Answers to the Anonymous Referee #3

Answers are in italic blue text.

RC3: 'Comment on egusphere-2024-594', Anonymous Referee #3

Processes on the Simulation of ice pellets using the Predicted Particle Properties microphysics scheme' The manuscript describes forecast experiments for a winter storm event that produced snow, freezing rain, and ice pellets. The forecast model does a remarkable job of reproducing the precipitation rates at the comparison site, which could in part be a reflection of the system being in a more predictable regime of synoptic forcing. The experiments conclude that the P3 scheme is able to produce realistic ice pellet accumulations with a parameterization of small ice production by shattering of freezing drops. I think this is nice study that presents a problem and a physically plausible solution. I have a just a few questions to clarify some points.

Thank you for your comments.

Minor Comments:

1. Line 112: 'Immersion freezing of cloud droplets and rain can occur when T < -4C, following the volume and temperature dependent formulation presented in Bigg (1953)' From Bigg's plot, highest practical mean temperature for freezing is about -20C for very large drops. I would not expect any freezing from that parametrization at -4C, but I'm not familiar with the Barklie and Gokhale (1959) formulation. Does P3 really produce much drop freezing from this process at temperatures higher than, say, -15C? Freezing by ice crystal capture could happen, of course. Also, Bigg 1953 used distilled water, so I consider it to be something of a lower limit for homogeneous freezing.

With the parametrization of immersion freezing used in P3, from Bigg (1953), we have calculated that <0.1% of raindrops with diameters of 1 mm would freeze at temperatures >-10°C during a fall of 1000 m. This calculation is presented in the Appendix A. As you mention in your comment, this is negligible. In the one-dimensional simulation, this process leads to the freezing of a minority of raindrops. In the absence of SIP with nCat1_noSIP simulation, this process explains the production of ice with a mass mixing ratio <10^{-5} g m^{-3} (Fig. R1b,f).

To avoid confusion, the word “small” will be changed for “negligible” in the following sentence (line 112):

*“In Appendix A, we show that this parametrization of immersion freezing leads to the freezing of a ~~small~~ **negligible** fraction of raindrops in the atmospheric conditions observed during ice pellet events.”*

2. Line 139: 'collect 1 mg of rain' Should 'rain' be 'droplets'? Studies of the HM process have used small droplet riming, which probably does not apply to collection of larger rain-sized drops.

Sensitivity studies of including cloud droplets in the HM process in P3, including its combination with raindrops, are shown in Cholette et al., (2024). It was found that the overall statistics of freezing rain remain similar when only cloud droplets are included in HM compared to raindrops. Since Cholette et al. (2024)[1] *used the same atmospheric model and microphysics, with similar grid spacing, we think that their conclusions will apply to this case as well.*

3. Concerning the modified merging criteria: Clearly this change produces a more realistic result in this case, but I'm curious if this was also tested on other types of convection to see if has any adverse affects.

No, it has not been tested yet, this is part of future studies, but we agree with the reviewer that it may also change properties of hail-type hydrometeors.

We will add a sentence in the last paragraph of the conclusion concerning this (near line 395):

"Finally, potential adverse effects of the modifications presented in this work should be studied in other types of weather, including hail formation during severe summer weather."

4. Line 217: 'but the critical success index for ice pellets was better with the experiments that included the FFD SIP process' I think calling it 'better' is an understatement. The base simulation has essentially zero CSI, and the differences with HM and then FFD are quite substantial and worth saying a bit more about.

Good points, the following sentence (L217-218):

"In general, statistics were similar among the four experiments, but the critical success index for ice pellets was better with the experiments that included the FFD SIP process."

will be changed to:

"For rain and snow, the critical success index was slightly improved for the simulations including SIP. For ice pellets, adding SIP clearly improved the critical index because the baseline simulation produced a negligible amount of this precipitation type. The two simulations that included FFD reached the highest critical success ratio. For freezing rain, adding SIP decreased slightly the probability of detection. However, for the simulation including FFD and our modifications, the probability of detection decreasing was counterbalanced by a slight success ratio increase."

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[1] Cholette, M., Milbrandt, J. A., Morrison, H., Kirk, S., and Lalonde, L.-É.: Secondary Ice Production Improves Simulations of Freezing Rain, Geophysical Research Letters, 51, e2024GL108490, https://doi.org/10.1029/2024GL108490, 2024.

5. Line 415: 'Snow was initialized from the model top' What were the values of number concentration, mass mixing ratio, etc. for the snow? What was the mean diameter of the particles?

In a first step, the variables Ni and Qi that were prescribed at the one-dimensional model's highest level were the same as those simulated by the three-dimensional model at 4 km MSL at locations where the precipitation rate was 3.5 mm h^{-1}. However, initiating the highest level with these values resulted in a precipitation rate of 1 mm h^{-1} in the one-dimensional model. Hence, we multiplied these values of Ni and Qi by 3, which resulted in a precipitation rate of 3.5 mm h^{-1}. The mean mass-weighted diameter of the initiated snow was approximately 1 mm.

The following sentences will be added (line 417):

"The mass and number mixing ratio, Qi and Ni, of the snow initiated at the model's highest level were chosen to reproduce the observed precipitation rate of 3.5 mm h^{-1}. To do so, Qi and Ni were first extracted from the three-dimensional simulations at 4 km MSL at locations where the precipitation rate was 3.5 mm h^{-1}. Then, the values of the extracted Qi and Ni had to be modified by a factor of three to obtain the observed surface precipitation rate."

6. Figure B1: The rain number by height seems to drop about an order of magnitude, which would be more than accounted for by air density change over 2km. Are there processes that are affecting the rain number (such as the liquid fraction)?

The number concentration of raindrops decreases from around 1800 m^{-3} at 2600 m MSL to around 500 m^{-3} at the lowest level. Investigations of the different processes activated in P3 revealed to this was almost entirely due to rain self-collection.

7. Figure B1: Why do FFD and FFD-MOD have abrupt melting of all ice compared to the first two (e.g., blue circles at 2-3km in panel i vs. panel j)?

Thank you for noticing this result. We found an error in the initiation of the vertical layers, which are needed for sedimentation, in the one-dimensional model used in the submitted manuscript. This error caused an unrealistic slow melting for experiments nCat1_noSIP and nCat2_HM.

The experiments were conducted again with a corrected script by using 41 evenly spaced vertical model levels up to 4 km MSL. All levels had a depth of near 100 m. Overall, these new simulations produced similar results to those presented in the submitted manuscript (Figs. R11-R12) and the unrealistic melting process that was previously simulated with nCat1_noSIP and nCat2_HM was not reproduced. Since the temperature increases rapidly in the melting layer, the new results presented in the figures below, show that ice completely melts after 2 or 3 vertical levels and before reaching T=1.5°C.

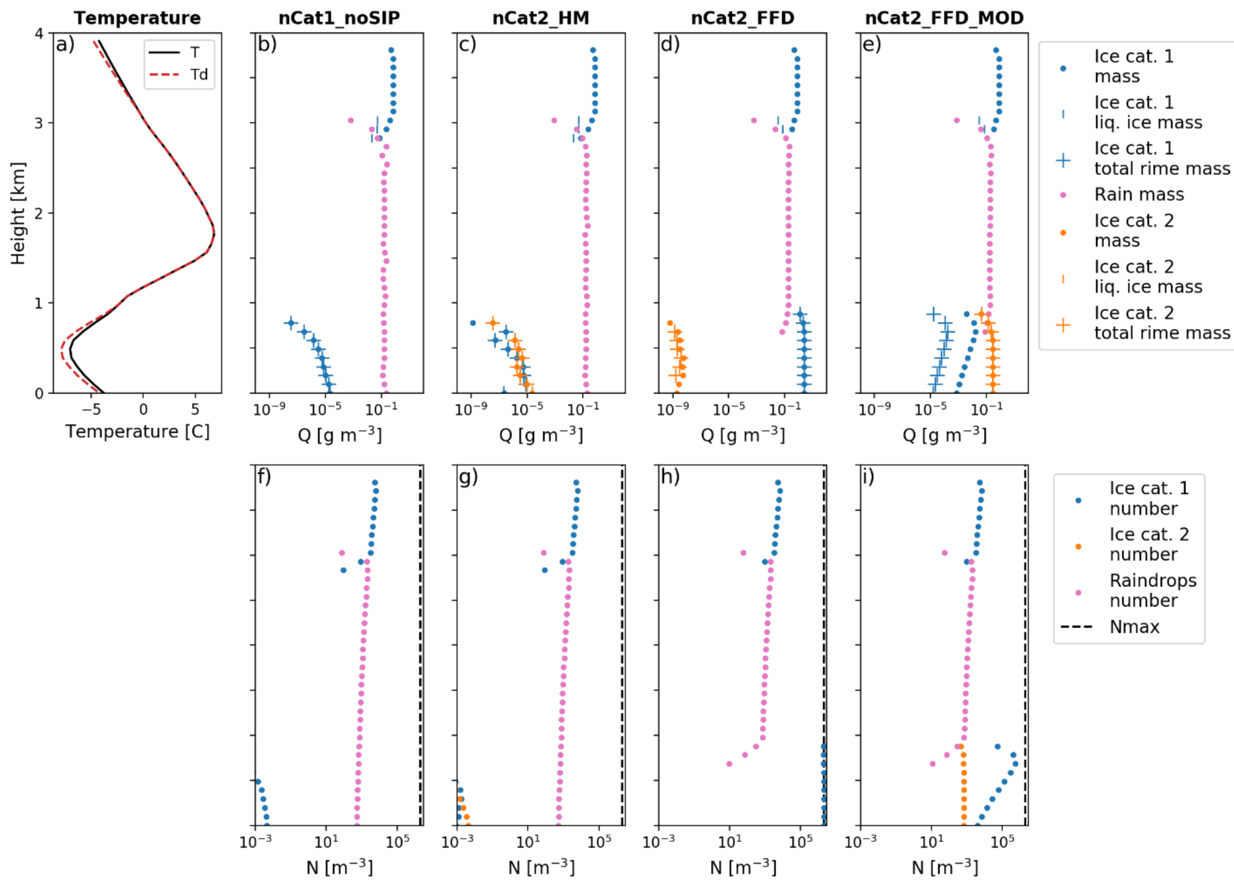

Fig. R1: Revised Fig. B1.

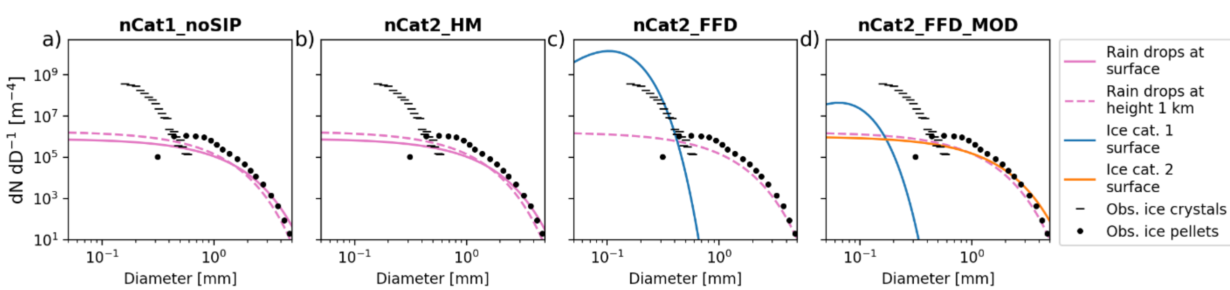

Fig. R2: Revised Fig. B2.

8. Line 454: 'or the precipitation rate was lower' Can you elaborate very briefly on how the precipitation rate affected freezing? Is it simply an insufficient production of ice crystals such that collection was too small to initiate freezing?

More context will be given to these tests at the beginning of this paragraph (new sentences are in bold):

"In addition to performing simulations with the observed precipitation rate and temperature profile, sensitivity tests were conducted by varying the precipitation rate and the minimum temperature in the subfreezing layer with nCat2_FFD_MOD. ***First, given the temperature***

threshold in our FFD parametrization, it was expected that secondary ice would not be produced in warmer conditions. Second, the FFD parametrization depends strongly on freezing raindrops diameter. Hence, higher precipitation rates are expected to produce larger raindrops, producing more ice particles. As expected, *… [rest of the paragraph]"*

9. Fig. B1: Would it be possible to plot the number concentration as number/m3 so that it is easier to compare different altitudes? Not a big deal if not. (Likewise in the upper row, mass content would be easier to compare vertically than mixing ratio.)

It has been changed. See the revised Figures R1 and R2 above.

10. Are panels B1a and B1g the same plot? If so, please make that clear. Or perhaps there is something else that could replace the second one.

They are the same plots. Panel g is deleted to avoid duplicates (see revised Fig. R1).

11. Fig. B1 (one more thing!): Does 'rain' here represent only qr (and nr) or does it include liquid mass on ice? Can you represent the liquid fraction on ice here, perhaps as a line plot in the range of 0-1?

Qr and Nr are rain mass and number. The mass of the liquid on ice is included in the total ice mass mixing ratio, Qi. We added the liquid mass on ice (Qi,liq) in Figure B1 (now revised Fig. R1; small vertical bars).

Editorial comments:
1. Line 239: 'This is consistent with our observation' Is this referring to the "UQAM-PK weather station in downtown Montreal"? If so, that could be made clear. Or is it a personal observation (if so, at what approximate times)?

This will be clarified by modifying the following sentence (changes are in bold):

"This is consistent with our observation ***conducted at UQAM-PK of small****, unrimed ice particles mixed with larger ice pellets that were 100% rimed (****LT22)****."*

2. Line 344: 'The hydrometeors simulated with nCat2-FFD were small and had a high number mixing ratio (Fig. 8f)' This is specifically for ice species 1, correct? Not all hydrometeors. The following sentence would then make more sense. (Although instead of "In parallel" I would suggest 'Conversely' or something that indicates opposite characteristics for ice2.)

To avoid this confusion, we will modify these two sentences for (changes are in bold):

"The hydrometeors simulated with nCat2_FFD ***for ice category one*** *were small and had a high number mixing ratio (Fig. 8f). In* ***contrast****, the ice in category two had a very low number mixing ratio."*

3. Line 434: 'In this experiment' I suggest clarifying this as 'In experiment nCat2FFD' to avoid confusion since two experiments are stated in the first sentence.

Thank you for the suggestion, it will be clarified.

4. Line 437: 'a similar size to the original raindrops' And what size are they?

The expression "the original raindrops" will be replaced with the expression "raindrops at the top of the subfreezing layer". We will also refer to Fig. B2 in the following sentence:

"The size distribution of the raindrops at the top of the subfreezing layer is presented by the dashed pink curve in Fig. B2."