# 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 June 2011, the University of Luxembourg has started in collaboration with the University of Nottingham a PhD project entitled “The Potential of Precipitable Water Vapour Measurements using Global Navigation Satellite Systems in Luxembourg (PWVLUX)”, which is funded by the Fonds National de la Recherche (FNR) Luxembourg. The research objectives of the project are to study the potential for improvements in short-term weather forecasts and long-term climate variability for Luxembourg and the Greater Region by inclusion of the observations from Global Navigation Satellite Systems (GNSS) in the existing techniques. 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. Through collaboration with the Administration du cadastre et de la topographie (Luxembourg) and the Service public de Wallonie (Belgium), the coverage of the available GNSS permanent networks is improved over the primary project area, although also data from other European and global networks are processed. The meteorological analysis of the PWVLUX products is supported through collaborations with the Meteorological Service of the Administration de la navigation aérienne and the EUMETNET project E-GVAP.

In this study we present the first ZTD and IWV estimates obtained from the near-real time processing systems in development at the University of Luxembourg. In a preliminary evaluation we compared their performance to some state-of-the-art systems already in operation and found that the ZTD estimates agree up to a few millimeters and the IWV estimates agree at the sub-millimeter level.

## The Project

### Research Objectives

- To study the impact of GNSS data on meteorological short-term forecasting.
  - *by incorporating GNSS data in NWM for Luxembourg*
  - *by studying the improvement in short-term forecasting*
- To investigate the climate variability using GNSS data in Luxembourg and the Greater Region

### Expected Outcomes

- Short-term Weather Forecasting:
  - *ZTD and IWV estimates for extreme weather periods*
  - *2D climatological maps of ZTD and IWV for extreme weather periods*
- Climate Monitoring:
  - *Long-term trends/time series of ZTD and IWV*
  - *2D climatological maps of ZTD and IWV variations*

### Benefits

- The project will develop a capability (in Luxembourg) for the use of GNSS data for meteorological applications
- Improved weather forecasts for aviation and general public
- Public availability of ZTD and IWV estimates for remote sensing applications
- Improved understanding of local and regional climate and its variability

### Technical Developments (at University of Luxembourg)

- A post-processing system for IWV estimation
- A near-real time (NRT) processing system for IWV estimation (completed)
- A real time (RT) processing system for IWV estimation

## The Near Real-Time Processing Systems

| System Type: | Hourly NRT | Sub-hourly NRT |
|---|---|---|
| **Update Cycle** | 1 hour | 15 minutes |
| **Processing Engine** | Bernese GPS Software 5.0 | Bernese GPS Software 5.0 |
| **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 data file from UK MetOffice* | Sub-hourly data file from UK MetOffice* |
| **Outputs** | • ZTD estimates<br>• IWV estimates (COST-716)<br>• 2D Plots<br>• Animations | • ZTD estimates<br>• IWV estimates (COST-716) |

* To be provided by Meteorological Service of Luxembourg

*Table 1 Features of the NRT processing systems at the University of Luxembourg*

### Daily Processes in the NRT system

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

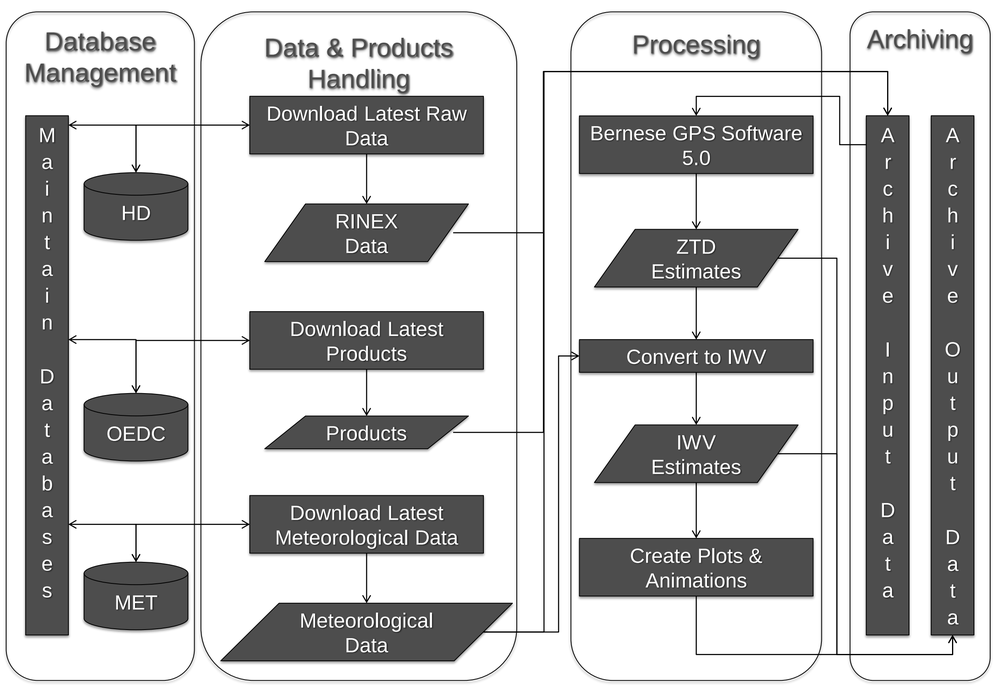


*Figure 1 Operational Diagram of NRT processing systems at the University of Luxembourg*

## Current Network

The network of GNSS stations has been selected with the aim of achieving good spatial coverage of Luxembourg and the Greater Region.

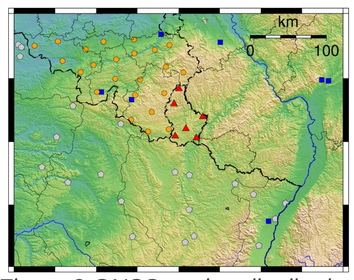


*Figure 2 GNSS station distribution in the Greater Region*

*Figure 3 GNSS station distribution in Europe*

| Network | Region |
|---|---|
| SPSLux ( ) | Luxembourg |
| WALCORS ( ) | Wallonie (Belgium) |
| RGP( ) | France |
| OSGB+Geonet ( ) | UK |
| EPN ( ) | Europe |
| IGS08 ( ) | Global |

*Table 2 List of GNSS data providers*

## NRT System Evaluation

The hourly NRT system has been evaluated by comparing its COST-716 format output to that of a state-of-the-art system (IES2) which is currently providing data to the E-GVAP project. For identification purpose, we call our system output as ULUX here. The figures and table below show the results of the comparison of ZTD and IWV estimates for the station CAMO (Camborne, UK) for a period of 48 hours (22-23 February 2012).

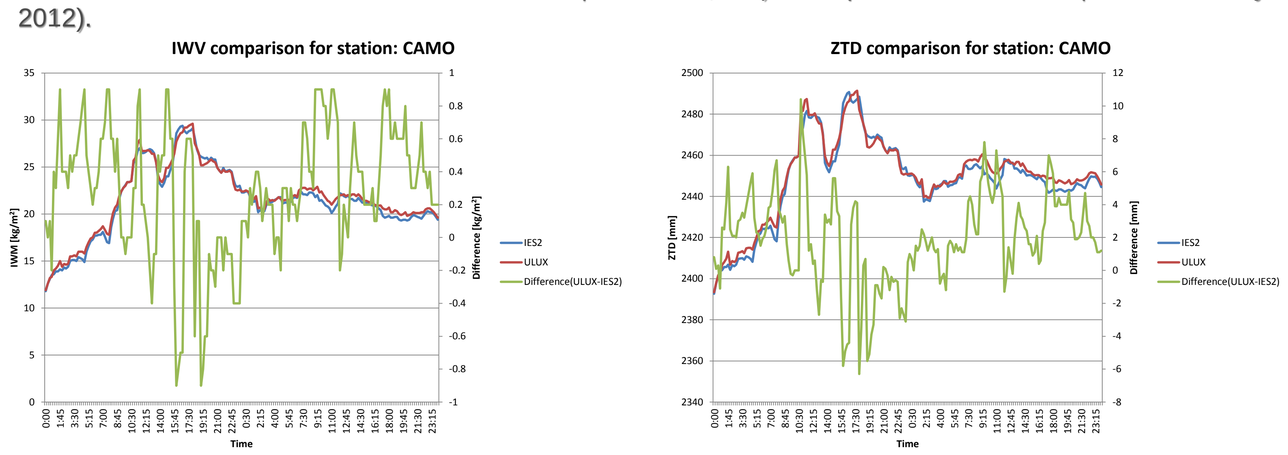


*Figure 4 Comparison of IWV (left) and ZTD (right) time-series obtained from ULUX and IES2 solutions (Note the different scales for the estimates and the difference)*

| ULUX vs. IES2 | |
|---|---|
| RMS Difference between IWV | 0.48 kg/m$^2$ |
| RMS Difference between ZTD | 3.36 mm |

*Table 3 RMS values of the difference between ZTD and IWV estimates obtained from ULUX and IES2 for the period of 22-23 February 2012*

## Preliminary NRT Results

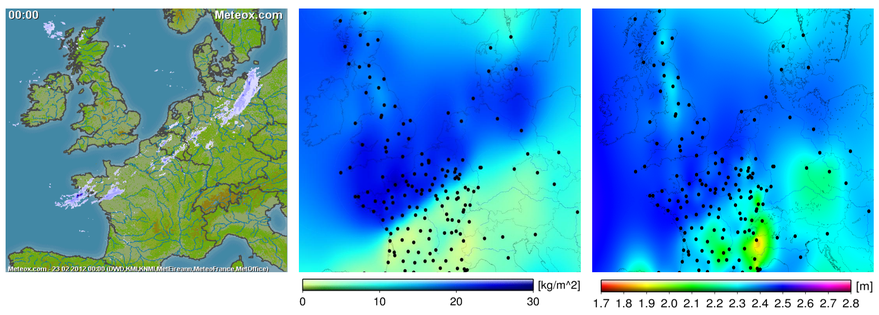


*Figure 5 Comparison of weather radar precipitation (left), GPS IWV (center) and GPS ZTD (right)*

From Figure 5, it is evident that the distribution of IWV is very similar to the pattern of the frontal system shown by the weather radar.

Figures 6 and 7 show the rise in the amount of IWV over Luxembourg and the Greater Region as this frontal system passes over the region.

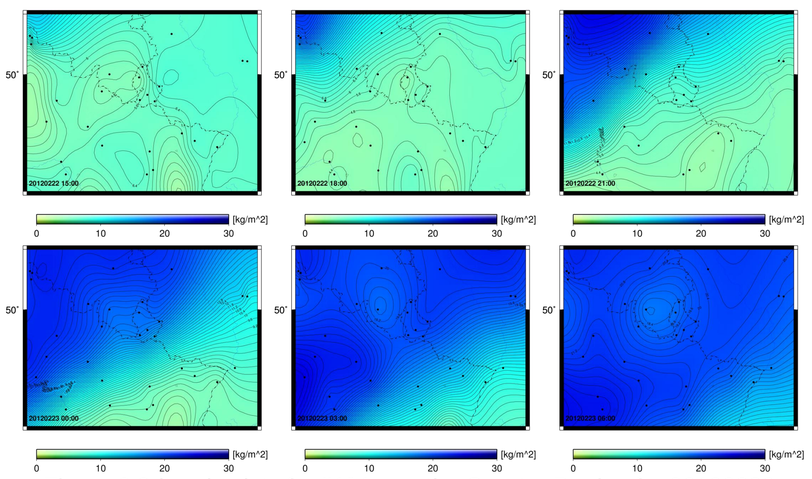


*Figure 6 3-hourly plots for IWV over the Greater Region for 20120222-15:00UTC to 20120223-06:00UTC*

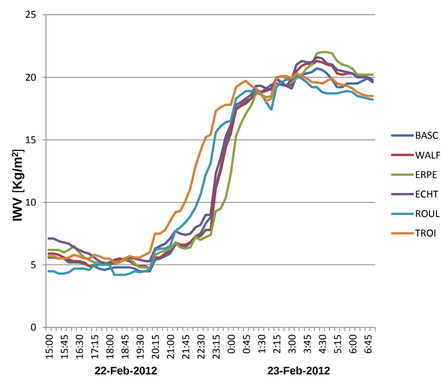


*Figure 7 IWV time series for 20120222-15:00UTC to 20120223-06:00UTC for SPSLux stations*

## Conclusions

So far, two NRT processing systems to estimate ZTD and IWV with hourly and 15-minute update cycles have been developed at the University of Luxembourg. During the initial phase of the project, we have investigated the GNSS networks available to the NRT systems in order to achieve an adequate spatial coverage for Luxembourg and the Greater Region.

An evaluation of the hourly NRT system was carried out by comparing it to a similar state-of-the-art system and an agreement up to a few millimeters between the ZTD and less than 1 kg/m$^2$ between IWV estimates was found. First preliminary results for the hourly NRT system for a frontal system crossing over Luxembourg and the Greater Region on February 23, 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 weather system.

## Acknowledgements

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