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GNSS tomography data assimilation into the NWP models

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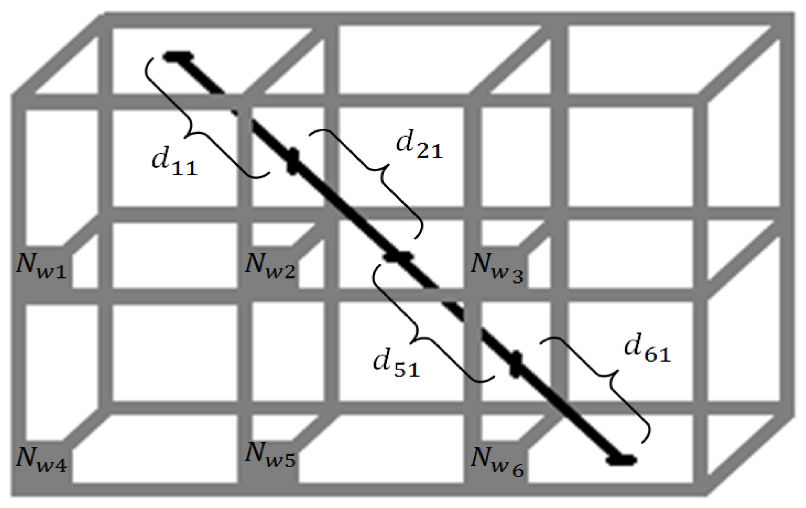
ABSTRACT

The GNSS signal propagating from the satellite to the receiver is subjected to the phase delay due to the presence of the atmosphere. The signal's troposphere phase delay is linked to the density of all gaseous constituencies, including one of the most important - water vapour. There are several techniques that estimate water vapor amount in the troposphere based on GNSS signal delay. One of them is tomography. This study shows the first results of the Near-Real Time tomography products assimilation into the WRF model using GPSREF observation operator. The assimilation was made using 3D-Var method, for two selected events in 2017 (summer storms and heavy precipitation; calm weather) in Poland. For the comparison, also the radiosonde data were assimilated using the same operator. The results were compared with four external data sources – GNSS IWV, synoptic stations, radiosondes, and ERA-Interim model.

1. GNSS TOMOGRAPHY IN NRT MODE



$$10^{-6}\int N_w ds = SWD$$

$$SWD = A * N_w$$

known — estimated

$$A = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}$$

GNSS signal ray in the tomography domain; solution scheme.

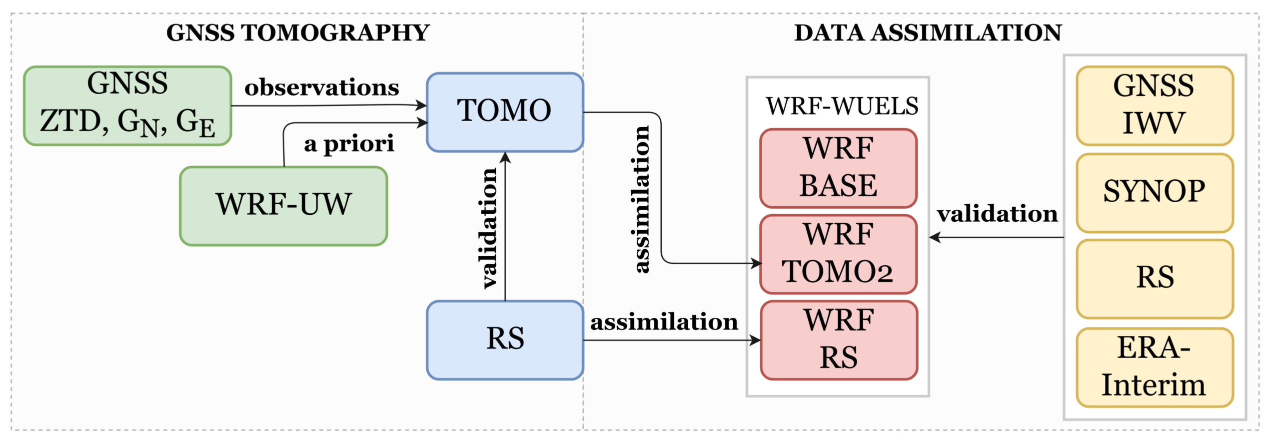
GNSS troposphere tomography aims to obtain 3D information about humidity in the lower atmosphere, based on the GNSS signal delays. Slant Wet Delay (SWD) can be calculated as an integral of the wet refractivity (N_w) along the ray path. The inversion of set of equations (scheme) leads to estimation of wet refractivity distribution.

GNSS observations
ZTD and gradient observations provided by WUELS processing center in NRT mode for ASG-EUPOS and Leica SmartNet stations

Satellite orbits
Prognostic Ultra-Rapid orbits of BKG GNSS Data Center

Additional data
Data derived from WRF forecasts were used as the a priori information about the state of troposphere for the whole domain

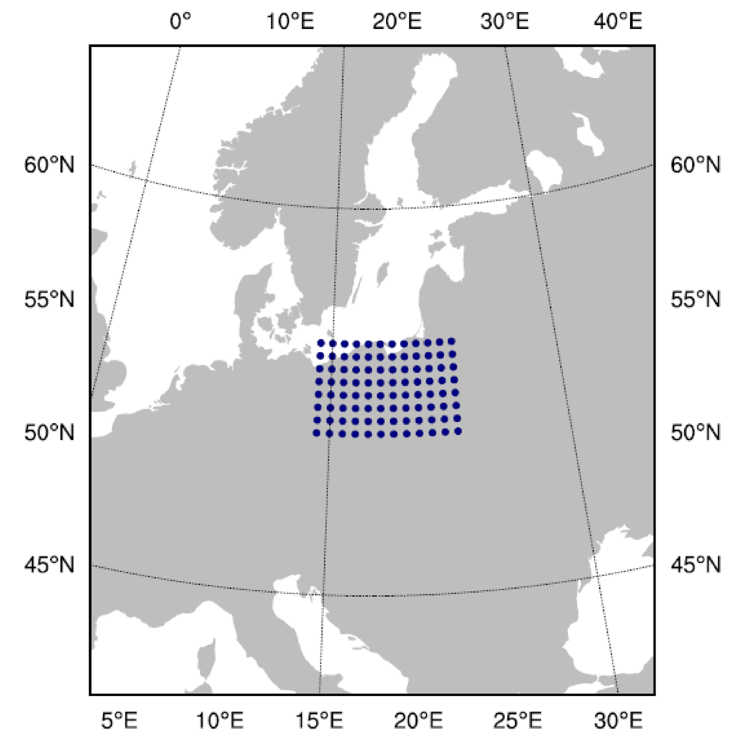
2. EXPERIMENT DESIGN



The GNSS tomography in NRT mode was made based on ZTD observations together with their gradients, as well as WRF data. The validation was based on comparison with radiosonde observations. There were 3 WRF model runs: BASE (no assimilation), TOMO2 (GNSS tomography data assimilation), and RS (radiosonde data assimilation, for the comparison). Validation of the assimilation was based on 4 external data sources: IWV from GNSS measurements, synoptic observations, radiosondes, and ERA-Interim model.
Two periods were chosen for the study:

08-15.08.2017	heavy precipitation events and quickly passing weather fronts
03-08.11.2017	calm weather, low and moderate precipitation

3. ASSIMILATION INTO THE WRF MODEL



Location of the observations in the assimilation domain.

Total refractivity was assimilated into the WRF model through Data Assimilation (WRF-DA) system using GPSREF operator. The wet part was derived from TOMO2 model and the hydrostatic part from the WRF base (no assimilation) run.

$$N = N_w + N_h$$

ASSIMILATED — TOMO2 — WRF

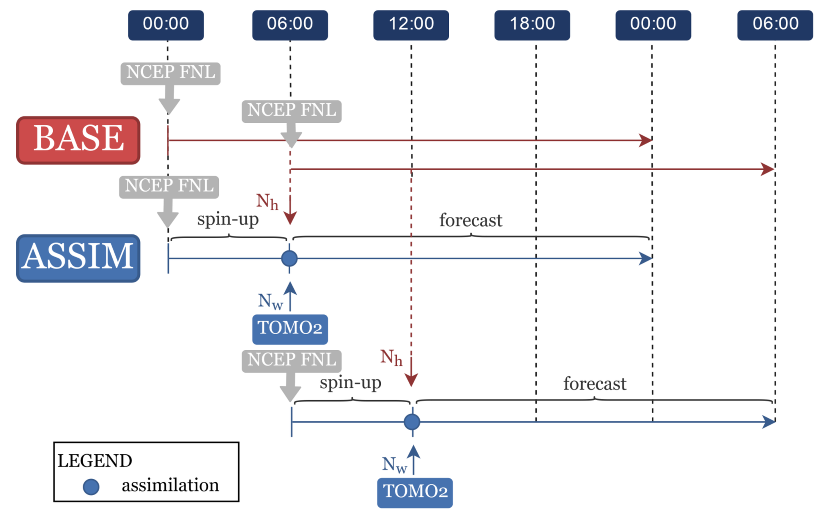
The WRF model version 3.9 was used with the following configuration:

Domain
- 36 km x 36 km

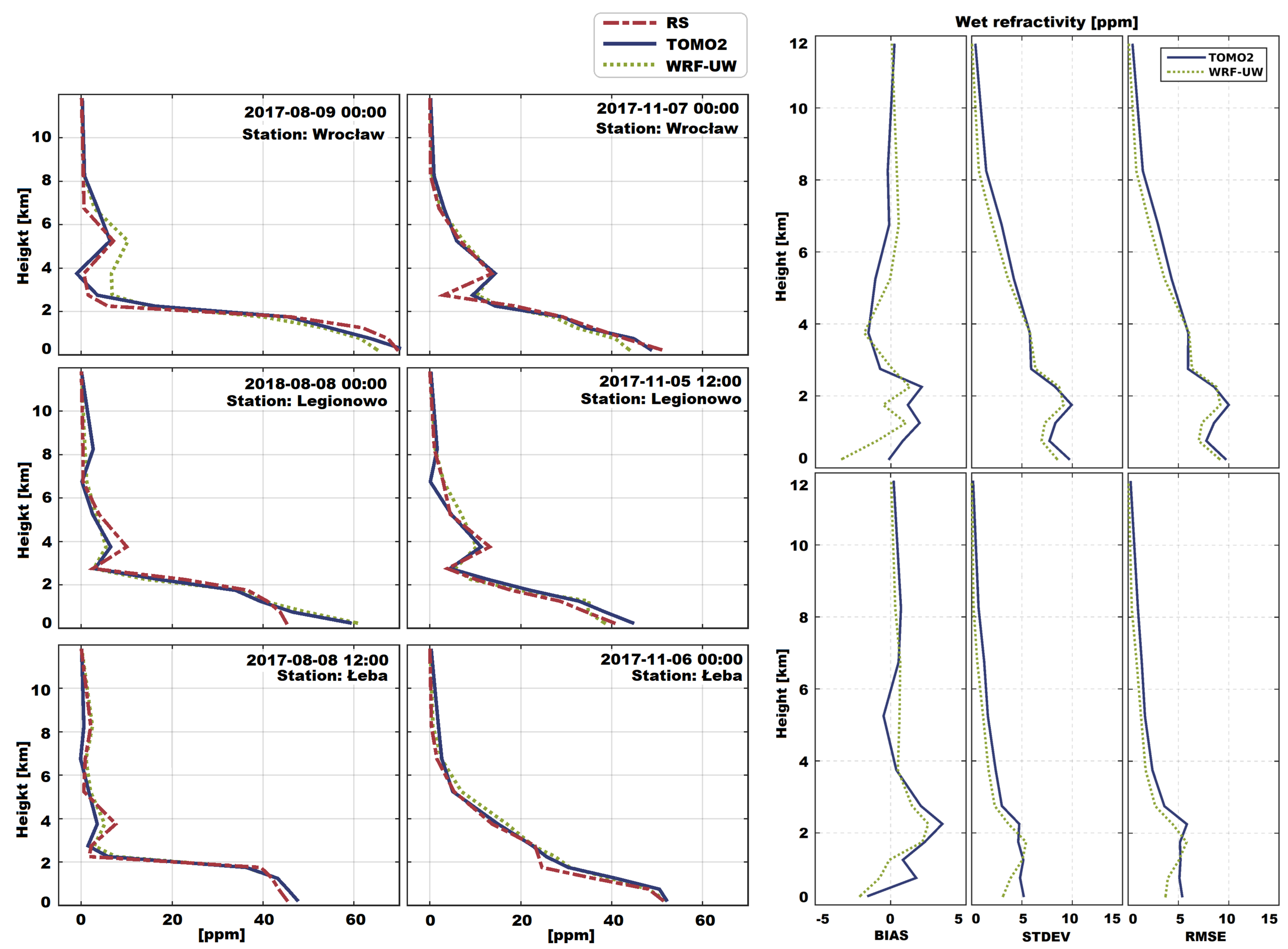
Initial and boundary conditions
- NCEP FNL 1° x 1°

Assimilation method
- 3D-Var

Assimilated observations
- 11 vertical layers
- 96 observations of N for each layer (fig. 3)



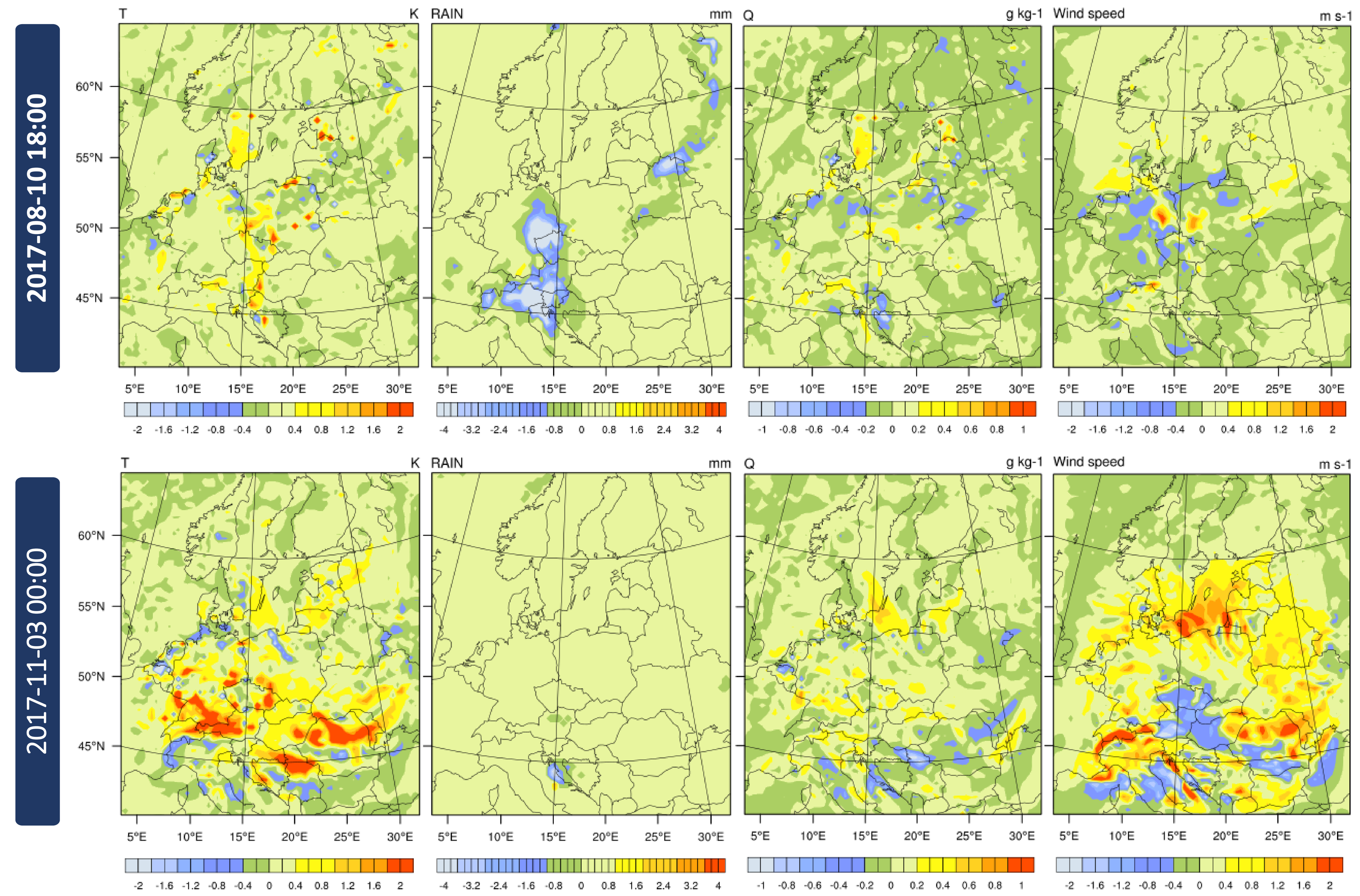
4. GNSS TOMOGRAPHY RESULTS



GNSS troposphere tomography results were validated by comparison with radiosonde (RS) observations from 3 RS stations in Poland. Also the WRF-UW model was compared with the results. The plots show the values and the statistics of wet refractivity in a vertical profile.

5. ASSIMILATION RESULTS

Assimilation impact on 6-hour forecast



Differences between TOMO2 assimilation and base run are shown on the maps (6-hours forecast). For T, Q and WS differences are evenly distributed in positive and negative values, while change in RAIN is mostly negative (less rain after assimilation), especially for the first period.

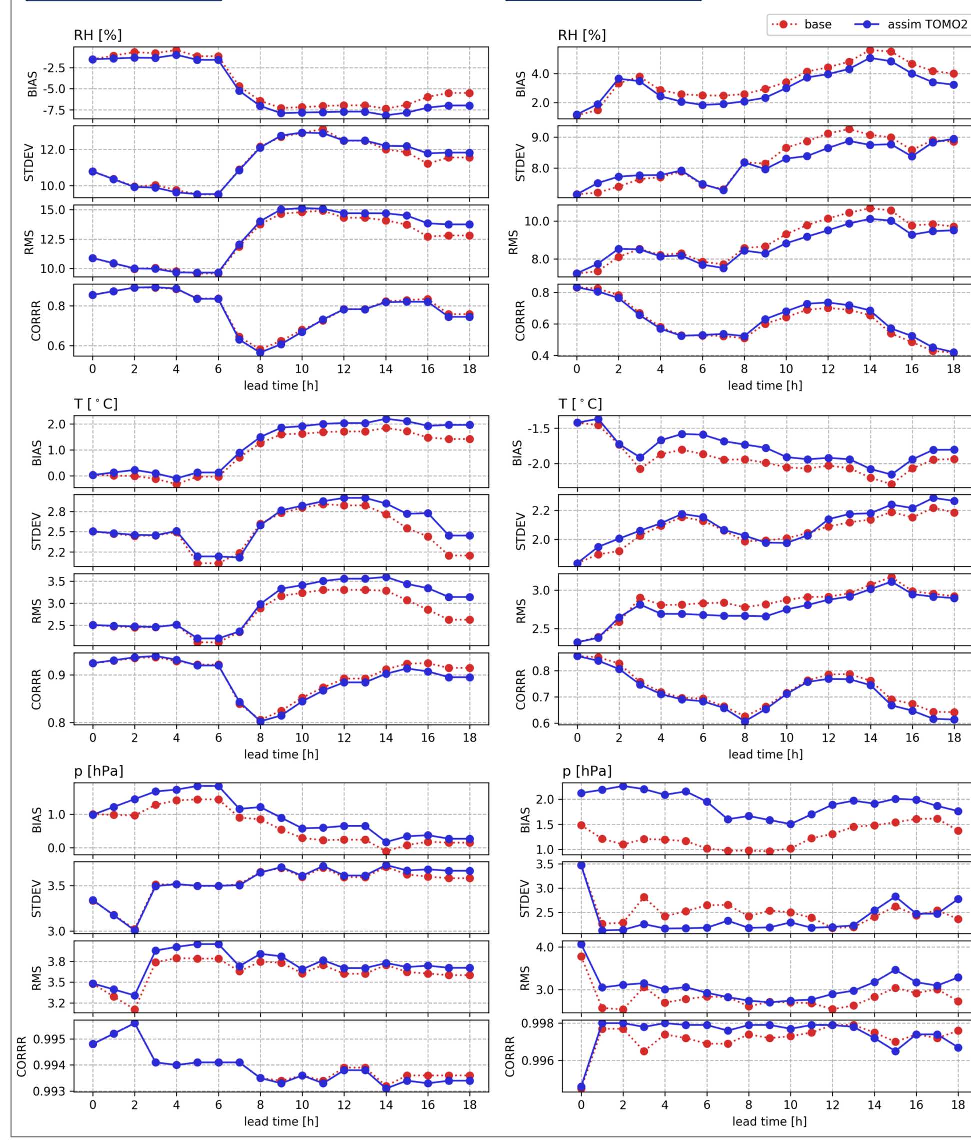
Temperature
- ± 2°C

Rain
- ± 4 mm

Mixing ratio
- ± 1 g/kg

Wind speed
- ± 2 m/s

Forecast validation with SYNOP



Validation in time of assimilation

			GNSS IWV [mm]	SYNOP RH [%]	SYNOP T [°C]	SYNOP p [hPa]	RS RH [%]	RS T [°C]	RS WS [m/s]
BASE	August	BIAS	2.68	-1.52	0.04	1.00	-1.61	0.11	0.08
		STDEV	3.63	10.79	2.51	3.33	16.72	1.49	3.61
	November	BIAS	1.68	1.11	-1.43	1.48	3.50	0.08	-0.04
		STDEV	1.31	7.15	1.84	3.48	10.33	0.88	2.26
TOMO2	August	BIAS	3.67	-1.52	0.04	0.99	-0.32	0.16	0.07
		STDEV	3.50	10.79	2.51	3.34	17.68	1.60	3.91
	November	BIAS	2.52	1.16	-1.43	2.12	6.82	0.02	0.87
		STDEV	1.20	7.14	1.84	3.47	12.83	1.16	2.82
RS	August	BIAS	2.90	-1.52	0.04	0.94	-0.94	0.13	0.03
		STDEV	3.60	10.78	2.51	3.37	14.91	1.58	3.76
	November	BIAS	2.01	1.12	-1.43	1.56	4.48	0.07	-0.14
		STDEV	1.42	7.15	1.84	3.49	10.21	0.87	2.29

The first validation was made in time of assimilation. The results are presented in the table. The colours indicate the relation to the base run (green: better; red: worse).
Also the validation of the forecasts in the consecutive lead times was conducted, based on comparison with synoptic observations of relative humidity, temperture and surface pressure. The results show improvement in RH and T forecasts for the second period (RMSE).

More results of the study can be found in the following paper:

Trzcina E. and Rohm W. *Estimation of 3D wet refractivity by tomography, combining GNSS and NWP data: First results from assimilation of wet refractivity into NWP.* Quarterly Journal of the Royal Meteorological Society. 2019; 1-18. doi: 10.1002/qj.3475.

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