

Note: All Line numbers refer to the No Markup version of the revised Manuscript.

Reviewer #1

Interesting and well-written report, however further insight could have been good, for example using the Desroziers method to quantify the relative impact of the different observations used in the experiments.

Thank you for your kind feedback and comments. In response, we have now included a quantification of the relative impact using the Desroziers method. We have computed Desroziers statistics for 220 data assimilation cycles using SYNOP data, ZTDs, and Tropospheric Gradients (for both the North and East gradients).

Please refer **Lines – 250 to 267**

“To quantify the relative impact of GNSS observations compared to other point observations in the study, specifically the SYNOP station data, we utilized the Desroziers method. Desroziers method is an effective diagnostic tool used to evaluate the impact of various observations. By analyzing the Innovation (Observation minus Background, OMB) and Residual (Observation minus Analysis, OMA) statistics, we can estimate the covariances of observation and background errors. This analysis helps us determine the relative influence of different types of observations on the overall analysis.

The relative impact of an observation is determined by the ratio of the estimated observation error covariance R to the estimated background error covariance B . The respective error covariances are calculated as below:

$$R = E[(y - Hx^a)(y - Hx^a)^T]$$

$$B = E[(y - Hx^b)(y - Hx^b)^T]$$

Here $(y - Hx^b)$ is the innovation and $(y - Hx^a)$ is the residual where x^a , x^b , and y are the model state vectors for analysis, background and observations, respectively.

The higher the value of the ratio B/R , the higher the impact of the observation. The observations likely to enhance the model or lead to effective assimilation fall within the range of 0.5 to 3. A value below 0.5 suggests that the observation has large error, making it unreliable for assimilation. Conversely, values above 3 indicate that the observation forces the background towards the observation, which may result from a small observation error or a bias in the observation. After analyzing 220 DA cycles, the average B/R ratios were as follows: SYNOP at 1.4, ZTD at 2.8, NG at 1.8, and EG at 1.5. These values indicate that the impacts of the observations are well within the acceptable range. Additionally, the TGs, have an impact in the assimilation system. The North and East gradient values indicate that the assimilation was effective. The ZTD observation has higher values, which might indicate that the observation error assigned to ZTDs could be higher than the current observation error value of 8 mm.”

row 72 is vague as it proposes that ZTD is the only source of moisture data used operational and should be clarified!

Thank you for the comment. The sentence was incomplete which resulted in a different meaning. The sentence is now corrected as below. Please refer to **Line 72**.

“ZTDs are the only GNSS-derived moisture data used operationally; however, they provide limited atmospheric information.”