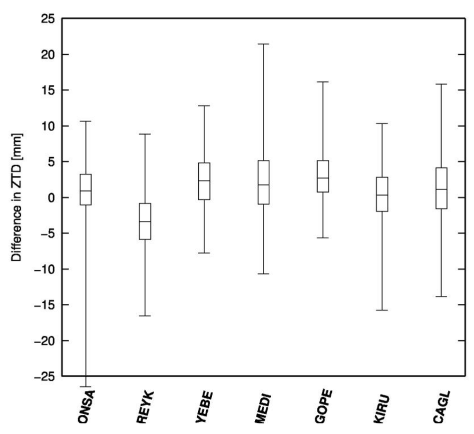

Figure 2: Box-and-Whisker plot showing statistics for the comparison between NRT1H and IGS Final Troposphere product

A post-processed solution with a sampling rate of 15 minutes was generated using final orbit and clock products from CODE using the GMF and then compared with NRT1H. Figure 3 shows a comparison of ZTD time series for some of the compared stations whereas Table 3 and Figure 4 summarize the statistics of this comparison. The comparison yields an overall mean difference of 0.40 ± 4.42 mm with an average RMS of 4.95 mm in ZTD or about 0.83 kg/m² in IWV.

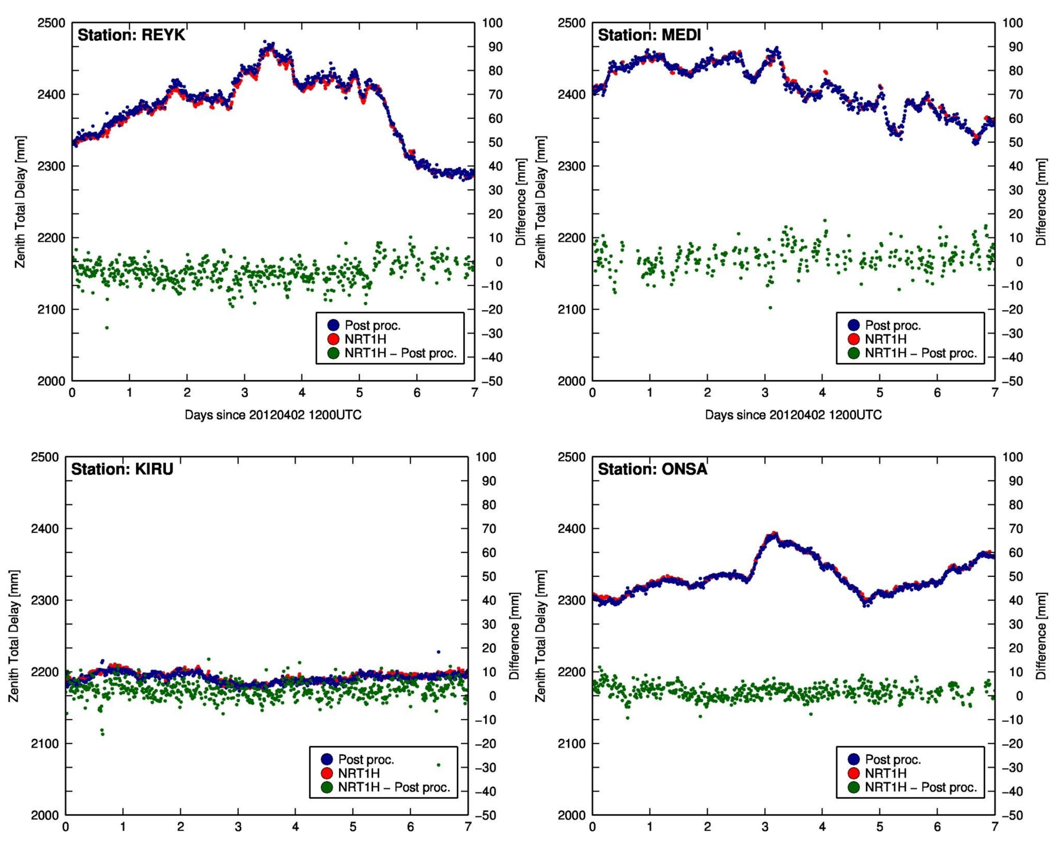

Figure 3: Comparison of ZTD time series obtained from NRT1H and post-processed solution for 4 stations for 2012-04-02 12:00UTC to 2012-04-09 12:00UTC (Note the different scales for the estimates and the difference)

Table 3: Statistics for difference between NRT1H and post-processed solution

Station	Mean [mm]	SD [mm]	RMS [mm]
ONSA	1.64	2.85	3.29
REYK	-4.57	4.67	6.53
YEBE	0.36	5.25	5.25
MEDI	1.52	5.31	5.51
GOPE	2.08	3.71	4.25
KIRU	2.35	3.81	4.47
CAGL	-0.59	5.34	5.37

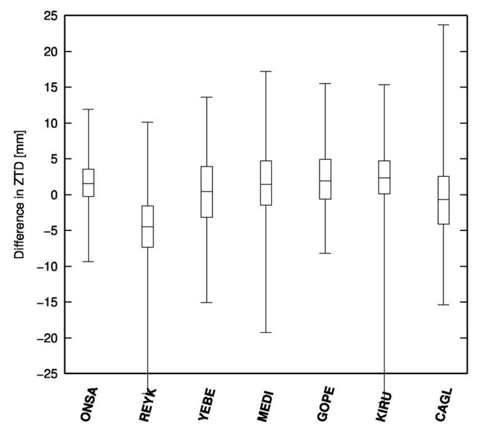

Figure 4: Box-and-Whisker plot showing statistics for comparison between NRT1H and post-processed solution

Accuracy Assessment of Real-Time ZTD Estimates

The BKG Ntrip Client (BNC)[3] is capable of performing precise point positioning (PPP) in real-time. In this section, we compare the ZTD estimates obtained by BNC v2.6 and the hourly near real-time system (NRT1H). The comparison has been performed for 6 stations from the IGS and EUREF permanent networks and for the time period of 2012-07-03 00:00UTC to 2012-07-11 00:00UTC. Characteristics of the compared solutions are shown in Table 4.

Table 4: Solutions compared for Real-time ZTD assessment

Solution	Clocks, Orbits and ERPs	Mapping Function	Software
Near Real-time	IGS Ultra-rapid	NMF	Bernese 5.0
Real-time	IGS Ultra-rapid	1 / cos(z)	BNC v2.6

For this study, BNC has been used to perform real-time PPP using streams of code plus phase observations, broadcast ephemeris and corrections for satellite orbits and clocks. During the process in BNC, the corrections from the real-time streams are applied to the broadcast ephemeris. Along with the precise position estimates, the total tropospheric delay estimates can also be obtained as one of the outputs. Time series comparison for 4 stations and overall statistics of this comparison are shown in Figures 5 and 6, and Table 5.

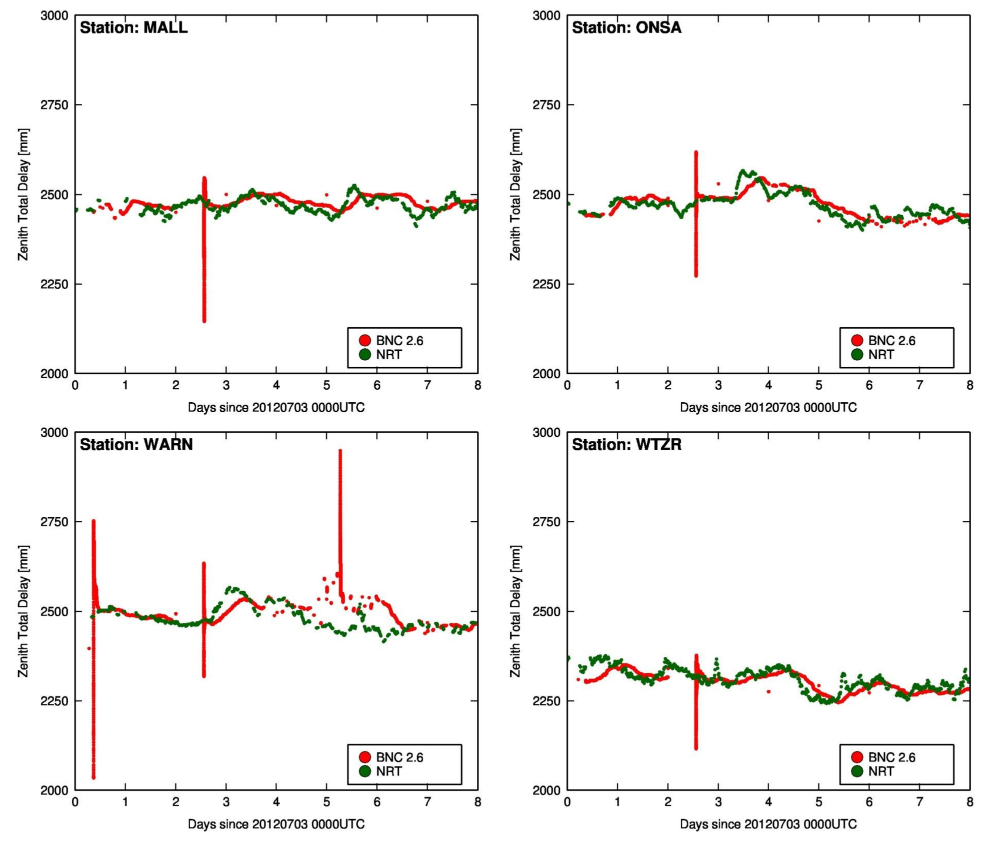

Figure 5: Comparison of ZTD time-series obtained in real-time and near real-time for 4 stations for 2012-07-03 00:00UTC to 2012-07-11 00:00UTC

Table 5: Statistics for difference between real-time and near real-time ZTD estimates

Station	Mean [mm]	SD [mm]	RMS [mm]
WTZR	-6.60	25.81	26.62
DRES	5.62	24.46	25.08
HOFN	11.48	12.99	17.32
MALL	9.36	19.14	21.29
ONSA	4.01	21.63	21.98
WARN	2.58	28.36	28.42

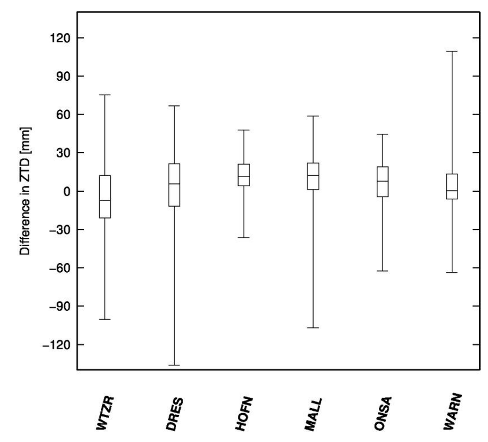

Figure 6: Box-and-Whisker plot showing statistics for comparison between real-time and near real-time ZTD estimates

This comparison has shown a relatively bigger mean difference of 4.41 ± 22.07 mm with an average RMS of 23.45 mm in the ZTD or 3.91 kg/m² in IWV. Here it is worthwhile to mention that during PPP processing, BNC does not apply corrections for the effects of receiver antenna PCVs, ocean and atmospheric loading, and polar tides.[3]

CNES has developed a real-time PPP with undifferenced integer ambiguity resolution (i-PPP) demonstrator[4] which is based on a modified version of BNC v2.4. In Figure 7, we show ZTD time series of 3 stations obtained in near real-time, and in real-time by BNC v2.6 and the i-PPP demonstrator from CNES. For most of the time, the i-PPP results follow the other two time series. For the periods where the three time series are comparable, the mean difference between i-PPP and NRT results is found to be 32.56 ± 6.86 mm and the mean difference between i-PPP and BNC v2.6 estimates is 107.45 ± 6.36 mm. However, the comparison is hampered by the excursions in the i-PPP ZTD estimates. We assume that these occur when ambiguities are re-initialized, but this needs to be further investigated.

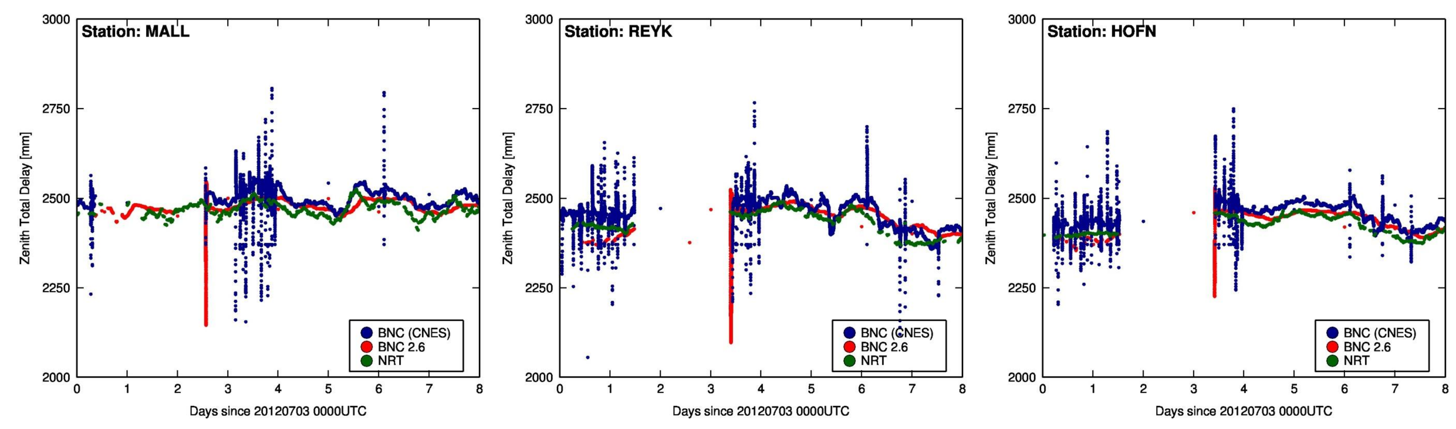

Figure 7: ZTD time-series obtained from CNES BNC (blue), BNC v2.6 (red) and near real-time system (green) for three stations for 2012-07-03 00:00UTC to 2012-07-11 00:00UTC

Discussion and Conclusions

The accuracy of the near real-time ZTD estimates generated at the University of Luxembourg has been assessed by comparing them to the IGS Final Troposphere product and a locally generated post-processed solution. A mean difference of 0.93 ± 3.99 mm was found between the NRT solution and the IGS Final Troposphere product whereas the mean difference between the estimates obtained from the NRT solution and the post-processed solution was found to be 0.40 ± 4.42 mm.

A comparison between real-time ZTD estimates obtained from BNC v2.6 and NRT estimates was performed in order to assess the accuracy of the real-time estimates. The comparison resulted in a mean difference of 4.41 ± 22.07 mm.

Finally, preliminary ZTD time series from the CNES i-PPP demonstrator were shown for 3 stations and compared to those from NRT and BNC v2.6. A mean difference of 32.56 ± 6.86 mm and 107.45 ± 6.36 mm in ZTD was found between i-PPP and NRT, and i-PPP and BNC v2.6, respectively.

If the averaged RMS difference are considered as a measure of absolute accuracy, the NRT and real-time ZTD (or IWV) estimates can be compared to the user requirements as described in the COST Action 716[5]. For the NRT estimates, accuracies of 0.75 kg/m² and 0.83 kg/m² for IWV, and 4.53 mm and 4.95 mm for ZTD were found. These meet the accuracy requirements for nowcasting and numerical weather prediction (1~5 kg/m² in IWV and 3~10 mm in ZTD). The accomplished accuracy of the real-time estimates of 3.91 kg/m² in IWV would also lie within the requirements for nowcasting.

References

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