Reviewer #2

General comments

1. This paper explored the effect of prognostic graupel density in WDM6. The goal of this modification was to better model snowfall events with more realistic fall speed-diameter and mass-diameter relationships. It was interesting to see assumptions in existing methods get replaced by theories in new studies with reasonable success (lower RMSE). However, the biggest concern I have with the comparison between WDM6_PD with WDM6_FD is that fall speed-diameter relationship does not converge when they have the same density (Figure 1). I understand that it might have been implemented this way because the authors tried to keep the off-the-shelf fixed density model unchanged, but this implementation fails to facilitate a fair comparison between fixed vs. prognostic density because no one knows if the difference in simulation results come from the prognostic density or the vastly different parameters (ag, bg). It also leads to physical inconsistency: starting L350 (also Figure 9), the graupel in WDM6_PD falls faster than WDM6_FD despite its lower prognostic density (250-350 kg/m3 vs 500 kg/m3 in WDM6_FD) and smaller size. I recommend adding a modified WDM6_FD that is simply WDM6_PD when rho= 500 kg/m3 " for a more meaningful comparison. This problem needs to be revisited because it could change the statistical skill scores shown in Table 4, but overall, this is a study worth publishing once this problem is resolved.

: We appreciate your valuable comments. To explain the reason why the fall speed-diameter relationship between WDM6_PD and WDM6_FD does not converge when they have the same density, we added the following sentences in the revised manuscript:

Line 153: "Note that the coefficients, a_G and b_G, are assumed as 330 $m^{1-b}\,s^{-1}$ and 0.8 in the original WDM6 scheme and these values differ significantly from those in Table 2. However, we adhere to the methodology presented in Milbrandt and Morrison (2013) to preserve the originality of the method."

Additionally, as the reviewer suggested, we conducted additional experiments to answer the question of whether the difference in simulation result comes from the prognostic density or the different parameters in the fall speed-diameter relationship. Specifically, we implemented a_G and b_G in the V_G–D relationship for ρ_G = 500 kg m^{-3} in WDM6_PD from Table 1 (as shown by the blue line in Fig. R3) into the WDM6_FD scheme (referred to as WDM6_FD_500).

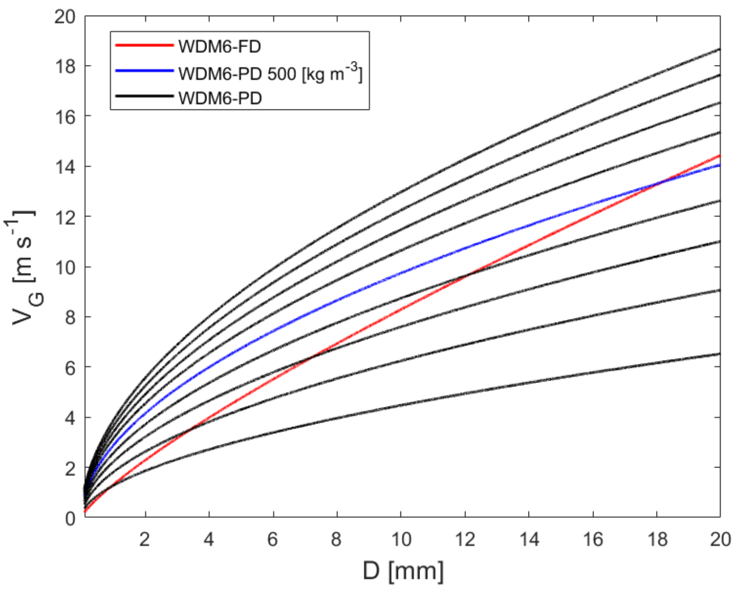

Figure R3. $\mathbf{V_G}$ as a function of D for the $\boldsymbol{\rho_G}$ range between 100 and 900 (kg m^{-3}). $\mathbf{a_G}$ and $\mathbf{b_G}$ in Table 1 are utilized. The $\mathbf{V_G}$-D relationships in the WDM6_FD and WDM6_FD_500 are also represented by a red and blue lines.

The results, comparing WDM6_FD_500 with WDM6_FD for the CL case, are displayed in Figures R4 to R6. As mentioned in section 4.2 of the original manuscript, WDM6_PD leads to an increase in surface graupel, especially in regions where WDM6_FD exhibits a negative bias compared to AWS observations (Figs. 7a-d of the original manuscript). However, WDM6_FD_500 presents a different response of surface graupel compared. By presenting a reduction of surface graupel, WDM6_FD_500 increases the negative bias over the central to western part of analysis domain, despite the use of higher graupel fall velocity than in WDM6_FD (Fig. R4b). This leads to a deterioration of RSME score in WDM6_FD_500 (Table R1).

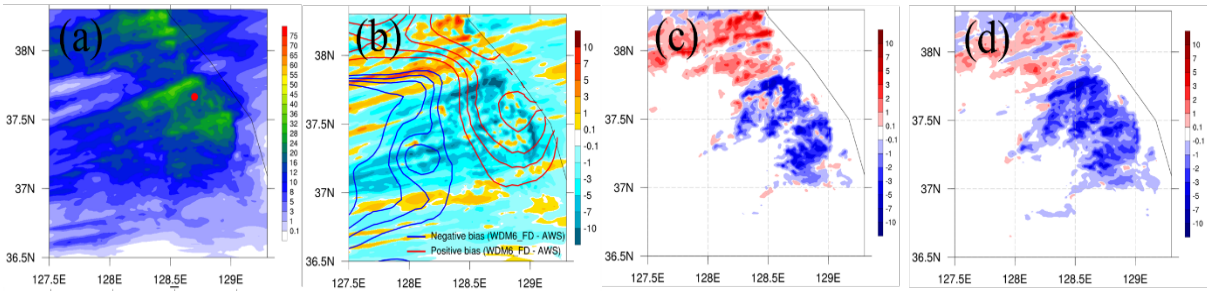

Figure R4. Accumulated surface precipitation amount (mm) for (a) CL case with WDM6_FD_500 during the analysis period. The differences in the amounts of surface precipitation (mm) between WDM6_FD_500 and WDM6_FD (WDM6_FD_500 minus WDM6_FD) for CL case are shaded in (b). The red (blue) solid lines represent the positive (negative) differences between WDM6_FD and AWS observations (WDM6_FD minus AWS). The contour lines for positive (negative) values are plotted at 3, 5, 7 and 10 (−3, −5, −7 and −10) mm. The differences in the amounts of surface snow (mm) between WDM6_FD_500 and WDM6_FD (WDM6_FD_500 minus WDM6_FD) for CL case are plotted in (c). The differences in the amounts of surface graupel (mm) are shown in (d).

Table R1. Statistical skill scores of the root mean square error (RMSE), bias, and equitable threat score (ETS) for the cases with WDM6_FD, WDM6_PD and WDM6_FD_500.

Case	**Experiment**	**RMSE**	**BIAS**	**ETS**
	WDM6_FD	**6.58**	**1.27**	**0.30**
CL	**WDM6_PD**	**6.01**	**1.61**	**0.31**
	WDM6_FD_500	**6.50**	**1.19**	**0.31**

WDM6_PD also exhibits a significant decrease in graupel mass mixing ratio in the atmosphere compared to WDM6_FD (Fig. 8c of the original manuscript), due to a relatively higher graupel fall velocity. However, WDM6_FD_500 (Fig. 5c), relative to WDM6_FD, shows a smaller reduction in graupel mass mixing ratio in the atmosphere, and the changes in other hydrometeor mixing ratios between WDM6_FD_500 and WDM6_FD are different from those between WDM6_PD and WDM6_FD, even though both WDM6_FD_500 and WDM6_PD have higher fall velocities than WDM6_FD. The analysis of the falling graupel mass mixing ratio (Fig. R6) reveals that the maximum level of falling graupel does not differ between WDM6_FD_500 and WDM6_FD. Meanwhile, Figure 9 of the original manuscript shows that the maximum level of falling graupel is simulated at a lower altitude in WDM6_PD compared to WDM6_FD.

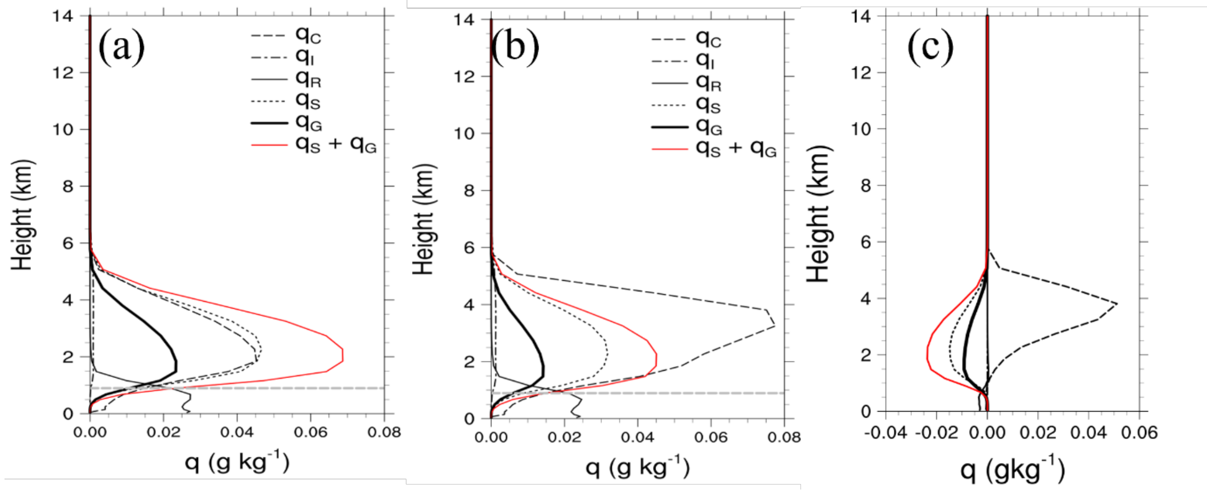

Figure R5. Vertical profiles for the time-domain-averaged mass mixing ratios (g kg^{-1}) of hydrometeors for (a) CL case with WDM6_FD. (b) is same as (a), but for WDM6_WDM6_FD_500. The differences in the mass mixing ratios of WDM6_WDM6_FD_500 and WDM6_FD (WDM6_WDM6_FD_500 minus WDM6_FD) for CL case are plotted in (c). In (a) and (b), the cloud ice mass mixing ratio ($\mathbf{q_I}$) is multiplied by 100. The sum of snow and graupel mass mixing ratios (g kg^{-1}) is indicated by red lines, and the 0°C level by the grey dashed horizontal line.

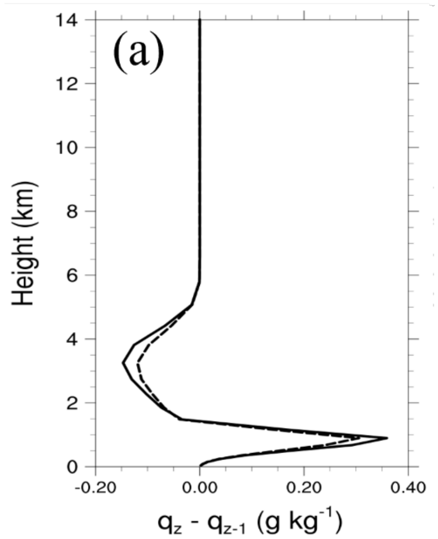

Figure R6. Time-domain averaged difference in graupel mass mixing ratio (g kg^{-1}) between the levels 'z' (q_z) and 'z-1' (q_{z-1}) due to sedimentation with WDM6_FD_500 and WDM6_FD for CL case is in (b). The solid and dashed lines represent WDM6_FD and WDM6_FD_500, respectively.

Consequently, the results of the additional experiment indicate that the findings presented in the manuscript for WDM6_PD are not solely attributable to higher fall velocity parameters when compared to WDM6_FD. Instead, the differences in simulation results originate from the predicted graupel density, which is calculated based on physically based microphysical processes, and the resulting variation in graupel fall velocity. The verification of the $\rho_G - V_G$ relationship using observed 2DVD data in Figure 11 of the original manuscript also suggests that WDM6_PD, with predicting graupel density and modified fall velocity, simulates a more realistic $\rho_G - V_G$ relationship compared to WDM6_FD.

Specific comments

2. **L138. Why are the parameters in Table 2 so far off from the ones in the original WDM6 scheme? I don't think you need an extensive explanation, but a one-sentence summary would be nice as it ties to points I made in the general comments.**

: In response to reviewer's suggestion, we have added the following sentences to the revised manuscript:

Line 153: "Note that the coefficients, a_G and b_G, are assumed as 330 $m^{1-b}\,s^{-1}$ and 0.8 in the original WDM6 scheme and these values differ significantly from those in Table 2. However, we adhere to the methodology presented in Milbrandt and Morrison (2013) to preserve the originality of the method."

Additionally, to expand on this discussion and explore potential avenues for further refinement of the simulated fall velocities, we have added the following sentences in "Summary and Conclusion" section of the revised manuscript:

Line 505: "The derived V_G–D relationship in our research could be refined by incorporating a broader range of graupel observational data, including hexagonal, conical, lump graupel, or graupel-like snow. Improvements in the representation of V_G–D relationship can lead to better simulation of precipitation and microphysical processes in environments where various types of graupel are generated."

3. **L316. Briefly explain equitable threat score (ETS) and why it's worth mentioning (even though the scores are similar).**

: Thank you for your comment. Equitable Threat Score (ETS) is a valuable metric for assessing forecast performance because it accounts for random chance and provides a balanced measure of forecast skill. To explain why we mentioned the ETS score, we have added the following sentences to the revised manuscript:

Line 358: "Despite these similar ETS scores, this comparison confirms that both WDM6_FD and WDM6_PD perform comparably well in predicting snowfall events."

4. **L350. Physical inconsistency as mentioned in the general comments.**

: In response to comment #1, we have carefully reviewed your comments and conducted additional experiments to address the concerns you raised. We believe that additional experiments and followed description have effectively addressed the identified issues.

5. **L379. The enhanced graupel fall velocity should not be attributed to the prognostic graupel density but rather the vastly different parameters (ag, bg) used.**

: In response to your comment, we modified sentences as follows:

Line 427: "The significantly enhanced graupel fall velocity, attributed to the prognostic graupel density in WDM6_PD, accelerates the sedimentation of graupel." → "The significantly enhanced graupel fall velocity, attributed to the newly derived parameters in the V_G–D relationship in WDM6_PD, accelerates the sedimentation of graupel."

6. **L391. The slight enhancement of vertical velocity in the range of 0.1-0.5 m/s seems about equally insignificant for both CL and WL. The authors might also want to reexamine this figure with the WDM6_FD with modified parameters.**

: We concur with your assessment that the differences in vertical velocity depicted in Fig. 10 are minimal and do not substantiate the suggested impacts of microphysical changes as robustly as required for a conclusive argument. Considering your comments and after careful consideration, Fig. 10 and its related descriptions are removed in the revised manuscript.