Assessing the Status of GNSS Data Processing Systems to Estimate Integrated Water Vapour for Use in Numerical Weather Prediction models

Furqan Ahmed(1), Norman Teferle(1), Richard Bingley(2), Denis Laurichesse(3)

1) Geophysics Laboratory, University of Luxembourg, Luxembourg
2) Nottingham Geospatial Institute, University of Nottingham, United Kingdom
3) Centre National d'Etudes Spatiales, France

Contact: furqan.ahmed@uni.lu

Abstract

Modern Numerical Weather Prediction (NWP) models make use of the GNSS derived Zenith Total Delay (ZTD) or Integrated Water Vapour (IWV) estimates to enhance the quality of their forecasts. Usually, the ZTD is assimilated into the NWP models on hourly intervals but with the advancement of NWP models towards higher update rates, it has become necessary to estimate the ZTD on sub-hourly intervals. In turn, this imposes requirements related to the timeliness and accuracy of the ZTD estimates and has lead to a development of various strategies to process GNSS observations to obtain ZTD with different latencies and accuracies. Using present GNSS products and tools, ZTD can be estimated in real-time (RT), near real-time (NRT) and post-processing (PP) modes. The aim of this study is to provide an overview and accuracy assessment of various RT, NRT, and PP IWV estimation systems and comparing their achieved accuracy with the user requirements for GNSS meteorology. The NRT and PP systems are based on the Bernese GNSS Software v5.2 using a double-difference network and Precise Point Positioning (PPP) strategy, and the RT systems are based on BKG Ntrip Client 2.7 and PPP-Wizard both using PPP. One of the RT systems allows integer ambiguity resolution with PPP and therefore the effect of fixing integer ambiguities on ZTD estimates will also be presented.

Introduction

GNSS Meteorology i.e. the use of GNSS-derived atmospheric information for numerical weather prediction, is in practice globally having a positive impact on the quality of weather forecasts. Long-term analysis of GNSS data is also being used for climatological studies. The University of Luxembourg (UL), under the framework of a research project, is studying the potential of GNSS meteorology and climatology for Luxembourg and its surrounding areas (the Greater Region). During this project, various data processing systems have been developed to estimate the ZTD and the IWV from GNSS observations in PP, NRT, and RT modes. Some characteristics of these systems are shown in Table 1. In this poster, we provide the current status of these systems along with their characteristics. Furthermore, results from the comparisons of these systems with the IGS Final Troposphere product and the established accuracy requirements for GNSS meteorology are presented.

Table 1: General characteristics of GNSS processing systems at UL

System	Update Cycle	Output Sampling	Processing Engine
PP	Post processed	1 hour	Bernese GNSS Software 5.2
NRT	Hourly	15 min	Bernese GNSS Software 5.0 [1]
RT-I	10 min	1 sec	BKG Ntrip Client 2.7 [2]
RT-II	10 min	5 sec	PPP-Wizard [3]

The EUMETNET EIG GNSS water vapour programme (E-GVAP) is a series of research projects to study the use of NRT GNSS data for numerical weather prediction (http://egvap.dmi.dk) since 2005. Analysis centres located all over Europe submit NRT GNSS-derived delay and IWV solutions to E-GVAP for validation, monitoring and research. The results from the hourly NRT system of UL are submitted to E-GVAP as a test solution namely "UL01".

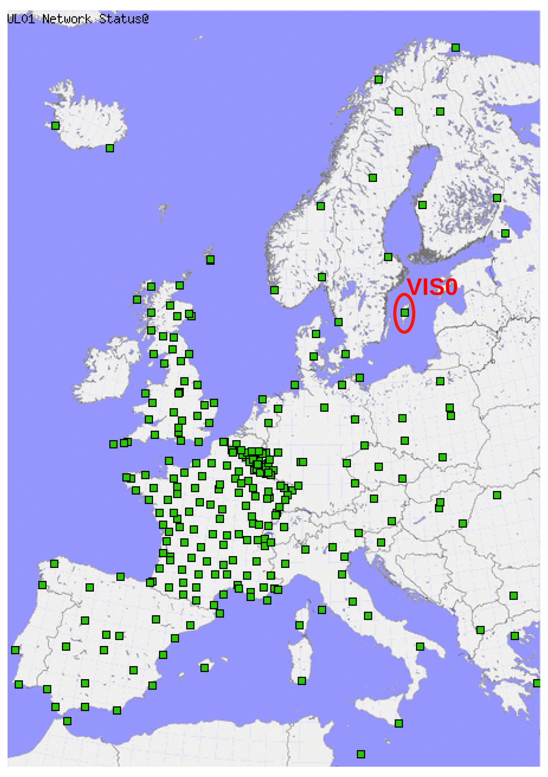

Figure 1: Network of stations processed by UL01 (E-GVAP, 2013)

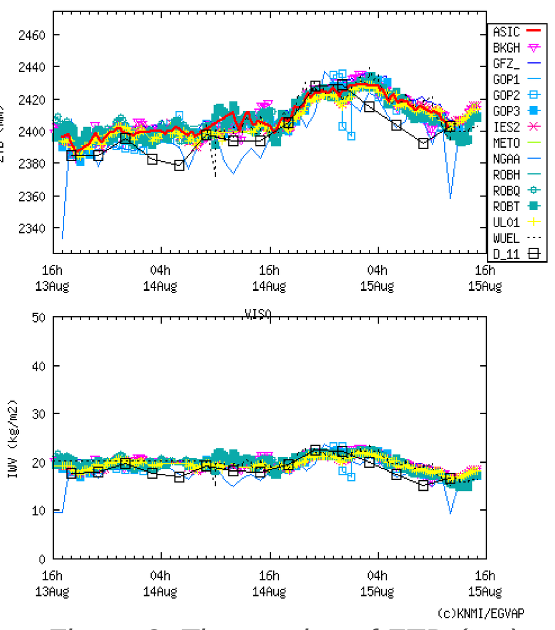

Figure 2: Time series of ZTD (top) and IWV (bottom) computed by UL01 (yellow) and other E-GVAP analysis centers for station VIS0 from 2013-08-13 16:00UTC to 2013-08-15 16:00UTC (E-GVAP, 2013)

The Europe-wide network of GNSS stations processed by UL01 is shown in Figure 1. Figure 2 shows recent ZTD and IWV time series from UL01 (yellow) in comparison with other solutions for the GNSS station Visby (VIS0). For this period and station, UL01 has a mean bias of -0.8 mm and a standard deviation (SD) of 14.8 mm. We note that for the stations used for this study, UL01 has a mean bias of 3.71 ± 11.9 mm. This compares well with the 3.42 ± 9.95 mm computed for all other E-GVAP analysis centers processing these stations.

Methodology

In order to assess the accuracy of the various processing systems at UL, a 20-day long (April 20 – May 10, 2013) dataset containing ZTD estimates has been extracted from their solutions. The selected GNSS stations belong to the IGS and the choice of stations is based on the availability of real-time observation data and the maximum number of epochs common in all the solutions. Figure 3 shows the location of the stations. The NRT system is based on double differencing and processes a Europe-wide network whereas the RT and PP systems are based on PPP and process a global network of stations. Table 2 shows some other characteristics of the various processing systems.

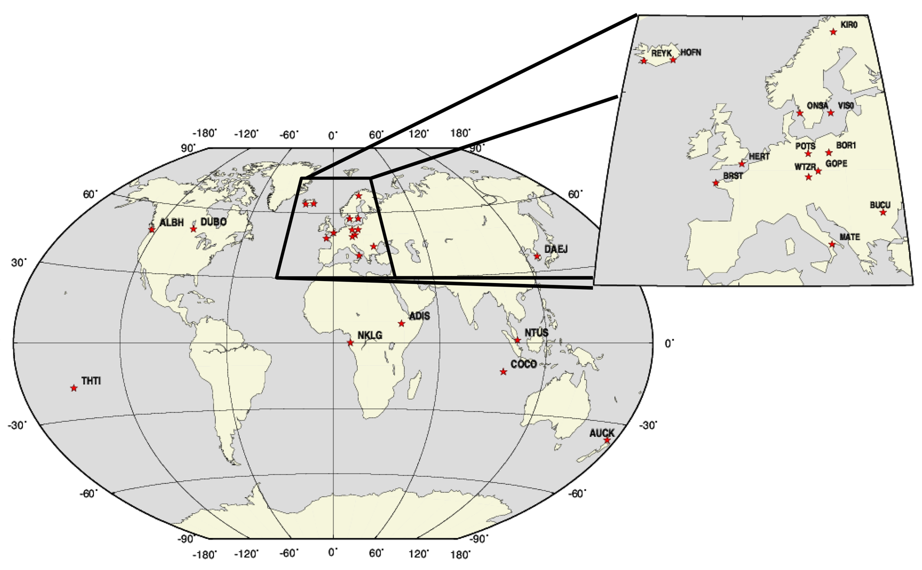

Figure 3: IGS Stations used in this study (small picture shows the stations which are common in NRT and RT systems)

The reference dataset used in this study is the IGS Final Troposphere product[4] (referred hereafter as IGFT) which contains the ZTD estimates in form of 27-Hour long sessions with a sampling interval of 5 minutes. For this study, the statistics of the comparison have been computed by taking the common epochs from the UL and reference datasets.

Table 2: Specific characteristics of GNSS processing systems at UL

System:	PP	NRT	RT-I	RT-II
GNSS Used	GPS	GPS	GPS	GPS
Processing Strategy	PPP	Double Differencing	PPP	PPP
Receiver PCV Correction	Yes	Yes	Yes	No
Satellite PCV Correction	Yes	Yes	Yes	Yes
Coordinates Computed	Yes	Yes	Yes	No
Input Raw Data Format	Daily RINEX	Hourly RINEX	RTCM-3 streams	RTCM-3 streams
Input Orbit/Clock Products	CODE Final	IGS Ultra-rapid	RTIGS	CNES
Ambiguity Resolution	No	Yes	No	Yes

Accuracy Assessment of the ZTD Estimates

This section provides the results of the assessment of the ZTD estimation systems at UL. The time series of the ZTD estimates obtained from all the four systems at UL follow the same pattern. As an example, Figure 4 shows the ZTD time series for four stations obtained by the four systems plotted with an artificial offset.

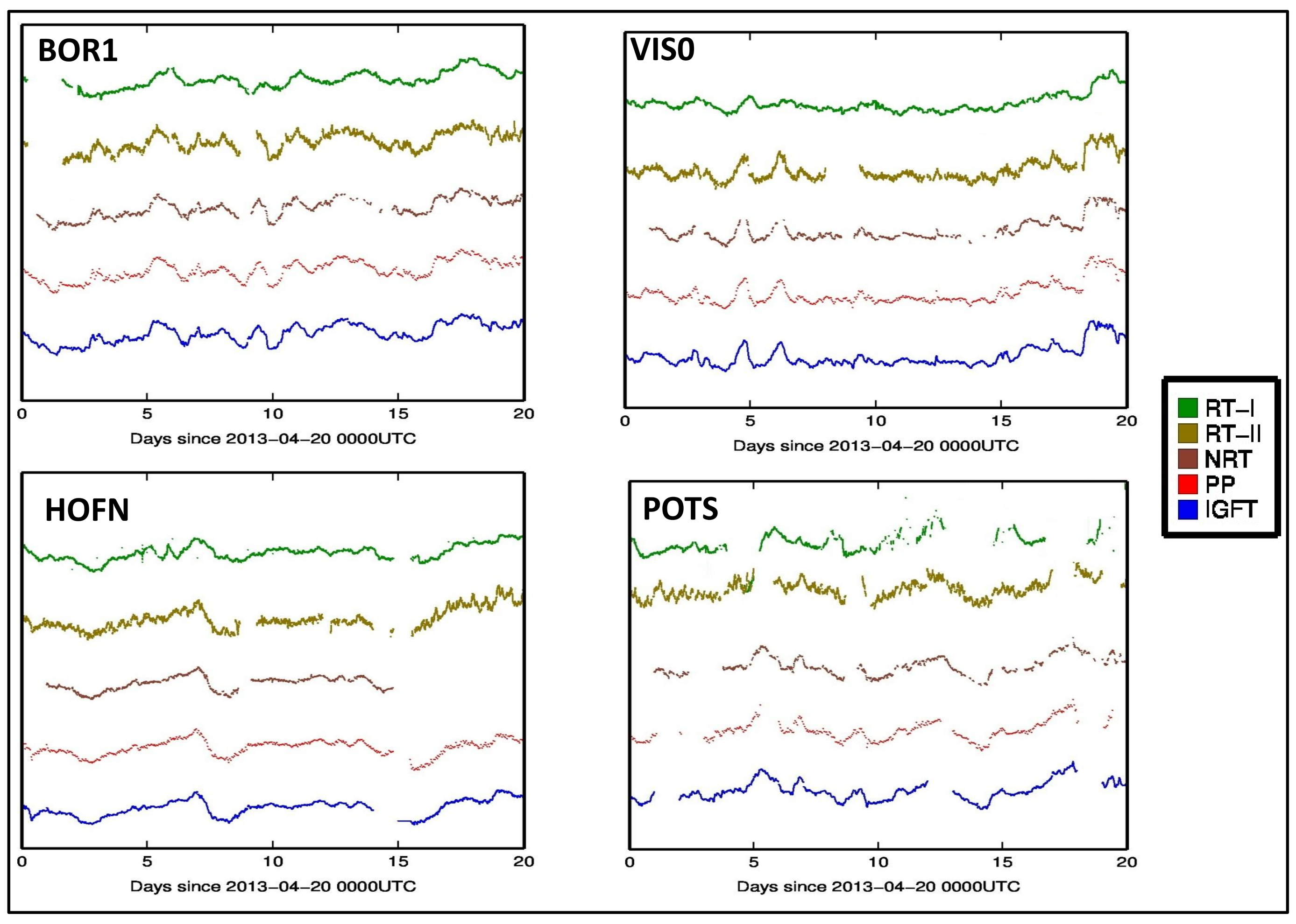

Figure 4: ZTD time series for the stations BOR1, VIS0, HOFN and POTS obtained using the four systems at UL

The solutions show various biases with the reference, however, for the assimilation into NWP models, this large bias in the ZTD estimates is not a major problem because station-specific biases are estimated in the models. Figure 5 shows the station-wise bias in ZTD estimates from the systems to the IGFT and Table 4 gives the overall statistics for each system. It is seen that the PP and NRT systems show a sub-millimeter level agreement to the IGFT whereas the mean bias between the RT ZTD estimates and the IGFT is on the order of tens of millimeters. For RT-II this is a consequence of the fact that currently the PPP-Wizard does not allow the application of antenna phase center models.

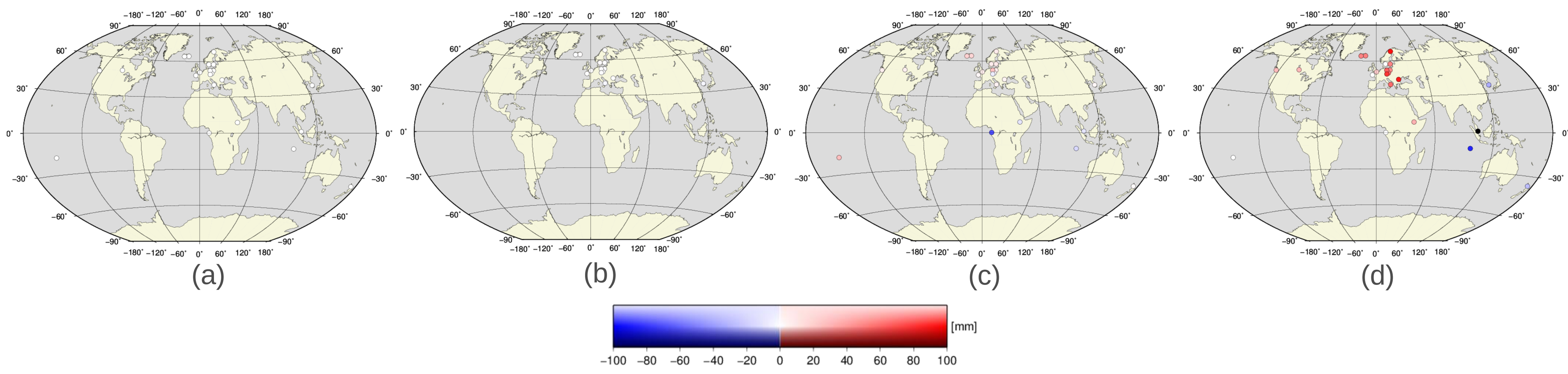

Figure 5: Station-wise bias of the ZTD estimates from a) PP, b) NRT, c) RT-I, and d) RT-II to IGFT

The PPP-Wizard is capable of resolving integer ambiguities in RT PPP. In order to study the effect of integer ambiguity resolution on the ZTD estimates, another RT solution for the same stations and time period has been obtained after disabling the ambiguity resolution feature in the PPP-Wizard. A mean difference of 0.4 ± 5.5 mm has been observed between the ambiguity float and ambiguity fixed solutions.

The COST Action 716[5] specified various user requirements for GNSS meteorology which specify threshold and target values on timeliness, accuracy and resolution etc. of ZTD and IWV estimates for use in nowcasting (Table 9). The accuracy requirements for IWV can be translated to their equivalent for ZTD (6 mm target and 30 mm threshold). If the RMS of the bias from IGFT is considered as a measure of relative accuracy, the obtained ZTD solutions can be compared to these requirements. Table 10 shows this comparison for each system at UL.

Table 3: User requirements for GNSS Meteorology as outlined by COST Action 716

Integrated Water Vapour (IWV)		
	Target	Threshold
Horizontal Domain	Europe to National	
Repetition Cycle	5 min	1 hour
Integration Time	MIN(5 min, rep cycle)	
Relative Accuracy	1 kg/m² (6 mm in ZTD)	5 kg/m² (30 mm in ZTD)
Timeliness	5 min	30 min

Table 4: Relative accuracy of the ZTD estimation systems and their comparison to the user requirements for nowcasting

System	Mean [mm]	SD [mm]	RMS [mm]	Difference from required target [mm]	Difference from required threshold [mm]	Remarks
PP	-0.7	7.1	6.2	0.2	-23.8	Meets the target
NRT	-0.3	4.7	4.8	-1.2	-25.2	Meets the target
RT-I	10.2	30.3	29.5	23.5	-0.5	Meets the threshold
RT-II	60.4	30.5	15.7	9.7	-14.3	Meets the threshold

Discussion and Conclusions

The four IWV and ZTD estimation systems at the University of Luxembourg have been introduced and their relative accuracy has been assessed by comparing them to the IGS Final Troposphere product. Mean differences of -0.7 ± 7.1 mm, -0.3 ± 4.7 mm, 10.2 ± 30.3 mm, and 60.4 ± 30.5 mm have been found for the Post-Processing, Near Real-Time, Real-Time I, and Real-Time II systems, respectively.

Considering the averaged RMS difference between each solution and the IGS Final Troposphere product as a measure of its absolute accuracy, the achieved accuracies have been compared to GNSS meteorology user requirements for now-casting as outlined in COST Action 716. As a result of this comparison, it was found that the Post-Processing and the Near Real-Time systems meet the target requirements whereas both the real-time systems currently only meet the threshold requirements.

The effect of integer ambiguity resolution on ZTD estimates was studied by using a modified version of the PPP-Wizard and it was found that the ambiguity fixed solution differs from the ambiguity float solution by less than a millimeter.

References

[1] Dach, R., Hugentobler, U., Fridez, P., Meindl, M. (Eds.) (2007) Bernese GPS Software Version 5.0, 612, Astronomical Institute, University of Bern
[2] BKG Ntrip Client (BNC) Version 2.6 Manual, Federal Agency for Cartography and Geodesy, Frankfurt, Germany
[3] Laurichesse, D., The CNES Real-time PPP with undifferenced integer ambiguity resolution demonstrator", Proceedings of the ION GNSS 2011, September 2011, Portland, Oregon
[4] Byram, S., Hackman, C., Slabinski, V., Tracey, J., Computation of a High-Precision GPS-Based Troposphere Product by the USNO, Proceedings of the ION GNSS 2011, September 2011, Portland, Oregon
[5] Exploitation of ground-based GPS for operational numerical weather prediction and climate applications, Final Report COST Action 716

Acknowledgements

This project is funded by the *Fonds National de la Recherche, Luxembourg (Reference No. 1090247)*. We are thankful to BKG for their software BNC 2.6. We also thank the BIGF, CODE, EUREF, IGS, SPSLux, and WALCORS communities for GNSS data and products.

Presented at: *IAG Scientific Assembly 2013, IAG 150 Years, Potsdam, Germany, September 1-6, 2013*