Referee Report — Major Revision

Manuscript ID: egusphere-2025-4381
Title: Retrieving Atmospheric Thermodynamic and Hydrometeor Profiles Using a Thermodynamic-Constrained Kalman Filter 1D-Var Framework Based on Ground-based Microwave Radiometer

Summary statement:

This manuscript comes up with a new method, TCKF1D-Var, to retrieve atmospheric profiles from GMWR. This method differs from conventional 1D-Var that employs a ratio-based cost function independent of prescribed background and observation error covariances, and integrate a diagnostic microphysics closure to represent liquid and ice water.

Clear results are shown that lower errors are achieved in cloudy circumstances. However, there are several issues need to be answered before acceptance. I recommend major revision.

Major Comments:

1. Line 211: In the figure, it is not clear that “the differences among the three products are mainly confined to the boundary layer.” The authors may clarify whether this statement is supported by the figure or revise it accordingly.
   Lines 217–219: In Fig. 5f, the random errors of the TCKF1D-Var temperature profiles remain significantly smaller than those of 1D-Var above 2000 m, which seems inconsistent with the statement “increase substantially” in the text.
2. In Section 4.1.4, the potential cause of the water vapor RMSE deficit is analyzed. As a reviewer not specialized in this field, I would appreciate if the authors could clarify why a similar phenomenon does not occur in the temperature vertical profile?
3. In the overall comparison among TCKF1D-Var, 1D-Var, and ERA5, it appears that temperature differences between TCKF1D-Var and ERA5 are generally small, whereas 1D-Var exhibits large errors in the upper atmosphere, and below 500 m errors remain high. These issues seem unresolved and warrant further discussion. For the first two points, could they be attributed to the dependence on the R and B matrices? If so, it may be slightly unfair to generalize, as in other cases (with different R and B) 1D-Var might perform better. Moreover, since the new cost function depends explicitly on GMWR observations, it is unsurprising that TCKF1D-Var outperforms 1D-Var when the distance between radiosonde and GMWR is minimal. Clarifying these points would be helpful.
4. Only seven sites are equipped with radiosonde observations. Therefore, in composite analysis, large differences may arise between mean bias and RMSE for the same variable. For instance, in Figs. 4c and 4d, the mean bias of water vapor at ~1700 m appears larger than the RMSE, which is mathematically implausible. A similar issue occurs between Figs. 5g and 5h. Please check these results.
5. What criterion is used for the histogram bins in Fig. 9? Are the results sensitive to the

division of water vapor ranges?

Minor comments:

1. Lines 75 and 78: The abbreviations should be unified—either GMWR or MWR.
2. In Figure 1, there are 44 stations, which does not match “43” in Line 75.
3. In Section 2.3, it is recommended to include the accuracy information of CPR_CLD_2A.
4. What is the underlying reason for the larger differences between TCKF1D-Var and ERA5 during daytime?
5. Lines 237–239: It seems that Figs. 6i and 6m (rather than 6n) are being analyzed. Moreover, the statement “TCKF1D-Var also exhibits reduced temperature errors below 5 km compared to ERA5 and 1D-Var, while above 5 km its performance is comparable to 1D-Var” corresponds to Fig. 6i, and “ERA5 shows similar errors to 1D-Var below 3 km but becomes less accurate above this level” corresponds to Fig. 6m. Please separate these analyses to avoid confusion.
6. Please ensure that the title and content of Table 1 appear on the same page.
7. Correct the repeated “Figure 8” in the title of Fig. 8.
8. Although Taylor et al. (2007) and Garcia-Carreras et al. (2010) are cited to justify using the temporal moving anomaly of virtual potential temperature as an early-warning indicator, it is recommended to briefly clarify the underlying mechanism.
9. The results in Figs. 10 and 11 are somewhat repetitive. It is recommended to either combine these figures and the corresponding analysis, or present the results without Fig. 11 for conciseness.