<u>Answers to the Community Referee Heather Reeves</u>

Answers are in italic blue text.

<u>CC1: 'Comment on egusphere-2024-594', Heather Reeves #3</u>

Recommendation: Accept with minor edits

Summary: This paper addresses advances to an NWP microphysics scheme that may allow for better prediction of ice pellets (PL). Specifically, it shows that secondary ice production (SIP) appears to have been pivotal for transitioning falling hydrometeors from all liquid to all ice, thus resulting in PL. Two processes that enhance the conversion from liquid to ice are parameterized in this paper (fragmentation of freezing drops FFD and Hallet-Mossep HM). Additional modifications were made to the FFD code to yield more representative results. This is a strong paper. It's clear and concise and the science is compelling. I have only minor thoughts below.

Thank you.

1. Line 134: It says the two SIP processes are studied independently (as opposed to simultaneously including both FFD and HM in the same experiment) because that requires the default implementation of HM to be modified. I don't understand why HM would have to be modified. It is described as being a different physical process than FFD, so up to this point I thought these were 2 separate processes. Can the authors clarify?

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

In parallel, sensitivity tests have shown that adding HM to a simulation that includes FFD does not impact the accumulation of ice pellets much. In our parametrization of these processes, HM and FFD both occurs 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.

2. Line 138: The paper describes the number of ice splinters produced per unit of rain at a certain temperature range and how it changes outward from there. Is there a citation for this is or is this something the authors of this paper prescribed? If the latter, how sensitive are the results to the number of ice splinters?

The parametrization that we have used is the same as in Milbrandt & Morrison (2016). The numbers used in this parametrization come from Mossop et Hallet (1974). We will add these references in the sentence at line 138.

On another note, the simulations are sensitive to the parametrization of HM. In our answer to the second comment of referee #1, we changed the ice diameter threshold included in the parametrization of HM. Decreasing this threshold from 4000 µm to 1000 µm increased the amount of simulated ice pellets and decreased the amount of simulated freezing rain (Figs. R1, R2, R3).

Following these results, the following sentences will be added to 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 parameterization of SIP for ice pellet and freezing rain simulation will require more observations and modeled cases.”

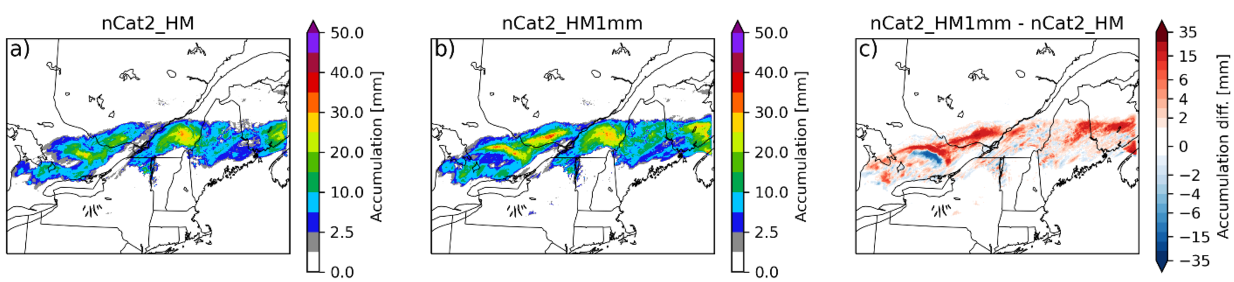


Fig. R1. Ice pellet accumulation simulated with (a) nCat2_HM configuration that used an ice diameter threshold of 4000µm, (b) nCat2_HM1mm configuration that used an ice diameter threshold of 1000µm, and (g,h,i) their differences.

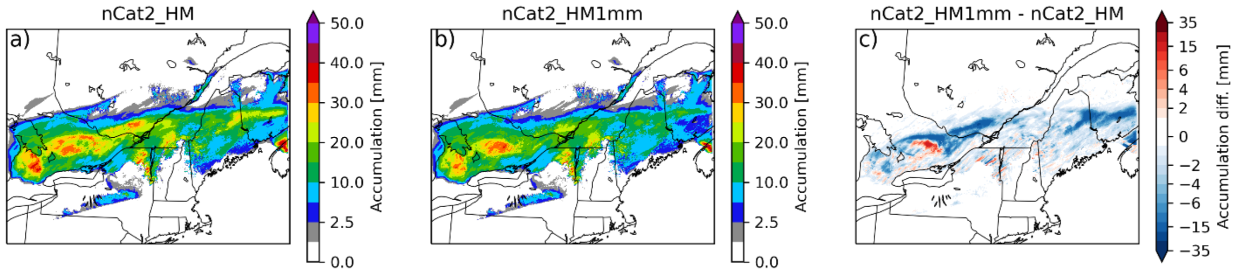
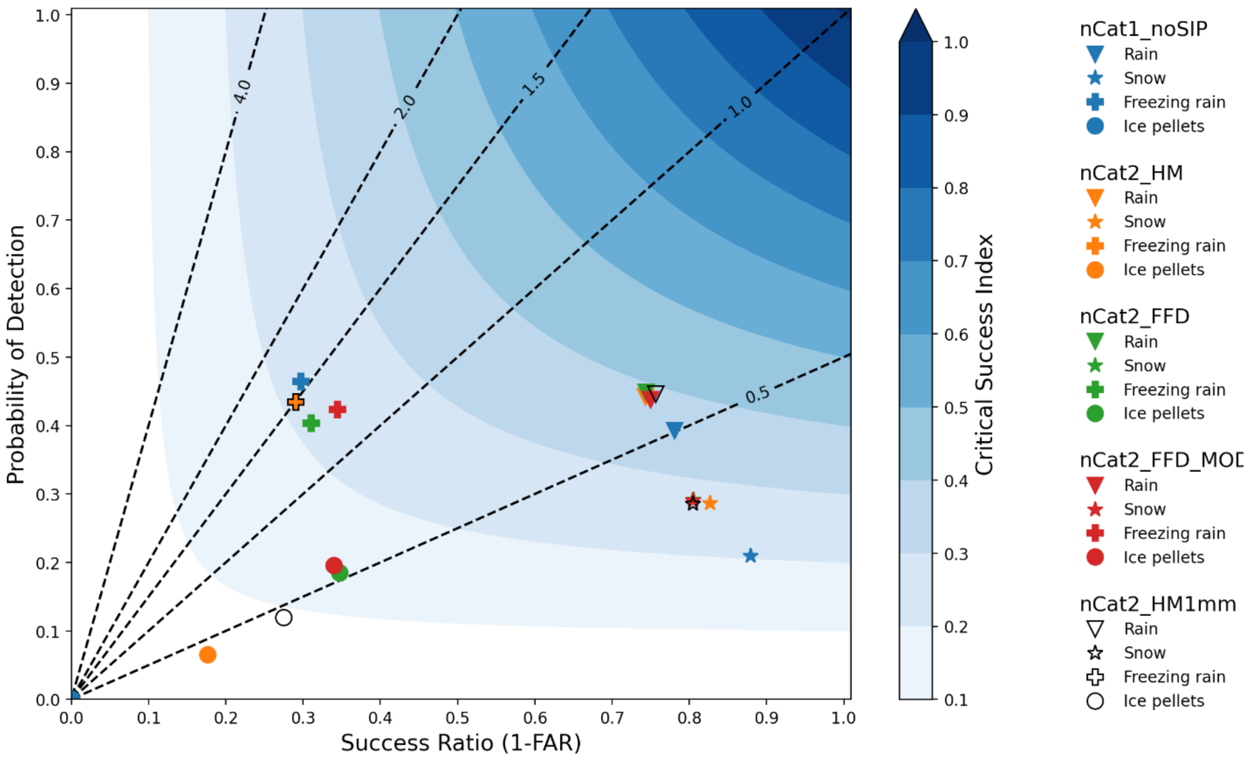


Fig. R2. Same as Fig. R1 but for freezing rain.



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. I'm confused by the Appendices. It's not clear to me why they're included in the paper as appendices. I think Appendix A could be moved into Section 2. I struggled with Appendix B since its first referenced on line 155, before we know anything about the case study or experiments. I think the sensitivity tests in appendix B give some broader context to the results of this paper that merit putting this in the main body of the paper. And, like above, I think the content in Appendix C could just be put in the main part of the paper as well. Both Appendices B and C include good content, but having them as appendices confuses me as a reader. Moving that content into the main body of the paper will strengthen the story line and give greater import to the creative work presented in these parts of the paper.

Thank you for the suggestion. We agree that the appendices could be moved into the main body of the text. However, although they present valuable results, we decided to leave them as appendices because they allow the manuscript to keep a better focus and flow between the Methodology and Results sections.

4. Paragraph starting at line 220: I like the air parcel trajectory approach, but I'd like to know to what degree that trajectory bobs up and down in the vertical. I think a simple way to address this is to add an inset to Fig. 1 that shows a vertical cross section along the trajectory that shows the position of the parcels from each experiment as a function of time/location. That way the reader can assess whether the changes made to the microphysics scheme impact the rate at which the parcels are advected and whether their vertical ascent/descent differs.

Fig. R4 shows the trajectory vertical heights for each experiment (Fig. R4).

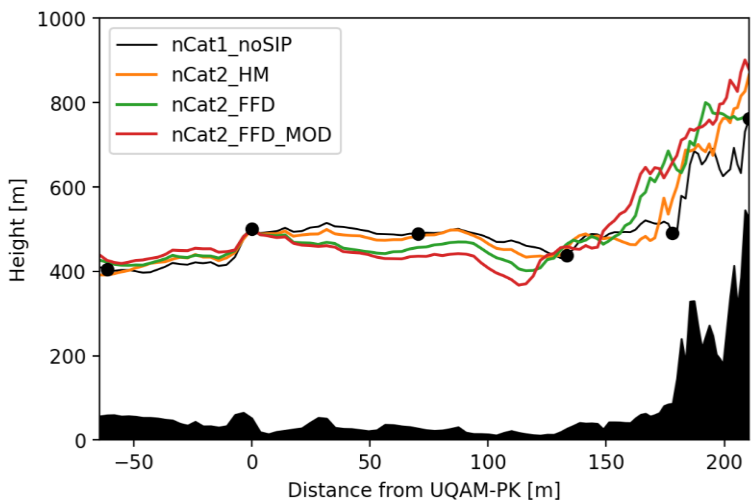


Fig. R4. Simulated trajectories height.

We will add the trajectory vertical height (Fig. R4) in Fig.1 (Fig. R5). Only nCat1_noSIP will be shown in Fig. 1. We think that including additional curves to the figure will bring confusion.

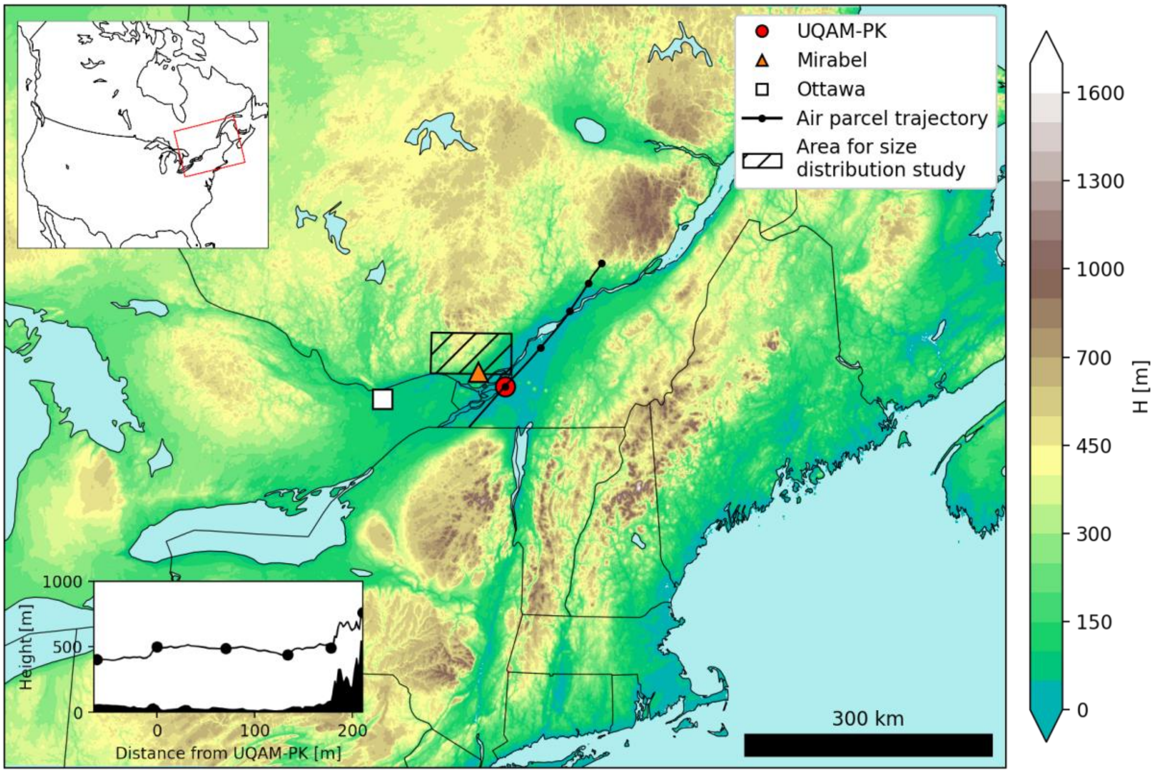


Fig. R5: Revised Fig. 1. The panel in the lower left shows the vertical height of the trajectory for experiment nCat2_noSIP; the trajectories calculated with experiments nCat2_HM, nCat2_FFD, and nCat2_FFD_MOD reached similar results (not shown).

5. I find Figs. 3,4,5 difficult to read. It's a lot of skinny lines and some colors are difficult to distinguish and some of the lines overlay each other enough to make it hard for the reader. I wonder if the authors would consider converting this to a "chicklet plot" for the ptype forecasts. This would be a lot easier for the reader to interpret. It would require putting the rates in a separate panel, but I think it's worth the extra real estate to make a clearer graphic.

We have improved these three plots by making them more compact (Figs. R6-R8 which will become revised Figs. 4-6). Observed precipitation rates for Ottawa will also be added (black dashed line in Fig. R8).

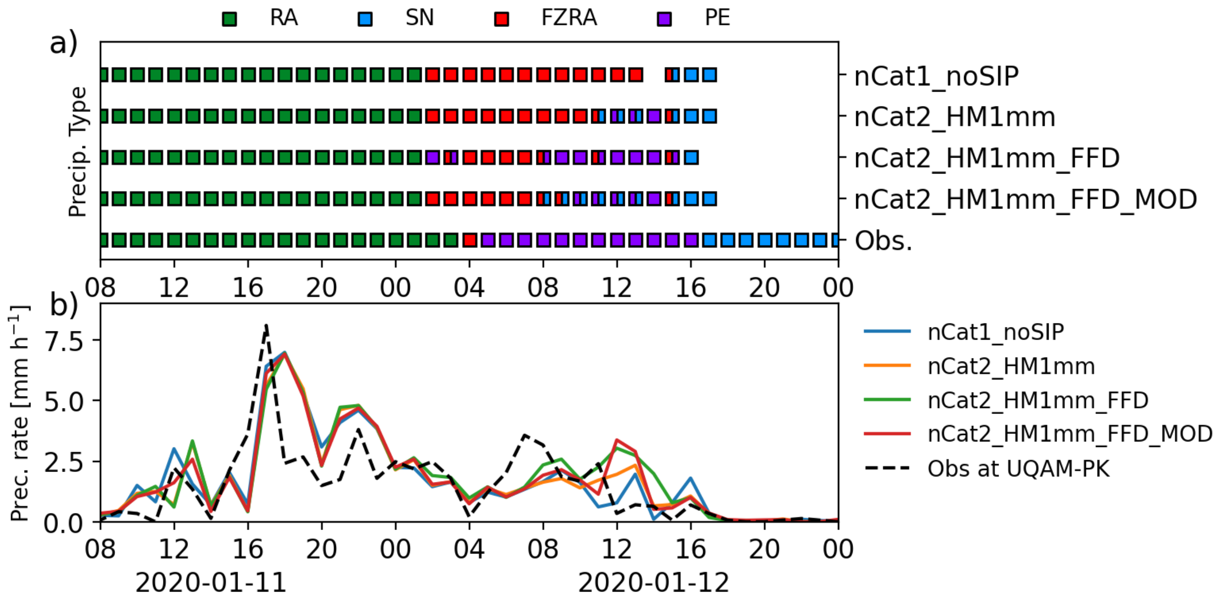


Fig. R6: Revised Fig. 3. (a) Hourly simulated and reported precipitation types at UQAM-PK for nCat1_noSIP, nCat2_HM1mm, nCat2_HM1mm_FFD, and nCat2_HM1mm_FFD_MOD. Precipitation types are rain (green), snow (blue), freezing rain (red), and ice pellets (purple). Note that between 0430 and 1600 UTC 12 January 2020, the macro photography analysis revealed the presence of tiny ice crystals (~ 200 µm) mixed with ice pellets. These were too small to be reported by manual observers. (b) Total precipitation rate simulated and observed at UQAM-PK for the same simulations. The dashed black line shows the precipitation rate measured by a single-Alter Geonor.

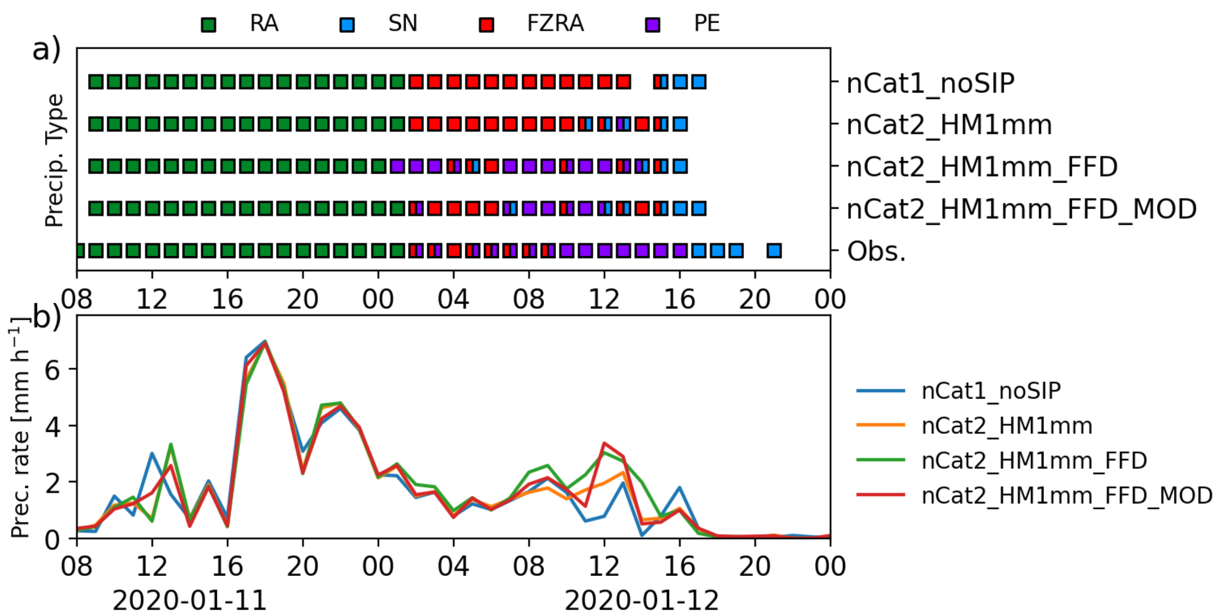


Fig. R7: Revised Fig. 4. Same as Fig. R6 but at Mirabel International Airport. The manual observations were conducted hourly. The measured precipitation rate was not available for this location.

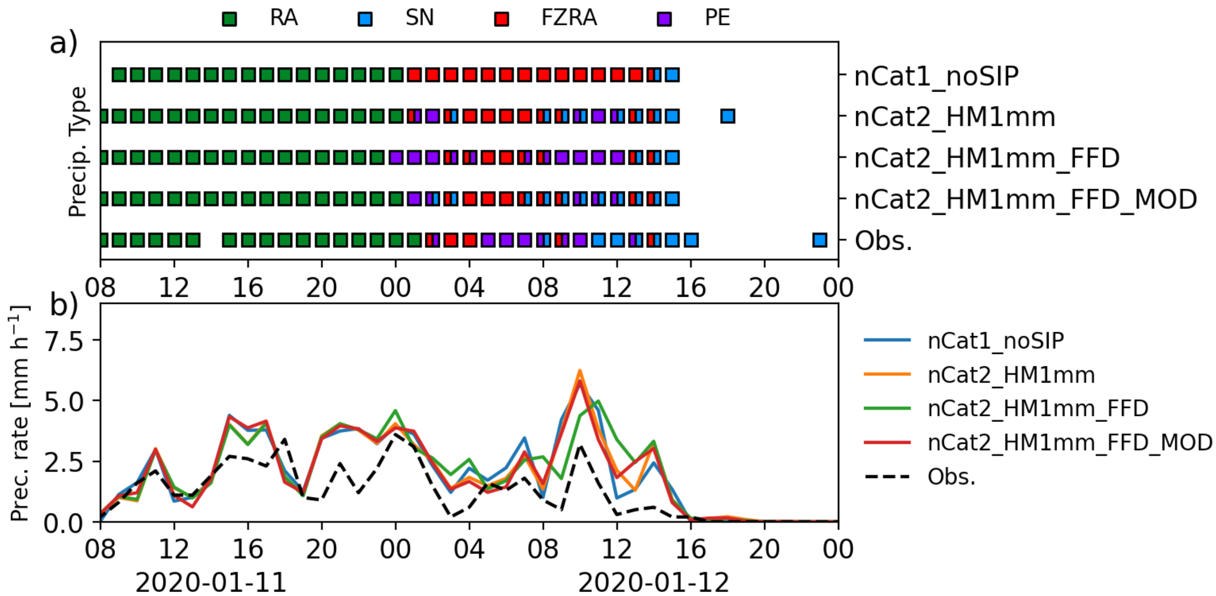


Fig. R8: Revised Fig. 5. Same as Fig. 3 but at Ottawa International Airport. The manual observations were conducted hourly. The precipitation rate was measured by a rain gauge installed at Ottawa airport.

6. It's interesting to me that in Fig. 6 the precip rate varies between the experiments (this is also evident in Figs. 3-5). Can the authors add some thoughts to the paper on why this is?

The following sentences will be added after the second paragraph in section 4.1:

"Adding SIP and other modifications had a non-negligible impact on the simulated precipitation rate because it impacted the particle size distribution and fall velocity. Smaller simulated particles fall at a slower velocity and are advected over longer distances by horizontal wind. In contrast, larger and denser ice particles fall at a higher velocity and reach the surface closer to their point of origin (e.g. Thériault et al. 2012[1]). This behavior suggests that simulating the accurate size distributions would improve the simulated precipitation rate. In section 4.2, we show that the hydrometeor size distributions simulated by nCat2_FFD_MOD were similar to those observed, unlike in the other experiments."

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[1] Julie M. Thériault, Ronald E. Stewart, et William Henson, « Impacts of terminal velocity on the trajectory of winter precipitation types », *Atmospheric Research*, Remote Sensing of Clouds and Aerosols: Techniques and Applications - Atmospheric Research, 116 (15 octobre 2012): 116-29, https://doi.org/10.1016/j.atmosres.2012.03.008.

7. I see there's MMR data that shows the vertical level at which the transition from FZRA to PL occurs (line 291). Out of curiosity, have the authors tried to reproduce synthetic MMR data from the simulation to see if the transition from FZRA to PL in the vertical is accurately handled by the FFD experiments?

Radar reflectivity diagnosed by P3 can be compared with remote sensing observations. Figs. R9 and R10 show the vertical reflectivity measured by the MRR2 installed at UQAM-PK in downtown Montreal, and the quasi-vertical reflectivity measured by Environment and Climate Change Canada scanning S-band radar in Blainville (near Mirabel), compared to the radar reflectivity simulated by nCat2_FFD_MOD.

The quality of the comparisons could be improved if the reflectivity was outputted at a higher temporal frequency. Overall, we see good agreement between the observations and the simulation at both locations, especially at the top of the melting layer. Additionally, the decrease in simulated reflectivity below 500 m between 0800 and 1400 UTC 12 January 2020, which was associated with ice pellet formations, compared well with the observed reflectivity at the CASBV radar (Fig. R10).

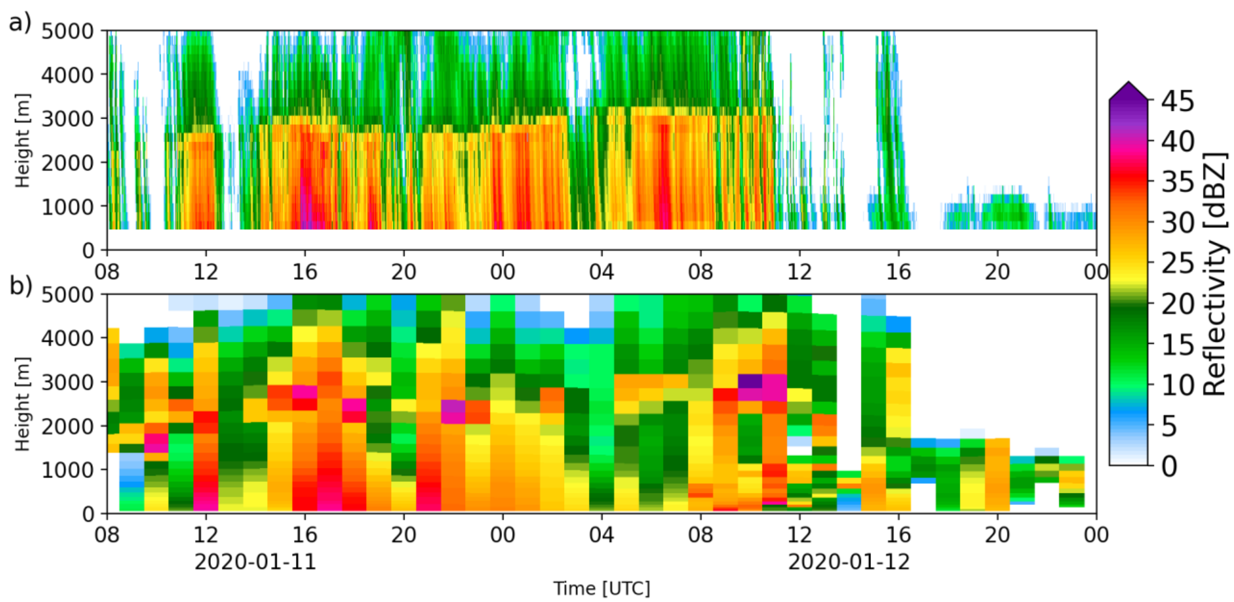

Fig. R9. Comparison between vertical reflectivity measured by UQAM-PK MRR-2 vertically pointing radar and simulated reflectivity extracted from the three-dimensional model at UQAM-PK coordinates.

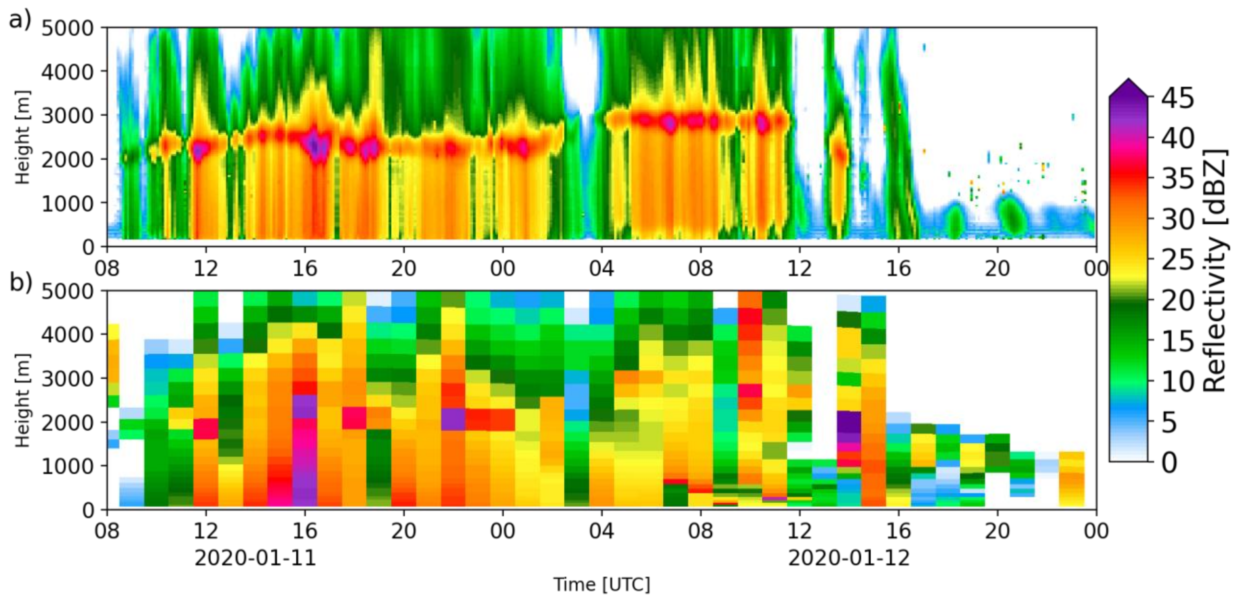

Fig. R10. Comparison between quasi-vertical reflectivity measured by CASBV ECCC scanning radar (near Mirabel) and simulated reflectivity extracted from the three-dimensional model at CASBV coordinates.