

Review of Schäfer et al. Simulations of primary and secondary ice production during an Arctic mixed-phase cloud case from the NASCENT campaign

Summary: This study is built around a modelling case study from a field campaign that investigated secondary ice production in arctic clouds. The authors ran three types of simulations with WRF with two commonly used microphysics schemes: 1) control experiments with unmodified microphysics, 2) experiments with primary ice production modified to be consistent with observations of ice nucleating particles, and 3) experiments with modified primary ice production and secondary ice production mechanisms added (only one of the two microphysics schemes is used for this). The simulations with secondary ice production are most realistic, but only when rime-splintering is modified to make it activate, as it is needed to kick-off the other secondary ice production mechanisms. The study makes excellent use of new field campaign observation and is an asset to the microphysics modelling community. I have many suggestions for improvement as the study was thought-provoking, and I think that this study will make a great contribution to the literature once these comments have been thoroughly addressed.

Major Comments

- **Run without contact nucleation:** The authors should re-run the simulations with contact nucleation turned off. In sentence 193, the authors say “we use the contact freezing parameterization by Young (1974), as no measurements of INPs in the contact freezing mode were conducted.” This contradicts an earlier sentence on 116, which says “If the concentration of the newly formed ice crystals is larger than the INPC, it can be concluded that SIP was occurring.” In choosing to leave contact nucleation in the simulations, the authors are positing that contact nucleation is occurring in the real atmosphere but is not reflected in the measurements of INPC. Therefore, if there are more ice crystals than measured INPC, it can not in fact be concluded the SIP is occurring; those “extra” ice crystals could have been formed through contact nucleation. It also, in my opinion, contradicts the sentence in lines 137-139 which says that the modification to immersion freezing “permits a correct quantification of heterogeneous cloud particle formation and also ensures than an agreement of the modeled cloud particle concentrations with observations is accomplished through the correct process,” because there is still a heterogeneous nucleation process that has not been constrained in any way with observations. I think keeping contact nucleation active somewhat defeats the purpose of having modified the immersion freezing to be more realistic. Fortunately, there is little evidence for contact nucleation actually occurring in the real atmosphere and, for this reason, it is turned off by default in the P3 scheme, which has otherwise similar ice nucleation as Morr. I think the authors can justify turning it off here and then would be more easily able to make the case that they have constrained the heterogeneous ice nucleation with observations to the best of their ability.
- **Clarify the connection to climate:** The authors show that the changes to the clouds due to the addition of secondary ice production makes the cloud microphysics more realistic, and changes the precipitation, but does not change the instantaneous radiative effect of the cloud. Might there still be a cloud lifetime affect resulting from differences in precipitation? Also, are the cloud macrophysics constrained so much by the nudging that the microphysics isn’t able to affect the cloud macrophysics like it might in the real atmosphere? In particular, nudging to moisture could “bake in” the cloud macrophysics. The authors might consider testing this by running sensitivity simulations with nudging to winds and temperature but not moisture. It is worth mentioning that this finding contradicts that of Young et al. 2019 (<https://doi.org/10.1029/2018GL080551>) and Atlas et al. 2022 (<https://doi.org/10.1029/2021AV000454>) and so it is useful to explore and discuss the different possible reasons for that disagreement.
- **Emphasize the cascade of secondary ice production:** I think the most interesting finding from this study is that you need rime-splintering to “kick off” collisional breakup. I encourage the authors to explain this point in the abstract.
- **Tighten up the writing:** There are many sentences that are unnecessarily verbose. I’ve pointed out a few but not nearly all of them in the minor comments. I recommend that the authors thoroughly edit the writing and remove excess words wherever possible.

Medium Comments

- **Line 107:** Can the authors justify assuming that all particle smaller than 25 microns are liquid?
- **Figure 2:** The information in this figure could be conveyed in a couple of sentences. I think the authors should either remove this figure or make it more informative to justify it being a figure.
- **Discussion of Figure 3:** I think the authors should remind the reader here that the simulations are being nudged to ERA5 reanalysis, to make it clear that this comparison is more of a test of the nudging than of something intrinsic to WRF. Can you mention whether or not these radiosondes are going into the GTS and thus also ERA5?
- **Table 1:** Listing Pasquier et al. (2022a) under deposition freezing is confusing because it represents immersion freezing. I suggest making another column for immersion freezing and listing “off” for MYdef and Pasquier et al. (2022a) for MYadap, and then listing “off” for deposition freezing for MYadap.
- **Discussion of Figure 5:** There is no mention of the simulated droplet concentrations being 2-3 orders of magnitude too small below 500 m, although a low bias in CDNC is mentioned in line 307. I also suggest putting vertical lines on this figure to show the fixed CDNC values used for the morr simulations.
- **Lines 319-322:** This sentence is very unclear and I don’t understand the reasons for the increase in ICNC and IWC in MYadap. Through what nucleation process are these extra ice particles forming? How is both the nucleation and particle growth affected by the changes to CCNC in updrafts?
- **Ordering of discussion/figures:** Figure 9 is first mentioned well after Figure 10 is mentioned so it seems that they should be switched. I also think it might make sense to have all of the discussion of precipitation and radiation (Figure 8) after the discussion of Figures 5-7, perhaps in its own section, so that the reader doesn’t need to go back and forth so much to tie the discussion to the figures. I also didn’t notice Figure 7 being mentioned in the manuscript at all although when I went back to check, I saw it was referenced one time. The authors might considering moving Figure 7 to the appendix.
- **Lines 456-457:** I’m confused about the statement that starts the conclusion section because section 4.2 and 4.3 describe several significant biases in both simulations with default microphysics. What does “reasonably” mean here?

Minor Comments

- **Line 1:** I agree that the fact that clouds play a role in Arctic warming is undisputed, but I think the specific role that they play is disputed. I suggest re-phrasing for clarity.
- **Line 21:** I find the phrasing “...special interest for climate research and particular efforts are made...” to be rather vague
- **Lines 45-46:** Could consider adding Järvinen et al. 2022 (<https://doi.org/10.1029/2021JD036411>) to the reference list
- **Lines 48-51:** There is an additional proposed mechanism described in Knight 2012 (<https://doi.org/10.1175/JAS-D-11-0287.1>)
- **Line 143:** Suggest changing “accomodate” to “account”
- **Line 151:** Suggest changing “whereof” to “of which”
- **Lines 171-175:** The wording “on one hand...on the other hand” implies that there should be a contradiction, which there is not here, so I suggest rephrasing
- **Line 177:** Suggest changing “during” to “when they are”
- **Line 179:** Suggest changing “selected” to “assumed”

- **Lines 183-185:** Suggest changing the two instance of “after” to “from”
- **Line 204:** Suggest changing “predefined to” to “predefined as”
- **Line 237:** Suggest changing “not overcome” to “never exceeded”
- **Line 250:** Suggest rephrasing “we ensure a satisfying model performance” to something like “we test the model’s ability to simulate the observed environment”
- **Line 280:** Suggest rephrasing “it is reassuring to see that” to something like “we show that”
- **Line 297-298:** List the corresponding figure panels just like they are listed in the previous sentence
- **Line 302:** Suggest removing the word “both”
- **Line 303:** Suggest changing “evident” to “evidenced”
- **Figure 5d:** The x-axis tick labels are partially covered by the axis label
- **Line 310:** Suggest changing “little” to “low”
- **Legend of Figure 5:** Suggest removing the word “continues” before “logarithmic”
- **Legend of Figure 8:** Suggest changing “divided in” to “divided into”
- **Line 327:** There are many places in the text where things are stated in an excessively wordy fashion that make the sentences less clear. For example, here, I recommend removing the words “follows” and “now shortly.”
- **Line 352:** Suggest removing the word “formed”
- **Line 362:** Suggest changing to “We expect that the decrease in ICNC from modifying heterogeneous nucleation will be counteracted by increasing secondary ice production in Morr3 following...”
- **Line 365:** Suggest changing “difference” to “differences”
- **Line 380:** I think this should say “SIP processes included in the Morr scheme and those by Sotiropoulou et al. 2001”
- **Line 387-389:** This sentence is very unclear and “overview over” definitely needs to be rephrased
- **Line 408:** Suggest removing the word “between”
- **Line 436:** Suggest changing “anyway” to “still”
- **Line 442-443:** Why is the overestimated precipitation likely due to excessive drizzle? Is it because most of the precipitation in the real atmosphere was observed to be solid?
- **Line 459:** Suggest changing “more numerous” to “overly efficient”
- **Line 481:** Suggest changing “apart from” to “in addition to the” and removing the word “also”
- **Lines 482-483:** The word “changes” appears twice. Also another example of how wordiness can be reduced is by removing “Regarding the cloud’s radiative effect,” at the beginning of the sentence and similar phrases throughout the text.
- **Line 487-488:** Suggest changing “across differences in the microphysical conditions” to “across different microphysical conditions”