Assimilation of zenith total delays in the AROME France convective scale model: a recent assessment

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Abstract

The Zenith Total Delay (ZTD) derived from Global Navigation Satellite Systems (GNSS) observations is presently being assimilated into many state-of-the-art Numerical Weather Prediction (NWP) models worldwide. This helps to improve the knowledge of the initial state of the atmosphere and the subsequent forecasts. The convective scale NWP model AROME is operational at Météo-France since December 2008. The AROME model has a resolution of 2.5 km and uses the three dimensional variational (3D-Var) data assimilation scheme with a Rapid Update Cycle (RUC) of 3 hours.

This study presents a recent assessment of the impact of assimilation of the GNSS derived ZTD observations into the AROME 3D-Var model. Two data assimilation experiments have been performed for a recent summer period of July 18, 2013 to August 20, 2013. The first experiment uses the ZTD from the stations and analysis centers available in real time through the E-GVAP. In the second experiment, additional stations processed by the University of Luxembourg have been added to the observations from E-GVAP. A third experiment without the assimilation of any GNSS ZTD observations has been performed to serve as a baseline for the first two experiments and to provide an impact assessment of GNSS ZTD data assimilation in the AROME model. From the output of these three experiments, various parameters have been extracted and statistics for the comparisons between those have been calculated. The impact assessment has been carried out in two parts i.e. studying the impact on the model analysis and studying the impact on model forecasts.

Introduction

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. The ZTD estimated from GNSS observations is currently being assimilated in many NWP models worldwide to determine the initial state of the atmosphere with higher accuracy and subsequently improve the forecasts (e.g. [1], [2]).

The EUMETNET EIG GNSS water vapour programme (E-GVAP) is a programme for collection and distribution of NRT ground based GNSS data from analysis centers all over Europe for operational meteorology since 2005 (http://egvap.dmi.dk). Other than the use in operational meteorology, E-GVAP also helps the gradual improvement in the GNSS data processing at various analysis centers by monitoring the ZTD solutions generated in experimental (or test) modes. "UL01" is one such test solution which is generated at the University of Luxembourg and is submitted to E-GVAP. The network of stations processed by UL01 contains stations located all over Europe with a densification over Luxembourg and the Greater Region. Figure 1 shows the Europe-wide network of GNSS stations processed by the E-GVAP analysis centers.

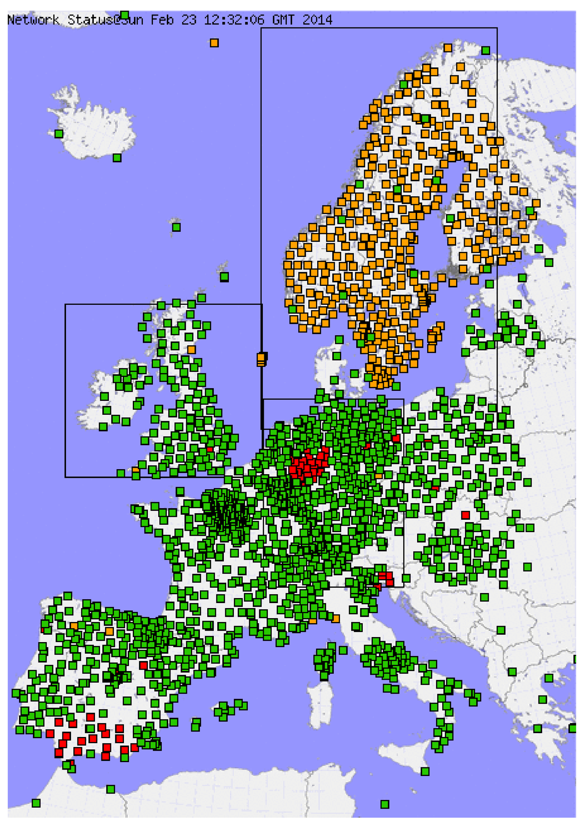

Figure 1: Network of GNSS stations processed by E-GVAP analysis centers (E-GVAP, 2014)

At Météo-France, a convection permitting NWP model AROME[3] is operational since December 2008. This model has a three dimensional variational (3D-Var) data assimilation system with a Rapid Update Cycle (RUC) of 3 hours and a dedicated background error covariance matrix allowing statistical balances of model variables at mesoscale. The AROME domain covers a significant part of western Europe. The horizontal resolution is 2.5 km on a Lambert projection centered at (46.4º North and 2.2º East) with 750 and 720 physical grid points in the east-west and north-south directions respectively. The domain is vertically divided in 60 layers with the center of the uppermost layer located at 1 hPa. Figure 2 shows the domain of the AROME model. The colored dots in Figure 2 show the GNSS stations processed by various E-GVAP analysis centers used for the assimilation of ZTD in AROME.

The goal of this study is twofold. First, a recent assessment of the impact of GPS ZTD data assimilation in the current version of the operational 3D-Var data assimilation system for the AROME model (which has undergone various upgrades and improvements since the past assessment studies) has been provided. Secondly, the impact of increasing the GNSS network through the addition of the UL01 solution has been examined.

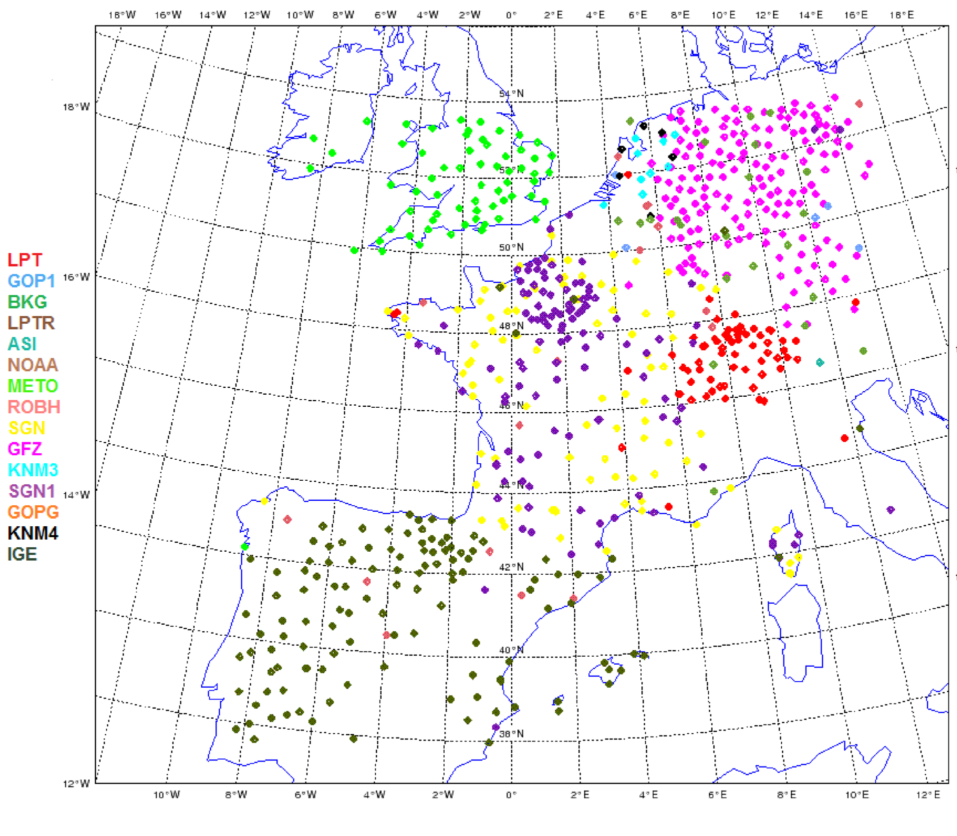

Figure 2: The domain of the AROME NWP model. The colored dots show the GNSS stations from various E-GVAP analysis centers used for ZTD assimilation

Methodology

This study has been conducted by performing three forecast experiments using the AROME 3D-Var NWP model for the period of July 18 – August 20, 2013. Table 1 shows some characteristics of these experiments.

Table 1: Characteristics of the forecast experiments

Experiment Name:	NOGPS	EGVAP	UL01
GNSS ZTD Assimilated	No	Yes	Yes
GNSS Networks Used for ZTD Assimilation	-	▪ E-GVAP Operational Solutions only	▪ E-GVAP Operational Solutions ▪ UL01 Test Solution

The experiment without the assimilation of GNSS ZTD observations was performed to serve as a baseline for the experiments in which GNSS ZTD assimilation was considered and to provide a recent impact assessment of such data assimilation in the AROME 3D-Var model. The two experiments with the GPS ZTD assimilation were performed for studying the impact of assimilating the ZTD estimates from the UL01 solution in addition to the operational EGVAP ZTD solutions. From the output of these three experiments, various parameters were extracted and statistics for the comparisons between those were calculated.

Figure 3 shows the flowchart for the EGVAP and UL01 experiments i.e. the experiments in which GNSS ZTD data has been assimilated.

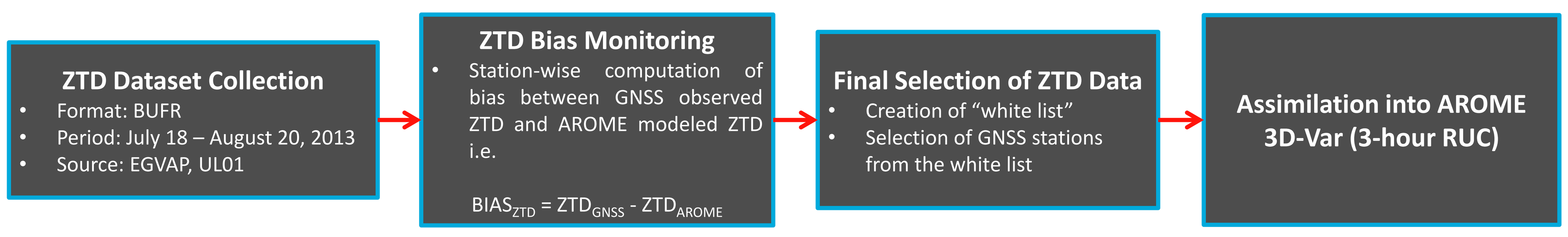

Figure 3: Flowchart of the GNSS ZTD assimilation experiments

Impact Assessment

The impact assessment of GNSS ZTD assimilation was carried out in two parts i.e. studying the impact on the model analysis and studying the impact on model forecasts.

Impact on Analysis

Figure 4 shows the distributions of the analysis departure (the difference between the ZTD observations from the equivalent from analysis) and the first-guess departure (the difference between the observed ZTD and the model equivalent ZTD computed from the 3-hour AROME forecast) for the whole period of the experiment.

The a priori data selection allows the first guess departures to follow a Gaussian distribution (which is an underlying hypothesis of the data assimilation optimality). Then observations outside three standard deviations are considered as outliers and rejected from what is called a "background check". When more than one processing center is available for a given station, the choice is made on the one having the best statistics available in the "white list".

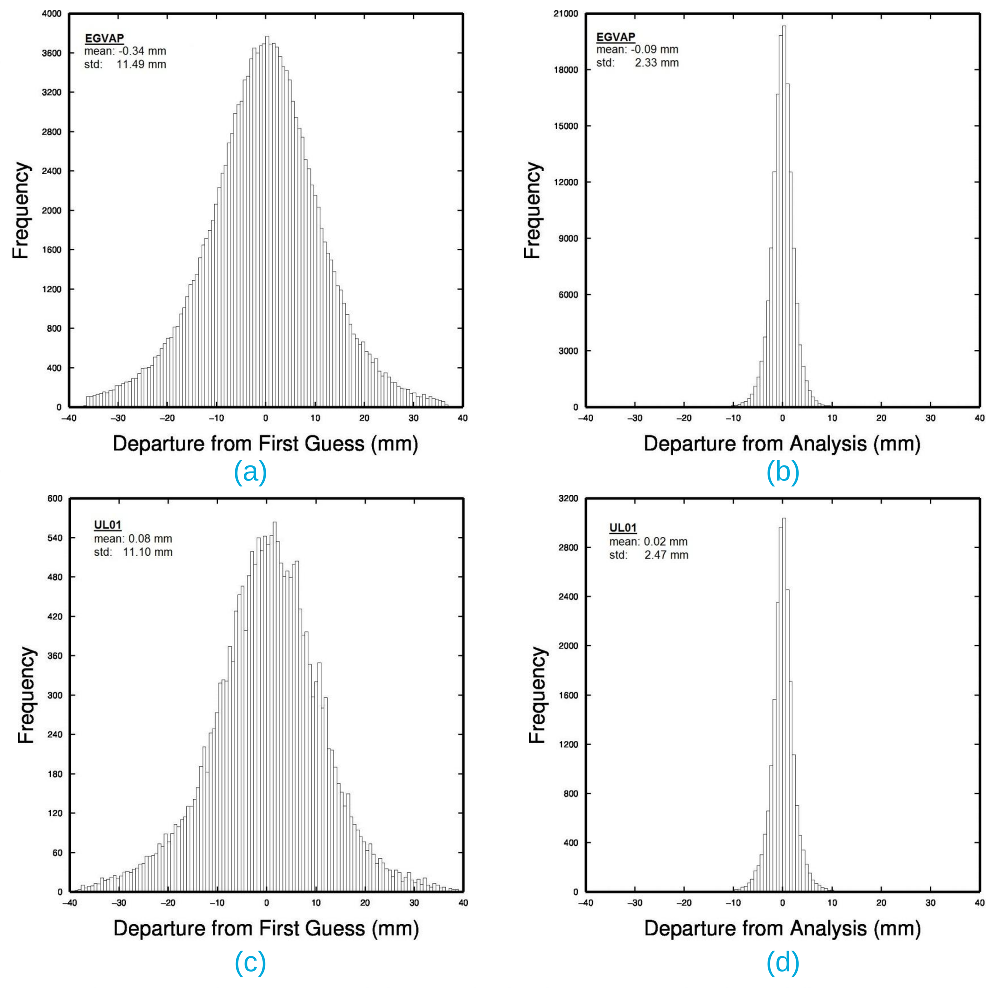

Figure 4: Histograms of the analysis departures (a,c) and first-guess departures (b,d) for all the EGVAP operational networks (sample size: 147591) and the UL01 network (sample size: 20572)

Figures 4(a) and 4(b) show the distributions of analysis and first-guess departures, respectively, of all the ZTD observations from the operational EGVAP solutions whereas Figures 4(c) and 4(d) show the distribution of analysis and first-guess departures, respectively, of ZTD observations from only the UL01 solution. It could be seen that the UL01 observations' analysis and first-guess departures follow a Gaussian distribution and that the distribution is narrower (smaller standard deviation) after assimilation showing that the 3D-Var has brought the model state closer to the ZTD observations. Even though the shape of the distribution is smoother with the EGVAP solution since the sample is larger than that of UL01, the means and standard deviations are very close to each other. Therefore the 3D-Var system behaves the same way for assimilating ZTD EGVAP or ZTD UL01.

Impact of Forecast

Forecast scores were computed from the three experiments to study the effect of assimilating various GPS ZTD datasets on atmospheric forecasts for the period of July 18, 2013 to August 20, 2013.

Figure 5 shows the bias and the standard deviation of the forecast scores for 2-meter temperature and Figure 6 shows the same for 2-meter relative humidity averaged over the whole domain of the AROME model. The scores have been computed by comparing the forecasts to a dedicated 2-meter analysis using surface observations from SYNOP and RADOME[4] networks. It can be seen that the results are rather neutral. The GPS ZTD data reduces slightly the bias in relative humidity but increases the bias in temperature. The impact of assimilating UL01 ZTD observations in addition to EGVAP is either neutral or slightly negative.

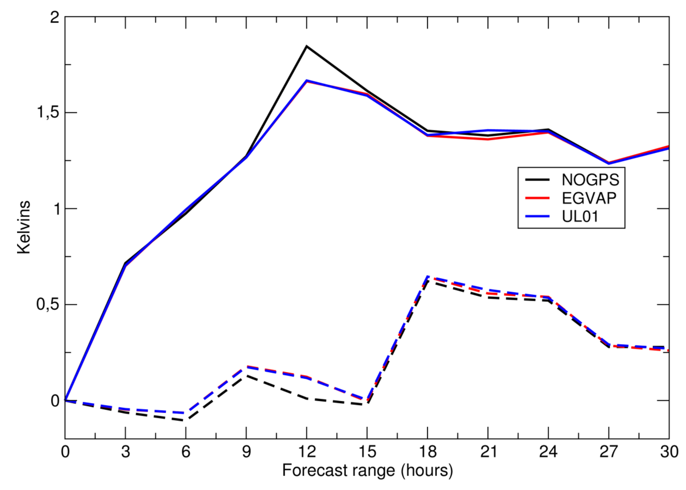

Figure 5: Forecast score for 2-meter temperature (18 July 2013 – 20 August 2013)

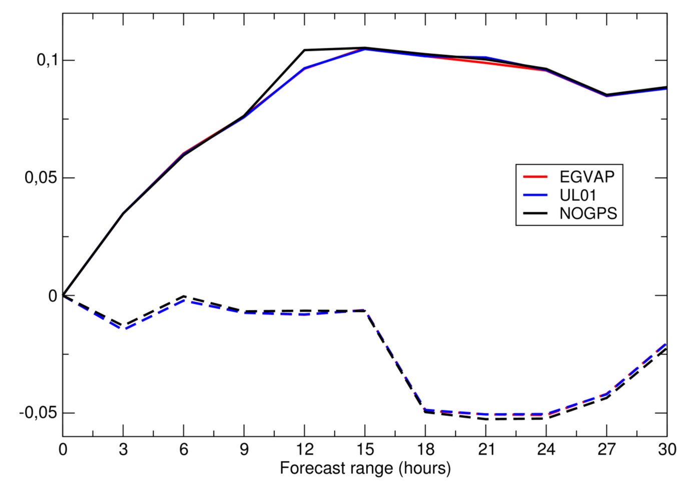

Figure 6: Forecast score for 2-meter relative humidity (18 July 2013 – 20 August 2013)

Conclusions

An impact assessment of the assimilation of GPS derived ZTD observations in the AROME 3D-VAR NWP model was conducted by experiments without GPS ZTD assimilation, with the assimilation of operational EGVAP ZTD solutions, and with the assimilation of ZTD observations from UL01 in addition to EGVAP solutions.

The analysis and first-guess departures of the ZTD observations selected for assimilation from the UL01 solution were found to be almost unbiased and following a Gaussian distribution comparable to the ZTD EGVAP data and in agreement with underlying hypotheses of the 3D-Var assimilation system. The mean and standard deviation of the analysis departures of UL01 ZTD was found to be slightly higher than those of the EGVAP only solution. From the three assimilation experiments, 30-h forecasts of the AROME model were run. Forecast scores for 2-meter temperature and 2-meter relative humidity were computed over the whole domain and rather neutral results were found. The GPS ZTD data seems to reduce slightly the bias in relative humidity but increase the bias in temperature. The assimilation of UL01 ZTD observations in addition to EGVAP solutions seems to have either a neutral or negative impact on the forecast scores. These preliminary forecast scores will be complemented by precipitation scores for specific severe weather events that took place during the period.

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