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Comment on acp-2021-513

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Referee comment on "Model emulation to understand the joint effects of ice-nucleating particles and secondary ice production on deep convective anvil cirrus" by Rachel E. Hawker et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-513-RC2, 2021

Review "Model emulation to understand the joint effects of ice-nucleating particles and secondary ice production on deep convective anvil cirrus" by R. E. Hawker, et al.

This modeling study quantifies the effects of INP number concentration, the temperature dependence of the INP concentration, and the Hallett-Mossop splinter production efficiency on the anvil of an idealized deep convective cloud using a Latin hypercube sampling method and statistical emulation. It is found that anvil ice crystal number concentration (ICNC) is determined predominately by INP number concentration, while anvil ice crystal size is determined predominately by the temperature dependence of ice-nucleating aerosol activity. The slope of temperature dependence of INP concentrations plays a key role for the secondary ice production (SIP) (via Hallett Mossop splinter). Generally, the research topics of INP and SIP effects on anvil properties and convection development are interesting and the results are novel. The manuscript is well-written and clearly to follow although some improvements are needed (see comments). I recommend that the manuscript may be accepted for publication after addressing my comments.

Main comments

- The manuscript is a bit too long. I would suggest that the authors condense some of sections, e.g., by moving the content and figures to the supplementary. For example, section 2.4 regarding the statistical emulation can be simplified by referring to previous studies.
- At times in the manuscript, there are mixed use between INP and dust aerosol, e.g., in section 2.2. To my understanding, INPs are a subset of dust (and other) aerosols that

are capable of nucleating ice. Even at -38°C (the lowest temperature for mixed-phase heterogeneous nucleation), their concentrations are not necessarily the same, although a positive correlation between them is expected.

- This study focuses on three parameters related to ice formation (i.e., INP number concentration, the temperature dependence of the INP concentration, and the Hallett-Mossop splinter production efficiency). It should be noted however, that there are many other uncertain microphysics parameters that can impact anvil cloud properties. In addition, MONC-CASIM is configured to be a two-moment scheme and uses multiple ice categories (cloud ice, graupel, snow) with fixed parameters for bulk physical properties. That can leads to large biases in ice properties, and more physical treatment of ice is now available for a continuous evolution of physical properties (e.g., density) of ice (e.g. Hashino and Tripoli 2007; Morrison and Milbrandt 2015; Jensen al. 2017).

Minor comments

- Line 18: "ice crystal size…". Please add "anvil" before this phrase.
- Line 77: "the occurrence and intensity of convection". Wet removal and dry deposition are two critical processes for dust transport from sources to remote regions. This should be added here.
- Line 99: "Variation in ice nucleation active site densities…" Please explain the reason for the large variation in ice nucleation active site densities.
- Line 122: "non-linear interactions between the two freezing mechanisms". Can you explain what the non-linear interactions are?
- Line 166: "Cloud droplet activation". It is more accurate to say "Cloud droplet nucleation" or "Aerosol activation".
- Lines 176-179: "The INP parameterizations…, but scavenging of INPs is not represented". For "aerosol concentrations within a grid box", are you talking about aerosol concentrations within the cloud droplets since here it is heterogeneous freezing of cloud droplets induced by INPs. "The supercooled droplets are depleted". Are the frozen droplets converted to ice crystals? What is the implication of not considering the wet scavenging of INPs? Will this overestimate the INP effects?
- Line 272: "N_{INP}^{-38}". Should this be N_{INP} not N_{INP}^{-38} in equation (1)?
- Line 279: "N_{INP}^{-38} of 1 cm^{-3}". Should this be dust concentration since Niemand et al. uses dust concentration as input?
- Line 361: "that". Change to "than".
- Line 569: "black". Should be "red" outline.
- Line 606: "Figure 11b" should be "Figure 12b".
- Line 630: "Figure 13a,d,g". here d,g should be e,i?
- Line 690: "10%". Should this be "90%"?
- Line 725: "Fig.15d" should be "Fig.15e", and "Fig.15e" should be "Fig.15d".
- Line 735: "Fig.16a" should be "Fig.16b", and "Fig.16b" should be "Fig.16c".
- Line 744: "Figure 16a" should be "Fig.16b".
- Line 767: "as parameterizations become available". The parameterizations for other SIP processes rather than H-M have been available and implemented in models (e.g., Zhao X., et al., ACP, 2021 among others).
- Line 783: "the INP number concentrations at -38C was fixed to be equal to the coarse

model dust number concentration". Again they should not be equal. INP is a subset of coarse dust even at -38C.

- Line 801: change "ti" to "to".
- Line 896. "Varble et al., 2020" is missing in the reference list.