Dear Editors and Reviewers:

We deeply appreciate your helpful comments and suggestions, which enabled us to improve the quality of our present study. We have made revisions and replied to all the comments. Please find the point-by-point responses to the comments below. The comments are given below in black, our responses are in blue, and proposed changes to the manuscript are in red.

Reply to Reviewer #1:

1. Firstly, I'd like to have more details about the 10-day period over which the assimilation experiments were conducted. Unless I'm mistaken, it's implicitly understood that this is a clear-sky period (especially when the cloud cover mask is mentioned), but this is explicitly stated only at the end of the article. On the other hand, I think it would have been nice to provide more justification for this particular period.

Response:

Thanks for your comments. The assimilation experiment was conducted under clear-sky conditions. Figure R1 illustrates clear-sky observation counts in the target region of Southwest China from the microwave radiometer (MWR). Among the available MWR observations spanning August to October 2023, a ten-day period (highlighted in blue in Figure R1c) from 13 October 2023 to 22 October 2023 exhibited a notably higher frequency of clear-sky MWR observations. As an initial study that mainly focused on direct assimilation of clear-sky MWRs, this period can better evaluate the impact of MWR assimilation. More details about the 10-day period over which the assimilation experiments have been added in the manuscript as below.

"The assimilation experiments were conducted under clear-sky conditions due to the uncertainties in the model and observation operators under cloudy or rainy conditions. All experiments were conducted over a ten-day period from 13 to 22 October 2023. Among the available GMWR observations from August to October 2023, this period exhibited a notably higher frequency of clear-sky data, which was more favorable for demonstrating the role and potential of GMWR assimilation. Before implementing bias correction, clear-sky screening, first-guess departure check, and whitelist check were sequentially applied to improve measurement quality. Subsequently, a relative departure check was applied prior to minimization. For the 6 h, 3 h, and 1 h assimilation intervals, 34 (0.91%), 70 (1.42%), and 76 (0.72%) observations were rejected, respectively. The detailed procedure prior to a single assimilation cycle is as follows:

(1) Observation Selection: The observation nearest to the analysis time within ±10 minutes is selected.

(2) Clear-sky Screening: Clear-sky GMWR observations were screened using the AGRI-based CLM, with background-simulated cloud liquid water path equal to zero.

(3) First-Guess Departure Check: Observations with (O−B) values greater than 20 K are excluded.

(4) Whitelist Check: Remove observations from stations identified as unreliable or displaying abnormal behavior.

(5) Bias Correction: a machine learning bias correction scheme was applied (see Section 3.2).

(6) Relative Departure Check: Applied when the absolute value of the O−B exceeds three times the standard deviation of the observational error, further rejecting questionable data."

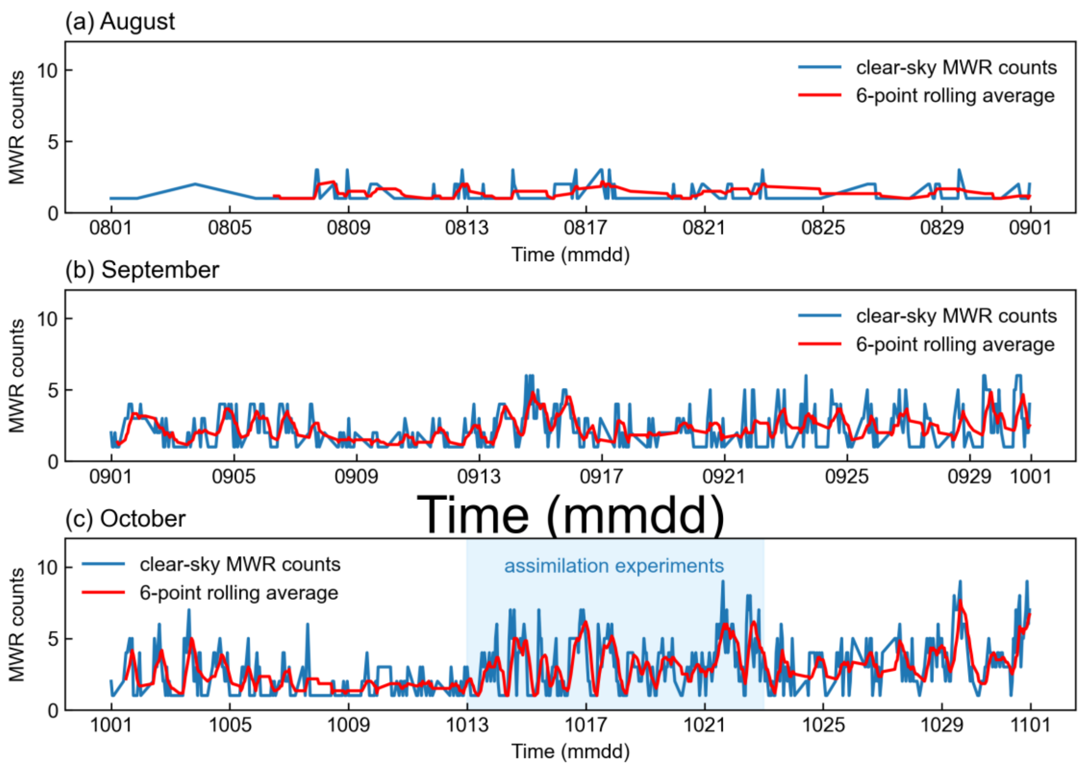

Figure R1. Clear-sky observation counts in the target region of Southwest China from the microwave radiometer (MWR) for (a) August, (b) September, and (c) October 2023. The blue line depicts hourly MWR counts, and the red line represents the 6-hour rolling average. The blue shaded region marks the 10-day period selected for assimilation experiments.

2. Still on the subject of this 10-day period, I'd like to know if you've carried out assimilation experiments over other periods? If so, what were the results equivalent? Why wasn't a longer period considered?

Response:

Due to cloud cover and rainfall, the number of clear-sky observations during other periods is small, except for this ten-day period. This study primarily focuses on implementing RTTOV-gb within WRFDA and conducting clear-sky assimilation based on machine learning bias correction. To this end, we mainly concentrate on assimilation during this specific period. As demonstrated in this paper, clear-sky assimilation of MWRs has significant potential to improve numerical forecasts. It would be interesting to implement cloudy-region assimilation for MWRs in the next step, as it could incorporate more MWR observations than clear-sky assimilation. Under such conditions, assimilation experiments would be conducted over other periods or extended to a longer period, given that assimilated MWR observations would be relatively more abundant. Nevertheless, a discussion about experiment periods has been added in the discussion as below.

"Moreover, only clear-sky GMWRs were assimilated in this study. Since precipitation processes are often accompanied by extensive cloud cover, few clear-sky GMWRs were available. To better explore the potential of GMWR assimilation, experiments were conducted during periods with abundant clear-sky GMWRs (e.g., a ten-day period in October 2023), which coincided with minimal heavy precipitation. Studies on satellite all-sky assimilation have shown that incorporating cloud- and precipitation-affected data improves forecasts (Ma et al., 2022; Xian et al., 2019), highlighting the need for future research on all-sky assimilation of GMWRs. Under such conditions, assimilation experiments could be conducted during a different or longer period, given that assimilated GMWR observations would be relatively more abundant."

3. Regarding the single observation experiment, I'd like to know why the specific humidity analysis increments aren't totally isotropic (although they're close) as they are for temperature.

Response:

In the single observation experiment, the background error covariance used in WRFDA is CV5. Pseudo relative humidity (RHs) is the control variable in CV5 and is minimized during assimilation. However, RHs is not a model variable, and its analysis increment is transformed into model variables (e.g., water vapor mixing ratio). During this transformation, the water vapor mixing ratio may not remain fully isotropic. As shown in Figure R2, while the analysis increment of RH appears isotropic, this is not the case for the water vapor mixing ratio.

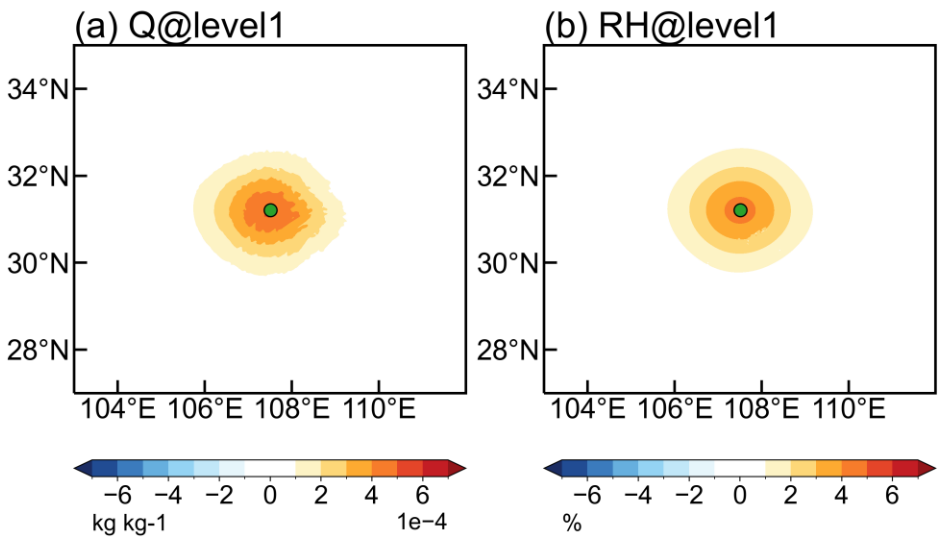

Figure R2 The horizontal analysis increments for (a) water vapor mixing ratio and (b) relative humidity in single-observation assimilation experiment.

4. My final comment concerns Figures 10 and 12. I think it would have been clearer to present the RMSE or FSS values directly, rather than the differences with the control experiment. I understand that this removes a curve from the graphs and perhaps improves readability. But having the RMSE values would be informative about the errors made by the model.

Response:

The RMSE and FSS for the CNTL experiment are shown as black solid lines in Figures 10 and 12. The corresponding changes we have implemented are as follows:

"The time series of RMSE for the CNTL experiment and RMSE differences (assimilation experiments minus the CNTL experiment) against surface station observations for 2 m temperature, 2 m relative humidity, and 10 m wind fields are shown in Fig. 11. In the CNTL experiment, the RMSE of temperature and relative humidity initially decreases and then increases with lead time, while the RMSE of the wind field exhibits the opposite trend, increasing at first and then decreasing. The mean RMSEs over the 24-hour forecast period are 2.32 K for temperature, 16.26% for relative humidity, 1.92 m s^{-1} for zonal wind, and 2.08 m s^{-1} for meridional wind. Regarding assimilation impacts, the RMSE reduction for temperature gradually decreases, approaching zero at a lead time of 6 hours, with higher assimilation frequency (GMWR_1H) achieving a greater RMSE reduction.

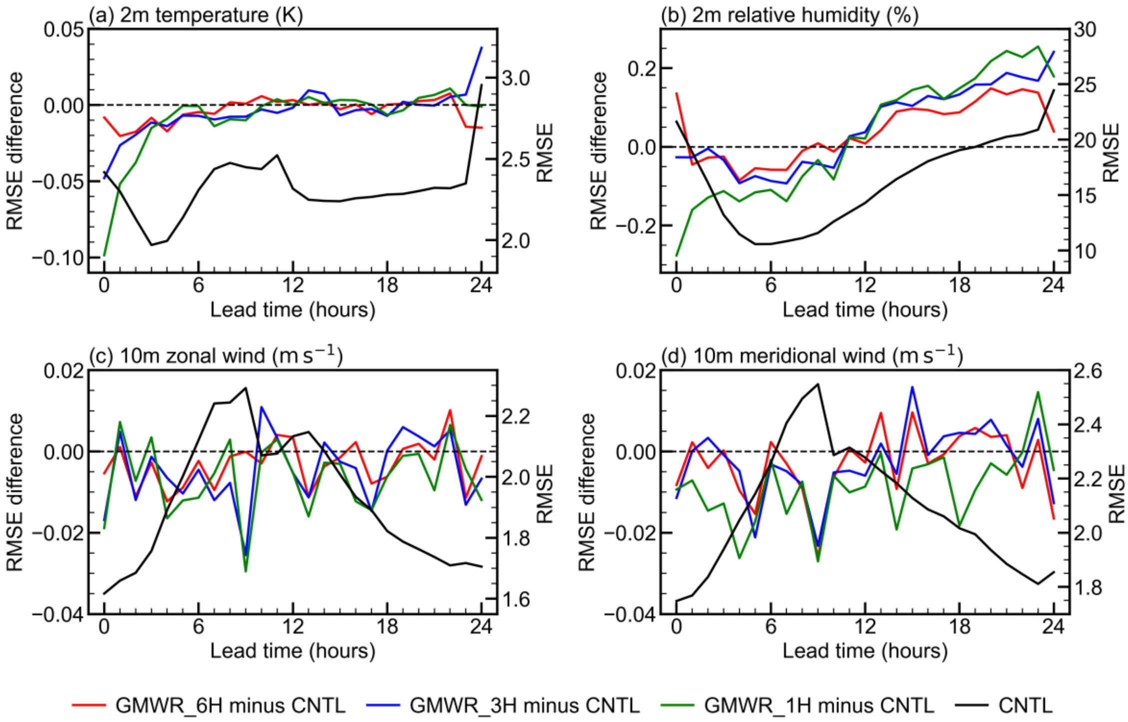

Figure 1: Verification of the forecast against surface station observations, based on the ten-day assimilation experiment conducted from 13 to 22 October 2023. RMSE (black line) for the CNTL experiment and RMSE differences (colored lines) between the assimilation experiments and the CNTL experiment for (a) temperature, (b) relative humidity, (c) zonal wind, and (d) meridional wind.

Figure 13 presents the time series of FSS for the CNTL experiment and FSS differences (assimilation experiments minus the CNTL experiment). The assimilation experiments were conducted during a period characterized by a higher frequency of clear-sky observations. Cloud cover and precipitation were limited throughout the 10-day period, resulting in the absence of frequent heavy rainfall events. Consequently, the FSS was calculated using small precipitation thresholds. In the CNTL experiment, the FSS for 3 h accumulated precipitation shows an initial decline followed by a subsequent increase with lead time, with relatively low FSS values observed around the 9 h forecast period. Moreover, the FSS generally decreases as the precipitation threshold increases. The time mean FSS values are 0.47, 0.45, 0.42, and 0.39 for thresholds of 3 mm, 4mm, 5mm, and 6 mm, respectively. Regarding the role of GMWR assimilation in precipitation forecasting, the results indicate that assimilating GMWR radiances enhances precipitation forecasts, with FSS differences increasing progressively at higher precipitation thresholds.

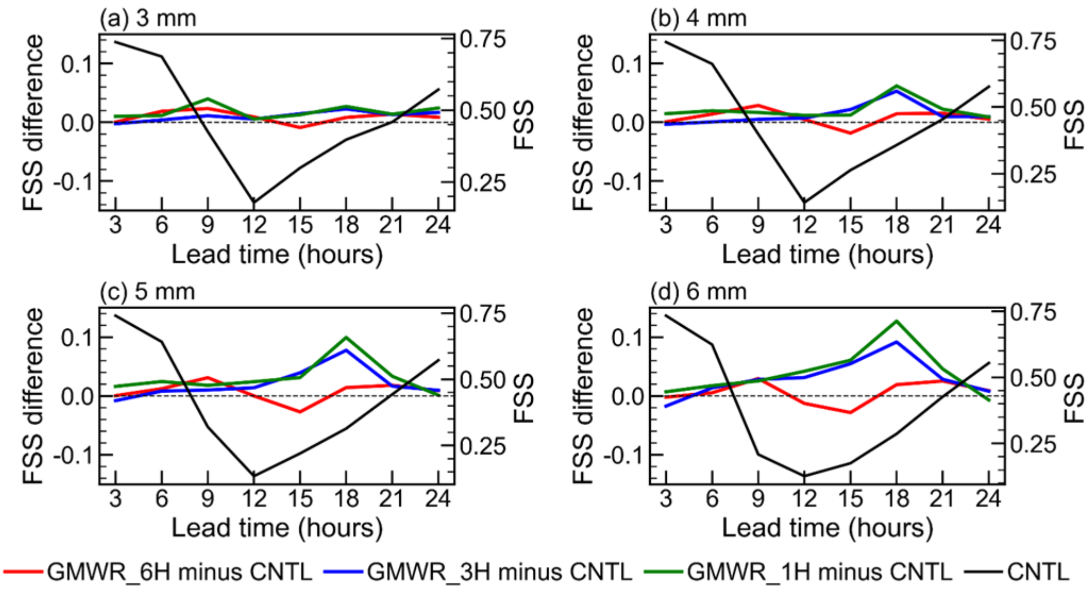

Figure 13: The time series of FSS (black line) for CNTL experiment and FSS differences (colored lines) between the assimilation experiments and the CNTL experiment. These experiments were conducted from 13 to 22 October 2023.The FSS was calculated for 3 h accumulated precipitation for thresholds of (a) 3 mm, (b) 4 mm, (c) 5 mm, and (d) 6 mm.