Response to Referee #3' comments

The authors appreciate the referee's insightful comments and constructive suggestions, which helped us significantly improve the quality of this manuscript. Below are itemized, point-by-point responses to the referee's comments. For clarity purpose, here we have listed the reviewers' comments in black plain font, followed by our response in blue plain font.

General Comments:

In this study, the authors investigate the potential of low-altitude meteorological drone MD (called UAV) observations to improve convective-scale short-term weather forecasts using the 3D-Var data assimilation system in the Warn-on-Forecast System. An Observing System Simulation Experiment (OSSE) is conducted for a rainfall event over the Beijing–Tianjin–Hebei region. Synthetic MD observations of temperature, specific humidity, and horizontal wind are generated from a free-running simulation treated as the "truth". Their results show that assimilating synthetic MD parameters including temperature and humidity observations can improve the thermodynamic analysis and precipitation forecasts.

This study is relevant for improving short-term forecasting of high-impact weather using synthetic MD observation. It also provides useful guidance for the design and deployment of meteorological MD observing systems. Overall, the manuscript addresses an interesting and relevant topic.

I have a few additional minor comments that may help improve the clarity of the manuscript:

1. Line 95-100: The manuscript uses the terms "tropical cyclone" and "typhoon" in different places. For consistency, I suggest using the "typhoon" throughout the manuscript, unless there is a specific reason to distinguish between these terms.

   Response: Thank you for this helpful suggestion. We have revised the relevant text to consistently use the term "typhoon". In addition, the subsequent sentence containing the term "tropical cyclones" has been removed as part of the streamlining of this paragraph in the Introduction. The corresponding revision is as follows:

   1) Lines 95-97: "In China, MD applications have expanded in recent years, including typhoon-oriented upper-air sounding, coordinated offshore observations, and multi-aircraft field campaigns (Wen et al., 2025)".

2. It is not clear that in the assimilation system others used only assimilated synthetic observation or additional observation also used. This is very important to know the actual impact of those observation.

   Response: In the present OSSE, only synthetic MD observations are assimilated in

the MD data assimilation experiments. Conventional and remote-sensing observations are not assimilated. This experimental design is intended to isolate the impact of the simulated MD observations and facilitate a direct comparison among different MD network configurations. Therefore, the resulting forecast improvements should be interpreted as an estimate of the upper bound of the information content provided by MD observations, rather than their incremental value in an operational multisource DA system that already assimilates conventional and remote-sensing observations. We have clarified this point in the experimental description and further discussed this limitation in the Summary and conclusions. The corresponding revisions are as follows:

1) Lines 337-347: "As our primary objective is to quantify the effects of assimilating thermodynamic and kinematic observations from different MD networks on convective-scale analyses and short-term severe weather forecasts, only synthetic MD data are assimilated in this study. Conventional observations, including radiosondes and surface stations, as well as satellite and radar measurements, are excluded. This experimental design allows a more direct attribution of forecast impacts to the simulated MD observations, although it may also overstate their relative contribution (Hoffman and Atlas, 2016). As a result, the DA experiments are designed to evaluate the upper bound of the information content provided by MD observations, rather than their marginal impact when added to an operational DA system that already assimilates a broad range of conventional and remote-sensing observations".

2) Lines 921-928: "In operational applications, part of the information provided by MD observations may overlap with existing observing systems, so their incremental benefit could be smaller than that obtained in the present experiments. Nevertheless, high-frequency MD observations may still provide complementary information within the data-sparse PBL. Future work should therefore evaluate the added value of MD observations when assimilated together with conventional, radar, satellite, and other dense observing networks".

3. Lines 180: In the 3D-Var data assimilation framework, the background error covariance matrices (B) are utilized; however, the significance of the B-matrix within the data assimilation system is not explicitly elucidated. It remains unclear whether the B-matrix is fixed or flow-dependent, and whether it varies across assimilation cycles. Providing additional clarification on this aspect would enhance the understanding of the assimilation process.

Response: Thank you for this helpful comment. In the present study, the ensemble-based, flow-dependent background-error covariance option is not used. Instead, a static background-error covariance formulation is adopted. The background-error standard deviations are estimated from multi-year statistics of 3-h forecasts from the Rapid Update Cycle (RUC) system, while the spatial correlations are represented using recursive filters. The horizontal correlation length scales are adjusted among the network-spacing experiments to account for their different sampling densities. We have revised Sect. 2 to clarify these points. The corresponding revisions are as

follows:

1) Lines 166-169: “The background error covariance matrix **B** specifies the magnitude and spatial correlations of background errors, thereby determining how strongly the analysis can depart from the background and how observational information is spatially spread through the analysis increments”.

2) Lines 188-196: “As the primary objective here is to evaluate the impact of assimilating MD data on convective-scale analyses and short-term forecasts, the ensemble-based background error covariance option available in the DA system is not employed (Gao et al., 2016; Gao and Stensrud, 2014; Wang et al., 2019). Instead, the background error covariance matrix is specified using a static formulation, constructed as the product of a diagonal matrix of background error standard deviations and a spatial recursive filter (Gao et al., 2004, 2013). The prescribed background-error statistics remain fixed throughout the assimilation cycles within each experiment”.

4. Lines 184-187: The control variables incorporated in the analysis system encompass the 3D wind components, pressure, potential temperature, water vapor mixing ratio, and hydrometeor mixing ratios for cloud water, rain, ice, snow, and graupel, consistent with the variables employed by Gao and Stensrud (2012). The influence of these control variables varies depending on the type of observations assimilated, as noted in the referenced study. It would be beneficial to know whether alternative sets of control variables were evaluated. Furthermore, clarification regarding the specific warm rain microphysics scheme implemented in the system is warranted.

   Response: The present study retains the standard control-variable set used in the NSSL3DVAR system, including the three-dimensional wind components, pressure, potential temperature, water vapor mixing ratio, and hydrometeor mixing ratios (described in lines 173-175). Alternative sets of control variables were not evaluated, because the primary objective of this study is to examine the sensitivity to MD observing-network configurations rather than to the formulation of the DA control vector. The same control-variable configuration is therefore used in all experiments to maintain consistency among the sensitivity tests. Regarding the microphysics scheme, the WRF simulations employ the NSSL two-moment four-ice bulk microphysics scheme (Mansell et al., 2010; Mansell and Ziegler, 2013; Ziegler, 1985), as already described in Sect. 2 (in lines 149-150). No separate warm-rain-only microphysics scheme is used in the present experiments.

5. Lines 342-344: Regarding the data assimilation experiment setup, the temporal frequency at which synthetic MD observations are assimilated within the 3D-Var system is not clearly specified. Although the OSSE is setup within a 6-hour cycling framework with analyses updated every 15 minutes, it is ambiguous whether this implies that all observations are assimilated at a 15-minute temporal resolution, corresponding to the assimilation update frequency. Further elaboration on the observation assimilation frequency would be valuable.

Response: Yes, the synthetic MD observations are generated at 15-min intervals and assimilated at every 15-min analysis cycle throughout the 6-h cycling period. Thus, each analysis cycle assimilates the synthetic MD observations valid at the corresponding analysis time, and no additional temporal subsampling is applied. We have revised the experimental description to explicitly state the observation assimilation frequency. The corresponding revisions are as follows:

1) Lines 309-310: "The synthetic observations are generated at 15-min intervals and are assimilated at each corresponding analysis time".

2) Lines 353-354: "Synthetic MD observations valid at each analysis time are assimilated at every 15-min analysis cycle".