

Atmos. Chem. Phys. Discuss., referee comment RC2
<https://doi.org/10.5194/acp-2021-323-RC2>, 2021
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Comment on acp-2021-323

Anonymous Referee #2

Referee comment on "Multi-thermals and high concentrations of secondary ice: A modelling study of convective clouds during the ICE-D campaign" by Zhiqiang Cui et al., Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2021-323-RC2>, 2021

REVIEW of the article "**Multi-thermals and high concentrations of secondary ice: A modelling study of convective clouds during the ICE-D campaign**"

by Cui et al.

This study explores the role of various parameters such as freezing onset temperature of INPs, mineral dust as INP, multi-thermals on secondary ice production in convective clouds observed during the ICE-D campaign. They carried out multiple simulations to investigate these aspects. Based on model simulations they conclude that the higher concentration of INPs with warmer freezing onset temperature may affect the secondary ice formation in these clouds. They also found that multiple thermal plays an important role in determining the secondary ice production in tropical clouds which is an important finding.

Overall, the research work done in the paper will be a valuable contribution in understanding the role of INPs with warmer onset temperatures and multiple thermal on secondary ice processes. However, with the current version authors need to work on a few sections.

I would recommend the manuscript be published after some specific points and minor corrections have been addressed.

Specific comments:

- To increase the readability of the manuscript, I suggest renaming the simulations and use some meaningful names. For example: 'control', 'double-HM', 'early onset1', 'cooper10x', 'early onset1 & cooper10x', 'early onset1 & 100xINP', 'early onset2 & 100xINP', 'Demott', 'early Demott', 'Demott 10xINP', 'multi-thermals' etc. It's hard to follow the results and conclusions with current names.
- One of the major objectives of the paper is to investigate whether multiple thermals in the clouds could explain the observed ice concentration. Therefore, some discussion

about previous studies on the conditions favorable for secondary ice production is expected (e.g. graupel fall velocity, updraft speed, broader drop size distribution, etc). (Reference: Cloud Conditions Favoring Secondary Ice Particle Production in Tropical Maritime Convection, Andrew Heymsfield¹, and Paul Willis). What are the limitations of the current understanding of these processes? How your study is going to explore these uncertainties.

- The default parameterization for primary ice nucleation used in the Morrison scheme is based on Cooper, 1986. The authors need to discuss the ice nucleation modes, supersaturation ranges w.r.t. water and ice for this scheme. It should be clear that which ice nucleation modes are active with the primary ice nucleation. Whether you have changed the onset temperature for only immersion-freezing mode?
- It will be good to have a separate section for the ICE-D Observation (Section 2). The text after line number 91 to 106 from the introduction and current section 2 can be merged in the new section. Include the brief discussion on quality control of ice number concentration from 2DC-data. What is the size range of ice particles from observations mentioned in the paper? Whether the particles smaller than 200 μm were considered? Show that the conditions were favorable in the observed clouds for secondary ice formation. e.g. presence of drop larger than 24 μm size, presence of graupel particles in HM zone, etc in the same section. Figures 12 and 13 and relevant results can be added to this section. It should be clear that the comparison between model-simulated ice particles and observations is for particles of a similar size range.
- Line 88: Authors mentioned previous work by Blyth and Latham (1997) on the role of multi-thermal in HM process. Mention in which aspects your simulations are different than theirs. What are the novel approaches of your study? Does your study agree/disagree with their simulations? How realistic are the simulated thermal in the model? The authors need to add some discussion on this.
- In the conclusions, the authors mentioned that the multiple thermal still cannot reproduce the observed highest concentration of ice particles. There should be more discussion about it. Other secondary ice mechanisms may not be fully absent at temperatures warmer than -10° . Observations indicated the presence of fragments of frozen drops. The parametrization of secondary ice particles from frozen drops by Phillips et al. 2017 indicates that at those warmer temperatures this process might have a considerable contribution to the secondary ice formation.

Minor/technical comments:

Line 76: Cite recent review articles on secondary ice formation e.g. Review of experimental studies of secondary ice production: A Korolev, T Leisner Atmospheric Chemistry and Physics 20 (20), 11767-11797; A new look at the environmental conditions favorable to secondary ice production: A Korolev, I Heckman, M Wolde, AS Ackerman, AM Fridlind, LA Ladino, Atmospheric Chemistry and Physics 20 (3), 1391-1429.

Line 91: Define ICE-D in the text also even if it is defined in the abstract.

Line 94: Rephrase/remove the sentence 'However....'

Line 101: Is FAAM defined earlier?

Line 119: Full stop is missing after ... and aerosol

Line 134: Correct the figure number. It is Figure 1a. Also add the axes titles (Lat, Long) on the plot. Correct the figure numbers in the rest part of the paragraph e.g. line number 135, 138, 141.

Figure 3: Check the legends for 2DC data. Add the axes title in X-axes (Ice particle number concentration). Mention the size range of ice particles considered here.

Figure 4: Add axes titles.

Line 150: Mention the lowest diameter of ice particles considered in estimating their concentrations. Are you considering particles smaller than 200 μm from the observations?

Line 151: Change -6,8 $^{\circ}\text{C}$ to -6.8 $^{\circ}\text{C}$.

Line 163: Add reference for Hallet Mossop process

Line 209: change 14C to -14 $^{\circ}\text{C}$

Line 213: Change the graupe to the graupel

Line 221: Check an empty bracket after velocity

Line 254: Do you mean 'starting freezing temperature'.

Line 255: How do you know the ice particles observed during aircraft observations are only originating from secondary ice processes.

Section 4.3: Be specific about simulations involving changes in freezing efficiency. Mention clearly what are the changes made for this.

Line 266: Correct 'TLXTEN'

Line 394: I think the Morrison microphysics scheme was applied for all the runs. It was modified for other sensitivity tests. Make this point clear in the text.

Line 420: Add some of the challenges in measuring full spectra of INP and CCN.

Figure 2: Check the X-axes title. What is HI? Is it defined in the text? Also, mention the Temperature on the color bar in the box. Also, change the title of X axes to Altitude (above MSL??) (m). Check its position w.r.t plot.

Figure 7: Check the spelling of 'ratio' in the figure title.

Table 1: RLX3X100 is the experiment where you relax the onset temperature in the **ice nuclei number** concentration and not the ice concentration. Similar to RLX2X100.