

Response to the Comments of Referees

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Title: Relative roles of aerosol size and hygroscopicity in modulating cloud responses under varying environments

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We thank the reviewers and editor for providing helpful comments to improve the manuscript. We have revised the manuscript according to the comments and suggestions of the referees.

The referee's comments are reproduced (black) along with our replies (blue). All the authors have read the revised manuscript and agreed with the submission in its revised form.

Anonymous Referee #1

The authors have addressed my comments satisfactorily. The revisions to the title, abstract, and model description resolve the main points I raised, and the remaining items (figure readability and captions) are minor and can be finalized during revision. I recommend the manuscript for acceptance.

We sincerely thank the reviewer for the thoughtful and constructive comments, which have substantially improved the quality of our manuscript. Regarding the figures, we have carefully reviewed all figures and revised the figure captions throughout the manuscript to make the content of each figure clearer and easier to interpret.

Anonymous Referee #2

Relative roles of aerosol size and hygroscopicity in modulating cloud responses under varying environments

Line 15-18, I wonder if the increase of aerosol size and/or hygroscopicity cause occurrence of precipitation and then reduce cloud water, while the effect could depend on the status of initial cloud/environment status.

Indeed, the variations in aerosol properties lead to alterations in precipitation and cloud water. Our experiments are designed to simulate the impacts of varying aerosol properties while maintaining consistent initial conditions. We acknowledge that the specific effects of aerosol properties can differ depending on the initial state. Therefore, by presenting a quantitative analysis based on a relatively typical case, this study offers a valuable reference for related research. Together with analyses of other cases in future studies, our findings will contribute to building a comprehensive understanding of the impacts of aerosol properties.

Line 26-27, I would suggest adding some recent review studies as supporting references.

Thank you for the suggestion. We have added citations to two relevant reviews published within the

past five years at this point (line 29 of the revised manuscript): Zhao et al., 2023 (<https://doi.org/10.1016/j.atmosres.2023.106899>); Zhao et al., 2025a (<https://doi.org/10.3878/j.issn.1006-9895.2503.25015>).

Line 34-36, In addition to these early studies, recent studies should be briefly mentioned, such as Niu et al. (2026, doi: 10.1007/s11430-025-1794-7) and Li et al. (2025, doi: 10.1029/2024JD042649) for impact of meteorological conditions, Zhao et al. (2025, doi: 10.1007/s00376-024-4165-z) and Liang et al. (2026, doi: 10.1029/2025JD045635) and for aerosol properties. Particularly, the latter study is also for roles of aerosol size, and the authors may discuss the same or different findings between them.

Thank you for pointing out these references. They have now been cited in Lines 37-39. Additionally, in the second paragraph of the conclusions, we discussed how our findings, in conjunction with these cutting-edge studies, elucidate the influence of aerosol size on clouds via the modulation of microphysics. We also detailed the differences between our approach (focusing on varying conditions over the ECO region) and the cited studies (focusing on land-sea differences).

Line 59, Personally, I wonder if the supersaturation is high over the Arctic. Please help explain, thanks.

Our intention was to emphasize that high supersaturation conditions frequently occur in the clean Arctic environment, as described by Bulatovic et al. (2021; <https://doi.org/10.5194/acp-21-3871-2021>, 2021), who noted that "the ss frequently reaches 0.5% and sometimes even exceeds 1%." To express this more clearly and accurately, we have revised the text in the manuscript to read: "in the pristine Arctic region where supersaturation frequently exceeds 0.5%."

Line 65, "show" should be "showed"?

Corrected.

Figure 1, the location of EC is not highlighted as ECO?

In this study, a nested simulation is conducted with the ECO region as the inner domain. As shown in Fig. 1, in addition to the text label, a red box outlines the extent of this inner domain, representing the specific coverage of the ECO region. Meanwhile, the EC, being part of the outer domain, is indicated solely by a text label to show its reference position.

Line 153-155, What do the authors mean for "NCEP et al., 2015", "NCEP et al., 2014" and "Satellite Services Division et al., 2004"?

These data source citations were initially added in accordance with the journal's requirements. We have now removed the citation information from this section and retained it exclusively in the Data availability section of the manuscript.

Line 208-209, There are some of most recent studies regarding the importance of aerosol size, which are worthy to mention and compare.

We have added a discussion on recent studies regarding the impacts of aerosol size, as well as the similarities and differences between our study and these works: 'Several studies have utilized land-sea

contrasts to illustrate how aerosol size modulates microphysical processes to affect clouds and their radiative effects (Liang et al., 2026; Zhao et al., 2025c). In parallel to these efforts, our study also investigates the microphysically driven impacts of aerosol size. By focusing on the ECO region and examining a case characterized by abundant variations in meteorology, aerosols, and clouds, we quantitatively resolve the effects of aerosol size and their environmental dependence by comparing SIZE_LARGE and SIZE_SMALL to the Control run'.

Figure 3 caption, meanings for each panel should be given.

Because the caption for Figure 3 is already quite lengthy (exceeding 110 words), to avoid a cumbersome reading experience, we have indicated the meanings for each panel through text labels on the left and top of the figure. Additionally, we have added the phrases "column-mean N_a and N_d ", "mean CER", and "averaged over the simulation period" to the Figure 3 caption to further clarify the content of the figure.

Line 281-283, the definition of clouds here uses different threshold values from many previous studies, an explanation or sensitivity analysis should be given to indicate the reliability.

To prevent the numerous low-CLWC and low- N_d samples with high uncertainties in the model output from biasing the averaged results and the represented aerosol-cloud relationships, this study adopts the screening criteria from Jia et al. (2019): "Only the clouds with $LWC > 0.05 \text{ g m}^{-3}$ and $N_d > 15 \text{ cm}^{-3}$ are selected for analysis". Building upon this, to analyze how different cloud parts respond to aerosol property changes, we further restricted our analysis to clouds present in three or more continuous vertical model layers.

Line 302-304, For low to medium N_a conditions, N_d increase of up to 2000 cm^{-3} seems too large to me, while it is somehow possible for extreme cases.

Indeed, the condition where the increase in N_d exceeds 2000 cm^{-3} is extreme and only occurs within a single cloud layer (the in-cloud mean or column-mean values are typically much smaller). Our original intention was to provide supplementary quantitative details, but we agree that this phrasing might be misleading. Given that we have already provided quantitative information in Figs. 9 and 10 to complement the 3D spatial plots, we have removed the phrase 'up to 2000 cm^{-3} ' from this section to avoid any confusion.