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GNSS tomography data assimilation into the NWP models

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Water vapour in the troposphere is one of the most important factors shaping weather conditions. Its magnitude and temporal variability influence the thermodynamics of the atmosphere and results in different meteorological phenomena or hazards. Currently, there are several methods to measure humidity in the troposphere, but the vast majority of them determine surface or column parameters without acquiring vertical profiles of the amount of water vapour. In contrast to the available humidity observation methods, GNSS tropospheric tomography is a technique that enables deriving 3D distribution of the wet refractivity at a low cost in all weather conditions. Although the GNSS tomography technique has been intensively developed in the last years, there are not many publications discussing the quality of the data in terms of assimilation into the Numerical Weather Prediction (NWP) models.

This study presents a Near-Real Time (NRT) tomographic solution in order to determine whether tomographic products meet the accuracy requirements and could be assimilated into operational NWP models. The solution was carried out using Zenith Total Delays (ZTD) and their horizontal gradients estimated in NRT by WUELS processing centre. The tomography is performed with a time step of one hour and spatial resolution of 80 km, in 11 vertical layers, from the ground up to 12 km. Since the wet refractivity from the GNSS tropospheric tomography has not been assimilated into the NWP models yet, there are no observation operators designed for this purpose. Nevertheless, the total tropospheric refractivity derived by the GNSS radio occultation technique has been successfully assimilated into the operational NWP models. The WRFDA system is equipped with the GPSREF operator for the total refractivity assimilation. In this study, we used the GPSREF operator for the assimilation of the total refractivity calculated as the sum of the wet part estimated using the $TOMO_2$ model and the hydrostatic part calculated from the NWP model (base run without assimilation). The assimilation was performed using a three-dimensional variational method, 3D-Var. Two case studies cover storms and strong precipitation events and for comparison also an autumn period with synoptic, low pressure systems passing Poland. The results were validated with four external data sources: GNSS IWV, synoptic observations, RS data, and ERA-Interim reanalysis. In order to properly interpret the results of this tomographic data assimilation, we also assimilated the radiosonde wet refractivity data, for the sake of comparison.

The assimilation of the $TOMO_2$ output results in an improvement of the bias of the relative humidity (0.30%) as well as its standard deviation (0.04%) in the bottom parts of the troposphere at the time of analysis. In the middle troposphere, the positive impact of the $TOMO_2$ data assimilation on the analysis was noticed during summer storms (relative humidity standard deviation decreased by 0.15%). The WRF-WUELS 18-hour forecasts were validated with synoptic observations and ERA-Interim reanalysis. We observed a positive impact of the $TOMO_2$ output assimilation on the WRF-WUELS forecast (reduction of RMSE by 0.5% in relative humidity and 0.25°C in temperature).