Response to Reviewer Comment

Dear Editors and Reviewers,

Firstly, we would like to express our sincere gratitude for the time and effort you spent reviewing our manuscript titled "[WRF-SBM Numerical Simulation of Aerosol Effects on Stratiform Warm Clouds in Jiangxi, China]" and for providing valuable feedback. We have carefully considered all the comments from the reviewers and have made comprehensive revisions to our manuscript. We believe these revisions significantly improve the quality of our paper. In the following sections, we will respond to each of the reviewers' comments in detail, explaining how we have addressed these issues in the revised manuscript.

For ease of reference for both the reviewers and editors, we have organized our responses according to the comments of each reviewer, detailing our reply, and have indicated the locations of the changes in the corresponding sections of the paper.

Here are our point-by-point responses to the reviewers' comments:

Response to Reviewer Comment 1

Minor comments:

Reviewer's comment 1: The abstract does not describe which were all the variations performed: how many cases? It also does not specify what is the simulation / observation length of the case study.

Response: Thank you for your suggestion! In the original abstract, we lacked descriptions of the experiments and case studies. In the latest revision, we have added information about the case study and the simulation duration to the abstract. The revision is as follows:

"This study uses a bin microphysics scheme (WRF-SBM) to simulate a warm stratiform cloud process in Jiangxi, China, from 18:00 on December 24, 2014, to 06:00 (UTC) on December 25, 2014. Satellite observation and aircraft observation data of the same period were used to validate the simulation results, and it is shown that the numerical simulation predicted the macro and microstructure of the cloud process well.

Further sensitivity experiments were conducted by increasing the concentrations of nucleation, accumulation, and coarse-mode aerosols, as well as the total aerosol concentration, to five times those of the control experiment."

Details can be found in lines 10-15.

Reviewer's comment 2: There are flight measurements that are not consistently mentioned in the text. Please include them early to not surprise the reader.

Response: Thank you for your suggestion! In Section 2.5, we have included descriptions of the aircraft observation data and the satellite observation data, providing an introduction and summary of the observational data used.

Reviewer's comment 3: How representative is the chosen case study? I understand that is great to compare a case for which there are observations available but it'd be great to know if this case is typical for that or other regions, or not.

Response: Thank you for your suggestion and question! The simulation is focused on the warm cloud process over Ganzhou, Jiangxi Province, China, located in the southeastern part of Jiangxi Province in the East China region. This area is a transition zone extending from the southeast coastal area to the inland, mainly characterized by mountains, hills, and basins. It is situated on the southern edge of the mid-subtropical zone and belongs to the subtropical monsoon climate zone.

In this study, we simulate the warm cloud process over Ganzhou on December 25, 2014. During the simulation period, the 500 hPa level was influenced by the southwesterly airflow ahead of an upper-level trough, and the 850 hPa level exhibited a convergent wind field. Meanwhile, the southern branch trough brought good moisture transport, which is typical of the common weather pattern in this region.

In fact, the aircraft observation data used in this study is one of seven consecutive observations from November 6 to December 25, 2014. During these seven observations, the cloud layers were mainly concentrated at altitudes of 2000-4500 m. According to the observational data, the maximum horizontal extent of the detected cloud areas exceeded 50 km, and all were classified as stratiform warm clouds. Therefore, the warm cloud process simulated on December 25, 2014, is representative of the common stratiform warm clouds in this region.

Before conducting the sensitivity experiments, we simulated all seven warm cloud processes in Jiangxi. After comparing the satellite-observed cloud top temperatures and the aircraft-observed cloud droplet spectra, we selected the December 25, 2014 process, which had the best simulation results, for the sensitivity experiments. Therefore, we believe that the simulated warm cloud process on December 25, 2014, can to some extent represent the common stratiform warm cloud processes in this region. In future work, we will also conduct more research and focus on the warm cloud processes in this region to compare the similarities and differences and assess the representativeness of this process.

Reviewer's comment 4: The first results of the simulations, where the cloud development is described, is not very thorough. First, some increasing/decreasing trends that are mentioned do not match the presented figures. Then, the magnitude of two of the properties are not so close when compared to the flight measurements, and there is no mention of that. Finally, the vertical resolution of the vertical-time plots is quite coarse, so the conclusions regarding cloud growth should be described carefully. In this sense, a more critical description, acknowledging the possible shortcomings of the chosen vertical resolution on cloud development could be included. Was there any way to validate cloud thickness for the reference case?

Response: Thank you for your suggestion! Previously, the images in our analysis focused only on hourly average results. In the revised analysis, we have considered the changes in cloud microphysical quantities at each time step and supplemented and improved the analysis content, which can be seen in Section 3 of the article.

In the previous comparison of aircraft observation results and simulation results, we used the average results of the aircraft observation data and all regions within the flight range during the observation period. In the newly revised paper, we selected a relatively complete cloud penetration process from the aircraft observations and compared it with the simulation results at the same time, height, and longitude and latitude, thereby verifying the simulation's accuracy.

Regarding height resolution, we have provided distributions of microphysical quantities at each height layer in the new article. As you mentioned, the simulation results have limitations in vertical resolution. Due to computational power constraints, we acknowledged this issue in the conclusion, specifically in lines 432-441.

Reviewer's comment 5: For the main figures of the study (Figs. 11-13), we do not know what the data points represent. Are they combining all the data, at all times, for all the domain? Please specify. If this analysis were categorized, would it be helpful for exploring different processes?

Response: Thank you for your suggestion! Previously, we did not clearly describe what the data points in Figures 11-13 specifically represent. In fact, they depict the distribution and correlation of the relative dispersion of cloud droplet spectra with Rv, Nc, and other cloud microphysical quantities within the cloud area during the analysis period from 00:00 to 05:00. In the latest revision, we have detailed the meaning of the data points in the images at the beginning of Sections 3.3.2 and 3.3.3.

Reviewer's comment 6: The two sections of results; first the time/height description, and then the aerosol statistics trends, seem a bit disconnected. For example, when aerosol statistics were analyzed by height in the first part, then that dimension was not mentioned again in the trend analysis. If the first part is not as important as the second, maybe the text could be simplified in order to be brief and to the point.

Response: Thank you for your suggestion. We also noticed the disconnect between the first and second parts of the article. The focus of the article is more on the relationship between the cloud droplet spectrum, the relative dispersion of the cloud droplet spectrum, and cloud microphysical quantities as discussed in the second part. Therefore, we have removed the analysis of the cloud droplet spectrum distribution across different altitude intervals and simplified the analysis content of the first part to highlight the focus of the second part. We now concentrate more on the overall distribution of the cloud droplet spectrum within the cloud area as it evolves, and on how the relative dispersion of the cloud droplet spectrum changes with increasing droplet size during cloud development, as well as the microphysical mechanisms influencing this process.

Reviewer's comment 7: The A1, B1, etc... notation in the figures is highly confusing since it makes the reader look at the caption very carefully every time instead of making good use of the plot labels/titles. I'd suggest replacing A1, B1 by the name of the case or the configuration shown in each subfigure.

Response: Thank you for your suggestion! The labels such as A1, A2, etc., were indeed too vague and made it difficult to interpret the results. We have revised the figure titles and labels. In the analysis of microphysical quantities, we have set the subfigure titles and labels corresponding to each experiment group to be the experiment names themselves, such as NM, AM, etc.

Line by line comments

Reviewer's comment 1: L50 Are these modeling studies?

Response: Thank you for your question! We realized that the description of the content of the referenced studies was not detailed enough. In fact, they include both numerical simulations and observational studies. The latest revision is as follows, specifically in line 50:

Many researchers have conducted causal analyses on the uncertainty of the effect of cloud microphysical properties on ε. The results indicate that the variability of ε is influenced by various factors, such as atmospheric temperature, humidity, and entrainment (Lu et al., 2013). Zhu et al. (2020) analyzed data from a flight observation conducted in Monterey, California, in July 2008 as part of the US POST (Physics of Stratocumulus Top) project, and found that in adiabatic clouds, vertical velocity plays a dominant role. An increase in vertical velocity promotes the activation of cloud condensation nuclei (CCN), leading to an increase in Nc and facilitating droplet coalescence and growth. On the other hand, Kumar et al. (2017) conducted idealized simulation experiments using direct numerical simulation (DNS) to study the mixing dynamics at cloud edges and their impact on the droplet size distribution (DSD). They showed that ε is also related to turbulent mixing and variations in vertical velocity within the cloud.

Reviewer's comment 2: L96 In this summary, it is not included that there are comparisons with observations, both satellite and flight derived.

Response: Thank you for your suggestion! We have added a description of the comparison of simulation results in the abstract. The specific content can be found in lines 13-15.

Reviewer's comment 3: L109 What is the vertical resolution of the smaller domain?

Response: Thank you for your question! We indeed lacked a description of the vertical resolution. The vertical resolution in the smaller region is the same as in the d02 layer. The simulations employ a two-layer nesting approach with 3 km and 1 km grid resolutions. The model is divided vertically into 57 layers, reaching a top pressure level of 50 hPa. We have supplemented this information in line 131 of the article.

Reviewer's comment 4: L110 Was any other PBL scheme tested?

Response: Thank you for your question. In this simulation, we used the Mellor-Yamada-Janjic (Eta) Turbulence Kinetic Energy (TKE) scheme for the planetary boundary layer (PBL). We did not compare this scheme with other PBL schemes in this study. The choice of this scheme was based on our successful experience with it in simulating warm cloud processes in other regions. While we recognize the importance of PBL schemes and vertical resolution in simulations, our focus in this paper was on the variations in aerosol concentrations and conducting sensitivity experiments, with the main variable being aerosol concentration. The impact of PBL schemes and vertical resolution could be considered for future research, and we appreciate your suggestion.

Reviewer's comment 5: L116 How representative is the chosen case study in that geographical context?

Response: Thank you for your suggestion and question! The simulation is focused on the warm cloud process over Ganzhou, Jiangxi Province, China, located in the southeastern part of Jiangxi Province in the East China region. This area is a transition zone extending from the southeast coastal area to the inland, mainly characterized by mountains, hills, and basins. It is situated on the southern edge of the mid-subtropical zone and belongs to the subtropical monsoon climate zone.

In this study, we simulate the warm cloud process over Ganzhou on December 25, 2014. During the simulation period, the 500 hPa level was influenced by the southwesterly airflow ahead of an upper-level trough, and the 850 hPa level exhibited a convergent wind field. Meanwhile, the southern branch trough brought good moisture transport, which is typical of the common weather pattern in this region.

In fact, the aircraft observation data used in this study is one of seven consecutive observations from November 6 to December 25, 2014. During these seven observations, the cloud layers were mainly concentrated at altitudes of 2000-4500 m. According to the observational data, the maximum horizontal extent of the detected cloud areas exceeded 50 km, and all were classified as stratiform warm clouds. Therefore, the warm cloud process simulated on December 25, 2014, is representative of the common stratiform warm clouds in this region.

Before conducting the sensitivity experiments, we simulated all seven warm cloud processes in Jiangxi. After comparing the satellite-observed cloud top temperatures and the aircraft-observed cloud droplet spectra, we selected the December 25, 2014 process, which had the best simulation results, for the sensitivity experiments. Therefore, we believe that the simulated warm cloud process on December 25, 2014, can to some extent represent the common stratiform warm cloud processes in this region. In future work, we will also conduct more research and focus on the warm cloud processes in this region to compare the similarities and differences and assess the representativeness of this process.

Reviewer's comment 6: L123 Is this horizontal or vertical wind shear? (du/dx or du/dz) Is that expected to affect the cloud development?

Response: Thank you for your question and suggestion. We apologize for the ambiguity in our description. In this context, "wind shear" refers to horizontal wind shear, indicating a convergence pattern at 850 hPa, in conjunction with a high-altitude trough at 500 hPa. This indicates an upward motion in the atmosphere over the region, which is conducive to cloud development and formation.

Reviewer's comment 7: Fig. 2. This is the first time that the flight is mentioned, we have not read that in the main text.

Response: Thank you for your question. We have provided a detailed introduction to the aircraft observation and satellite observation data in Section 2.5.

Reviewer's comment 8: Fig. 3. The CM and ORG cases look the same. Is this a plotting issue? I was expecting the CM to be larger for greater D.

Response: Thank you for your suggestion! Indeed, as you pointed out, the aerosol spectra after changing the concentration of coarse-mode aerosols do not show much difference from the control experiment. In this experiment, the number concentration of coarse-mode aerosols in the initial aerosol spectrum was small, only 0.720 /cm³. Even after increasing the concentration of coarse-mode aerosols by 5 times, the concentration is only 3.6 /cm³. Therefore, compared to the maximum value of 3500 /cm³ on the axis, the difference in the initial aerosol spectra between the coarse-mode experimental group and the control group is relatively small. We have adjusted the axis settings for the initial aerosol spectra, and the revised figure is shown in Figure 3, located in Section 2.3 of the paper.

Reviewer's comment 9: L173 Here is the first mention of the flight, although Fig. 4. is not mentioned in the text. Is Fig.4 useful at all if it's not even discussed?

Response: Thank you for your question. We have provided a detailed introduction to the aircraft observation and satellite observation data in Section 2.5. Additionally, in

Section 3.1, we have updated the comparison between the simulation results and the aircraft observation results.

Reviewer's comment 10: L186 Here it mentions that "the simulation results are generally consistent" but the magnitudes of Clw and D are quite different according to Fig. 6. It'd be better to describe that and explain if that is significant or not.

Response: The significant differences between the aircraft observation profiles and simulation results in our previous version of the manuscript were due to averaging the entire observation period's aircraft data and the cloud microphysical properties simulated over the entire observation range. In the revised manuscript, we have adopted a different approach. We selected a more complete segment of the cloud-penetration process from 04:10 to 04:20 on the 24th, and compared it with the simulation data for the same period, height, and geographic location.

The new results show that the distribution of simulated cloud microphysical properties with height is much closer to the aircraft observations. While there are still some differences in specific values and peak heights, these differences arise partly from model errors and partly because the aircraft observations represent samples from a narrow spatial volume along the flight path. The resolution of the aircraft observations can reach several meters, which differs from the simulation results. Detailed comparisons can be found in the descriptions of Figures 6 and 7.

Reviewer's comment 11: Fig. 6. What is the normalized height? Why is it only used in this Figure? Upper and bottom rows don't have the same x axis limits. What is the vertical resolution of the A plots?

Response: Thank you for your suggestion! We apologize for not explaining the concept of cloud height normalization clearly in the figure. In Figure 7, we selected the cloud region based on cloud droplet liquid water content greater than 0.001 g/m^3 and cloud droplet number concentration greater than 10 /cm^3. Subsequently, due to differences in vertical resolution between aircraft observation and simulation results, we set the cloud base height to 0 and the cloud top height to 1 to better reflect the distribution of cloud microphysical properties inside the cloud in both observation and simulation. We have corrected the x-axis scaling in the new simulation results verification, located in Section 3.1 of the manuscript. In the simulation, we divided the vertical direction into 57 layers, with the top layer at 50 hPa. Each layer has varying heights, with lower layers having higher vertical resolution. As height increases, the thickness of each layer increases, leading to greater vertical resolution.

Reviewer's comment 12: 3.2.1 Here it starts mentioning the growth of the cloud layer but in a very qualitative way. If the time resolution of the simulations is finer than 1 hour, I'd suggest to add time evolution plots for a better description.

Response: Thank you for your suggestion! We indeed encountered the issue of low temporal resolution in the analysis of cloud microphysical properties. To address this, we have modified the figures in sections 3.2 and 3.3 to show the temporal evolution of cloud microphysical properties with height. Additionally, we have revised the text related to the comparative analysis to better align with the objective changes depicted in the figures.

Reviewer's comment 13: L202 I don't see the Clw and D decrease but an increase, and the opposite for Nc.

Response: Thank you for your suggestion! We apologize for the inaccurate description of the trends in physical quantities. In the newly revised results, we have modified the description of this section as follows (specific details can be found in lines 249-257):

Figure 8-10 reflects that the cloud thickness significantly increases as the cloud system develops. Both Clw and Rm increase with height, show high consistency. In contrast, Nc exhibits different trends with height at different times. From 00:00 to 02:00 UTC, when the cloud system is in initial stage of development, Nc decreases with height, and many small cloud droplets appear at the cloud base, which is the main area for droplet activation. As the cloud system further develops, from 03:00 to 04:00 UTC, Nc shows relative uniform distribution with height. From 04:00 to 05:00 UTC, this trend changes again, with the maximum Nc appearing at the cloud base. Large numbers of small cloud droplets present at the cloud base, the primary area for droplet activation. The peak of Clw appears at higher cloud layers. In contrast, the maximum cloud droplet radius occurs in the middle to upper cloud layers, indicating that the main region of cloud droplet size increasing is near the top and middleupper parts of cloud regions.

Reviewer's comment 14: L206 You say that the cases with greater concentration promote cloud growth but basically all the cases are showing that behavior. Same in L211, how noticeable is it when it seems like it is just 1 more grid point?

Response: Thank you for your suggestion. In our original figures, the changes in the cloud top region were indeed not very significant. In the new version of the article, we have made the changes in cloud microphysical properties with height clearer in the figures. As you mentioned, the increase in cloud top height is not very significant. However, what we can observe is that the timing of cloud top development to above 3.5 km appears earlier, especially in the AM experiment. We have revised the conclusions, abstract, and analysis sections accordingly. Specific details can be found in section 3.2 of the paper.

Reviewer's comment 15: L220 Is this analysis done for all simulation times or only 05 UTC? If separating the analysis by height is useful, why don't you continue using this approach later on?

Response: Thank you for your feedback. Previously, this part of the analysis was based on the average results over the entire analysis period. Now, based on your suggestion, we have simplified the first part of our research, which focuses on the variation of cloud microphysical properties with aerosol concentration. We have removed the analysis of cloud droplet spectra distribution at different height ranges and instead focused on the overall change in cloud droplet spectra throughout the process. We also focused on the characteristics exhibited by the cloud droplet particles as a whole and the correlation between cloud droplet spectra dispersion and changes in cloud microphysical properties.

Reviewer's comment 16: Fig. 8. What time is this data from? 05 UTC?

Response: Thank you for your question. The data in Figure 8 originally came from the entire observation range. We normalized the cloud height and divided the cloud into upper, middle, and lower parts, calculating the height distribution of cloud droplet spectra at different heights over the entire observation period. Now, we have simplified this part of the content. In section 3.2.2 of the revised article, we mainly focus on the evolution of cloud droplet spectra distribution with the development of the process, as well as the differences in experiments with varying aerosol concentrations.

Reviewer's comment 17: L223 I'm not sure if it's an exponential decay.

Response: Thank you for your suggestion. We have adjusted the content in section 3.2.2 and no longer analyze the changes in cloud droplet spectra at different height ranges. Therefore, we have removed the part you mentioned. We have also made corresponding modifications to the descriptions in the rest of the paper to reduce inconsistencies in objective descriptions.

Reviewer's comment 18: Fig. 11. This is probably one of the central results of the study. Not much is said about the data itself. Are all the points combining all the states in the whole domain and throughout the simulation? Were these results separated by height, time, etc.

Response: Thank you for your suggestion! Previously, we did not clearly describe what the data points in Figures 11-13 specifically represent. In fact, they depict the distribution and correlation of the relative dispersion of cloud droplet spectra with Rv, Nc, and other cloud microphysical quantities within the cloud area during the analysis period from 00:00 to 05:00. In the latest revision, we have detailed the meaning of the data points in the images at the beginning of Sections 3.3.2 and 3.3.3.

Reviewer's comment 19: Section 3.3. Here many correlations are mentioned but no correlation factor is ever reported. Would that add value to the analysis?

Response: Thank you for your suggestion! In section 3.3.2, we did not provide the correlation coefficient. This is because the simulation results involved a large number of cloud droplets, resulting in a low correlation coefficient between the fitted dispersion and volume-weighted mean diameter. In this section, our focus was more on reflecting and describing the trend of change and the corresponding microphysical mechanism change. Therefore, the correlation coefficient has a limited role in describing the microphysical mechanism and the change in dispersion, so it was not included in the paper. In the revised version of the paper, we did not add correlation coefficient data in the main text, but instead added statistical results of correlation coefficients in different cloud droplet size ranges in the appendix, as shown in Table S1.

Reviewer's comment 20: Section 4 There's no need to repeat what was already described in the Introduction. Simplify if possible.

Response: Thank you for your suggestion. In the discussion section, we indeed repeated some content that had already been introduced in the introduction. We have simplified this part and revised the description in the introduction, as shown in lines 378-400.

Reviewer's comment 21: L347 Is it possible to consider the processes mentioned here in the analysis?

Response: Thank you for your suggestion! As you mentioned, factors such as updrafts or turbulent mixing can indeed affect the cloud-aerosol interactions and cloud droplet spectra changes in warm clouds. However, this study primarily focuses on the impact of aerosol modal differences on cloud-aerosol interactions, as well as the response of processes such as collision, condensation, and droplet activation in clouds to cloud-aerosol interactions. This part of the content can be expanded upon in future research.

Reviewer's comment 22: Conclusions: What are the future directions for this work?

Response: Thank you for your suggestion! The cloud-aerosol effect is a significant source of uncertainty in precipitation simulations, and its complex mechanisms require more attention and research. This study focuses on the impact of different aerosol modes on cloud microphysical processes. In the future, we can consider enhancing the model's vertical resolution to describe cloud processes more thoroughly. Additionally, focusing on the effects of aerosols with different properties and types, as well as the differences in cloud-aerosol effects in various regions and cloud types, especially between cold and warm clouds, would be beneficial. We have supplemented the conclusion section with the limitations and prospects of this study. For specific details, please refer to lines 432-441：

“ Lastly, in this study, due to computational power limitations, the vertical resolution of our simulation setup is relatively coarse. Future research could consider enhancing the resolution to reveal the variations of cloud-aerosol effects more effectively within the vertical profile of clouds. Moreover, while this study has explored the effects of variations in aerosol concentrations across different modes on the macroscopic and microscopic characteristics of warm clouds, mainly focusing on the influence of these variations on the relationship between ε and cloud microphysical properties, the interaction between clouds and aerosols is a complex process influenced by multiple factors, including cloud dynamics and supersaturation levels.

Therefore, future research should investigate other vital factors affecting cloud-aerosol interactions further. Additionally, incorporating case studies from diverse regions could effectively reduce the regional dependency of cloud-aerosol effect research, thereby enhancing our comprehensive understanding of these complex interactions on a global scale.”

Writing comments / suggestions

Reviewer’s comment 1: L13 Cloud base height?

Response: The change in cloud height is not significant. We have revised the description to indicate that the development of the cloud top to above 3.5 km occurs earlier. This can be seen in lines 17-18.

Reviewer's comment 2: L16 You can specify that "generally" is in the context of your results.

Response: We have revised this part to "it is also found that" to indicate that it is a finding of this study. This can be seen in lines 21-22.

Reviewer's comment 3: L90 "dependent"

Response: We have rewritten this part of the introduction. For details, please see lines 108-112.

Reviewer's comment 4: Fig. 1. It should not be described mentioning "the figure".

Response: The figure captions have been revised. For details, please see line 150. "Figure 1: Simulated Region and Nesting Configuration. The shading represents the elevation (m) of the terrain, and the area within the red box is the analysis range。"

Reviewer's comment 5: Table 1-2: Maybe you could skip the decimals in the large numbers

Response: The numbers in the table have been modified, removing trailing zeros after the decimal point.

Reviewer's comment 6: L176 04:45

Response: The description of the numbers has been revised. Please refer to line 203 for details.

Reviewer's comment 7: Clw or C_{lw}? Also, you alternate between using the symbol and description throughout the text, which at times can be confusing.

Response: The abbreviation for cloud liquid water content has been standardized to "Clw."

Reviewer's comment 8: L259 Avoid starting a sentence with a symbol.

Response: The description in line 259 has been modified. Details can be found in lines 297-305.

Reviewer's comment 9: Fig. 7, 10. Please add the x axis labels for each row.

Response: The figures in sections 3.2.1 and 3.3.1 have been replaced with distributions of physical quantities with height over time.

Reviewer's comment 10: Fig. 10. Improve image resolution.

Response: The resolution of all figures in the paper has been increased.

Reviewer's comment 11: Fig. 11, 13. In the y axis label: Should it be xi (ξ) or epsilon(ε)?

Response: The abbreviation symbol for relative dispersion of cloud droplet spectra has been changed to "ε."

Response to Reviewer Comment 2

Specific comments：

Reviewer's comment 1: The title of this paper seems quite conventional and covers a broad area of Aerosol Effects on Stratiform Warm Clouds. The authors could consider narrowing the area to the more specific focus of this study, which could more accurately reflect the contents of this paper.

Response: Thank you for your valuable suggestion. Regarding the modification of the paper's title, we have revised it based on your guidance. The original title might not have accurately reflected the specific content and methodology of our study. Following your recommendation, we have changed the title to " Numerical Simulation of Aerosol Concentration Effects on Cloud Spectral Evolutions of Warm Stratiform Clouds in Jiangxi, China" to describe our study of the effects of aerosol concentrations more specifically on the microphysical properties of warm stratiform clouds in Jiangxi using numerical simulation. We believe the new title more accurately reflects the core content and scientific value of the paper.

Reviewer's comment 2: In the abstract, several important symbols and abbreviations are used without definition, i.e., ε and Nc, which makes it difficult for the readers to understand the meaning.

Response: In the abstract, several important symbols and abbreviations are used without definition, i.e., ε and Nc, which makes it difficult for the readers to understand the meaning."

We apologize for the oversight in not defining certain symbols and abbreviations such as ε and Nc in the abstract, which may have caused confusion for the readers. To address this issue, we have added the following definitions in the abstract:

"cloud droplet spectrum relative dispersion (ε)"

"cloud droplet number concentration (Nc)"

Reviewer's comment 3: The authors should consider re-arranging the introduction part and combine the paragraphs about the same topic. Line 48-53 is suggested to move forward before discussing the "cloud droplet spectrum correlations". Overall, there is a lack of a clear descriptions of what has been done, what remains uncertain, and what needs to be done, especially what is to be solved in this study. There is also a lack of description on the related research about the target area – Jiangxi, China or eastern China.

Response: Thank you very much for your suggestion. Based on your feedback, we have moved lines 48-53 forward and subsequently discussed the relative dispersion of the cloud droplet spectrum. Please see the updated text around lines 50-58. Additionally, we have revised the text of the entire introduction to summarize the previous research efforts.

Your comments also pointed out a lack of clear descriptions of completed work, uncertain work, and work that needs to be completed. Accordingly, we have supplemented the introduction with a description of the research objectives and the work that needs to be completed. Please see the added content around lines 105-116:

In summary, under the context of climate change, changes in the physicochemical properties of aerosols significantly affect the microphysical characteristics of warm clouds. Existing studies often rely on exploring the relationships between aerosol concentration and microphysical cloud quantities such as Nc and Rv, and further research on ε, a key factor affecting the cloud-aerosol effect, is still needed. However, the response of warm clouds to aerosol physicochemical properties depends on the region and cloud type, and due to limitations in observational methods, the response of ε to changes in aerosol concentration varies significantly across studies, making this issue a crucial and controversial scientific question in climate prediction.

This study utilizes the SBM-FAST bin microphysics scheme within the Weather Research and Forecasting (WRF) model to simulate a stratiform warm cloud event in Jiangxi, China. The numerical experiments aim to explore the impacts of changes in nucleation, accumulation, coarse, and total mode aerosol concentrations on the macroscopic and microscopic characteristics of warm clouds in this region. The paper is organized as follows: Section 2 outlines the numerical simulation setup, aircraft, and satellite observations to validate simulation results, and the computational formulas used in the analysis. Section 3 conducts validations of the control experiment's simulation results through comparisons with concurrent aircraft and satellite cloud top temperature observations, uncovering the effects of different aerosol modes on the macroscopic and microscopic physical properties of clouds, with a particular focus on the correlation between ε and cloud microphysical properties. The last two sections include the discussion and conclusions.

Additionally, we have supplemented the manuscript with previous case studies conducted in East China and Jiangxi:

For example, Zheng et al. (2021) utilized merged Cloud Sat-CALIPSO-MODIS products to compare the macro- and microphysical properties of precipitating and non-precipitating clouds during the warm season in central-eastern China, focusing on parameters such as cloud optical thickness and the effective radius of cloud droplets. Their findings indicated that the probability of precipitation increased with increasing cloud optical thickness, liquid water path, and ice water path but showed a decreasing trend when the cloud droplet effective radius exceeded 22 micrometers.

Jin et al. (2021) conducted aircraft observational studies on stratiform warm clouds in Jiangxi, China, indicating that ε in both precipitating and non-precipitating warm clouds is negatively correlated with Nc.

Fan et al. (2012) conducted a numerical simulation on variations of aerosol concentration in Eastern China, demonstrating that an increase in CCN leads to an increase in Nc and cloud droplet mass concentration, reduces the number concentration of raindrops, and delays the onset of precipitation.

Furthermore, the aerosol concentration settings for the sensitivity experiments were also referenced from studies by Qian et al. (2009) and Fan et al. (2012) on the impact of aerosols on clouds in Eastern China.

Reviewer's comment 4: The authors should have added a section in part 2 to describe the data used for validation purpose. The flight observations and FY2G satellite observations should be described in more details. This is very critical point.

Response: We apologize for the oversight regarding the addition of a section in Part 2 to describe the data used for validation purposes, as you pointed out. Following your suggestion, we have now expanded Section 2 to include detailed descriptions of the aircraft observation data and the FY2G satellite observations of cloud top temperatures. The detailed content can be found in Subsection 2.5. We believe that this addition will help readers better understand the structure of the datasets and their application in our study. Thank you once again for your valuable comments.

Reviewer's comment 5: Please explain how you determine the analysis range (the red box in Fig. 1). Maybe it is related to the flight tracks?

Response: Thank you for your query. Indeed, there is a lack of description regarding the analysis area delineated by the red box in Figure 1. The delimitation of the analysis area combines the aircraft observation path with the results of cloud top temperature observations for this event. The analysis area was defined to include not only the aircraft flight area but also to encompass as much of the warm cloud regions involved in this event as possible, to better reflect the characteristics of stratiform warm clouds in the Jiangxi region. However, during the simulation period, as the warm cloud event developed, cold clouds appeared in the southern and southeastern parts of Jiangxi. Therefore, the analysis area was determined to cover as many warm cloud regions as possible while avoiding areas where cold clouds were present during the analysis period, as shown in Figure 1.

Reviewer's comment 6: The authors set the numerical simulations with aerosol concentrations of 5 times of the original value. Do you have some clues on why 5 times is a reasonable choice?

Response: Thank you very much for your question. We have based our aerosol concentration settings on previous studies conducted in Eastern China, including Jiangxi. According to the aircraft observational study on the impact of aerosol concentration changes on precipitation in Eastern China (Qian et al., 2009) and the numerical simulation study on the effect of aerosol concentration changes on clouds and precipitation in Eastern China (Fan et al., 2012), increasing the initial aerosol concentration to five times realistically reflects the background concentration of continental aerosols under polluted conditions in Eastern China. This adjustment is beneficial for demonstrating the realistic impacts of aerosol concentration changes on warm clouds in Eastern China.

Reviewer's comment 7: Section 3.1: the validation part seems not very convincing. Considering the scales of aerosol-cloud microphysical processes, the FY2G observation may be too coarse. FY4A or Himawari-8 observations may be a more suitable substitute.

Response: Thank you for your question. We also acknowledge that the FY-2F satellite's cloud top temperature data has a lower resolution compared to the model simulation results. The FY-4A and Himawari-8 satellites, which you suggested, do indeed offer higher resolution cloud top temperature observations. However, FY-4A was launched in December 2016, and the earliest available data from Himawari-8 is from July 2015. The warm cloud process in Jiangxi, selected for this study, occurred on December 25, 2014. Therefore, the FY-2F data is currently the best available cloud top temperature observation data for our study.

In fact, at 02:30 and 03:30 UTC, while there are some differences in the specific values of cloud top temperatures between the simulated results and FY-2F satellite observations (partially due to model errors and partially due to resolution differences), the overall distribution trend of warm and cold clouds is quite similar. The development of the cloud system is also similar, which to some extent indicates the reliability of the model's simulation of the macroscopic development of clouds.

Reviewer's comment 8: The A1A2B1B2 style numbering of Figure 5 etc., is really confusing and inconvenient. Please consider a change. Additionally, what's the spatial resolution in Figure 5? Why the A1 and B1 panels seem to have very different spatial resolutions?

Response: We apologize for the confusion caused by our figure captions. We have revised the captions for clarity. For the same set of data, we now use the labels A, B, C, and D for easier reference. For the results of different sensitivity experiments, we use the experiment names directly to describe the subplots, such as ITM and NM.

For the data in Figure 5, they represent the cloud top temperature data observed by the FY-2F meteorological satellite and the simulated cloud top temperature. The resolution of the FY-2F observed cloud top temperature is 5 km, while the resolution of the simulated cloud top temperature is 1 km.

Reviewer's comment 9: Figure 6: How do you define the "normalized height"? The authors described the "Still, the magnitudes of the number concentrations of the

control experiment and the observation are generally consistent. Additionally, the average particle size in both groups increases with height, and their vertical distribution trends are consistent." But to me, the simulation and the observation are far from "consistent" no matter in terms of magnitude or vertical distribution pattern. Please double check. Moreover, the observation-simulation comparison should have been carried out in higher temporal resolution, i.e. hourly, for better illustrations of the cloud property variations.

Response: Thank you for your suggestion! We apologize for not adequately explaining the concept of normalized cloud height in the figures. In Figure 6, we first identified cloud regions based on cloud droplet water content greater than 0.001 g/m³ and cloud droplet number concentration greater than 10 cm^{-3}, removing non-cloud data from both aircraft observations and simulation results.

For the concept of "normalized height," we set the cloud base height to 0 and the cloud top height to 1 to better reflect the distribution of cloud microphysical properties within the cloud as observed and simulated.

The significant differences between the aircraft observation profiles and simulation results in our previous version of the manuscript were due to averaging the entire observation period's aircraft data and the cloud microphysical properties simulated over the entire observation range. In the revised manuscript, we have adopted a different approach. We selected a more complete segment of the cloud-penetration process from 04:10 to 04:20 on the 24th, and compared it with the simulation data for the same period, height, and geographic location.

The new results show that the distribution of simulated cloud microphysical properties with height is much closer to the aircraft observations. While there are still some differences in specific values and peak heights, these differences arise partly from model errors and partly because the aircraft observations represent samples from a narrow spatial volume along the flight path. The resolution of the aircraft observations can reach several meters, which differs from the simulation results. Detailed comparisons can be found in the descriptions of Figures 6 and 7.

Reviewer's comment 10: Figure 10: what is "cloud-rain auto-conversion intensity (T)", or "cloud droplet collision and coalescence intensity (T)"? Why the terms are different in the main text and in Figure 10 caption?

Response: Thank you for your question! We apologize for the inconsistency in describing "cloud-rain auto-conversion intensity" (T) in the main text and Figure 10. The calculation of T is based on the cloud-rain auto-conversion threshold function proposed by Liu et al., 2005, 2006, which measures the automatic conversion of cloud to rain. Its value reflects the intensity of cloud droplets converting into raindrops. If T=0, it means no cloud droplet collision-coalescence occurs, and if T=1, it means complete collision-coalescence of cloud droplets. We have now unified the description of T in Figure 10 and the main text. The new figure is labeled as Figure 11.

Reviewer's comment 11: Line 280-294: You may consider combing the paragraphs as they are discussing the same point?

Response: Thank you for your suggestion. We have merged this paragraph and reorganized the analysis content. Details can be found in Section 3.3.2. Additionally, we have also refined the physical mechanism diagram illustrating the relationship between dispersion and Rv in Section 3.3.2, as shown in Figure 18.

Reviewer's comment 12: Line 340: "This difference may arise from variations in cloud height and cloud water content." – please explain more.

Response: Thank you for your question. We further compared the research results and found that this difference may stem from the classification of aerosol particle sizes. In the WRF-SBM scheme, the distribution of different aerosol modes is assumed to follow a normal distribution. Therefore, for the nucleation mode, some aerosol particles also reach the size scale of the accumulation mode, promoting an increase in Nc and a rise in T values. More details can be found in lines 380-385.

Reviewer's comment 13: Generally, the reviewer has an impression that the descriptions and discussions in the main text are not very consistent with what can be seen from the figures. Suggest to double check.

Response: Thank you for your suggestion. In our previous analysis, the low temporal resolution of the data presented in our paper indeed led to some discrepancies between the analysis and the figures. To address this, we have increased the temporal resolution of the analysis figures and reorganized the analysis content in Sections 3.1-3.3. We have also conducted a more detailed analysis of the trends in microphysical variables and their impacts on physical processes.

Reviewer's comment 14: Many typos and grammar mistakes are found (see minor points) but much more needs to be found. A thorough proofread is badly needed.

Response: Thank you for your suggestion! There were indeed spelling and grammar errors in the previous version of the manuscript. We have proofread and improved the text, as well as checked and adjusted the formatting.

Minor points

Reviewer's comment 1: Line 28: The authors should be careful with their narration. They say "many researchers" but only give 2 references, which is not very convincing. Additionally, the authors should have described the 2 references in more details before they blame on the references to be overlooking something.

Response: Thank you for your suggestion. We acknowledge that there was insufficient summary of previous studies and lack of detailed description of the references. In the revised version of the manuscript, we have made modifications from lines 34 to 45, clarifying the research content of the references and pointing out the shortcomings of the research.

Reviewer's comment 2: Line 38: What is "macroclimate"?

Response: Thank you for your suggestion. "Macroclimate" is actually intended to refer to "climate." This has been corrected in the revised version of the manuscript. Please refer to line 49 for details.

Reviewer's comment 3: Line 39: "cloud droplet spectrum correlations" – correlations between what?

Response: Thank you for your suggestion. We have revised the content to: "Many researchers have conducted causal analyses on the uncertainty of the effect of cloud microphysical properties on ε," to express the impact and relationship of cloud microphysical properties on ε. Details can be found in line 50.

Reviewer's comment 4: Line 48: "its variations" – what do you mean?

Response: Thank you for your suggestion. We have corrected the reference of "it" to refer to "cloud droplet spectrum relative dispersion," and adjusted the introduction accordingly. Details can be found in line 50.

Reviewer's comment 5: Line 54: "In recent years," – how recent do you mean? 2010 and 2019 covers a decade, and is not very recent to 2024. Similarly, Line 58 "currently" is not suitable to reference 2016, 2018, and 2019. This will confuse the readers.

Response: Thank you for your suggestion. We have modified the description here and adjusted the introduction to:

"Studies by Ma et al. (2010) and Wang et al. (2011, 2019) have shown that changes in ε are highly sensitive to aerosol concentration and its activation process. Additionally, alterations in aerosol concentration or size distribution significantly impact the cloud-rain auto-conversion process through changes in ε. Consequently, ε becomes a critical link connecting the aerosol-cloud interaction effects (Liu and Daum, 2002)." Details can be found in lines 73-76.

Reviewer's comment 6: Line 105: "Apart from aerosol concentrations" – I think you mean "except for", please check.

Response: Thank you for your suggestion. We have modified the wording as follows: "Except for aerosol concentrations, all groups kept the initial field data and simulation settings consistent. The simulations used the fifth generation of ECMWF atmospheric reanalyses of the global climate (ERA5) hourly data on pressure levels as the initial field, with a resolution of 0.25° × 0.25°." Details can be found in line 128.

Reviewer's comment 7: Figure 2: "the area within the red box indicates the starting point of the flight." – this is too rough to be understood. You should give the full information about the flight observations, not only the starting point. Please provide more details (full flight tracks, etc).

Response: Thank you for your suggestion. We have added detailed descriptions of the aircraft observations in Section 2.5.

Reviewer's comment 8: Line 114: Out of curious, how do the authors consider the spin-up of WRF simulation, give the simulation period is relatively short here?

Response: Thank you for your question. The duration of our simulation is 12 hours. In fact, we have considered the spin-up time of the WRF model. Therefore, we removed the first 6 hours of model startup to reduce simulation errors, and placed the time corresponding to the aircraft observations in the last 6 hours of the simulation.

Reviewer's comment 9: Line 142: "computed using supersaturation"?

Response: Thank you for your suggestion. We have modified the description to: "The calculation of cloud droplet nucleation considers the effect of supersaturation, and the accuracy of the algorithm is verified through comparison with large-eddy simulation results (Ilotoviz et al., 2015)." Details can be found in lines 165-167.

Reviewer's comment 10: Line 212: "more small cloud droplets" – more cloud droplets of small sizes?

Response: Thank you for your suggestion. We have modified this to "more cloud droplets of small sizes." Details can be found in line 263.

Reviewer's comment 11: Line 259: "which defined as" – is defined as

Response: Thank you for your suggestion. Here, we have removed the definition of dispersion, which was already described in the introduction, and modified the analysis in this section. Details can be found in Section 3.3.1.