We thank the Referee 2 for useful comments after referring previous papers about the symmetric error model. We reply all comments at length.

Major comments

1. For satellite assimilation, departures (or bias) mean O minus B (OMB), where B is calculated from the background using the observation operator in the DA model. However, the B obtained in this manuscript is calculated using the Unified Post-Processor (UPP) software package, so this B may differ from the B in the DA model. Please check the specific operator and provide an explanation.

Response:

The algorithm of diagnostic reflectivity (dBZ) included in UPP softward package can be used as an operator of reflectivity assimilation. This algorithm is based on rain, snow, and graupel mixing ratios was designed by Stoelinga (2005):

$$Z = 10\log_{10}(Z_{er} + Z_{es} + Z_{eg}) \qquad \text{(R0)}$$

Following some assumptions, the reflectivity contributed by rain droplets is given by:

$$Z_{er} = \Gamma(7)N_{r0}\lambda_r^{-7} \qquad \text{(R1)}$$

$$\lambda_r = \left(\frac{\pi N_{r0}\rho_l}{\rho_a q_{ra}}\right)^{1/4} \qquad \text{(R2)}$$

where N_{r0} is 8×10^6, ρ_l and ρ_a are the liquid water density and dry air density respectively and q_{ra} is the rainwater mixing ratio in background.

Assumed snow particles are spheres, the reflectivity contributed by snow is given by:

$$Z_{es} = \alpha\Gamma(7)N_{s0}\left(\frac{\rho_s}{\rho_l}\right)^2\lambda_s^{-7} \qquad \text{(R3)}$$

$$\lambda_s = \left(\frac{\pi N_{s0}\rho_s}{\rho_a q_{sn}}\right)^{1/4} \qquad \text{(R4)}$$

where α is 0.224, N_{s0} is 2×10^7, ρ_s is the density of snow 100 kg m^{-3} and q_{sn} is the snow water mixing ratio in background.

Similarly, the contribution of graupel particles can be obtained:

$$Z_{eg} = \alpha\Gamma(7)N_{s0}\left(\frac{\rho_g}{\rho_l}\right)^2\lambda_g^{-7} \qquad \text{(R5)}$$

$$\lambda_g = \left(\frac{\pi N_{g0}\rho_g}{\rho_a q_{gn}}\right)^{1/4} \qquad \text{(R6)}$$

where α is also 0.224, N_{g0} is 2×10^7, ρ_g is the density of graupel 400 kg m^{-3} and q_{gn} is the graupel water mixing ratio in background.

According to above formulas (R0-R6), the reflectivity predicted by model can be computed by the rainwater, snow water and graupel water mixing ratios. It can transform model variables to reflectivity. Thus, this algorithm of diagnostic reflectivity can be used as the forward operator in reflectivity assimilation. Actually, similar forward operator of reflectivity based on double-moment Thompson microphysics was employed by Liu et al. (2022).

Reference:

Liu, C., H. Li, M. Xue, Y. Jung, J. Park, L. Chen, R. Kong, and C. Tong, 2022: Use of a Reflectivity Operator Based on Double-Moment Thompson Microphysics for Direct Assimilation of Radar Reflectivity in GSI-Based Hybrid En3DVar. Mon. Wea. Rev., 150, 907–926, https://doi.org/10.1175/MWR-D-21-0040.1.

2. Rain rates from other sources (e.g., the FY-4A QPE hourly rainfall product) have also been selected as predictors for this radar symmetric error model. However, satellite and radar are two observations of different character and perspective, please add an explanation of the rationale for this way.

Response:

Although the geostationary satellite and ground radar are different measurements in meteorology, they can observe the same weather system and then provide similar information about the variation of convective systems. The FY-4A QPE can indicate the shape, strength and location of convective storms as rain rate retrieved by reflectivity does. Thus, the differences between satellite and radar allow us to investigate how the accuracy of predictor affects the symmetric error model. Authors explained why the third-party observations are used from line 79 to 82 and described details of third-party observations in section 3.2.

3. Line 157-158: This manuscript needs to provide a description of the quality control algorithm for 'misses and false simulations', which determines the Quality of the later presentations on 'any-reflectivity' and 'both-reflectivity' analyses.

Response:

Authors did not employ any quality control algorithm for misses and false simulations except that reflectivity less than 5 dBZ in either the observations or the simulations was excluded. The miss means an occasion where the reflectivity is observed but is not simulated. The false simulation means an occasion where the reflectivity is simulated but is not observed. By comparing the PDFs of ‘any-reflectivity’ and ‘both-reflectivity’, this study discussed what give rise to the non-Gaussian error distribution of OMBs.

To avoid possible misunderstandings, authors emphasized that the ‘both-reflectivity’ scenario is only used to illustrate what give rise to the non-Gaussian error distribution of radar reflectivity. In this study, the effects of more or less accurate observations and the logarithm transformation on the symmetric error model are discussed in ‘any-reflectivity’ scenario. Authors did not advise any reader to remove the misses and false simulations in reflectivity assimilation.

4. For the assimilation system, the symmetric error model serves to estimate the observation error at different observation points and does not change the value of the OMB, whereas the Gaussianity of Figures 10 and 11 changed. Please explain why the normalization is done by "symmetric rainrates"? Does this operation consider both the

observation error and the OMB?

Response:

As shown in Figure 8 and 9, each OMB bin, 0.5 mm h^{-1} interval, is normalized separately, i.e. OMBs of reflectivity are normalized by different standard deviations. Although the PDF of all samples is not Gaussian, the PDF in each bin (a subset of all OMBs) could approximate to Gaussian. This is the heteroscedasticity of reflectivity, i.e. 'The error of equivalent reflectivity can change as a function of precipitation' as stated in Introduction. Thus, the Gaussianity can be improved because this study normalized the OMBs by using different standard deviations which are a function of rain rate. Authors would like to add some sentences in revision to explain the reason why the Gaussianityof OMBs can be improved.

5. In describing the predictors for the radar symmetric error model, this manuscript has given the equal weight to the rain rate simulated by the model and the rain rate calculated from radar observations. Is it likely that the radar observations will be more accurate than the background? Please add an explanation of assigning the weights in this way.

Response:

Changing the weights of observation and simulation of the symmetric error model (Eq. (2) in manuscript) has not been examined in this study or previous studies, and possibly it is a good idea. After carefully examining the PDF of 'any-reflectivity' (red line in Figure 4), the left and right parts of PDF show different distributions. The left part (observations less than simulations) is lower and smoother than the right part (observations larger than simulations), illustrating the PDF is not symmetric. Probably, an asymmetric predictor is the best predictor for an asymmetric PDF. It could be an interesting topic in further study.

However, the current work mainly focuses on whether the symmetric error model can improve the PDF of OMBs. According to Figure 10 and 11, the symmetric error model of radar reflectivity can improve the Gaussianity. Thus, authors would like to add a short discussion about the asymmetric predictor in revision, but not attempt to investigate the optimal weights for observation and simulation.

Minor comments:

1. Line 124: The formula number is missing.

Response: authors did not number this formula because it is not mentioned in the following manuscript.

2. Line 180: Please add the strategy and time resolution for calculating r_{model}. In addition, the rain rate is an instantaneous variable, while the precipitation output from the WRF is an accumulated variable, and the rain rate calculated from it is an average value, please add an explanation of not using the reflectivity output directly from the WRF.

Response: the r_{model} is the average of two consecutive hourly precipitations produced by WRF. The rain rate simulated by WRF represents the simulated precipitation better.

3. Line 248: Remove the ‘the’ before ‘the Figure 7c shows that’.
Response: authors can delete this word in revision.

4. Line 307: Replace ‘more Gaussian’ with ‘and results in a PDF distribution that is closer to the standard Gaussian distribution’.
Response: authors can rewrite this sentence in revision.