The reviewer's comments are in black, and responses are in blue.

Chen et al. investigates how turbulence modulates the effects of AgI cloud seeding in shallow stratiform clouds over flat terrain. Using LES simulations based on a real seeding event over North China on 20 January 2022, this study creates an artificially enhanced shear layer and finds that increased turbulence enhances AgI dispersion, ice nucleation, and crystal growth, which accelerates faster glaciation. Although stronger turbulence fosters enhanced SLW generation, the rate of ice growth outpaces condensation leading to a rapid depletion of SLW and faster transition to glaciated cloud. Turbulence amplifies short term precipitation directly downwind of seeding, it suppresses further downwind precipitation. This study highlights the delicate balance between turbulent mixing and glaciation in determining the spatial extend and efficiency of cloud seeding impacts. Overall, I felt like the study was well written but could benefit from several clarifications to enhance the study. Therefore, I am recommending major revisions.

Reply: We appreciate your insightful comments. The paper has been revised accordingly and has been improved. Please see our point-by-point response below.

General Comments:

In Fig. 1, the visible and infrared imagery show a clear depression in the cloud top along the flight track. However, it would be beneficial to demonstrate whether this displacement is consistent with the large-scale flow pattern. Specifically, could the flight track be transposed or advected downwind using the wind vectors from the ERA5 reanalysis fields shown in Fig. 1a–b? This would better contextualize the observed cloud top depression and support the attribution of the cloud signature to seeding effects.

Reply: We appreciate your comment. The wind at the seeding height is southwest, as indicated by the wind barb in the pink box in Fig. 1a. Consequently, the seeding trajectory in Fig. 1c presents northeastward displacement over time. The wind speed was about 10 m/s, and the observed depression was about 20 km downwind of the seeding trajectory. Since the observation was about 30 minutes after the seeding, indicating an advection distance of 18 km, it can be concluded that the observed displacement is consistent with the large-scale flow pattern, which facilitates the attribution of cloud signatures to seeding effects.

Similarly, in Fig. 2, the location of the S-band radar relative to the flight track is unclear and should be explicitly marked on a map. The reflectivity evolution shows a clear enhancement along one of the flight legs but not the other—why does the enhanced reflectivity from the eastern leg fade later in time? Was there a difference in cloud properties, wind shear, or moisture that could have contributed to the disparity between the seeded legs?

Reply: We appreciate your comment. The ground-based S-band radar is located north of the flight area. This is added to Fig. 1. The seeding started from the eastern flight leg, resulting in an initial enhancement of radar reflectivity on the east side. Subsequently, this reflectivity gradually diminished as precipitation particles fell. The delayed enhancement of radar reflectivity on the western side is due to the later seeding in the flight leg, while the differences in cloud properties, wind shear, or moisture may also affect the reflectivity intensity of different flight legs, but this cannot be revealed using idealized LES model.

The choice of background aerosol concentration (N_0 = 4000 cm^{-3}) seems quite high for a wintertime stratiform cloud and may not be representative of the conditions aloft over rural North China. Is there observational support for this aerosol profile? Were vertical variations in aerosol concentration considered, and how sensitive are the results to these assumptions? Given that aerosol background can strongly influence microphysical pathways, this deserves more justification or discussion.

Reply: According to previous studies, the aerosol number concentration over the North China Plain in winter typically ranges between 10^3 - 10^4 cm^{-3} (Zhang et al., 2020; Wang et al., 2024). Sorry, we do not have measurements of aerosol concentration for this case. To test the impacts of aerosol concentration on the results, we designed an experiment considering enhanced wind shear, seeding, and natural ice nucleation with a background aerosol concentration of 2000 cm^{-3}. The results show that the modelled radar reflectivity and changes in precipitation induced by seeding have similar magnitudes compared to the case with higher concentrations. The reason is that in this case there is no warm rain process, and the ice particles grew through the vapor diffusion and WBF process, which are mainly controlled by the liquid water content rather than the droplet concentration. For other cases in which the microphysics are sensitive to the droplet concentration, the seeding effect would be different between cases with clean and polluted environments. This is out of the focus of our paper, but it would be interesting to investigate the aerosol impact in the future, this discussion is added in the manuscript in Section 2.2.

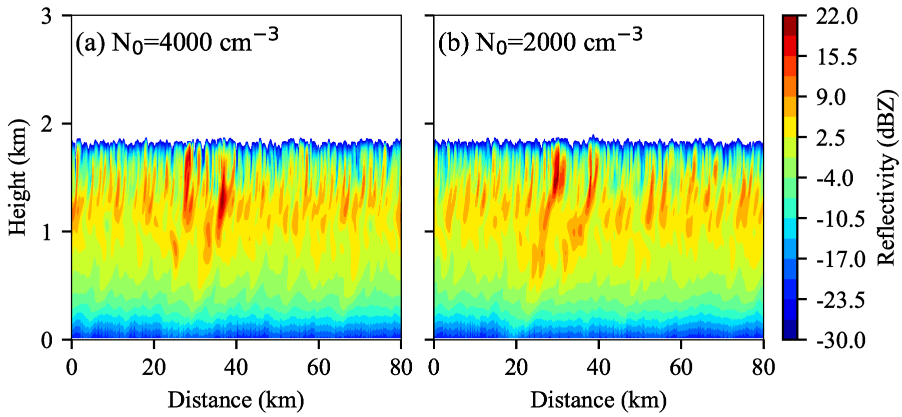

Figure R1. East-west cross-sections of reflectivity from the experiment with (a) N_0 = 4000 cm^{-3}, and (b) N_0 = 2000 cm^{-3} at 03:00 Model Time. Natural ice nucleation and enhanced wind shear are allowed in this case. The cross-sections are selected at y = 20 km.

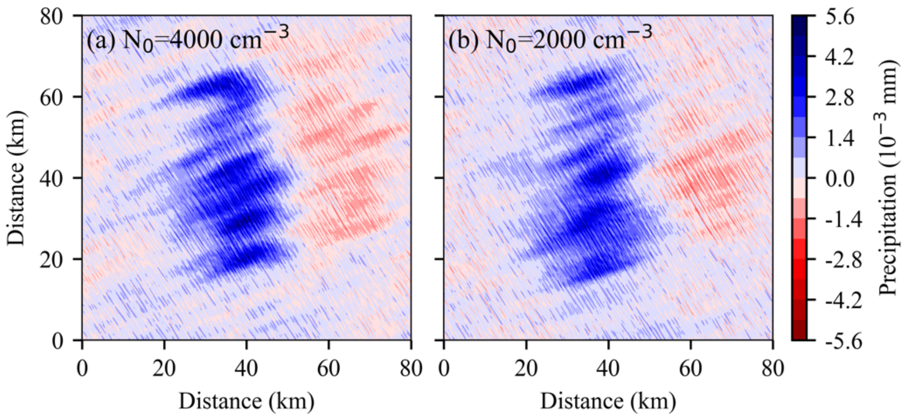

Figure R2. Maps of difference in cumulative precipitation compared to the average natural precipitation from the experiments with enhanced shear for (a) N_0 = 4000 cm^{-3}, and (b) N_0 = 2000 cm^{-3}.

A brief explanation of how cloud was forced and maintained in the model would benefit the reader. While the use of a constant profile and a single sounding is mentioned (Section 2.2), it was not immediately clear how the cloud was maintained within the LES framework, particularly given the absence of evolving large-scale forcing. I found myself needing to read through this section twice to piece together how the cloud structure was sustained. A concise summary early in the model setup section—perhaps explicitly stating the role of the initial liquid water mixing ratio, the static thermodynamic profile, and discussing how cloud was maintained after it was initialized— would improve clarity.

Reply: We appreciate your comment and apologize for the lack of clarity in this explanation. Since this is an idealized LES driven by a single real sounding, it is necessary to artificially introduce the cloud water mixing ratio at the initial time. The cloud layer is located at the height where the water vapor is saturated, and an inversion layer exists above the cloud top. An adiabatic cloud water mixing ratio is used. This allows supercooled liquid water to persist below the inversion, enabling the cloud to be maintained for a long time in the model. This explanation is added to the paper.

The LES is driven by a single sounding with no horizontal heterogeneity or time-evolving large scale forcing. This idealized setup limits realism, especially in terms of representing synoptic evolution and mesoscale variability. How might the results differ if the full 3D ERA5 meteorological fields were used to initialize and force the model? Would the cloud form in a similar vertical structure, and would radar reflectivity fields appear more similar to observations? A brief discussion of this limitation would improve transparency.

Reply: We appreciate your comment. With accurate 3D reanalysis data used to drive the model, the model results may be more consistent with observation. The reason we used idealized LES is that we focused on the impact of turbulence on the seeding effect. We hope the dynamics that influence liquid water formation and cloud glaciation are only driven by turbulence, so the conclusions would not be contaminated by any influence from larger-scale dynamics. If turbulence is imposed on a larger-scale dynamic forcing, it may have different impacts on cloud microphysics such as enhancing the riming and aggregation processes, which may in turn result in a different impact on the seeding effect.

One of the more confusing aspects of the paper is the comparison setup (especially compared to other seeding studies). The so-called "Control" simulation includes AgI seeding, but there is no true baseline simulation without any seeding. This makes it difficult to isolate the seeding effect, especially since fall streaks and reflectivity enhancements appear in the Control run, which undermines the attribution of microphysical or dynamical responses to seeding. Including a no seeding case—or clearly differentiating it from the "Control"—would clarify the results and interpretation. I think running a true control and comparing it to the observations and other simulations would add a lot of value to the manuscript.

Reply: We appreciate your comment and apologize for the lack of clarity in the comparison setup. In this study, the field measurement had seeding performed, and we primarily focused on the impact of turbulence on the cloud seeding effect, so we didn't consider the simulation without any seeding. Since the seeding signature is unambiguous, analysis between SEED and NOSEED areas inherently provides the necessary contrast between seeding and no seeding simulations. To address your comments, we have renamed all the experiments. The revised names will facilitate the comparison between different experiments and clarify the results. The modified table of the experiment design is presented below, with related revisions added throughout the paper:

Table 1. Design of numerical experiments.

Experiments	Natural ice nucleation	Enhanced wind shear	Enhanced AgI concentration
Control	No	No	No
NI	Yes	No	No
NI_WS	Yes	Yes	No
NI_AgI	Yes	No	Yes
NI_AgI_WS	Yes	Yes	Yes

The simulations use only a one-hour spin-up period before seeding is introduced at 2:00 MT. However, at 2:30 MT (the first output shown in Fig. 7), the cloud field and reflectivity structure still appear immature. For instance, in all simulations including the Control, reflectivity increases dramatically in later time steps. This raises the possibility that early reflectivity enhancements are a spin-up artifact rather than a response to seeding. A longer spin-up or justification for the current choice is needed, particularly since the cloud system being simulated is shallow and sensitive to small thermodynamic changes. Also, in Fig. 7, the radar reflectivity differences between SEED and NOSEED areas are subtle, especially in the early time steps. The seeding signature is difficult to identify without annotations or overlays. Annotating the plots to highlight the SEED plume location, expected signal from seeding, and NOSEED comparison regions would make the figures much more interpretable. As it stands, the reader must infer these spatial relationships without guidance.

Reply: We appreciate your comment and apologize for the misunderstanding caused by this description. The statement that "a spin-up time of at least 1 hour is needed" is because noticeable differences between the default and enhanced wind shear experiments in Fig. 7 begin to appear after 1 hour. In fact, we implemented a two-hour spin-up period to ensure the sufficient development of the cloud. This is now clarified in the revised paper. To highlight the SEED areas, we added two arrows pointing to the plumes in Fig. 7a.

While the discussion offers some thoughts on generalizability, the study's findings are drawn from a highly specific case: a shallow, capped stratiform cloud in a quiescent wintertime environment. The conclusions regarding turbulence-enhanced glaciation and the transition from positive to negative seeding effects may not extend to deeper, more dynamic clouds. A more tempered framing of the conclusions, emphasizing the case-specific nature of the results, would strengthen the overall presentation.

Reply: We appreciate your comment. The conclusions have been revised accordingly, with particular emphasis on the case-specific limitations of the results.

"For shallow, capped stratiform clouds in a quiescent wintertime environment, stronger turbulence can accelerate the seeding effect by enhancing AgI particle dispersion, ice nucleation, and ice growth through the WBF process, resulting in faster consumption of LWC and cloud glaciation in the SEED area, even though stronger turbulence also enhances the liquid water formation."

"It is the competition among liquid condensation, mixing, and cloud glaciation that determines the downwind effect of glaciogenic cloud seeding. For the shallow cloud presented in this paper, neither the liquid condensation nor the turbulent mixing can overcome the cloud glaciation intensification by turbulence."

"This study is based on case analysis with limitations. To further understand the role

of turbulence in natural and seeded clouds under different conditions, more observational and modelling studies are needed in the future."

Specific Comments:

Line 103 – "...brightness temperature increased by about 2 °C..." Is this value within the noise level of the satellite product? What's the uncertainty?

Reply: The uncertainty of brightness temperature measurement is within 1 °C (Geng et al., 2020).

Geng, X., Min, J., Yang, C., et al. 2020. Analysis of FY-4A AGRI Radiance Data Bias Characteristics and a Correction Experiment. Chinese Journal of Atmospheric Sciences (in Chinese), 44(4): 679−694. doi:10.3878/j.issn.1006-9895.1907.18254

Line 116 – "...radar echo appeared about ten minutes after seeding..." Is this consistent with modeled ice nucleation onset time? If not, why not? Feel like this was not discussed later in the text.

Reply: In observation, it takes about 10 minutes for the ice to grow big enough to be detected by radar. In the model, ice nucleation started at 02:00 MT (Model Time), and it also took about 10 ten minutes to see the radar signature (as shown in Fig. R3 below). So the model is consistent with observation.

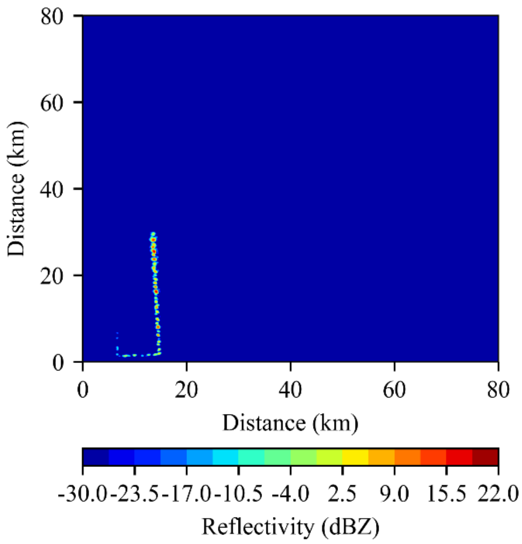

Figure R3. Map of composite reflectivity from Control experiment at 02:10 Model Time.

Line 135: "...periodic lateral boundaries..." Could periodic boundaries introduce artifacts in this stratiform cloud case?

Reply: This study employs an idealized LES to simulate stratiform clouds, which do not consider large-scale forcing effects. The physical quantities within the model domain maintain horizontally homogeneous distributions. Under this condition, the periodic boundary will replicate this homogeneity without introducing artifacts.

Line 158 – "A single sounding is used to drive the model…" Can the authors clarify when and where the sounding was launched relative to the seeding flight track and time? Was it an operational sounding, and how representative is it of the cloud environment during the seeding event? Spatial and temporal offsets could influence the initial conditions and evolution of the simulated cloud.

Reply: The sounding was launched at the Luancheng station (which is located in the research area shown in Fig. 1) at 00:00 UTC on 20 Jan 2022. We added the relative humidity to the profiles. It is seen that the sounding well captures the saturated cloud layer and the inversion above it. Since the station is in the research area, the impact of spatial offsets would be small.

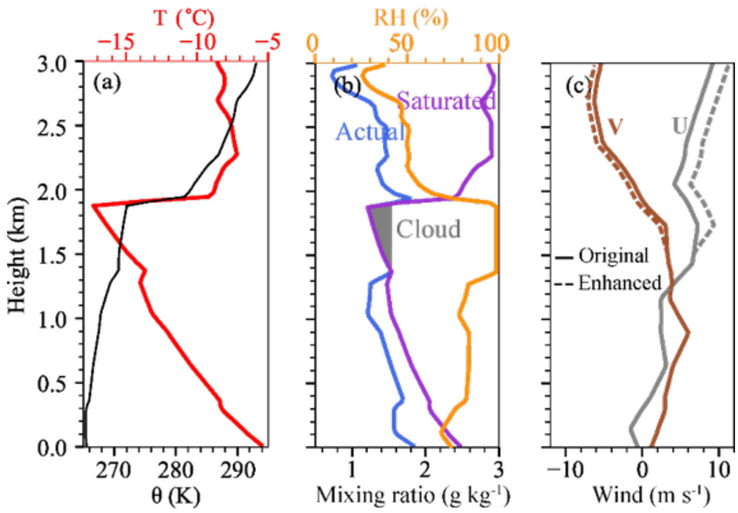

Figure R4. The initial vertical profiles of (a) temperature and potential temperature, (b) actual vapor mixing ratio, saturation vapor mixing ratio relative to water and relative humidity, and (c) original and enhanced U and V components. The grey shaded area in (b) indicates the initial liquid water mixing ratio.

Line 164: "...Richardson number...from 16.81 to 0.67..." This is a large reduction. Can you show whether turbulence actually became dynamically unstable (e.g., Ri < 0.25)?

Reply: The bulk Richardson number was never smaller than 0.25 in this study. In general, Ri < 0.25 indicates dynamic instability, but turbulence can also be triggered for 0.25 < Ri < 1 (e.g., Galperin et al., 2007), Ri > 1 indicates laminar flow. In this study, Ri was decreased to 1/25 of its original value (from 16.81 to 0.67) at the height of 1519–1733 m, when the wind shear was enhanced by five times, indicating favorable conditions for turbulence development, but not enough to achieve dynamic instability.

Galperin, B. et al., On the critical Richardson number in stably stratified turbulence. Atmos. Sci. Lett., 2007, 8, 65-69.

Line 265: "...IWC up to 0.06 g/kg..." How does this compare with in-situ observations from similar seeded clouds?

Reply: We apologize that there are no in-situ measurements of IWC for this case. However, the magnitudes of radar reflectivity are similar between the model and observation, and there is a positive relationship between IWC and radar reflectivity based on many previous studies.

Line 286: "...generation of liquid water was significantly slower..." Can this be quantified more directly using a rate ratio (e.g., production/consumption)?

Reply: In the model, the liquid water condensation rate is calculated based on mass change per unit time. A negative condensation rate indicates that the consumption of liquid water exceeds production. The statement that "the generation of liquid water was significantly slower than its consumption by ice growth" refers to the condition with weaker turbulence. As shown in Fig. 9c, enhanced turbulence results in a notably decreased condensation rate, indicating an accelerated consumption rate.

Line 311: "...cumulative precipitation decreased after 4:40 MT..." What was the baseline precipitation without seeding during this period?

Reply: Under default wind shear condition, the cumulative precipitation in the NOSEED area was 3.61×10^{-3} mm, 4.04×10^{-3} mm, and 4.48×10^{-3} mm at 04:40 MT, 04:50 MT, and 05:00 MT. With default AgI amount and wind shear, the differences in cumulative precipitation between SEED and NOSEED areas remained small after 04:40 MT.