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From ground- to space-based GNSS tomography - initial results and concepts

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Monitoring the Earth's atmosphere is a fundamental activity aimed at understanding its structure and the processes occurring within it. These efforts contribute significantly to improving the quality of numerical weather models and forecasts.

In recent years, GNSS (Global Navigation Satellite System) observations have emerged as one of the primary sources of information about the troposphere, the lowest layer of the atmosphere. The use of electromagnetic wave properties, which respond to changing atmospheric conditions, is gaining recognition due to its stability, availability in all weather conditions, and the density of observations. GNSS observations are increasingly considered a viable alternative to traditional weather stations, radiosondes, and microwave satellites. However, their application is limited by challenges in deploying receivers in aquatic or mountainous regions. Furthermore, the effectiveness of ground-based GNSS observations is hindered by poor vertical resolution.

An alternative to ground-based GNSS observations is their space-based counterpart—radio occultations (RO). These observations, which are independent of ground infrastructure, serve as an ideal complement to traditional ground-based methods. However, their horizontal and temporal resolution is very limited. Their exclusive use in experiments, such as ROMEX, may not demonstrate their full potential, which can be better realized through integration with other tools, particularly GNSS tomography.

Recent studies have shown that integrating ground-based and space-based GNSS observations in a tomographic solution improves solution quality by approximately 10% on average and reduces total solution errors by about 5%. In regions without GNSS ground stations, the error reduction can reach as much as 30%.

Therefore, in this study, we extend this research by testing the feasibility of using a modified INTOMO (INtegrated TOMOgraphy) software with space-based observations only. The program employs 3D ray tracing to simulate RO ray paths between Low Earth Orbit (LEO) and Global Positioning System (GPS) satellites, along with a Kalman filter to calculate the variability of the system of equations. The observation errors are assessed using a pre-defined formula based on

RO geometries.

The results presented in this study are derived from the initial phase of research conducted over five days in sea and water-land areas using RO observations from publicly available UCAR services as well as ROMEX data. Each day represents different atmospheric conditions, ranging from sunny weather to tropical cyclones. Additionally, we estimate the errors in the tomographic solution and validate our results using the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 and Weather Research and Forecasting (WRF) models and RO processing package (ROPP), with the GPT2 model serving as the a priori data input for tomography.