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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Initiation of secondary ice production in clouds" *by* Sylvia C. Sullivan et al.

Anonymous Referee #2

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The manuscript investigates the role of three secondary ice production mechanisms (rime splintering, frozen droplet shattering, and breakup), more specifically the evolution of the total ice number concentration depending on secondary ice production, the thermodynamic limitations of the secondary processes and the dependence on the chosen parameterization. The authors found that the evolution of the total ice number concentration is determined by the involvement of two phases and the non-linearity of the collision process. However, in case all processes are active none of them is dominant over the others. They also found that only breakup needs a minimum number of ice nuclei, all other processes are more sensitive to the number of cloud condensation nuclei and thermodynamic conditions. The results are summarized in Fig. 8 where they show in which thermodynamic region and also for which ice nuclei concentration

and rates secondary ice formation if favorable. The manuscript adds some interesting aspects to the question what bridges the gap between ice nuclei and ice crystal measurements.

1 Major comments:

The simulations show some interesting aspects of secondary ice production. However, the interpretation aspect could be stronger emphasized. What do the findings have for consequences in terms of modeling of mixed-phase clouds? How are the results connected to field observations? Do the findings agree with observations? Do the findings make sense in the general context/understanding of the microphysics of a mixed-phase cloud? Which further aspects would need to be investigated?

2 Specific comments:

- page 2, line 23-26: Could you not calculate the number of INP from the nucleation rates?
- page 3, line 4: How do you derive a nucleation rate from the INP concentration given in DeMott et al. 2010?
- page 3, line 4: Why a heaviside function?
- page 3, line 9: How is the connection between DS and $DScoll$? From the description ($DScoll$=collision between large droplet and ice crystals?) it sounds like two different processes. Add more explanation to this point.
- page 3, line 9: Why is it 1% and not 0% outside of the temperature range?

- page 5, line 3-4: Explain that more explicit, example?
- page 7, Eqn. 2: What is the physical concept or idea behind this formula or approach?
- page 9, line 2: Where do I see that in the figure?
- page 9, line 9: Again: where and how do I see that in the figure?
- page 10, line 14-17: What is the reason for these differences?
- Section 3.3: Make it clear what process which paragraph is referring to, it starts with Break up, page 11, line 4 DS...
- page 13, line 10: Please also describe what can be seen in panel (b).
- page 14, line 1: You did not really explain the single versus two-phasedness before? It is an interesting aspect and maybe you could explain that a bit further (here or in the sections before).
- page 14, summary point 1: It could be interesting to illustrate this point in a table or figure. In figure 8 it is not really depicted for each process separately.
- page 14, line 23: What do you mean by emissions? Aerosol emissions?
- page 14: It could be interesting to plot the dominant regions of each process on a 2D-Plot with the vertical velocity and the temperature on the axis.
- page 15, line 13: You could add more references here, e.g. Conen et al. 2011, Steinke et al. 2016.

- Figure 1: Panel (d) is not mentioned/explained in the text. Either remove it or explain it in the text as well.

- Figure 2: Explain in Caption what n=2, n=10 means (is only indirectly explained in the text).
- Figure 3: In the case of $BRth$ and $RSth$: does the same argument yield as in $DSth$ for choosing a velocity of 0.5 instead of the smallest value of 0.1?
- Figure 3: Why are there no meaningful enhancements by breakup if the updraft is larger? Less collisions?
- Figure 4: Why are there no meaningful enhancements by breakup at colder T_0?
- Figure 8: It is a nice summary of the outcome of the paper and can be quite a useful Figure. You could strengthen that a bit more. In the current version of the manuscript is not very prominent.
- Figure 8: What is meant by diminished INP efficiency?
- Figure S1: You could add BR, RS and DS.
- Figure S1: The process rime-splintering is not clearly depicted (how does the ice multiplication happen).

3 Small remarks,typos:

- The INP subscript is not nice to read, reduce the space between the letters or write it non-italic (which is standard for physical subscripts?).
- page 1, line 20: Year missing at citation Ladino et al..
- page 2, line 28: Delete above.

- page 4, line 3: Replace freezing by melting. 272 K is the melting temperature. Freezing normally happens at lower temperatures.
- page 4, line 6: Also F_{DS} and F_{RS}?
- page 4, line 7: The parameters for the functional form are β and γ, if yes add in brackets after "...per shattering droplet"
- page 5, line 13: Remove brackets around citation.
- page 5, line 15: Add "explained in" before Section... .
- page 5, line 25: What does "its magnitude" refer to?
- page 5, line 30: Has to be $N_{ice}^{(max)}$ instead of $N_{INP}^{(max)}$?
- page 7, line 16: Add brackets around the citation "(Paukert et al., 2017)" instead of "Paukert...".
- page 14, line 19: Should or is?
- page 14, line 28: The brackets are strange.
- page 15, line 2: The term "supercooled liquid fraction" might need a sentence of explanation.
- page 16, line 22: This is also a leading coefficient?
- page 17, line 17: D (diameter) is missing in the variable list. Either add it or exchange it here with r.

- Table 1: In the Caption there is a run mentioned denoted INP below, which does not exist in the Table?

- Table 1: Reformulate in the Caption (since thermodynamic simulations is ambiguous, $BRth$ etc. is also a thermodynamic simulation): "Thermodynamic simulations run with ... are shown solely ...".
- Table 1: For the simulations only shown in the Supplement ($BRDSth$...) no Table with conditions of the simulations exists. However, this could be helpful in comparison to Table 1.
- Table 1: Run $DSpp$: What does the D mean in the range of values for F_{DS}?
- Table S1: F_{RS} and F_{DS}: What is frag? fragments?
- Table S1: p_{sh}: What is N?
- Table S1: p_{rf}: What is A?

- Legend Figure 5 (a), (b), (c), Fig. 6 (a) and Fig. 7 (a) needs to be bold to be consistent (matters most in case of Fig. 5).
- Figure 5 a, b, c: It is a bit unlucky that most points are in the blueish range of the color scale. It is quite difficult to differentiate the different color tones of blue.
- Figure 5 and 6 and 7: Is the color scale in the legend the same for the green traces and the yellow traces (also only color of green traces is shown)? Mention in the Caption or add the colors for the yellow traces also to the legend.
- Figure 7: The coloring is only similar to Fig. 1 c.) for the first color of the green and yellow traces? I found this comment a bit confusing and it did not add necessary information, so maybe delete it.
- Figure 8: Are the arrows from one panel to the other needed? What do they symbolize?

- Figure 8: What is s_M? (left panel)
- Figure 8: What is D_v? (left panel)
- Figure S2 Caption: line 1: add on $BRpp$ in the end.
- Figure S2 Caption: line 2: (b) shows the effect of the minimum... function on ... .
- Figure S2 Caption: line 3: ...droplet due to F_{DS}?
- Figure S2 Caption: (d) What is plotted here? Freezing probabilities? Does not fit to the plot.
- Figure S3: Replace um with μm.
- Figure S3 Caption: Add: in dependence of D_R.
- Figure S3 Caption: How is the second sentence connected to this figure?
- Figure S4 Caption: Shift bracket behind "number".
- Figure S7: Difficult to read legend (a).

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