First Zenith Total Delay and Integrated Water Vapour Estimates from the Near Real-Time GNSS Data Processing Systems at the University of Luxembourg

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Abstract

Since September 2011 the University of Luxembourg in collaboration with the University of Nottingham has been setting up two near real-time processing systems for ground-based GNSS data for the provision of zenith total delay (ZTD) and integrated water vapour (IWV) estimates. Both systems are based on Bernese v5.0, use the double-differenced network processing strategy and operate with a 1-hour (NRT1h) and 15-minutes (NRT15m) update cycle. Furthermore, the systems follow the approach of the E-GVAP METO and IES2 systems in that the normal equations for the latest data are combined with those from the previous four updates during the estimation of the ZTDs. NRT1h currently takes the hourly data from over 200 GNSS stations in Europe whereas NRT15m is primarily using the real-time streams of the EUREF Permanent Network. Both networks include additional GNSS stations in Luxembourg, Belgium and France, with those from Luxembourg and Belgium also providing real-time streams. The a priori station coordinates for all of these stem from a moving average computed over the last 20 to 50 days and are based on the precise point positioning processing strategy.

In this study we present the first ZTD and IWV estimates obtained from the NRT1h and NRT15m systems in development at the University of Luxembourg. In a preliminary evaluation we compare their performance to the IES2 and IES4 systems at the University of Nottingham and find the IWV and ZTD estimates to agree at the sub-millimetre and millimetre level respectively.

Introduction

It is widely known that the delay encountered by GNSS signals while passing through the atmosphere can be manipulated to estimate the amount of water vapour in the troposphere. This information can then be fed into numerical weather models for use in weather forecasting. This field of research, which has largely benefited in Europe from the COST Action 716, TOUGH and e-GVAP projects, is known as GNSS meteorology and numerous leading meteorological organizations nowadays use GNSS-derived products either experimentally or operationally.

Using GNSS data in weather forecasting has many benefits over conventional methods, such as high temporal and spatial resolutions, easy access to the observational data and low operational costs. Recent developments in GNSS now provide exciting new possibilities and challenges for GNSS meteorology and some of these are the inclusion of observations from modernized and new GNSS, such as GLONASS and Galileo (as well as their optimal combination), development of GNSS processing strategies that are efficient in terms of timeliness (there is a drive towards real-time for now-casting applications) and required computing power, and the assimilation of the GNSS-derived products into the numerical weather models itself.

"The Potential of Precipitable Water Vapour Measurements using Global Navigation Satellite Systems in Luxembourg (PWVLUX)" is a collaborative research project between the University of Luxembourg and the University of Nottingham and is funded by the Fonds National de la Recherche (FNR) Luxembourg. The research objectives of the project are to study the potential for GNSS meteorology and climatology for Luxembourg and the surrounding regions of Belgium, France and Germany, the so called the "Greater Region". To achieve the research objectives, systems are being set up at the University of Luxembourg which process ground-based GNSS data for the provision of zenith total delay (ZTD) and integrated water vapour (IWV) estimates in real-time, near real-time and post-processing modes. Figure 1 shows the GNSS stations used by the near real-time (NRT) systems and Table 1 provides information on contributing networks. In the following box we describe the features of the hourly and sub-hourly NRT processing systems which have already been developed.

GNSS Networks

The network of GNSS stations has been selected with the aim of achieving good spatial coverage of Europe with a focus on Luxembourg and the Greater Region. Triangles represent the GNSS stations providing hourly data and circles represent those providing real-time streams. The hourly NRT system processes data from the stations that either provide real-time streams or hourly data. On the other hand, the sub-hourly NRT system only processes data from the real-time stations.

Network	Region
SPSLux (*red*)	Luxembourg
WALCORS (*orange*)	Wallonie (Belgium)
RGP(*gray*)	France
OSGB+Geonet (*yellow*)	UK
EPN (*blue*)	Europe
IGS08 (*black*)	Global

Table 1: GNSS data providers

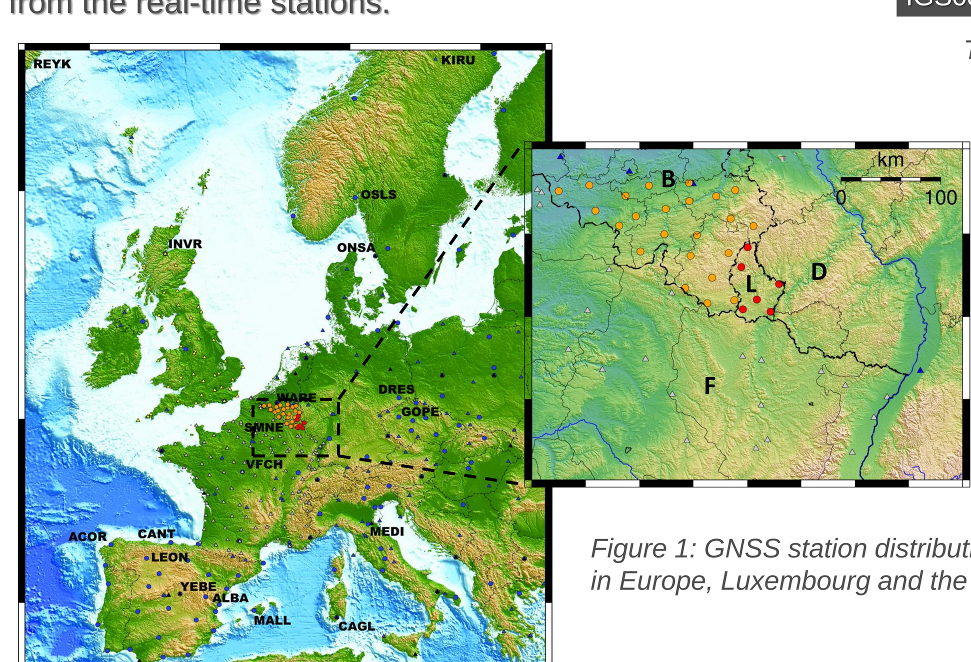

Figure 1: GNSS station distribution in Europe, Luxembourg and the Greater Region

The Near Real-Time Processing Systems

The hourly and sub-hourly NRT systems are based on Bernese GPS Software 5.0 and run on a UNIX server. Table 2 summarizes the features of both systems. In Figure 2, we present the operation of the NRT systems which is divided into database management, data and products handling, processing and archiving parts. The strategy of normal equation stacking used in the NRT systems is illustrated in Figure 3. The results of an evaluation of the NRT systems have been shown in the following box.

System:	NRT1h	NRT15m
Update Cycle	1 hour	15 minutes
Processing Engine	Bernese GPS Software 5.0	Bernese GPS Software 5.0
GNSS Used	GPS	GPS
Development Language(s)	Perl, Python	Perl, Python
Input Raw Data	RINEX 2.11 (hourly)	Real-time stream
Input Products	IGS Ultra-Rapid	IGS Ultra-Rapid
Antenna Calibration	Absolute	Absolute
Input Meteorological Data	Hourly file of meteorological data	Sub-hourly file of meteorological data
Outputs	• ZTD estimates • IWV estimates (COST-716) • 2D Plots • Animations	• ZTD estimates • IWV estimates (COST-716)

Table 2: Features of the NRT processing systems at the University of Luxembourg

Daily Processes in the NRT systems

- Computation of a priori coordinates for all stations using precise point positioning
- Obtaining updated station information
- Obtaining updated antenna information

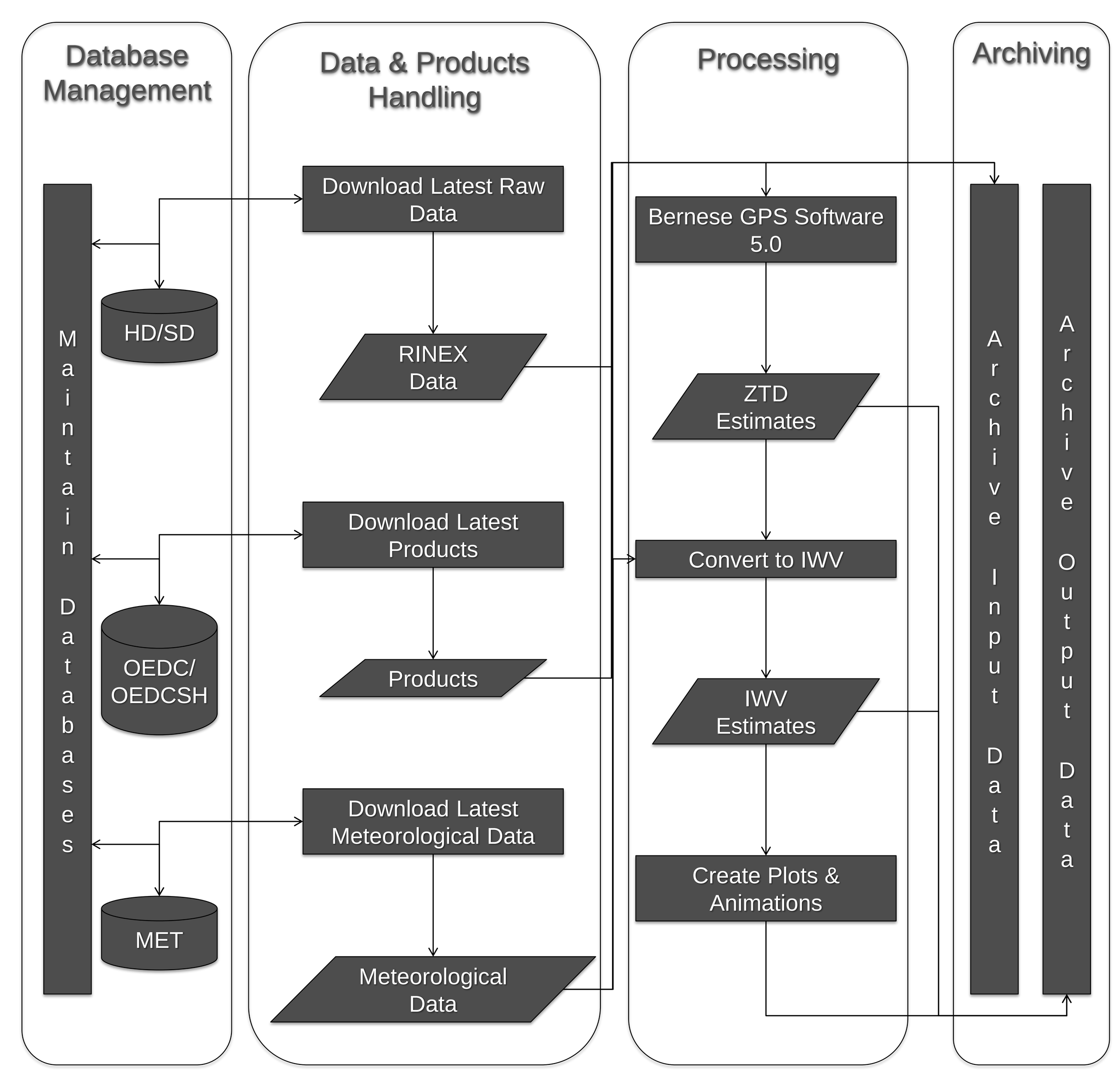

Figure 2: Operational Diagram of NRT processing systems at the University of Luxembourg

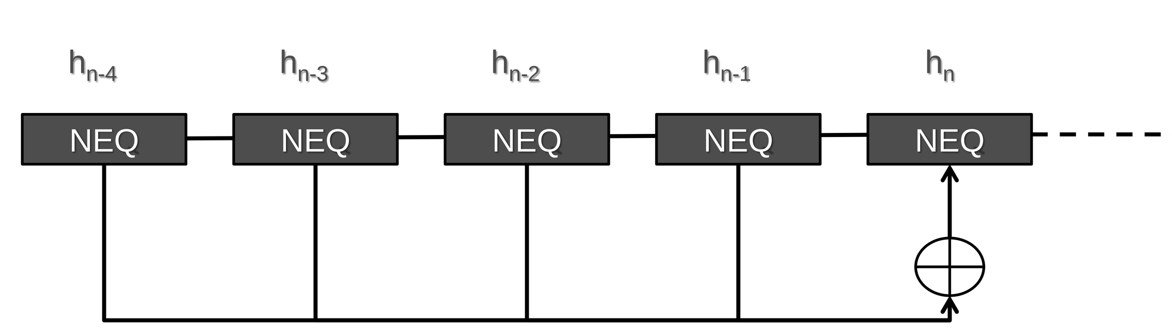

Figure 3: For consistency and continuity in the solutions, the strategy of stacking normal equations (NEQ) from the previous solutions has been implemented in the NRT systems i.e. the solution for the current session is computed by stacking the NEQ's from the solutions of 4 and 16 sessions for the hourly and sub-hourly system respectively.

NRT Systems Evaluation

The NRT systems have been evaluated by comparing their COST-716 format output to that of two equivalent systems in operation at the University of Nottingham. In this regard, the hourly system (NRT1h) has been compared to the E-GVAP solution IES2 (includes E-GVAP supersites) and the sub-hourly system (NRT15m) has been compared to the IES4 solution. Figures 4 and 5 show example time series of IWV and ZTD for this comparison. The numerical results for 10 selected stations are shown in Tables 3 and 4. Table 5 compares the NRT15m with the IES4 and the NRT1h results. In the following box, we describe the NRT results during a recent weather event.

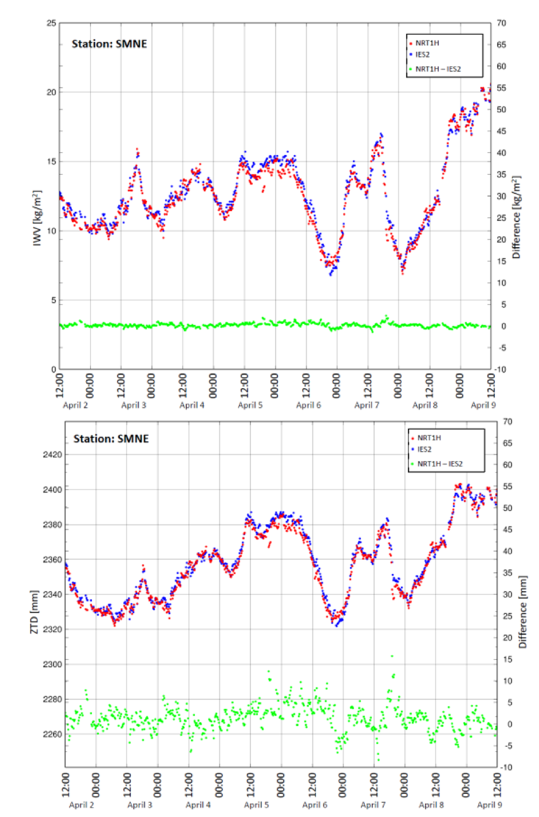

Figure 4: Comparison of IWV (top) and ZTD (bottom) time-series obtained from NRT1h and IES2 solutions (Note the different scales for the estimates and the difference)

RMS Difference from IES2 (NRT1h)		
Station	IWV [kg/m²]	ZTD [mm]
ACOR	0.44	2.79
CAGL	0.33	2.10
DRES	0.26	1.68
GOPE*	0.37	2.42
KIRU	0.14	0.91
MEDI*	0.50	2.16
ONSA*	0.23	1.48
REYK	0.46	2.96
SMNE*	0.50	3.17
YEBE*	0.45	2.86
Mean:	0.36	2.25

*Table 3: Comparison results for selected stations. * indicates an E-GVAP supersite*

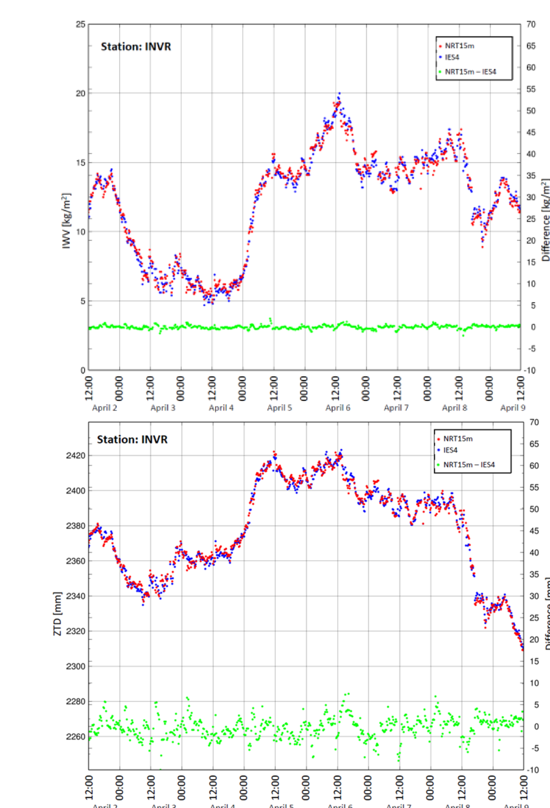

Figure 5: Comparison of IWV (top) and ZTD (bottom) time-series obtained from NRT15m and IES4 solutions (Note the different scales for the estimates and the difference)

RMS Difference from IES4 (NRT15m)		
Station	IWV [kg/m²]	ZTD [mm]
ACOR	0.23	2.83
ALBA	0.15	1.19
CANT	0.20	1.24
DRES	0.18	1.17
INVR	0.38	2.49
LEON	0.31	2.12
MALL	0.33	2.35
OSLS	0.61	2.78
VFCH	0.16	1.31
WARE	0.13	1.03
Mean:	0.27	1.85

Table 4: Comparison results for selected stations

NRT15m		
	IWV [kg/m²]	ZTD [mm]
RMS Difference from IES4	0.38	2.49
RMS Difference from NRT1h	0.70	6.16

Table 5: RMS of the differences in IWV and ZTD estimates obtained from NRT15m and IES4, and NRT15m and NRT1h (station: INVR)

NRT Results Weather Event 22-23 February 2012

During 22-23 February 2012, a weather event passed over Europe reaching Luxembourg and the Greater Region in the evening of 22nd February. For this event it is possible to compare the 2D IWV maps generated by the NRT1h system with precipitation information obtained from the weather radar (www.meteox.de). It can be seen that the zones with the largest gradients in IWV roughly overlap with frontline of the precipitation events identified by the weather radar (Figure 6). Figures 7 and 8 show the temporal evolution of the IWV estimates over Luxembourg and the Greater Region.

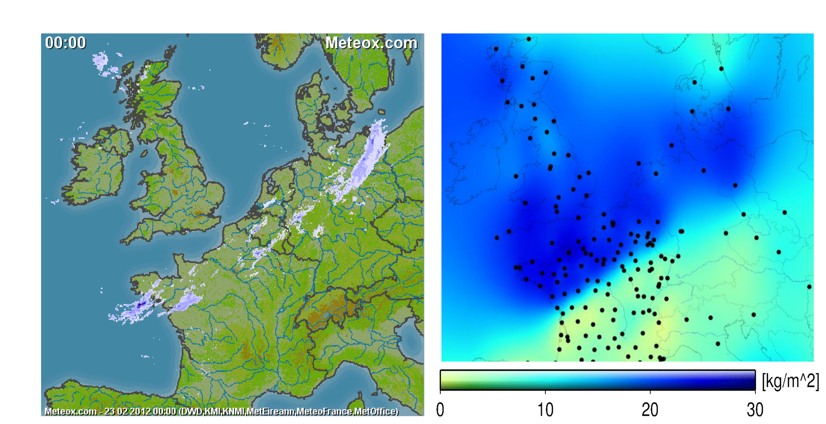

Figure 6: Comparison of weather radar (left) and IWV (right) at 2012-02-23 00:00UTC

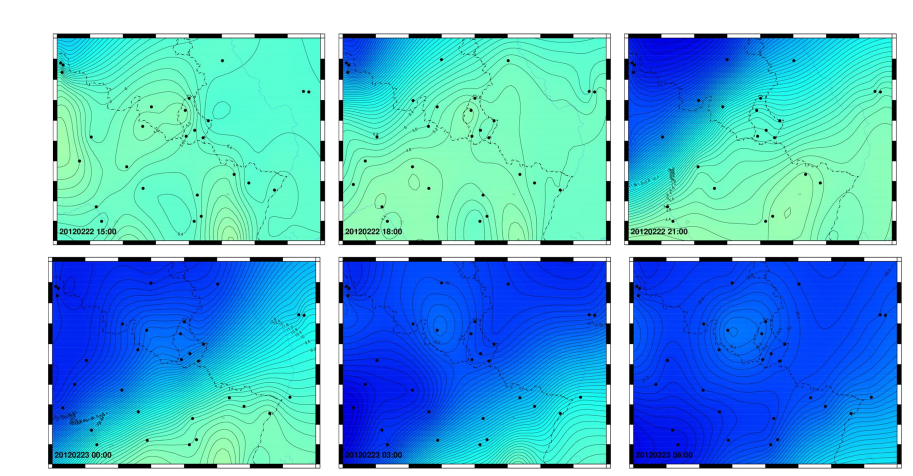

Figure 7: 3-hourly plots for IWV over Luxembourg and the Greater Region for 20120222-15:00UTC to 20120223-06:00UTC.

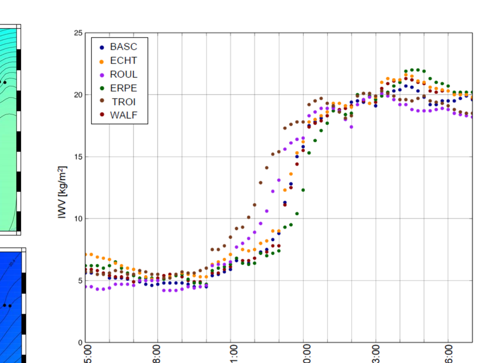

Figure 8 IWV time series for the 6 GNSS stations in Luxembourg for the period 20120222-15:00UTC to 20120223-06:00UTC.

Conclusions

Two NRT processing systems, NRT1h and NRT15m, developed at the University of Luxembourg to estimate ZTD and IWV with hourly and 15-minute update cycles respectively have been presented. An initial evaluation has been carried out by comparing them to the equivalent systems IES2 and IES4 in operation at the University of Nottingham.

The comparison results yield that our systems show sub-millimetre and millimetre level agreements in IWV and ZTD respectively. The results suggest that the differences between the two sub-hourly systems are smaller than the differences between the sub-hourly and the hourly system. This is a result of the higher similarities in the networks used by the sub-hourly systems (NRT15m, IES4) than by the hourly systems (NRT1h, IES2).

First preliminary results for the hourly NRT system for a weather system crossing over Luxembourg and the Greater Region on 22-23 February, 2012 are presented. We compared the maps of IWV with precipitation maps from weather radar data and show good agreement in the location of the foremost extent of the precipitation events.

These results are encouraging and show that the NRT systems at the University of Luxembourg give comparable results to the other E-GVAP AC solutions.

Acknowledgements

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