ASSIMILATION OF GNSS TOMOGRAPHY IN NEAR-REAL TIME MODE PRODUCTS INTO THE WEATHER RESEARCH AND FORECASTING MODEL

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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 paper shows the first results of the Near-Real Time tomography products assimilation into WRF model using GPSREF observation operator. The assimilation was made in 3D-Var, for the period of 08-15.08.2017 when heavy precipitation events occured in Poland. The results were compared with GNSS IWV data, showing improvement in standard deviation and correlation. Comparison with relative humidity from RS observatins shows the improvement in BIAS and not in the standard deviation.

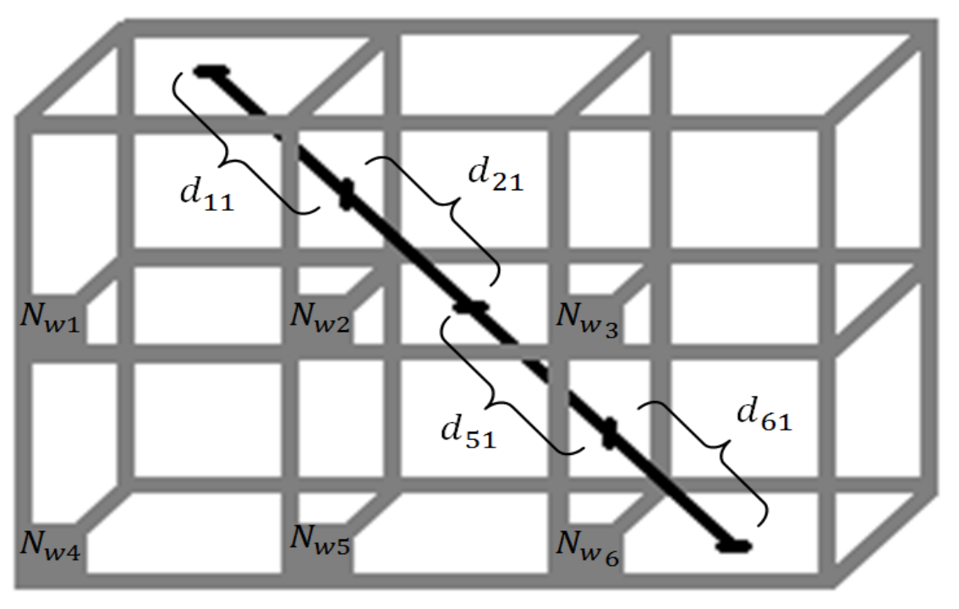
GNSS TROPOSPHERE TOMOGRAPHY IN NRT MODE

GNSS TROPOSPHERE TOMOGRAPHY

GNSS troposphere tomography is a technique that aims to obtain the spatial distribution of wet refractivity or water vapor density in the lower atmosphere based on satellite signal delays. Slant Wet Delay (SWD) can be calculated as an integral of the wet refractivity (N_w) along the ray path:

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

The same relation applies for the Slant Integrated Water Vapor (SIWV) and the water vapor density (WV). The estimation is obtained by the inversion process (fig. 2). Slant delays are calculated from: GNSS observations of Zenith Total Delays (ZTD), meteorological parameters and mapping functions.



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

$$\underset{\text{known}}{\underset{\uparrow}{SWD}} = A * \underset{\text{estimated}}{\underset{\uparrow}{N_w}}$$

Fig. 1. GNSS signal ray in the tomography domain; solution scheme.

TOMO2 SOLUTION

The troposphere tomography solution was performed in Near-Real Time (NRT) mode for the area of Poland using TOMO2 model, with time resolution of 1 hour. Horizonal resolution is about 80 km, domain consists of 11 vertical layers (up to 12 km). The following settings were applied:

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

TEST CASE

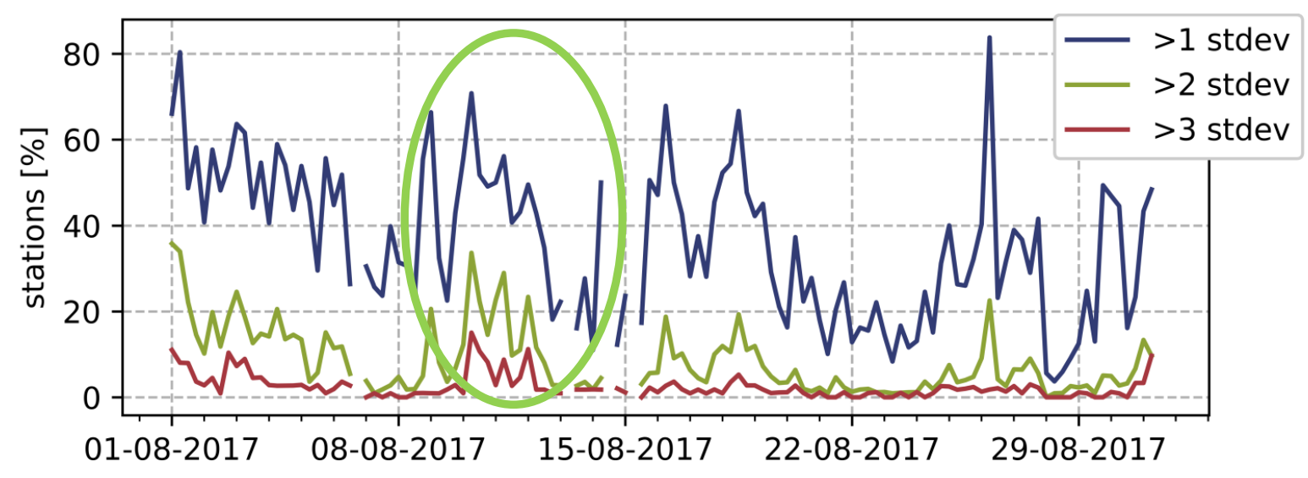


Fig. 2. Number of GNSS stations where differences between Integrated Water Vapor (IWV) values observed by GNSS and modelled by WRF where higher than 1, 2 and 3 standard deviations.

The test period is 08-15.08.2017 when heavy precipitation events occured in Poland. Fig. 2 shows number of GNSS stations where differences between IWV observed by GNSS and modelled by WRF were significant, for August 2017. The largest discrepancies can be seen for the chosen period, which means that the GNSS observations might improve WRF forecast significantly.

TOMOGRAPHY RESULTS

Wet refractivity derived from TOMO2 model was compared with radiosonde (RS) data from three RAOB stations: Wrocław, Legionowo and Łeba. In general tomography data represents vertical profile of troposphere with the accuracy comparable to WRF data (or better, eg. Wrocław station, August 9th 00:00). There are some cases where TOMO2 is not elastic enough (Łeba, August 8th 12:00). The overall RMS is similar to WRF data, better for 2-4 km height (5-10 ppm). TOMO2 results were also compared with Global Precipitation Measurement (GPM) data (fig. 4) for the event of precipitation in Central Poland.

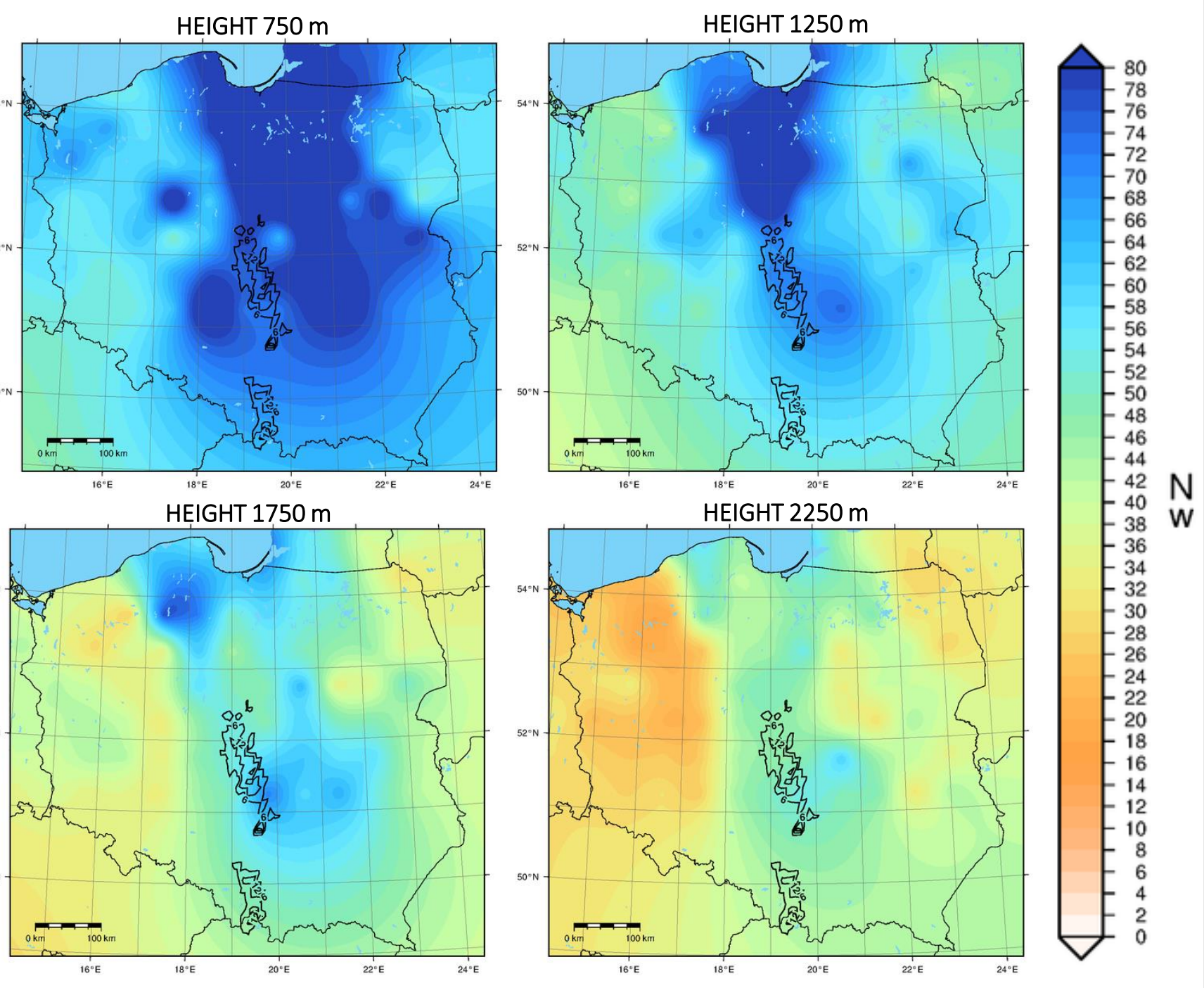


Fig. 4. TOMO2 wet refractivity values (background) with GPM precipitation (isolines) for 2017-08-12 -6:00 on different levels (for more plots visit: http://geo2.igig.up.wroc.pl/).

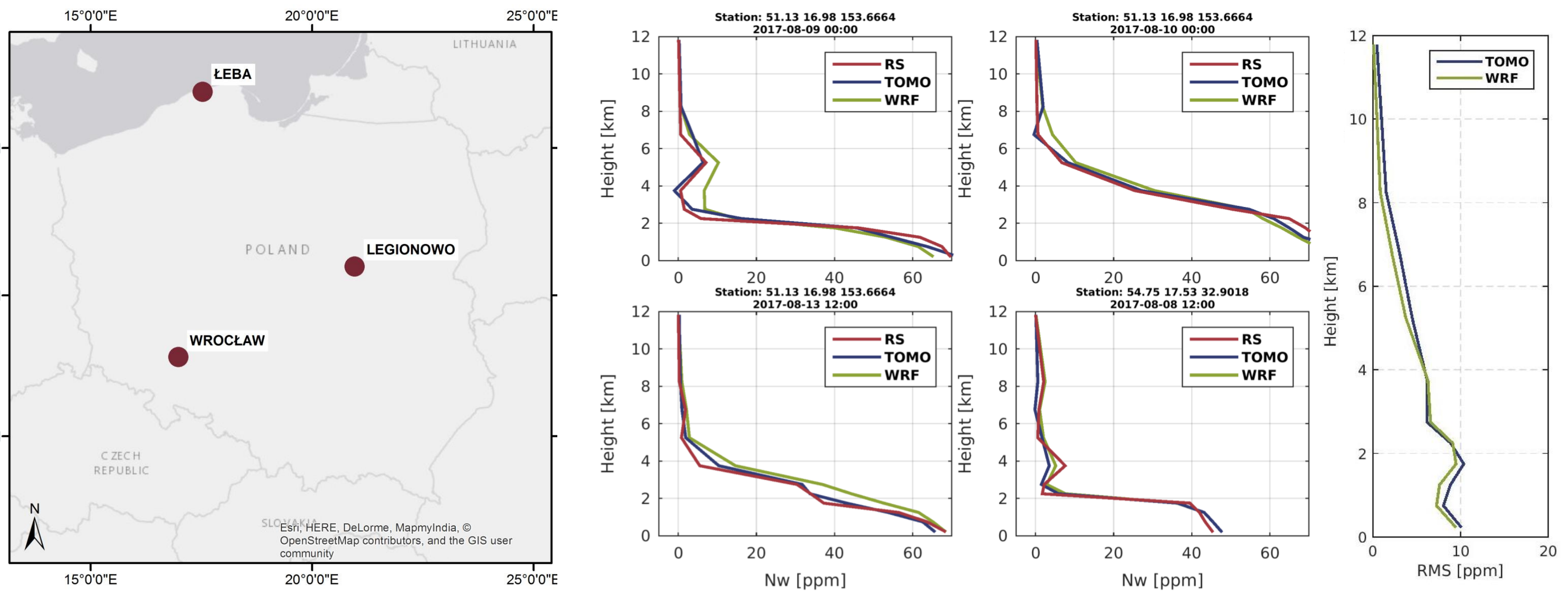


Fig. 3. Comparison of TOMO2 wet refractivity with RS data. Localisation of RS stations (left), Nw vertical profiles (centre) and RMS error (right).

ASSIMILATION INTO THE WRF MODEL

Total refractivty derived from TOMO2 (wet part) and WRF model (hydrostatic part) was assimilated into the WRF model through Data Assimilation (WRF-DA) system using GPSREF operator.

$$N = \underset{\text{TOMO2}}{\underset{\uparrow}{N_w}} + \underset{\text{WRF}}{\underset{\uparrow}{N_h}}$$

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

Domain
- 36 km x 36 km

Vertical levels
- 35

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

Assimilation method
- 3D-Var

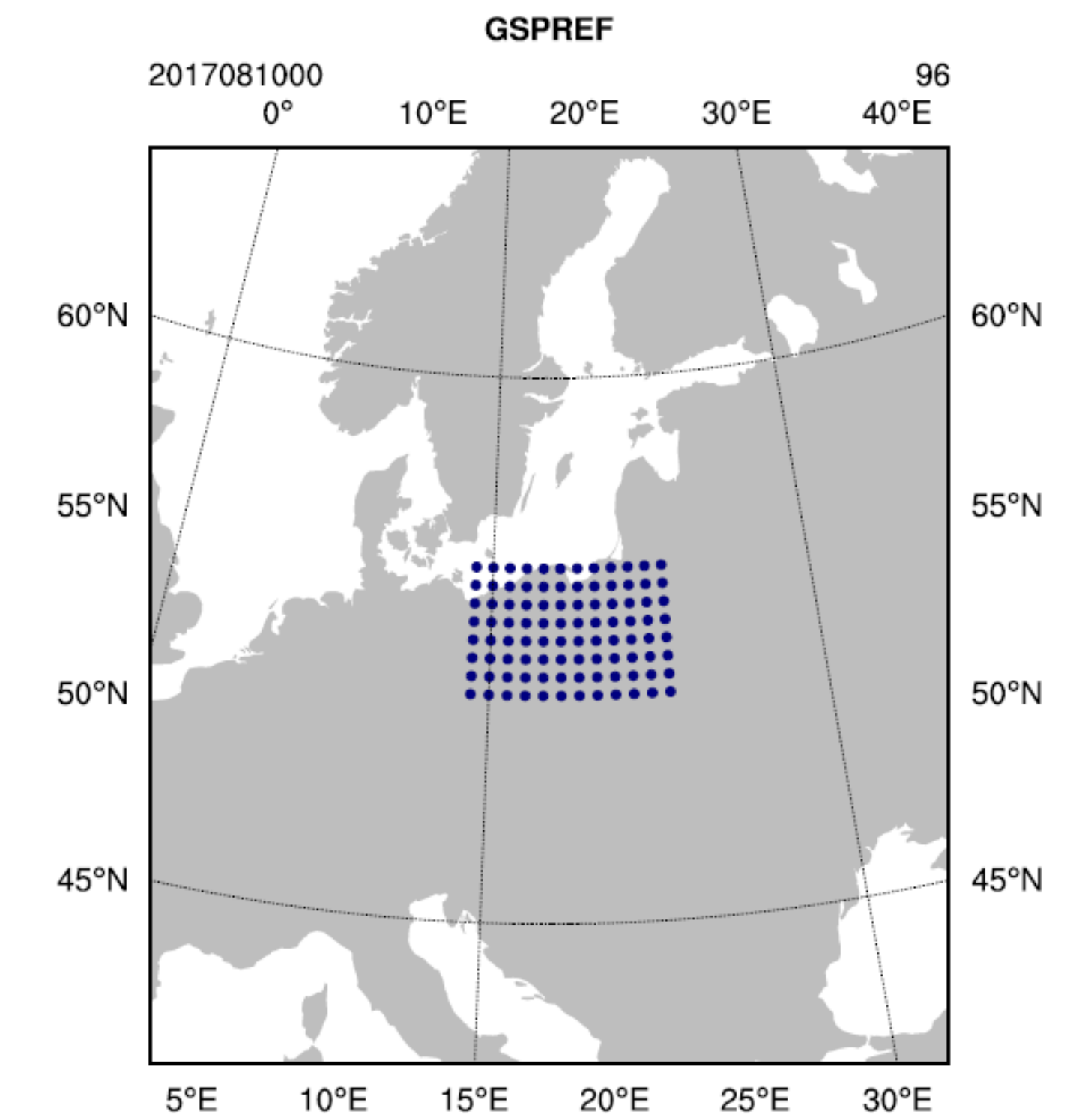


Fig. 5. Localisation of observations in the assimilation domain.

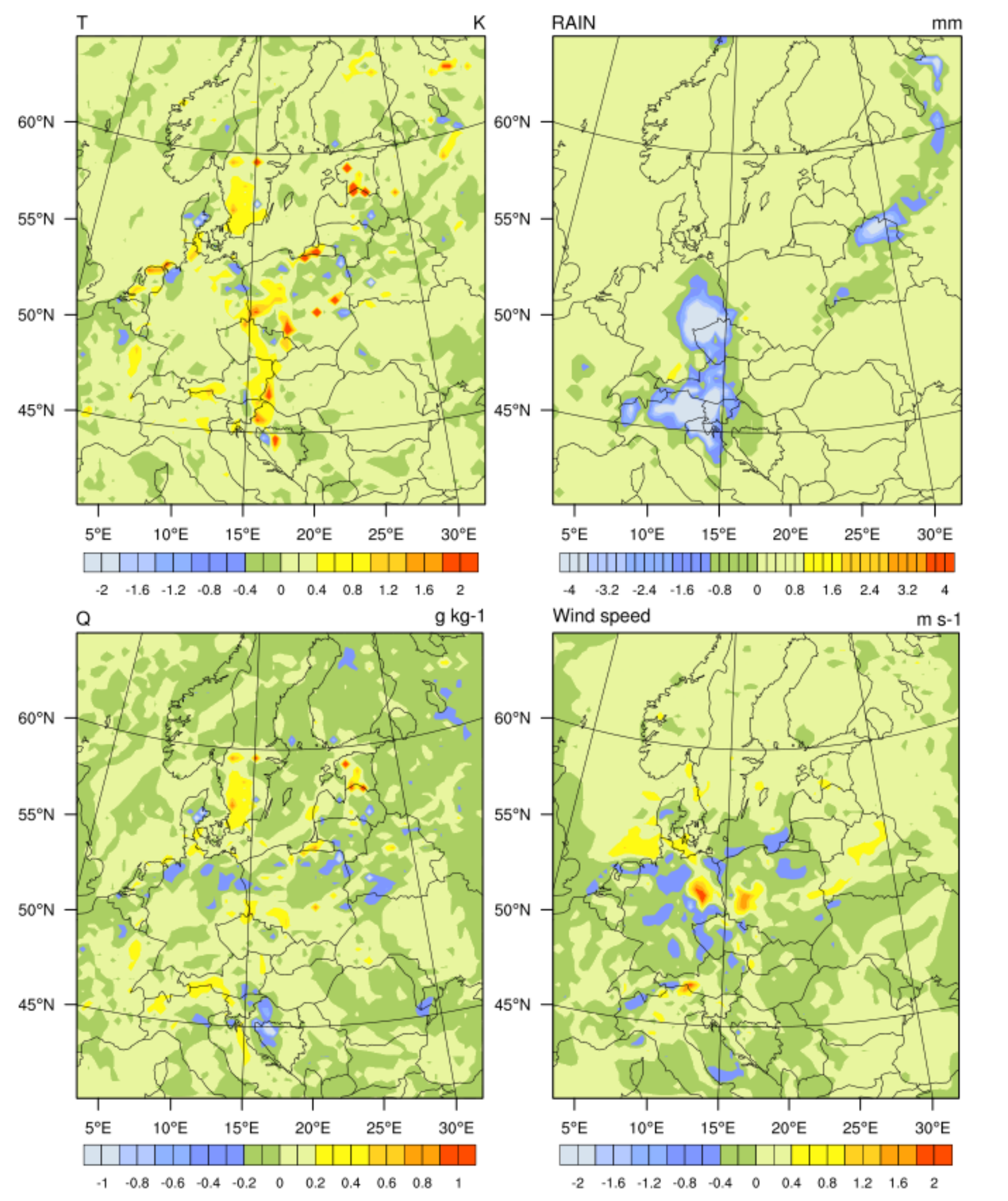


Fig. 6. Differences between base and assimilation run, 10.08.2017 18:00, 6 hours affter assimilation.

The test period started on 08.08.2017 00:00 and covered 7 days, with 1 hour assimilation window. The assimilation was made 6 hours after launching the simulation. For each assimilation epoch TOMO2 data from 11 vertical layers were used, 96 observatoins for each layer (fig. 5). Figure 6 shows differences between base and assimilation run for one case, 6 hours after assimilation. For air temperature differences are in range of 2°C, for rainfalls 4mm, for mixing ratio 1g/kg and for wind speed about 2m/s. For T, Q and WS differences are evenly distributed in positive and negative values, while RAIN is mostly negative (less rain after assimilation).

GNSS IWV COMPARISON

IWV calculated from base and assimilation run was compared with IWV estimated from GNSS solution (fig. 7). Model after assimilation shows larger BIAS, but the standard deviation and correlation is better than in the base run.

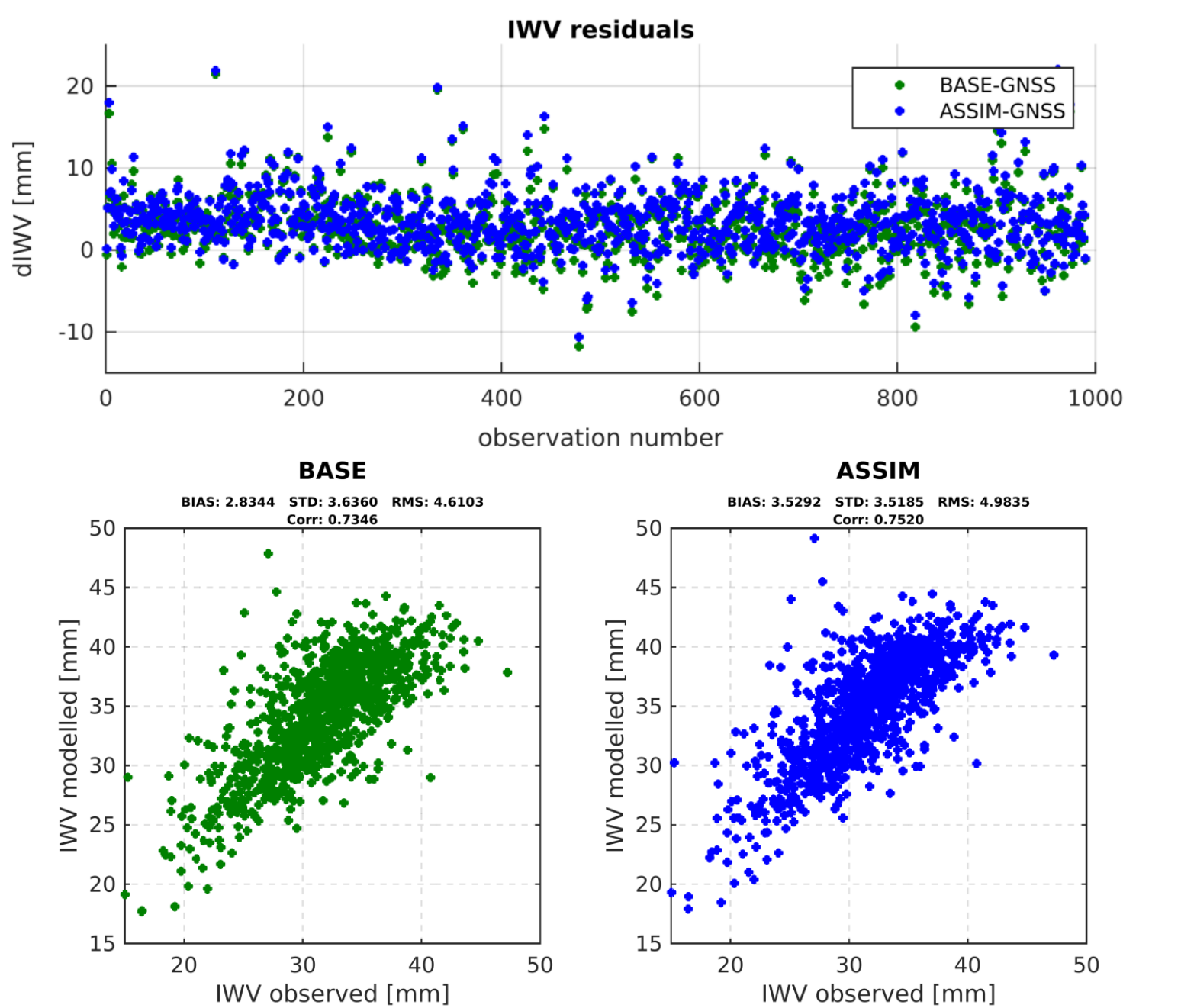


Fig. 7. Comparison of assimilated data with GNSS IWV observations.

RS DATA COMPARISON

Relative humidity (RH) calculated from base and assimilation run was compared with RS profiles (fig. 8). Statistics show lower BIAS for assimilation run, but the standard deviation and correlation are better in the base run (fig. 9).

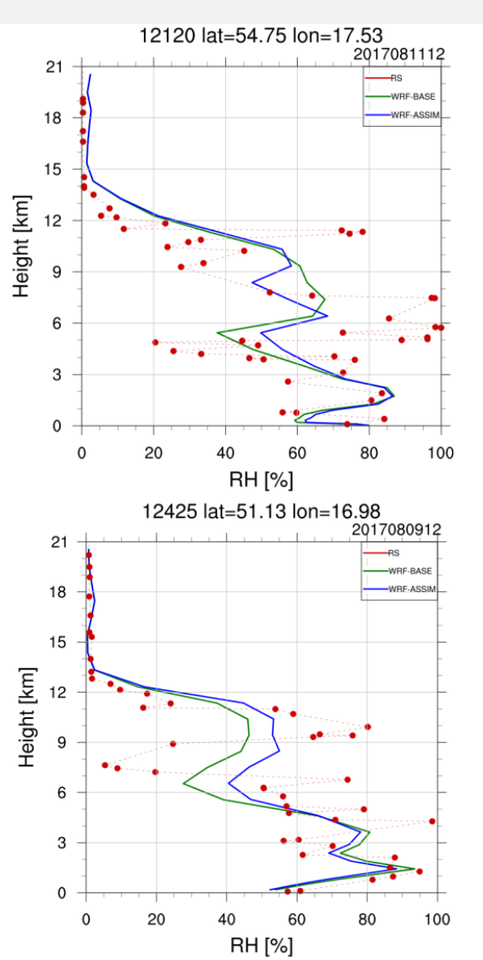


Fig. 8. RH vertical profiles.

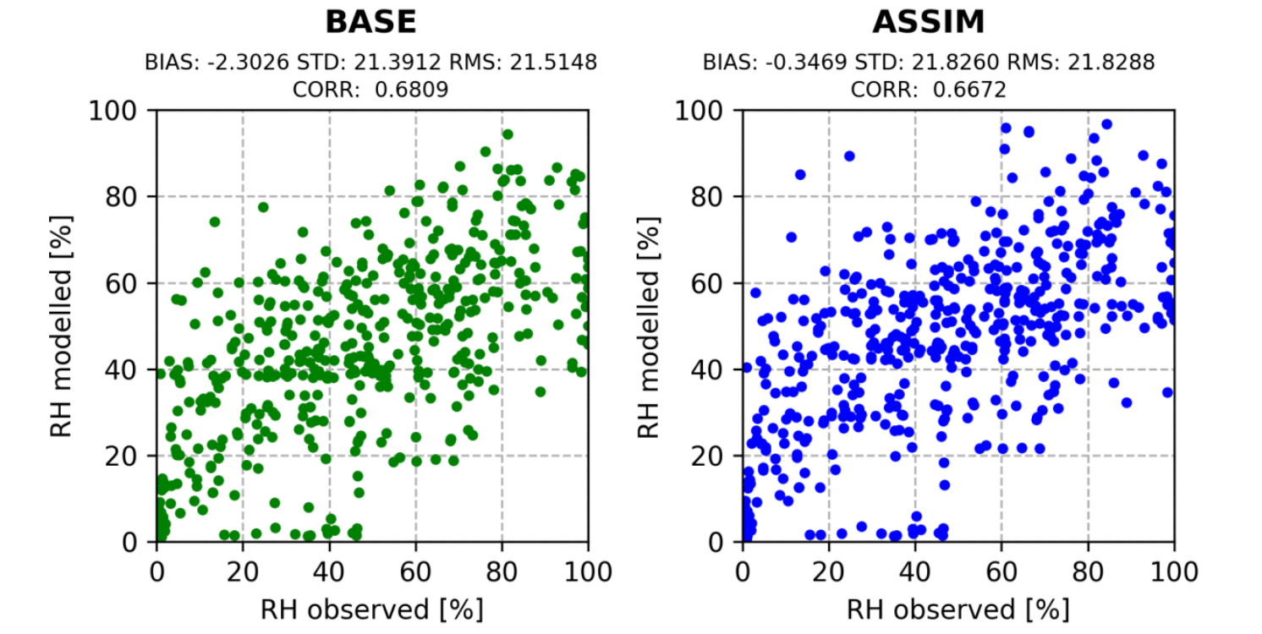


Fig. 9. Statistics for relative humidity from base and assimilation run.

SUMMARY

GNSS troposphere tomography in NRT mode is conducted for the area of Poland using TOMO2 model. Values of wet refractivity are estimated every 1 hour in 3D grid (80 km resolution, 11 vertical layers). Accuracy of the solution is 5-10 ppm for the altitude below 6 km when compared with RS, which is comparable to the accuracy of WRF model (beter for the altitudes 2-4 km). Wet refractivity is connected to the amount of water vapor in troposphere thus the TOMO2 results can be assimiliated into NWP models. First attempts of assimilation into WRF, using GPSREF operator and 3D-Var method, show improvement in terms of standard devaiation and correlation when compared with GNSS IWV observations. When compared with RS data, improvement is visible in terms of BIAS but not in the standard deviation. The inconsistency between two comparisons shows the need of further work on the assimilation.

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