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

This study investigates the impacts of two cloud-seeding strategies for hail mitigation using a 3D numerical simulation of a supercell storm, employing advanced three-moment microphysics and mostly explicit aerosol representation. Three simulations are performed: a control experiment without seeding and two experiments in which aerosol particles acting as ice nuclei are introduced to emulate the effects of silver iodide seeding. The authors provide a comprehensive analysis of the resulting changes in hydrometeor mass and numbers, as well as the associated microphysical process rates.

The results indicate that both seeding approaches modify hail characteristics, leading to reductions in hail kinetic energy and the surface area exposed to damaging hail. In contrast, the total hail mass and accumulated hail precipitation remain largely unchanged. These findings suggest that the proposed seeding strategies may reduce the damage potential of hail without substantially suppressing hail production itself. Furthermore, the differences between the two seeding approaches are relatively small, implying that the specific seeding strategy may be less important than the overall introduction of ice-nucleating particles.

The paper provides a detailed and generally well-written analysis of the conducted simulations and addresses the highly relevant topic of weather modification. However, the manuscript is overly long in its current form, and the presentation of the results does not always clearly reflect the main findings of the study. In particular, some statements may overemphasize conclusions that are not directly supported by the analyses presented. I therefore recommend that the following major issues be addressed before the manuscript can be considered for publication.

Major comments

- **Conclusions on hail suppression:** Figures 6 and 20 clearly show that neither the total hail mass nor the accumulated hail precipitation changes substantially between the control and the seeding experiments. Is this outcome consistent with the authors' initial hypotheses and the intended objectives of the respective seeding methodologies? Based on the presented results, the primary effect appears to be a reduction in hail size and hail kinetic energy, which could potentially lessen crop damage, rather than a reduction in the overall amount of

hail produced. This distinction should be emphasized more clearly throughout the manuscript, particularly in the abstract and conclusions. As currently written, some statements may give the impression that hail suppression was achieved, whereas the results suggest a modification of hail characteristics and associated damage potential rather than a decrease in total hail occurrence or mass.

- **Length of the manuscript:** With 23 Figures and a long appendix, the manuscript is quite lengthy. Consider shortening some text and figures. For instance, the difference figures such as Fig,. 19 are hard to read and do not add significant new information. I strongly suggest revising each figure and reevaluating if new information is shown to support the key findings of the paper or which figures are redundant.

- **Effectiveness for hail crop damage reduction:** A key result highlighted in the abstract is that the study "indicates that both strategies effectively reduce hail-induced crop damage." However, the impact on hail-induced crop damage is not directly investigated in this work. Rather, the potential reduction in crop damage is discussed as part of the rationale for selecting and evaluating the cloud-seeding strategies. To avoid giving readers the impression that crop damage was explicitly assessed, the abstract should clarify that this conclusion is inferred from the intended objectives of the seeding strategies rather than from a direct analysis of hail impacts on agriculture.

- **Introduction:** The physical process of how cloud seeding works in the context of hail suppression is not explained clearly. It would be very useful to explain this in the introduction of the paper. In addition, it would be helpful if the authors would state an overall aim and the more specific research questions that are subject of this paper in the introduction.

- **Limitations and implications of this study:** In the context of relevance for policy makers, it seems important to properly indicate the limitations and caveats of this study such that it becomes clear which questions need to be addressed before weather modification technologies like hail suppression can effectively be implemented. I suggest adding a brief discussion of some limitations of this study, including the fact that this study focuses on the effects of a single supercell rather than any effects on a larger surrounding. What could be potential impacts of the analyzed cloud seeding methodologies on weather systems and the environmental air in vicinity to the seeding? Are there potential effects beyond the three hours of the simulation period? How could the results of this study be combined with physical experiments or observational data (e.g. data that related

the listed hail properties more to crop damage)? Would it be feasible to conduct similar experiments for a larger domain at a lower horizontal resolution or is the aerosol scheme too computationally expensive for that and not suitable for lower resolutions (e.g. km-scale)? Can the authors think of any other follow up studies that would make these results more generalizable?

- **Connecting the results with the respective seeding cycles:** I think it would be very useful to **indicate the seeding cycles in all time series figures** to make better sense of how the aerosol mass changes in each hydrometeor class in response to the seeding. Based on the presented results, do the authors think that timing of the seeding would have a large effect? Given that the two methodologies give similar results, I wonder if a main conclusion of this paper is also that the microphysical effects are not too strongly dependent on when and where the seeding is conducted, as so on as it targets the major convective region of the cloud. Would you agree?

Detailed comments

L. 16: Remove “very explicit” because it is a bit subjective and hard to understand what exactly this means. This occurs at multiple locations throughout the manuscript (e.g.”highly explicit”). I suggest being more conservative with those words and instead explain how aerosols are treated and how this is different from more conventional aerosol schemes.

L. 50: To which extent are the risks associated with field experiments also a reason why numerical simulations are used as the primary tool to investigate cloud seeding effects?

L. 62: Can you clarify whether in this study, the cloud seeding strategy that was simulated was aimed at suppressing rainfall or forcing rainfall? In general, it would be useful to contrast these two concepts (precipitation suppression vs. enhancement) in

the introduction and make clear what the difference is in terms of which clouds seeds are chosen.

L. 80-82: It is not entirely clear how the assessment of hail crop damage relates to cloud seeding. Did Ursu et al. (2025) analyze the impact of hail on crop damage or were they also able to investigate the effectiveness of cloud seeding through this method? If so, how?

L. 86-90: I would move this paragraph to the introduction because it still describes the overall scientific challenge that is addressed in this paper.

L. 113: Do you mean that you are conducting a storm-following simulation in which the domain moves along with the storm such that the storm center stays in the center of the domain? Please clarify this and consider moving this sentence after the description of the domain setup, since it appears to be unrelated to the sentences before that focus on the aerosol types rather than on the model domain.

L. 116: When are the large and the small timesteps used respectively? Is the used model a model that uses adaptive timesteps?

L. 121: Please add a reference to the sounding if it is a well-known one. In addition, please clarify if the sounding is an artificial one or if this is a sounding from real observations.

L. 136: Please explain the term "beneficial competition”.

L. 211: Why is a northward movement anomalous?

L. 211-213: I am slightly confused by the identification of the seeding zone. From the method description, it seemed that both cloud seeding methodologies have specified criteria to identify the seeding zone. So why do the authors choose to further restrict this to the main updraft region in the cloud? Or in other words, would the criteria listed in tables 2 and 3 not automatically result in a seeding zone close to the maximum updraft?

L. 224-245 and Fig. 2: Consider moving this paragraph and figure to the method section because this explains the chosen sounding to initiate the supercell rather than presenting results that are relevant for the cloud seeding related science questions.

L. 264: In l. 113, it was indicated that the model domain moves along with the storm. Does the anvil grow so large that it leaves the domain nevertheless?

L. 291: What does this imply? Would a higher aerosol number in the non-precipitating hydrometeor classes mean that one of the methods is more effective because that is what you want to achieve?

L. 305: remove: “due to the large number of figures”

Fig. 6: Water vapor is shown in the figure but not mentioned in the text. Why is the total water vapor of the domain constant throughout time? Should that not vary as hydrometeors form? Also, what is the cyan line: total of all hydrometeors? Why is that line constant when most hydrometeors vary over two orders of magnitude throughout the lifetime of the supercell?