



Synergy of GNSS Tomography and Radio Occultation: Methods for Assimilating Refined Water Vapor Fields

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Global Navigation Satellite Systems (GNSS) tomography is a rapidly developing method in meteorology that provides 3D grid-based information about water vapour distribution in the lower troposphere. The standard tomographic solutions are derived by processing signal delays between satellites and ground-based GNSS receiver networks. As the technique has advanced, additional observational data sources have been integrated into the process, enhancing its accuracy and applicability.

Low Earth orbit (LEO) satellites can provide signal delays similar to those from ground-based networks by tracking GNSS signals. This technique is known as GNSS radio occultation (RO) and relies on radio transmissions from GNSS satellites, where signals pass through the atmosphere and undergo refraction. The degree of refraction is influenced by atmospheric temperature and water vapor concentration. With the exponential increase in the number of LEOs satellites over the past 30 years, this technique has been a cornerstone for atmospheric measurements. It is widely used in meteorological offices as a tool for weather forecasting and shows strong potential for improving tomographic applications.

The Weather Research and Forecasting (WRF) Model, equipped with its tomographic operator *tomoref*, facilitates the integration of tomographic products into meteorological fields. In recent years, several studies have explored available practices for tomographic data assimilation. In this work, we present two variants for assimilating combined RO and tomographic solutions.

In the first approach, radio occultation-derived wet refractivity profiles from the UCAR COSMIC program were incorporated into the tomographic solution using the ATom tomographic software, enhanced with its RO extension. The 3DVar assimilation of tomographic wet refractivity fields into the WRF Data Assimilation system was performed for both combined and ground-based solutions at selected epochs when radio occultation events occurred within the defined domain. The model's performance was further validated by comparing it to a solution that assimilated conventional GNSS observations. For ground-based stations, GNSS signal delays, expressed as Zenith Total Delays (ZTDs), were assimilated using the *gpsztd* operator, while space-derived total refractivity profiles were incorporated using the *gpsref* operator. The resulting meteorological

parameters were then compared to external data sources, including radiosondes, meteorological sites, and ERA5 data.

As part of the ongoing OPUS NCN project, an alternative approach to observation integration is being developed. This integrated tomographic solution combines ground-based GNSS observations with RO excess phase data from SPIRE Global within a unified tomography model on the phase observation level. Since RO events are often unevenly distributed across space and time, the combined tomographic observations address these limitations by filling data gaps with ground-based observations. The resulting wet refractivity fields are then assimilated using a variational approach, incorporating the tomographic data into the model over a broader assimilation window. With further fine-tuning, the presented methodology for assimilating tomographic products demonstrates significant potential for future testing in meteorological centres.