Response to Referees

Explicit Numerical Simulations of Hailstorm Seeding with a Three–Moment Microphysics Cloud–Resolving Model: A Comparison of Two Operational Methodologies for Hail Suppression

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Dear editor and referees,

We would like to thank the Referees and Editor for the time invested in reading and evaluating the manuscript. We highly appreciate the constructive comments, which have been addressed in detail in the document below. The Referee's comments are shown in blue, while the author's responses are provided in plain text.

Kind regards,

Darko Savić et al.

Response to Referee #1

Dear authors, thank you for answering the reviewers' questions in such detail and with care. Reviewing your manuscript again, I still have several comments that should be resolved before I would reconsider the manuscript for publication.

- Statistical significance: I fully understand that running these simulations with such detailed aerosol and cloud microphysics is costly. Hence, any ensemble approaches are not feasible. Nonetheless, I would like to at least see a statistical significance of the changes upon seeding. Are these changes statistically significant from the domain mean and variance of the CTRL simulation? I believe this is the absolute minimum that needs to be done, such that the results can be interpret in its context. Otherwise, given the chaotic nature of convective systems, these results may well be disproved with an ensemble approach. Here it would also be needed to state in the methods part how this numbers are calculated, e.g., with a cloud mask and then averaging etc. This is currently missing.

We thank the Referee for this constructive suggestion. We previously misunderstood that a statistical evaluation was being requested for ensemble data rather than the data presented in the original manuscript. We fully agree that performing a statistical analysis on the current data is both feasible and crucial for this study.

Accordingly, we compared the data from the seeding experiments (RHSS and AB23) with the CTRL experiment. These new results are presented in Section 3.3 ("Statistical Significance of Seeding Effects"). Within this section, the mean values of mixing ratios and number concentration profiles from the seeding experiments are compared against the CTRL standard deviation range. Furthermore, the Wilcoxon Signed-Rank (WSR) test was used to confirm the

significance of the seeding effect on changes in mean hail diameter and hail kinetic energy flux at the lowest model level. The WSR test was performed on both the spatial fields and the temporal evolution of these metrics. A detailed explanation of the exact statistical methodology has been added to Section 2.4 ("Statistical Evaluation") and Section 3.3.

- Visual presentation of the results: The authors greatly reduced the amount of figures, which is great because it avoids needing to flip through several pages of the manuscript to understand their conclusion points. Several propositions follow here: (1) for the process rates I would increase the lienwidth by more such that it is visible, especially, Figure 8, the grey lines for the processes "Sedimentation" and "Convert small raindrops to cloud droplets" are barely visible. Here I am also wondering if a larger averaging window than 1 min could be applied because this detailed information is not needed on a timescale of 170 min. This would also help with the quite noisy pattern in several of the variables. I also caution the authors again to check the numerical precision they actually can achieve. Figure 17, e.g., is not well readable given the strong noise in "Conversion of graupel to hail" (2) The addition of the vertical lines of the seeding cycles in **all** figures makes them even busier and less reader-friendly. Would it be possible to only have them in the section describing the aerosol microphysics (Figure 4) and omit them in the other figures? A different suggestion would be to have the plotted lines with markers at the time of seeding to represent when the seeding cycle starts. (3) Combine the mass and number figures for each category and aim for having the same family of color for similar processes (this won't be identical of course given processes acting on either mass or number). Currently, the reader always needs to refamiliarize themselves with each figure, because the number of processes (naturally) changes, which is challenging to fully understand the results. Having the mass and number next to each other as two subplots further reduces the number of figures and helps with clarity of arguments because they can be more easily compared. In the same spirit, figures 20 and 21 could also be combined into one. For Figure 7, please adapt the process name for cloud droplet activation from "Nucleation of cloud droplets" to "Activation of cloud droplets"; cloud droplets do not nucleate in our atmosphere. For Figure 18, the contour line for 1 mm h-1 can be removed because this is the mask by which it is filtered by 1 mm h-1 from the CTRL simulation? How does actually the green dashed line emerge if the masking is done?

(1) The linewidths have been increased by a factor of two across all figures depicting microphysical source and sink terms to improve readability, particularly for lighter colors. Regarding the averaging window, while a larger window dampens high-frequency noise, it also smooths out rapid physical responses—such as the sharp ice nucleation peak following AgI seeding. To illustrate this trade-off, we tested a 5-minute averaging window (shown in Figure 1 below). As demonstrated, the 5-minute averaging primarily dampens the already noisy processes, whereas critical short-term signals (e.g., the rapid response in AgI ice nucleation) are no longer clearly visible. Therefore, we have retained the original time resolution to preserve these fast microphysical dynamics while relying on increased line thickness for visual clarity.

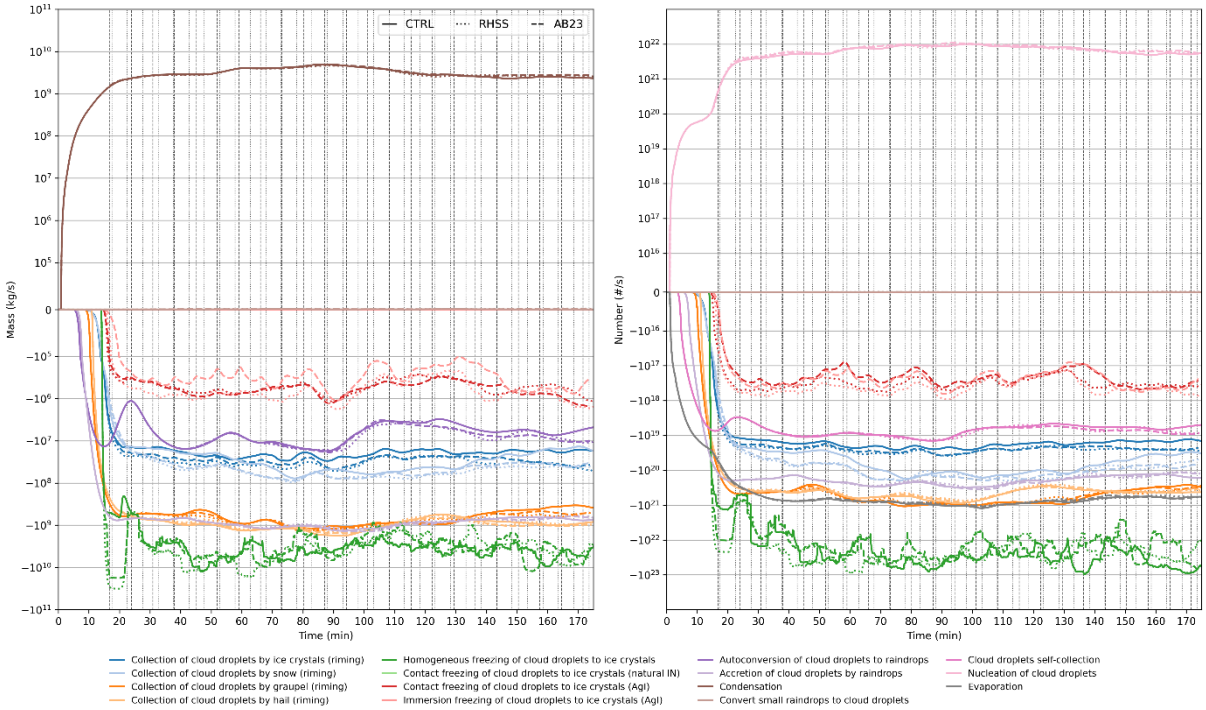


Figure 1. The time series of source/sink terms for the cloud droplet total mass (a) and number (b) in the domain for CTRL (solid), RHSS (dotted) and AB23 (dashed) cases. Different microphysical processes are depicted with different colors indicated in the figure's legend at the bottom. The values of the quantities are averaged over 5 minute.

(2) We agree that the vertical lines corresponding to the seeding cycles add unnecessary visual clutter from Figure 6 onward without providing additional value. Consequently, we have removed these lines from all subsequent figures and retained them exclusively in Figure 4, where aerosol microphysics is explicitly described.

(3) We thank the Referee for these excellent formatting suggestions, which have greatly enhanced the clarity and readability of the manuscript. We have combined the mass and number figures for each microphysical category into side by side, two panel subplots, including merging former Figures 20 and 21. Additionally, we standardized the color scheme so that the same microphysical process retains a consistent color across both panels, making comparisons significantly easier. Regarding process terminology, we updated the name in Figure 7 and throughout the text from "Nucleation of cloud droplets" to "Activation of cloud droplets." Finally, in Figure 18, we removed the redundant 1 mm h^{-1} contour line as suggested. Regarding the green line, it originally appeared because the contour lines were plotted prior to applying the 1 mm h^{-1} precipitation mask used for calculating changes in mean hail diameter.

- Streamlining of discussion and conclusion: I believe the last sections will benefit from streamlining all the points, because now it is evident that it emerged from merging two sections.

We thank the Referee for this comment and have adapted the new section accordingly in the revised version of the manuscript.

- Incorporating of minor comments from reviewers: In several instances comments of minor nature from the reviewers should be incorporated as well, such as the splitting if timesteps, etc.

Of course not all, but it should be done to a larger extent because future readers might have similar questions.

Thank you for the suggestion. This is implemented in the revised version.