Answers to the Anonymous Referee 1

Answers are in italic blue text.

RC1: 'Comment on egusphere-2024-594', Anonymous Referee #1, 28 Mar 2024

Review of "Effect of Secondary Ice Production Processes on the Simulation of ice pellets using the Predicted Particle Properties microphysics scheme" by Lachapelle et al.
The authors of this manuscript examined the effect of secondary ice production (SIP) processes on the simulation of ice pellets using an NWP model with a double moment bulk microphysical scheme (P3). Both Hallett-Mossop (HM) and fragmentation of freezing drops (FFD) processes are examined. It is found that adding HM or FFD would significantly improve the simulation of ice pellets for this specific case (both full simulation and 1D idealized simulation). I enjoyed reading this manuscript which is well written, and the results are clearly presented. I made several suggestions below that may help.

Thank you for your comments.

Main comments:

1. L134-136: I believe that the modification of the default HM parameterization in P3 should not be a major obstacle to examining the combined effect of HM and FFD. The interaction between HM and FFD could be quite complex and sensitive to how both HM and FFD are parameterized, which could be a continued study on it alone. Nevertheless, I think it would be worth mentioning in the manuscript about this complexity which warrants further studies.

Preliminary tests (not shown here) have demonstrated that adding HM to a configuration of P3 that includes FFD does not change significantly the accumulation of ice pellets. In our parametrization of these processes, both HM and FFD occur under similar conditions, when supercooled drops are collected by ice particles. Hence, because the parametrization of FFD is more efficient than the parametrization of HM, adding HM to FFD did not have much impact.

The sentences at lines 134-136 included too many details that were possibly confusing and misleading for the reader. The original sentences at lines 134-136 was:

"Observations collected in the field suggest that FFD and HM were active SIP processes during the 12 January 2020 ice pellet episode (LT22; Lachapelle et al., 2024).The two SIP processes were analyzed individually; no simulation used more than one SIP process simultaneously because this would result in the production of secondary ice through two distinct processes freezing the same raindrop and would require the default implementation of HM to be modified."

For clarity, the sentences will be changed to (changes are in bold):

*"Observations collected in the field suggest that FFD and HM were active SIP processes during the 12 January 2020 ice pellet episode (LT22; Lachapelle et al., 2024). **However, because the objective of this work is to examine how SIP affects simulated precipitation types and particle size distributions, the two SIP processes, HM and FFD, were used individually. This approach facilitated the understanding of their respective effects.**"*

We will also add the following sentence mentioning future studies in the conclusion (near line 395):

"Future research should also include simulations combining multiple SIP processes, from which could emerge complex interactions and feedback processes."

2. L137-138/L428-429: the default HM parameterization in P3 scheme with a threshold of 4000 µm for the mean-mass D of ice particles seems extremely large, e.g. some graupels could be much smaller than 4000 µm. Some of the previous studies have disregarded this threshold or using a smaller one. Would it be possible to test different thresholds which might have significant impacts on the results?

Different studies used different ice diameter thresholds to parametrize HM (e.g., Sullivan et al., 2018; Sotiropoulou et al., 2021, 2020; Qu et al., 2022). An ice diameter of 4000 µm is large and limits SIP compared to using lower thresholds. Since the submission of the manuscript, the default threshold diameter for HM in P3 has been changed to 1000 µm (Cholette et al., 2024; based on Qu et al., 2022). For this reason, the threshold will be changed to 1000 µm in the revised version of the manuscript in all simulations (1D and 3D).

As expected, lowering the threshold increased the amount of ice pellets and decreased the amount of freezing rain (Figs. R1, R2, R3). Although Fig. R3 suggests an improvement in ice pellet statistics for this case, the region of accumulated ice pellets and the simulated particle size distributions are similar to nCat2_HM in the submitted manuscript. Hence, the main conclusions of this study are the same.

The following sentences will be added in the methodology section (line 140):

"Different ice diameter thresholds were used in different studies to activate HM (e.g., Cholette et al., 2024; Qu et al., 2022; Sotiropoulou et al., 2021; Sullivan et al., 2018). Sensitivity tests showed that the accumulated amounts of ice pellets and freezing were sensitive to this value (e.g., ice pellet amounts decreased with a larger ice diameter threshold)."

And in the conclusion (near line 395):

"The simulations are sensitive to the parametrization of SIP. For example, increasing the ice diameter threshold for HM decreases the amount of ice pellets produced. The identification of an optimal SIP parameterization for ice pellet and freezing rain simulation will require more observations and modeled cases."

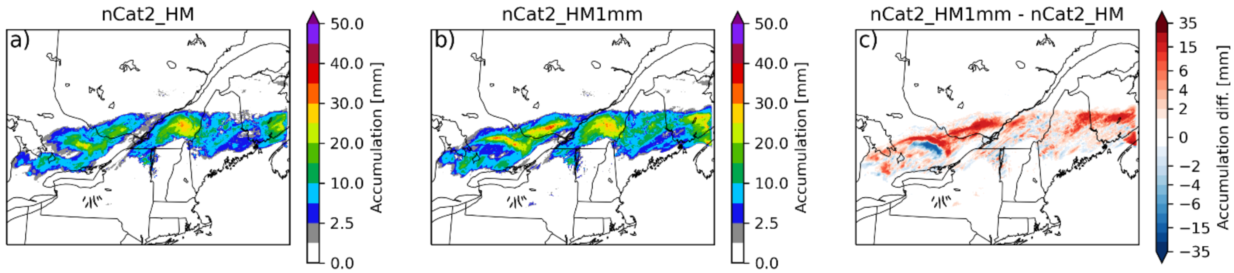


Fig. R1. Ice pellet accumulation simulated with (a) nCat2_HM configuration that used an ice diameter threshold of 4000µm, (b) nCat2_HM1mm configuration that used an ice diameter threshold of 1000µm, and (g,h,i) their differences.

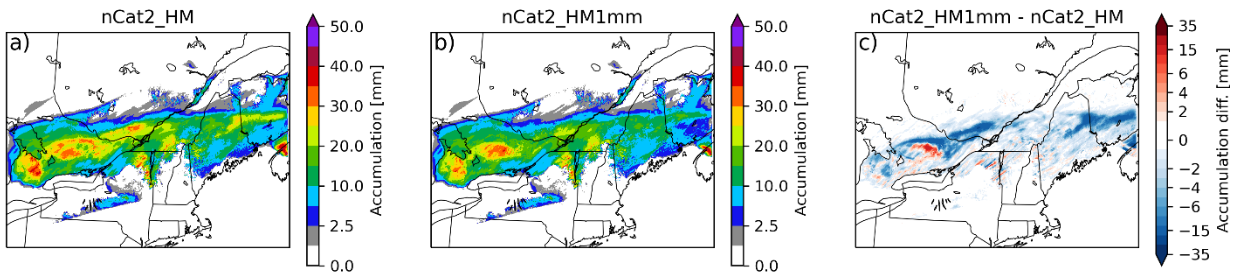
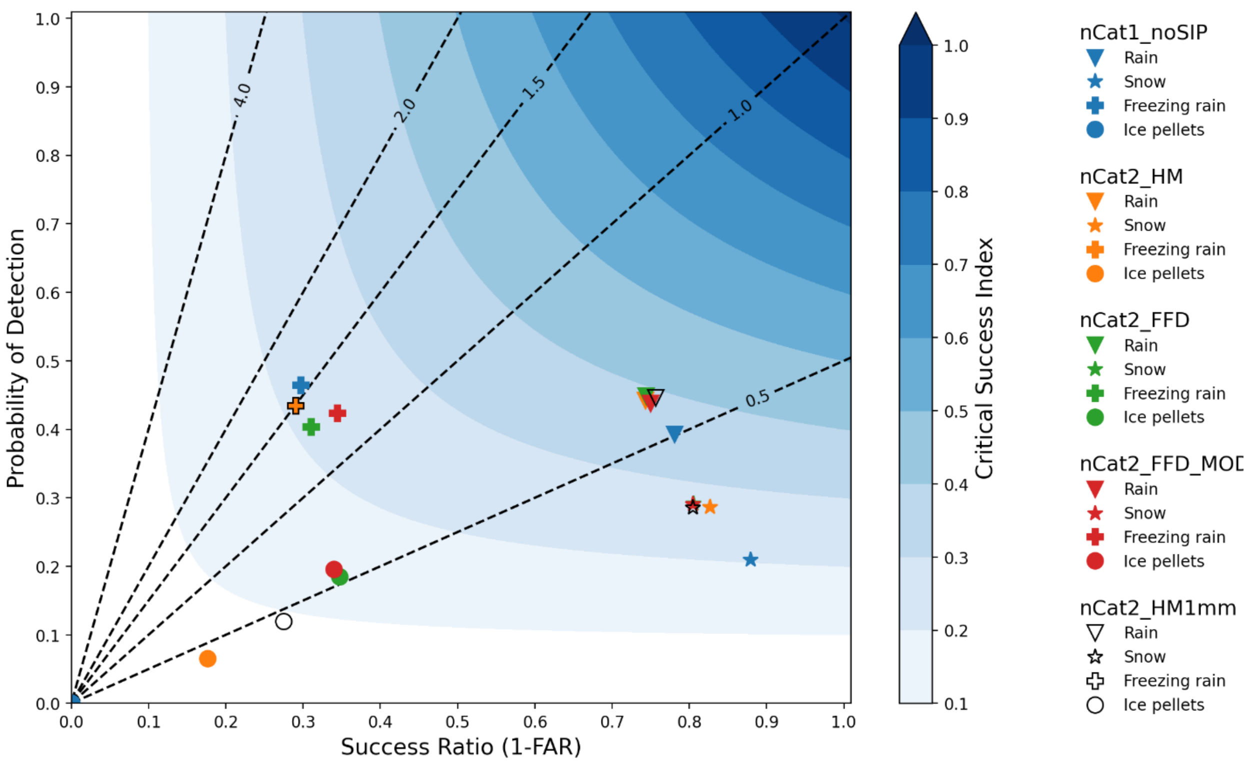


Fig. R2. Same as Fig. R1 but for freezing rain.



R3. Same as Fig. C1 in the submitted manuscript with the new simulation nCat2_HM1mm. In the revised manuscript, the simulation nCat2_HM will be replaced by nCat2_HM1mm.

3. L432-433: the maximum number allowed (2×10^6 m^{-3}) for ice number concentration seems quite small. In situ data suggests that much larger values are possible even without counting those ice particles smaller than ~50 µm. As SIP will produce a large amount of tiny ice splinters, the number concentration might peak locally at a high value. Although the exact maximum value is arguable, 2×10^6 m^{-3} seems definitively too low. This means some large Ni will be automatically clipped at this lower value and the total Ni is therefore reduced. I'm wondering if the author tested other thresholds and whether the results are significantly different.

Gultepe et al. (2015)[1] mentioned that ice can reach a number concentration > 10^6 m^{-3}. Girard and Blanchet (2001)[2] suggest that ice fog number concentration is always < $4\times10^6 m^{-3}$. Hence, we think that an upper limit of 2×10^6 m^{-3} is realistic in most cases, but we agree that it might be too small under some circumstances.

The concentration of ice reached the limit of 2×10^6 m^{-3} in the experiments nCat2_HM and nCat2_FFD but not in the experiments nCat1_noSIP and nCat2_FFD_MOD. nCat2_FFD_MOD did not simulate such a high concentration because the modifications added limited the ice multiplication to realistic concentrations; the observed concentration of ice crystals was estimated to be between 1×10^4 and 1×10^5 m^{-3} during the ice pellet storm presented in this study[3]. Increasing the limit could result in more ice pellets produced by experiments nCat2_HM and nCat2_FFD. Sensitivity studies could be conducted in the future to explore the impacts of modifying this limit for other winter events in which SIP processes play an important role.

4. L169: could the authors describe more about the simulation results of using more than 2 ice categories? My understanding is that with more ice categories, the different sizes of ice particles should be better represented. Although for many reasons, such as our limited knowledge of SIP, etc. a better physical model might not produce better prediction results. I believe more discussion on this would be helpful.

At line 169, the variable "n" does not refer to the number of ice categories but rather to a new parameter that we introduced. To avoid this confusion, we will improve the following lines (166-169):

"To avoid this dilution effect, we added a new routine to P3 to redirect large-collected raindrops to the most appropriate ice category when the mean mass-weighted diameter of rain is n times as large as the mean mass-weighted diameter of ice. Although the simulations were sensitive to the n variable, the best results were obtained for n = 2."

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[1] I. Gultepe et al., « A review on ice fog measurements and modeling », *Atmospheric Research* 151 (2015): 2-19, https://doi.org/10.1016/j.atmosres.2014.04.014.

[2] Eric Girard et Jean-Pierre Blanchet, « Microphysical Parameterization of Arctic Diamond Dust, Ice Fog, and Thin Stratus for Climate Models », *Journal of the Atmospheric Sciences* 58, nº 10 (1 mai 2001): 1181-98, https://doi.org/10.1175/1520-0469(2001)058<1181:MPOADD>2.0.CO;2.

[3] M. Lachapelle et J. M. Thériault, « Characteristics of precipitation particles and microphysical processes during the 11–12 January 2020 ice pellet storm in the Montréal area, Québec, Canada », *Monthly Weather Review*, 2022, 1043-59, https://doi.org/10.1175/mwr-d-21-0185.1.

to this revised sentence:

“To avoid this dilution effect, we added a new routine to P3 to distribute large-collected raindrops to the most appropriate ice category when the mean mass-weighted diameter of rain is twice as large as the mean mass-weighted diameter of ice.”

Concerning using P3 with more than two ice categories, the results of one-dimensional simulations with 3 and 4 ice categories are shown in Figs. R4-R7. The results, including the PSDs, are similar to those obtained with two ice categories. The authors’ hypothesis is that two ice categories are enough to simulate winter precipitation types and processes, as particles remain relatively small. During convective weather, however, a higher number of ice categories may be necessary as hail sizes’ range can be wide. This hypothesis will be pursued in further studies.

A sentence will be added to the methodology, after the description of the conducted experiments (line 197):

“One-dimensional simulations were also performed using three and four ice categories. Similar results were obtained with these simulations (not shown) compared to those obtained using two ice categories, suggesting that two ice categories are enough to represent the precipitation types and properties observed during this ice pellet storm.”

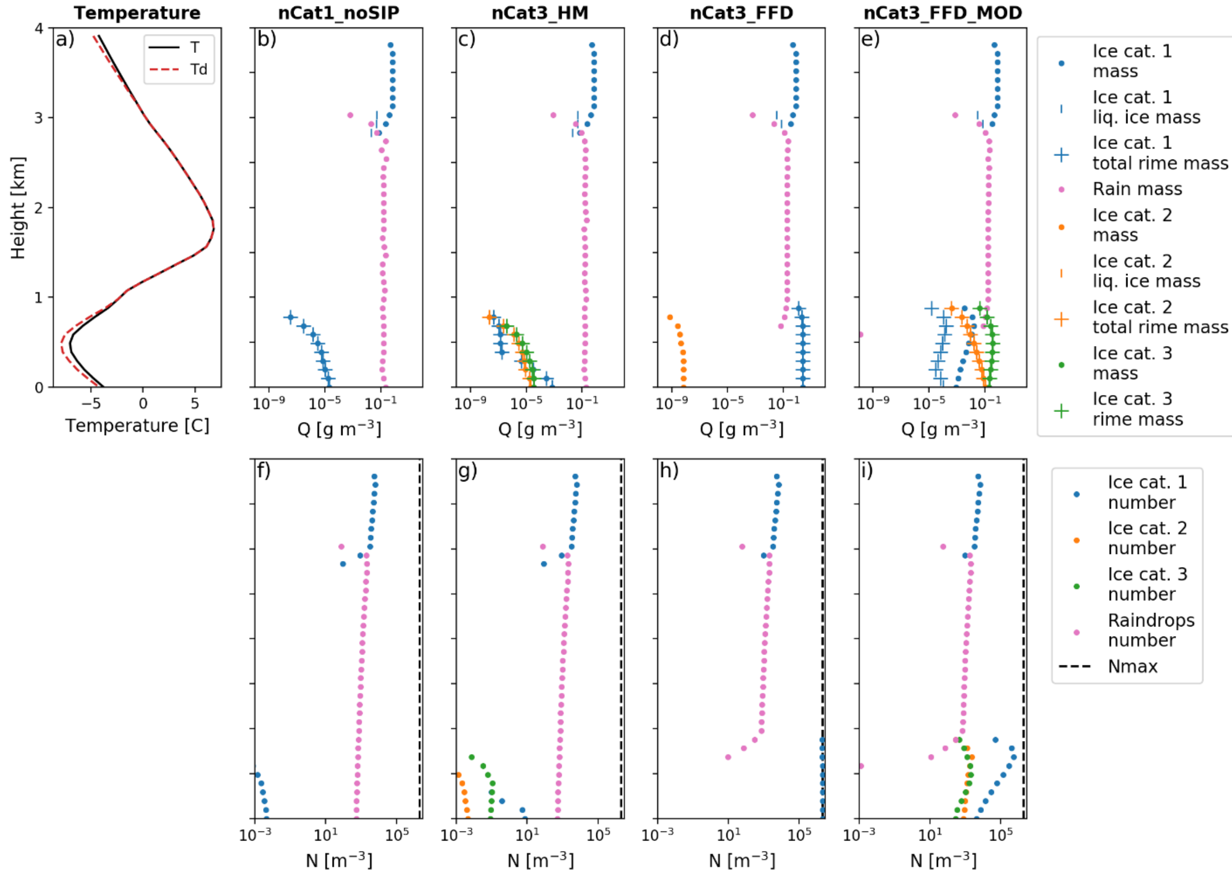

Fig. R4. Same as Fig. B1 but with 3 ice categories.

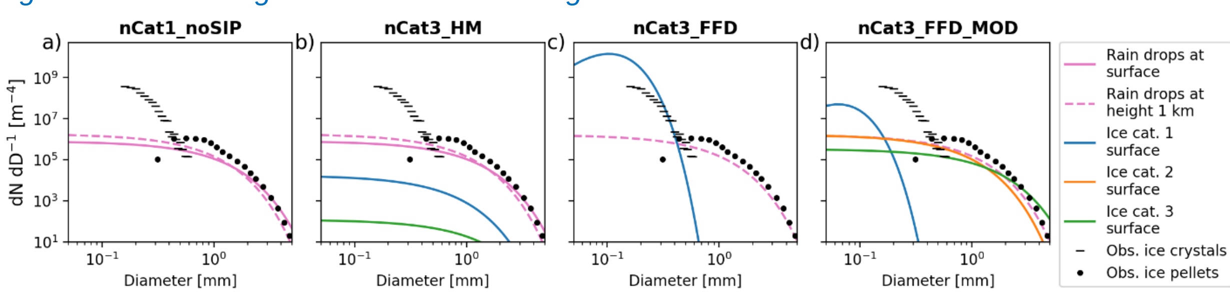

Fig. R5. Same as Fig. B2 but with 3 ice categories.

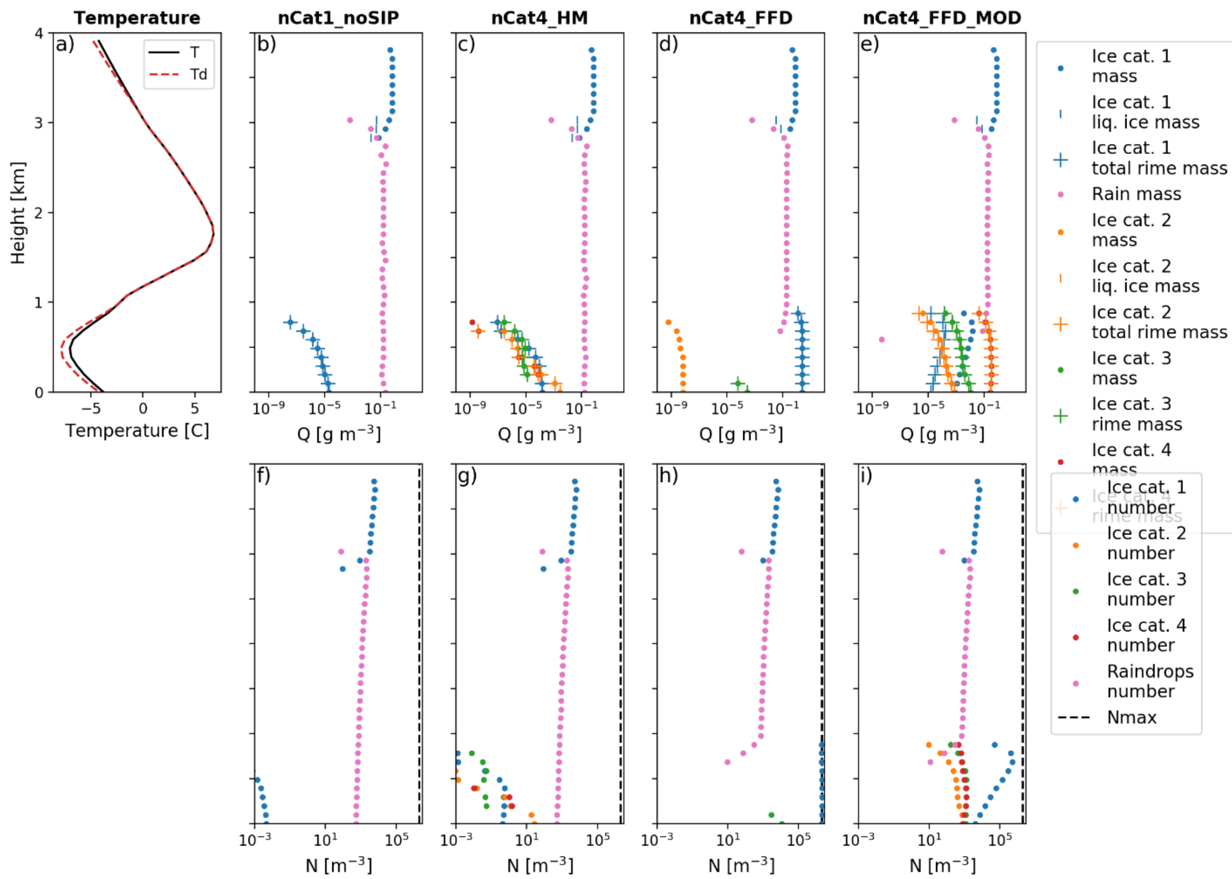

Fig. R6. Same as Fig. B1 but with 4 ice categories.

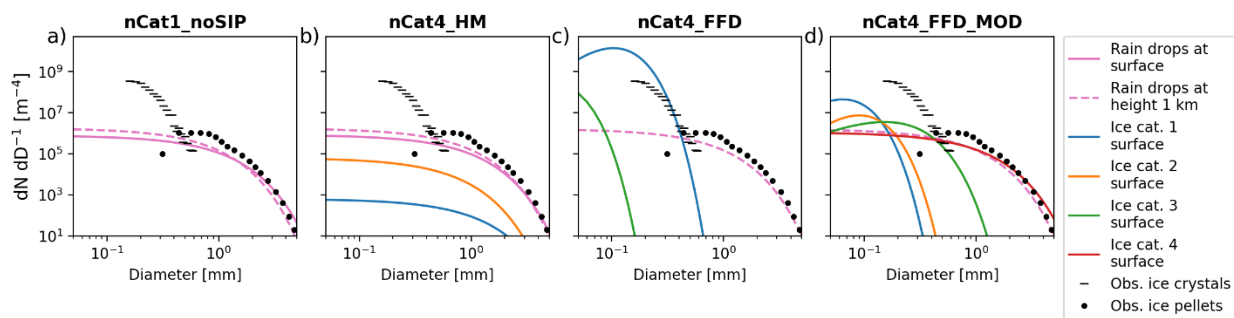

Fig. R7. Same as Fig. B2 but with 4 ice categories.

5. Figure 3-5: it seems the best results from nCat2_FFD_MOD still overestimated the period of freezing rain compared to the observation, particularly for UQAM-PK. Might this suggest that current SIP rate in this study is not fast enough to convert liquid into ice?

Yes, it might. As shown with the experiment in which we reduced the ice diameter threshold for HM (i.e., answer to your comment #2), the accumulated freezing rain and ice pellets are sensitive to how SIP is parameterized. We only based our comparisons on the observed types of precipitation (temporal evolution mainly) and PSDs at a specific location. Although we show *that the modified nCat2_FFD_MOD better reproduced ice pellets, we think that more cases and more observations are needed to improve the parameterizations.*

We will add the following comment in section 4.1:

"In addition, all the experiments produced fewer hours of ice pellet than those observed. This suggests that increasing the efficiency of SIP could decrease the difference between simulated and observed precipitation types. However, more cases and observations are needed to improve the parameterizations."

6. Fig. B1: nice results from the 1D simulation which illustrates well the impact of modifying the FFD process (section 2.3), e.g. rime ice with similar size to raindrops + much smaller ice crystals!

Thank you!

7. Fig. B2d: the ice cat 2 (orange line) is missing.

Thank you for noticing this. Here is the corrected figure.

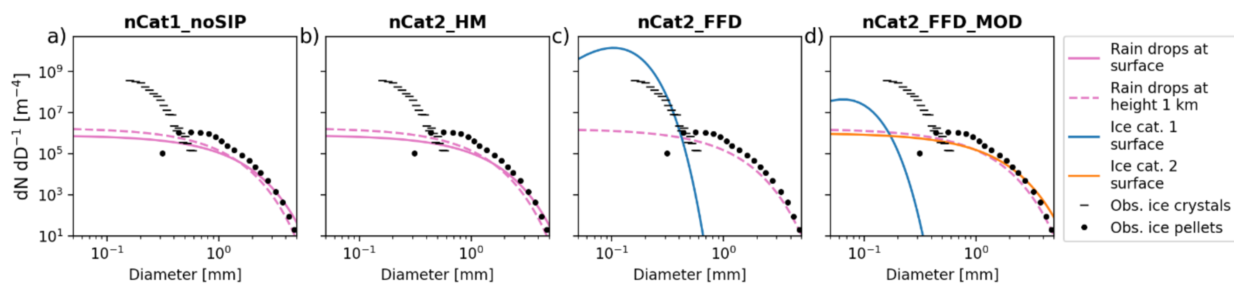

Fig. R8. Corrected Fig. B2.