Authors' response to Review of "Interplay between aerosol and updraft velocity in Large Eddy Simulations of marine stratocumulus clouds" by Dogra, G., Boucher, O., and Bellouin, N. (egusphere-2025-5711)

The Reviewers' comments are repeated below in black while our response is in blue.

Reviewer 1

This manuscript uses LES simulations, initialized with observational data from the DYCOMS-II field campaign, with a bulk microphysics scheme to simulate and study stratocumulus clouds under varying aerosol burdens and latent heat fluxes. The increased latent heat flux is chosen to produce stronger updrafts, this response is confirmed throughout the manuscript. Therefore, the parameters varied to study the response of the stratocumulus-topped boundary layer are aerosol number concentration and updraft velocity. The authors use the obtained data to gain information about the behavior of more realistic cloud systems in the so-called aerosol-limited and updraft-limited regimes of condensating cloud droplets and to demonstrate the ability of their model to capture both regimes, as well as the transition from one into the other.

While this study provides interesting proof-of-concept data and some key points of the responses of the cloud system, I do not think that the work is developed enough to be published. The additional efforts required to elaborate on the simulations, as well as model, physical, and numerical responses in my opinion exceed a major revision process. Inadmissible reasoning is found in crucial places. I suggest re-submission after narrowing down the reasons for observed effects and clarification of the overall intention and result of the paper.

We thank the Reviewer for critically and deeply reviewing our manuscript and for noting that it provides an interesting proof-of-concept and insight in the cloud system response to aerosols. Thanks to their comments, we have analysed and illustrated some aspects of the simulations more deeply, which allowed for a more complete and better justified reasoning, and a clearer statement of the scope and intention of the manuscript. These points are addressed in the responses below.

Main Comments

1. Aerosol number over time. As the aerosol concentration will decrease due to collision and coalescence (and maybe deposition if included in the simulations), a time series of the mean aerosol concentration (and cloud droplet concentration) over time would be very informative to interpret the results. It was also not clear to me if there is an aerosol source.

Response: In the present simulations, aerosol number and mass are prescribed only as initial conditions. No additional aerosol source terms (e.g., surface emissions or boundary inflow) are applied during the simulations. Aerosol fields evolve prognostically due to advection, turbulent mixing, activation, and microphysical processes. Aerosols activated into cloud droplets are removed from the atmosphere when precipitation reaches the surface, some aerosols are lost during each simulation. The extent of that loss depends on the amount of precipitation in each simulation.

We agree that time series of domain-mean aerosol number and cloud droplet number would clarify those aspects, so we have included these time series in Figure 1 of the revised manuscript. Figure 1, reproduced below for convenience, shows that domain-averaged aerosol concentration remains almost constant, with only a small decrease during the initial spin-up period when precipitation occurs. The decrease is small because aerosol concentrations above the cloud layer dominate the domain average but do not experience wet deposition. The cloud droplet number time series is also shown to illustrate the temporal evolution of cloud activation.

The text in revised manuscript at line 186 is updated as "*It can also be observed in Fig. 1e, that domain-averaged aerosol concentration remains almost constant, with only a small decrease during the initial spin-up period when precipitation reaches the surface. The decrease is small because aerosol concentrations above the cloud layer dominate the domain average but do not experience wet deposition. The cloud droplet number concentration in Fig. 1f, illustrates a constant concentration, except for A-10000, where there are bursts of droplet formation that are associated with enhanced supersaturation, while decrease is due to evaporation of droplet due to entrainment and collision-coalescence.*"

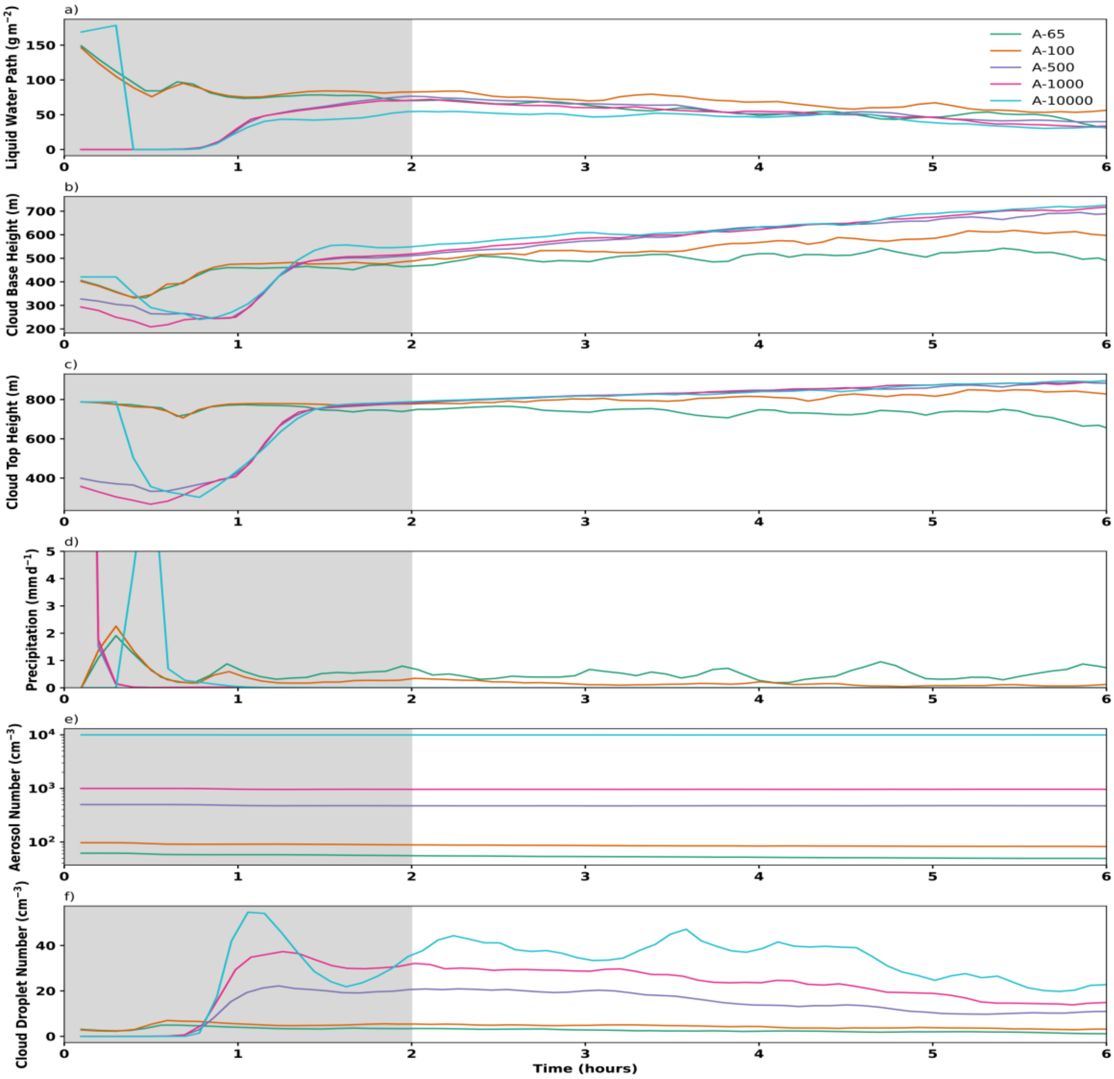

Figure 1: Domain averaged time series of a) Liquid water path (g m^{-2}), b) cloud base height (m), c) cloud top height (m), d) precipitation rates (mm d^{-1}), e) aerosol number concentration (cm^{-3}) and f) cloud droplet number concentration (cm^{-3}), for AERO simulations with aerosol concentrations of 65 (teal green, A-65), 100 (orange, A-100), 500 (purple, A-500), 1000 (magenta, A-1000), and 10000 (sky blue, A-10000) cm^{-3}

2. Microphysics model. The work presented relies heavily on the representation of activation at cloud base. The authors should add a chapter critically evaluating the employed microphysics scheme and elaborating on the representation of supersaturation in it. While it is substantial to investigate the

effects and behavior of the, compared to more sophisticated bin or Lagrangian schemes, less accurate but more efficient bulk schemes in aerosol-cloud-interactions, it is necessary to position the used scheme in the variety of used parameterizations.

Response: The Abdul-Razzak and Ghan (2000), hereafter denoted ARG, activation scheme is applied everywhere in the domain and this scheme then applies its criteria of supersaturation and updraft velocity for activation of aerosol. We agree that the representation of aerosol activation at cloud base and its dependence on supersaturation is central to the interpretation of our results.

In response, we have added a new paragraph to the revised manuscript in the **Methodology** section that explicitly describes the aerosol activation treatment used in this study. The added text explains that cloud droplet activation follows the ARG bulk parameterization, in which activation is determined by the diagnosed maximum supersaturation resulting from a balance between adiabatic cooling and condensational growth. We clarify that supersaturation is diagnosed rather than prognosed in contrast to bin or Lagrangian microphysics scheme that explicitly resolves the droplet growth.

We further discuss the limitation of ARG scheme that are relevant for present study:

a) ARG assumes approximately adiabatic parcel ascent in estimating supersaturation. This assumption may break under the conditions of strong entrainment which can reduce supersaturation and droplet activation. However, in the current study of marine stratocumulus, entrainment is typically at the weaker end, making the approximation more applicable.
b) ARG follows equilibrium Köhler theory for droplet activation. That means that ARG cannot represent the increased competition for water vapour that occurs at very high aerosol concentrations, so it will overestimate activation. That is probably occurring in our simulations with the largest initial concentrations. We have updated it in result section of revised manuscript at Line 398 *"It should be noted that at this highest aerosol concentration, ARG does not represents the enhanced competition for water vapour and may therefore overestimate activation"*
c) ARG uses mean updraft velocity and does not account for its sub-grid variability. Neglecting the variability in updraft velocity can over and under-estimate activation, depending on local variability, and so will influence droplet number concentration in complex ways.

The new revised text that has been added in the manuscript's Methodology section is "*Aerosol activation in the model is represented using the bulk activation parameterization of Abdul-Razzak and Ghan (2000), hereafter denoted ARG, which underlies the CASIM microphysics scheme employed in this study. ARG parameterization determines cloud droplet activation as a function of the maximum supersaturation reached during ascent, diagnosed from a balance between adiabatic cooling associated with the resolved updraft velocity and condensational growth of aerosol particles. The formulation explicitly accounts for competition among multiple aerosol modes through their influence on the supersaturation balance, linking aerosol size distribution and hygroscopicity to cloud droplet number concentration via Köhler theory. Supersaturation is diagnosed rather than prognosed, in contrast to bin or Lagrangian microphysics scheme that explicitly resolves the droplet growth.*

As a bulk activation parametrization, ARG relies on several assumptions that are relevant for the interpretation of the results presented in the current study. ARG assumes approximately adiabatic parcel ascent in estimating supersaturation. This assumption may break under the conditions of strong entrainment which can reduce supersaturation and droplet activation. However, in the current study of marine stratocumulus, entrainment is typically at the weaker end, making the approximation more applicable. The scheme is further based on equilibrium Köhler theory and therefore does not explicitly *represent kinetic limitations or enhanced competition for water vapour at very high aerosol concentrations, which may lead to an overestimation of activation under such conditions. In addition, the use of a grid-mean updraft velocity neglects sub-grid variability in vertical motion, which can influence the diagnosed cloud droplet number concentration."*

3. Figure 8. The plots in this figure are very interesting, but lack sufficient discussion

Response: We agree and have added additional clarification and discussion of what is now Figure 9 in revised manuscript.

• The authors should mention how they define a cloud droplet.

Response: In the ARG scheme, cloud droplets are defined as aerosol particles that become activated when their critical supersaturation, determined from Kohler theory, is lower than the diagnosed maximum supersaturation achieved during ascent. The resulting cloud droplet number concentration is therefore the number of activated aerosol particles. We also define that the threshold for cloudy points is where liquid water content qc > 0.001 g/kg.

• It is not clear which time points are used for the data in this plot. This should be mentioned.

Response: We have now mentioned that the last 2 hours of simulation are used for this plot.

• Especially for decreasing aerosol concentration in the domain, it might be useful to plot the activated fraction of aerosol instead of the absolute activated cloud droplet number. I would like to suggest to the authors to see if this gives less noisy plots, which might turn out not to be the case.

Response: This is a very interesting suggestion but unfortunately, CASIM does not provide the framework to track aerosol activated at cloud base in a separate variable. Aerosol number and mass are prognostic variables in CASIM, which also tracks activated aerosol mass, i.e., the aerosol mass that is diluted into cloud droplets. CASIM does not track activated aerosol number however, because that is equal to cloud droplet number at the moment of activation, although the two then evolve differently. That is why we focus our analysis on cloud droplet number.

• I cannot follow the argumentation of lines 300 to 303. The reference given mentions varying activated number fractions for similar aerosol conditions and lower updrafts (but different thermodynamics). Moreover, roughly 40% activated number fraction is a barrier in all presented plots in Figure 8. I wonder if this is a drawback of the microphysics parametrization or some other effect. I would like to request a clarification of this distinct feature in the plots. I think it is not very likely to be realistic, as, e.g., 65 aerosols per cubic centimeter should have a significantly higher activated fraction than 40% for a mean radius of 0.06µm and 2m/s updraft velocity.

Response: We agree that the original discussion in line 300 to 303 was not sufficiently clear. To better understand the origin of the second branch in Fig. 8, we performed additional diagnostics of the ARG activation parameterization. The Fig. 8 of original manuscript is updated to Fig. 9 of revised manuscript and is shown below.

In a first step, let us neglect aerosol and thermodynamical variability in the ARG calculations. To do so, an offline activation curve (green line) was computed using ARG by prescribing aerosol number concentrations at the number corresponding to each simulation (i.e. from 65 to 10000 cm^{-3}). Updraft velocity varies along the x-axis. The Fig. 9 branch showing relatively high cloud droplet number concentrations at low updraft velocities is consistent with this offline ARG activation curve, indicating that a subset of the simulated cloud base experiences conditions close to parcel-model assumptions. The Reviewer is correct that an aerosol concentration of 65 cm^{-3} at an updraft velocity of 2 m s^{-1} results in higher activation, as illustrated by the offline activation curve (green line). This demonstrates that the apparent upper limit on the activated fraction does not come from the ARG scheme itself.

In a second step, let us consider aerosol variability. Aerosol number concentrations averaged at cloud base from the model output were used as input to the ARG scheme, with the same prescribed range of updraft velocities, to compute a second, “semi-offline” cloud-base activation curve (red line). That curve suggests that the lower branch arises because the aerosol number concentrations diagnosed at cloud base in the simulations are substantially lower than the initial values, reflecting aerosol depletion by prior activation and cloud processing.

For very high aerosol concentrations (e.g., 10 000 cm^{-3}), aerosol availability remains sufficiently large for the cloud-base and offline activation curves to nearly coincide. Moreover, in the simulations, strong updrafts at cloud base are relatively infrequent and often short-lived, and the diagnosed supersaturation is further constrained by local thermodynamic conditions and cloud-scale mixing. As a result, the simulated cloud-base droplet number distributions predominantly give values below the theoretical activation curve.

See further reply below for the changes made to the manuscript in response to that additional analysis.

• The reasoning in lines 306 to 308 is not clear to me. I cannot follow why high cloud bases produce such high activated number fractions for low updraft velocities, notably the only activated number fractions above 40%. While the fact that this branch stems from higher cloud bases is indeed shown in the appendix, the reasoning for it is invalid. It is absolutely necessary to rigorously track down what is causing this, as there are multiple possible reasons with varying implications for this work. Processes that should be investigated include convergence from advection schemes that are not divergence-free, accumulation of cloud droplets in an updraft by additional sedimentation from above, spurious supersaturations (https://doi.org/10.1175/1520-0493(1996)124 <1034:TSPOCE>2.0.CO;2), errors in supersaturation calculation, and the spatial and temporal resolution of the simulation.

Response: We agree with the Reviewer that the occurrence of higher activation at low updraft velocities, particularly at higher cloud bases, requires clarification. The offline evaluations of the scheme discussed above showed that substantially higher activated fractions are possible for the same aerosol conditions under sufficiently strong updrafts, indicating that ARG does not impose a 40% upper limit.

In Fig. 2 of the study, we observed that simulations with lower aerosol concentrations exhibit open cellular structures, which transition to closed cells with increasing aerosol concentration. We also observe that the secondary branch in what is now Figure 9 has more datapoint density at lower aerosol concentrations and diminishes as aerosol concentration increases. In the LES, this branch is associated with cloud-base conditions that exhibit larger variability in cloud-base height, particularly in cases with lower aerosol concentrations and more open-cell cloud morphology. We emphasize that we do not attribute this behaviour to a single physical mechanism, and numerical causes cannot be ruled out. The occurrence of relatively high activated fractions at low updraft velocities may result from a combination of physical and numerical factors, including aerosol availability at cloud base, the intermittency and variability of updraft velocities, and cloud-base thermodynamic conditions. We do not think that advection related convergence or accumulation of sedimentating droplets by updrafts impact the results strongly, as they would affect both branches. As noted by the Reviewer, additional factors such as spurious supersaturation, and spatial and temporal sampling may also contribute. We have revised the manuscript to clarify this feature, and see below for corresponding changes.

• Particularly, elaborating on Figure 8 would be informative with respect to deviation from parcel theory. A solid line in the plot showing the activated aerosol number of an adiabatic parcel using the same microphysics parametrization could be shown. I suppose this might be the line of high density approaching roughly 40% for stronger updrafts. From this, the other features observable in the plots might be discussed and explained thoroughly. This would also enable a discussion of the deviations of more realistic clouds from parcel-theory-driven aerosol- and updraft-limited regime discussions.

Response: In a third step to understand what is now Fig 9, let us consider both aerosol and thermodynamic variability. ARG is again used offline, this time using both cloud-base thermodynamic and aerosol properties diagnosed from the LES. Figure B2 shows that the resulting Nd–w relationship reproduces the main features of Figure 9 of the revised manuscript. This strongly indicates that the differences between the parcel-theory curve and the LES results arise from the cloud-base conditions experienced in the simulations rather than from numerical artefacts of the activation scheme.

The revised text and Figures in revised manuscript corresponding to above comments are as follow:

"*Additionally, a second branch is observed, showing higher droplet concentration at low updraft velocities. This second branch of higher cloud droplet number concentration in Fig. 9 arises from the cloud-base conditions realized in the simulations. To analyse the origin of this second branch, additional analysis is performed using the ARG scheme in an offline way, adding aerosol or thermodynamic variability in three steps. In the first step, aerosol and thermodynamic variability is neglected and an offline activation curve (green line) is computed by prescribing aerosol number concentration at the number corresponding to each simulation (i.e., from 65 to 10000 cm^{-3}) and varying updraft velocity. The branch in Fig. 9 showing relatively high cloud droplet number concentrations at low updraft velocities is consistent with this offline ARG activation curve, indicating that a subset of the simulated cloud-base conditions experience conditions close to the assumptions made in the ARG parcel model. The offline activation curves also demonstrate that substantially high cloud droplet numbers are possible for the same aerosol conditions under sufficiently strong updrafts, confirming that the activation parameterization itself does not impose an upper limit to activated fraction.*

In the second step, aerosol variability is now considered by using aerosol number concentration averaged at cloud base from the model output as an input to the ARG scheme with the same range of prescribed updraft velocities to compute a second "semi-offline" cloud base activation curve (red line). The red curve is lower than the green curve because the aerosol number concentrations diagnosed at cloud base in the simulations are substantially lower compared to the initial values, reflecting aerosol depletion by prior activation and cloud processes. Figure B3 in appendix shows *that the secondary branch preferentially occurs under cloud-base conditions that also exhibit larger variability in cloud-base height; however, cloud-base height variability is a consequence rather than a driver of this behaviour. The most linear relationship between updraft and droplet number is observed in Fig. 9e corresponding to an aerosol number concentration of 10000 cm*$^{-3}$ *in which both the green and red curve coincides. At this aerosol concentration, the secondary branch becomes substantially weaker and effectively disappears. It should also be noted that at this highest aerosol concentration, ARG does not explicitly represents the enhanced competition for water vapour and may therefore overestimate activation. Moreover, in the simulations, strong updrafts at cloud base are relatively infrequent and often short-lived, and the diagnosed supersaturation is further constrained by local thermodynamic conditions and cloud-scale mixing. As a result, the simulated cloud-base droplet number distributions predominantly give values below the theoretical activation curve.*

In a third step, the ARG parameterization is applied offline using both cloud-base aerosol number concentrations and thermodynamic properties diagnosed from the LES output and is shown in Appendix B. A similar behaviour is apparent in BRATIO simulations (Fig. 9f-j), though the density distribution is broader, indicating a higher droplet number for comparable updrafts. A slight increase in the maximum updraft velocity is also evident as observed in Fig. 9j.

In summary, the emergence of branches in Fig. 9 reflects a combination of physical variability at cloud base, namely aerosol availability, updraft velocities and thermodynamic conditions. Numerical effects cannot be ruled out, however advection-related convergence or accumulation of sedimentating droplet within updrafts would affect both branches, yet the green curve fits the parcel model; spurious supersaturation (Stevens et al., 1996) and limitations in spatial and temporal resolution may contribute".

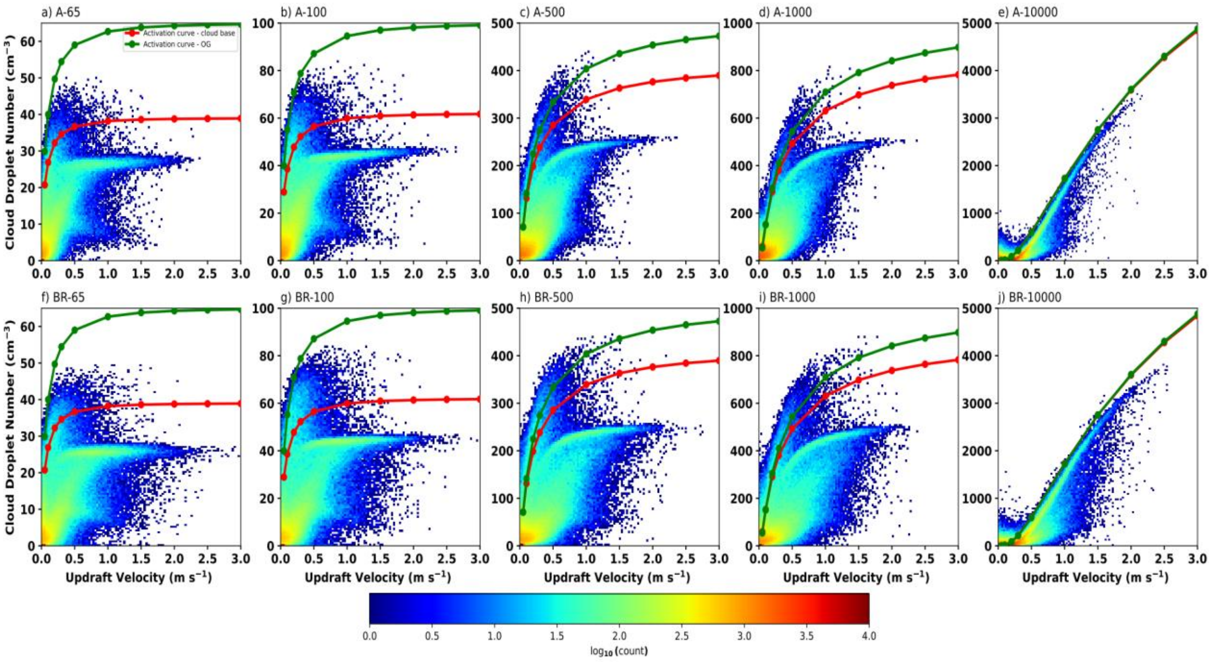

Figure 9: Joint distributions of cloud droplet number concentration (cm^{-3}) and updraft velocity (m s^{-3}) at cloud base (lowest level where liquid water contents exceed 0.001 g kg^{-1}) for all simulations, computed from model output over the last 2 simulation hours. The colour shading represents $\log_{10}$(count). The green curve shows the offline parcel-model activation curve computed using the ARG parameterization for prescribed aerosol number concentrations and a range of updraft velocities. The red curve shows the activation curve obtained by applying the same parameterization using aerosol number concentrations averaged at cloud base from the LES output. The top row (panels a–e) shows the AERO simulations with increasing aerosol number concentrations (A-series): 65, 100, 500, 1000, and 10000 cm^{-3}. The bottom row (panels

f–j) shows the BRATIO (BR-series) simulations with enhanced updrafts, using the same corresponding aerosol concentrations.

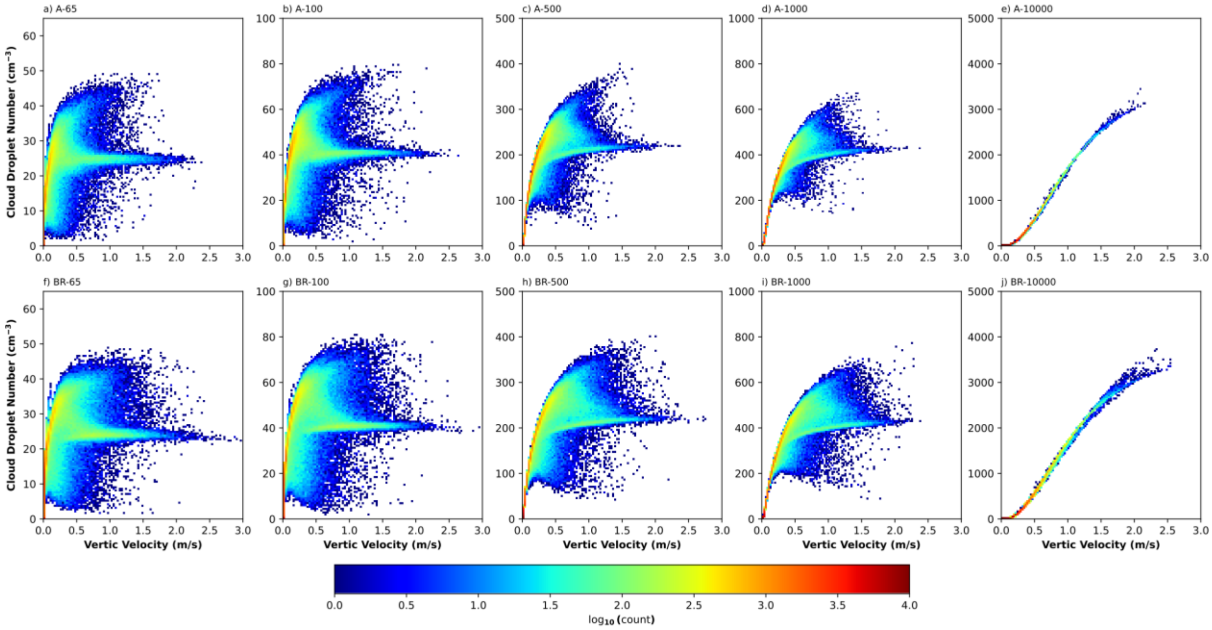

Figure B2: Joint distribution of cloud droplet number concentration (cm^{-3}) and updraft velocity (m s^{-1}) at cloud base (lowest level where liquid water content exceeds 0.001 g kg^{-1}) for the last 2 hours of all simulations with Abdul-Razzak and Ghan (2000) parameterization in offline mode using cloud-base thermodynamic and aerosol properties diagnosed from the LES

Minor Comment

1. Model response or physical response? In the light of the authors' aim to investigate their models capability of representing the aerosol- and updraft-limited regimes, a more critical evaluation of the microphysics scheme and its strengths and weaknesses in these simulations would be appropriate. This is partly covered in the main comments.

Response: As stated above, we have clarified that the results should be interpreted within the context of the employed bulk microphysics and the limitations of the ARG scheme. Deviations from idealized parcel-model activation behaviour have been illustrated and discussed through the offline activation curves presented above.

2. LWP distribution. In Lines 157 to 158, it is stated that a larger number of cloud droplets leads to a wider LWP distribution with lower peak values. This statement has not been reasoned. The word "Consequently" is not adequate and elaboration is necessary. I also am not convinced that this is actually apparent, since the effect which is significant from Fig. 2 is the transition to closed cells due to precipitation suppression, but the broader LWP distribution is, if evident, more likely to be caused by vanishing precipitation-induced cold pools which cease to create strong updrafts. Aerosol increases beyond that lead to a decrease in LWP due to evaporation-entrainment feedback, as indicated by the authors in lines 197-198. The total liquid water content does not stay the same.

Response: We thank the Reviewer for this insightful comment. As suggested, we have revised the paragraph describing the LWP distribution to provide a clearer and more physically consistent interpretation. In the revised manuscript, we emphasize that the reduction of high-LWP peaks and the broadening of the LWP distribution with increasing aerosol concentration are primarily associated with precipitation suppression and the resulting transition from open-cell to more closed-cell cloud organization, rather than a simple redistribution of a fixed total liquid water content.

We have updated the text originally at line 157 of the old manuscript to line 197 in the revised manuscript as follows: "*In particular, the cloud pattern in the A-65 simulation resembles the small-domain footprint of a larger open-cell cloud structure, with smaller clouds in comparison to simulations with higher aerosol concentrations, which may indicate more closed-cell structures. The transition from open- to closed-cell cloud structures with increasing aerosol concentration is primarily linked to precipitation suppression. The lower aerosol cases show higher peak LWP values, while the high-LWP peaks become less pronounced as aerosol concentration increases. In precipitating cases of lower aerosol concentration, precipitation-induced cold pools promote strong, localized updrafts, which generate regions of very high LWP. As aerosol concentration increases, precipitation is suppressed, causing the cold pools to dissipate, leading to weaker localized updrafts and a more spatially homogeneous cloud field. Although mean LWP decrease at higher aerosol concentrations due to enhanced evaporation–entrainment feedbacks, LWP is distributed over a larger number of grid cells*"

3. Stratocumulus or cumulus? The small patches of high liquid water path in Fig. 1 and the behavior described in line 224 indicate beginning cumuli-form convection behavior. A representative x-z slice showing cloud water content through the domain could give the reader a better idea of the clouds in the simulations.

Response: As suggested by the Reviewer, we now include an instantaneous x–z cross-section of cloud liquid water content at a fixed y location (y = 4 km) at the end of the third hour of simulation, and have added the corresponding figure and text in Appendix of revised manuscript as " *Figure A3 shows that for all simulations the cloud layer remains shallow, with cloud-top height remaining approximately constant despite changes in aerosol concentration and updraft velocity, indicating that the clouds retain a stratocumulus character, although localised vertical structure is present.*"

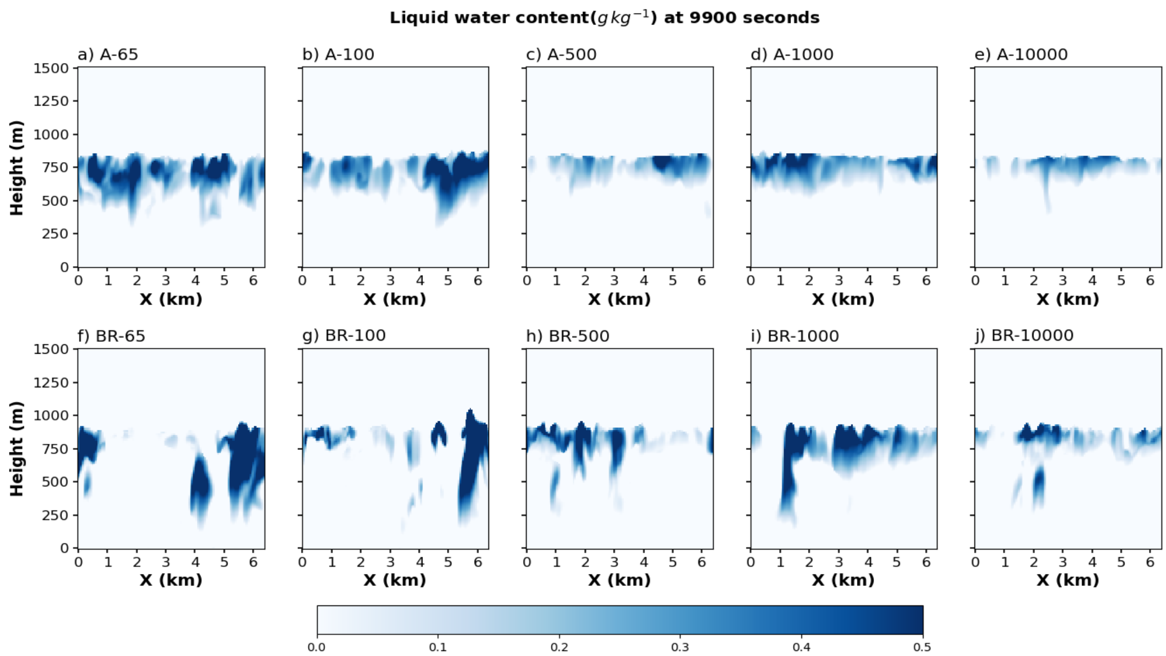

Figure A3: X-Z cross-section of Liquid water content (g kg^{-1}) for y = 4 km at the end of the 3rd hour of AERO a) A-65, b) A-100, c) A-500, d) A-1000, e) A-10000, and also for BRATIO f) BR-65, g) BR-100, h) BR-500, i) BR-1000, and j) BR-10000.

Technical comments:

1. Consistent layouts should be used for Figs. 1 and 5, since they show the same thing for two different sets of simulations.

Response: We have now used consistent layouts for Figures 1, 5 and updated in the revised manuscript.

2. Figure 4c: It could be useful here to average only over cloudy grid boxes to give more realistic values of cloud droplet numbers.

Response: We now compute and plot cloud droplet number concentration averaged only over cloudy grid points, defined using a threshold of q_c > 0.001 g/kg. The updated Figure 4 is shown below, with cloud droplet number plotted on a logarithmic scale for clarity.

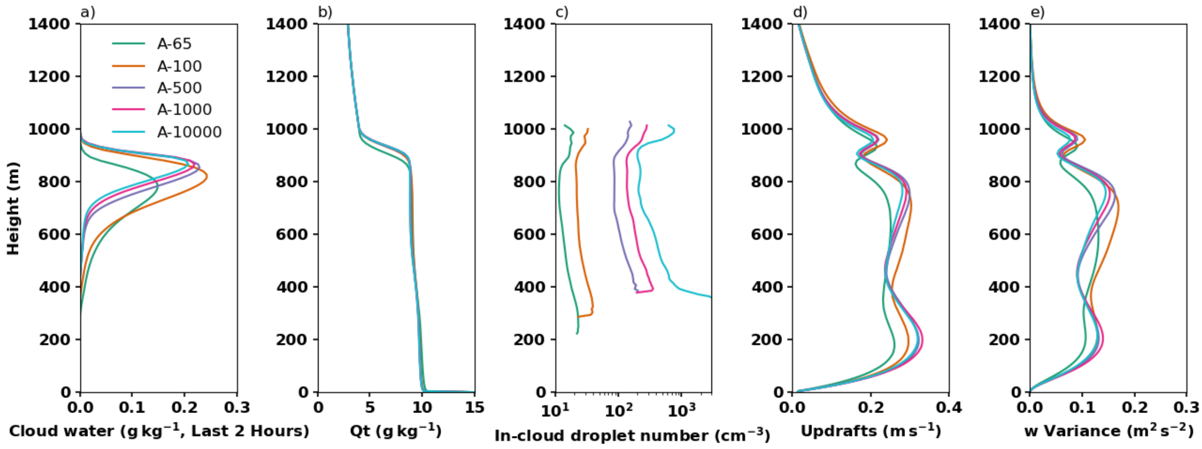

Figure 4: Vertical profiles averaged horizontally and over the last two hours of simulation for (a) cloud water content (g kg^{-1}), (b) total water mixing ratio (g kg^{-1}), (c) in-cloud droplet number concentration (cm^{-3}) on log scale, (d) updraft velocity (m s^{-1}), and (e) vertical velocity variance (m^2 s^{-2}) for AERO simulations.

3. Figs. 1 and 5: The definition of cloud base height and cloud top is not clear.

Response: We now give the definition of cloud base as the lowest grid point where cloud liquid water content (qc) is greater than 0.001 g/kg, and cloud top as the highest grid point for the same condition, and updated in line 161 of the revised manuscript.

4. Ll. 26-28: The second part of the sentence might be misleading, as the limited vertical extent is not the crucial factor, but the combination of low cloud base and limited vertical extent. I suggest reformulation to "Being low-level clouds with limited vertical extent, their effect on longwave radiation at the top of the atmosphere is minimal."

Response: As suggested, we have changed the confusing line to "*Being low-level clouds with limited vertical extent, their effect on longwave radiation at the top of the atmosphere is minimal*".

5. Ll. 33: The word „Thus" implies that the aforementioned is the reason for the following statement. This is not true in this case, as the susceptibility of marine stratocumulus is neither due to supersaturations ranging between 0.1% to 2%, nor from being warm clouds (but rather due to limited aerosol concentration and LWP).

Response: The susceptibility was not the focus of this statement; however, we agree that the word "Thus" is leading to an unintended relationship.

As suggested, we have revised the wording to: "*These clouds are highly sensitive to aerosol perturbations, as they often occur in environments with low aerosol concentrations and limited liquid water path. Consequently, any change in aerosol amounts or properties will readily impact stratocumulus microphysical and radiative properties, with further impact on the cloud evolution, including updraft velocities, precipitation formation, and cloud lifetime (Albrecht, 1989).*"

6. Line 49: The word „adiabatically“ is superfluous here, since no parcel in the atmosphere is lifted truly adiabatically.

Response: We agree and the word "adiabatically" is removed from revised manuscript.

7. Line 116: The words „varied across four cases“ are followed by five numbers. This might be a typo.

Response: We thank the Reviewer for pointing out the error. We have now corrected the typo.

8. Line 150: It seemed to me that there is no precipitation for aerosol concentrations above 100 per cubic centimetre. There cannot be any subsequent precipitation suppression then. While the cloud base plots do show an increase for increasing aerosol concentrations, the cloud tops seem to stay at the same level. The increased cloud base might be due to a drying boundary layer. This is the result from increased mixing with dry above-cloud air for larger aerosol concentration, which was indicated by the authors.

Response: We thank the reviewer for pointing to an interesting phenomenon. We agree that there is no precipitation after the spin period for aerosol concentrations greater than 100 cm^{-3} and therefore precipitation suppression alone cannot explain the observed increase in cloud-base height. The time series shown in Figure 1 of manuscript indicates instead a gradual rise in cloud-base height with increasing aerosol concentration, which is also consistent with the instantaneous x–z cross-sections discussed above. We therefore now attribute the increase in cloud-base height primarily to boundary-layer drying associated with enhanced entrainment and mixing of dry air from above the cloud layer.
We have revised line 150 from previous manuscript to line 180 in revised manuscript as: "*Moreover, cloud-base height increases gradually with increasing aerosol concentration, while cloud-top height remains approximately constant for aerosol concentrations greater than about 100 cm^{-3}. From 65 to 100 cm^{-3}, this increase is partly associated with precipitation suppression; while for higher aerosol concentrations, when precipitation is absent, the continued rise in cloud-base height is primarily linked to boundary-layer drying due to enhanced entrainment (Fig. A1) and mixing of dry air from above the cloud layer*".

9. Line 171: A consistent threshold to identify cloudy regions should be used to increase accessibility and consistency of the manuscript. In Fig. 2, it is 2 g/m2, while in line 171, it is 5 g/m^2.

Response: As suggested, we have now used the consistent threshold of 5 g/gm^2 for Fig. 2 and Fig.3 and updated the revised manuscript.

10. Line 181: There also seem to be clusters at 2 and 3km.

Response: Thanks for pointing out. We have revised the line 181 from previous manuscript to line 227 of revised manuscript as "*The simulation with aerosol concentration 100 cm^{-3} shows the same behaviour but with fewer smaller clouds and the appearance of a few cloud structures with a cluster size ranging from 2 to 5 km*".

11. Line 181: „These“ should be „The“, otherwise the 5km clouds are regarded to as smaller sized.

Response: As suggested, we have now changed the word from 'These' to 'The'.

12. Line 361: „z_i is the minimum height of the total water gradient" - This statement is not clear. The total water content has a gradient everywhere. Maybe the height of the maximum total water gradient was meant.

Response: Yes, that was an error. We have now corrected the definition of z_i as the height of maximum total water gradient and updated the manuscript.

Reviewer 2

This study shows that the MONC LES model can simulate stratocumulus clouds in both aerosol-limited regime and updraft-limited regime. However, the aerosol effects on stratocumulus cloud droplet number concentration, LWP, and also cloud morphology shown in this study are pretty much similar to results in previous studies. It is also known from previous studies that more aerosol would be activated to cloud droplets, and clouds would have higher susceptibility, when updraft velocity is stronger. Therefore, this study actually does not show much new findings regarding the aerosol effects on stratocumulus clouds. Nevertheless, the manuscript shows that the model has the ability to simulate cloud susceptibility in different regimes, and the conditions under which the regime can shift from aerosol-limited to updraft-limited or from updraft-limited to aerosol-limited. I think the manuscript provides very clear results on the conditions for these transitions for the simulated stratocumulus case. Below are some suggested revisions to improve the manuscript:

We thank the Reviewer for this detailed and constructive assessment. Although aspects of this study are broadly consistent with results reported in previous studies, the Reviewer's comments helped us better articulate the objective of this study, which is to demonstrate how to obtain with LES aerosol-limited and updraft -limited regimes, especially the latter, which is not trivial. We discuss and explain the differences in cloud properties between regimes and quantify these regimes in terms of cloud property change using susceptibility. As suggested by the Reviewer, we now more clearly base our analysis on the quantification of susceptibilities and have added susceptibility to updraft velocity to more objectively separate the two regimes.

1. The values of cloud susceptibility parameter beta shown in lines 259-263 are very useful. These values can give us an idea when aerosol effect is very important and when it is not so important. I would suggest these values of susceptibility parameter are presented in the Abstract. A quantitative description of susceptibility parameter can help us understand the arguments in the Abstract. In addition, is it possible to use the susceptibility parameter to set a criterion for determining whether it is aerosol-limited or updraft limited?

Response: We agree that the susceptibility values are important and, as suggested, we have revised the abstract and the analysis to make susceptibilities more prominent. However, our limited set of simulations does not allow us to identify a threshold on susceptibility that would determine the regime in a generic way. Figure 7 has been updated by adding susceptibility of cloud droplet number to the 90th percentile of updraft velocity and discussion has been added. We now move the change in susceptibility with LWP to the Appendix. The updated Figure 7 and revised text are as below:

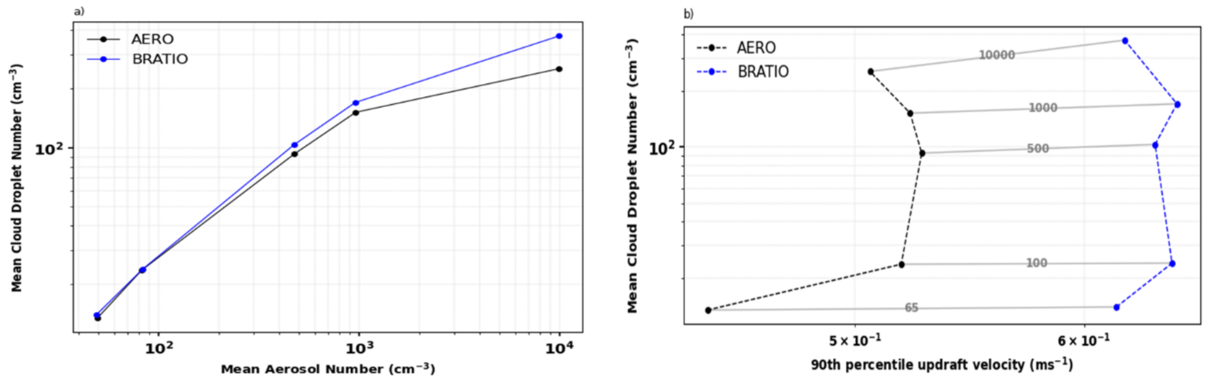

Figure 7: Dependence of mean cloud droplet number concentration (cm^{-3}) on (a) aerosol number concentration (cm^{-3}) and (b) 90th percentile of updraft velocity for two experiments: AERO (black line) and the BRATIO (blue line). In panel (b), grey lines connect the AERO and BRATIO results for identical initial aerosol number concentrations.

"*Figure 7b illustrates the relationship between cloud droplet number and the 90th percentile updraft velocity for different aerosol concentrations in AERO and BRATIO. In order to further understand the impact of aerosol and updraft on cloud droplet number, updraft susceptibility parameter* $\beta_{w90} = \frac{\partial \ln N_d}{\partial \ln w_{90}}$ *is introduced, where* w_{90} *is the* 90^{th} *percentile of updraft velocity. This parameter complements the aerosol susceptibility* β *shown in Figure 7a and helps diagnose the dominant activation regime. For both AERO and BRATIO, the dependence of updraft on aerosol concentration is weak, except for 65 and 100* cm^{-3}*, where an increase in aerosol concentration increases updraft velocity. However, in the aerosol limited regime (aerosol 65 and 100* cm^{-3}*) where* β *is equal to one for both cases,* β_{w90} *is only around 0.1, indicating that increases in updraft velocity do not substantially enhance cloud droplet number because activation is already saturated. In the transitional regime for aerosol concentration 500 and 1000* cm^{-3}*,* β_{w90} *increases to 0.57 and 0.54, while* β *falls to 0.8-0.6, confirming that both aerosol availability and updraft strength jointly controls activation. For 10000* cm^{-3} *in the "aerosol rich regime",* β_{w90} *is greater than 1, show that dependence of cloud droplet number on updraft velocity is strong.*"

2. It is quite interesting to discuss the open-cell and closed-cell structures for AERO in Figure 3. But the manuscript does not seem to provide enough discussions on this issue for BRATIO. For the AERO experiments, we can see that cloud morphology changes from open-cell to closed-cell structure as aerosol concentration increases. My question is: does the open-cell structure belongs to aerosol-limited regime, whereas the closed-cell structure belongs to the updraft-limited regime? If so, do you find the transition of cloud morphology to more open-cell structure in the BRATIO experiments (since BRATIO experiments show shift toward the aerosol-limited regime)? I can see from Figure 2 that BRATIO experiments have LWP fields that are more inhomogeneous than AERO. It would be very interesting to see the cloud cluster size for BRATIO and see if there is transition to more open-cell structure.

Response: We agree that, in the original manuscript, the discussion of cloud morphology was more focused on the AERO experiments.

Following the Reviewer's suggestion, we now include an analysis of cloud cluster size for the BRATIO simulations, computed over the last two hours of the simulations. The updated Figure 3 in the revised manuscript, and revised the text are below:

"However, for the BRATIO case (Fig. 3b), none of the BRATIO simulations exhibit cloud cluster sizes comparable to the domain size, and the number of large clusters is significantly lower than the AERO.

The cloud field in BRATIO experiments is more fragmented and spatially inhomogeneous, consistent with a shift toward more open-cell–like structures and consistent with the distribution shown in Fig. 2. The difference plot (BRATIO minus AERO; Fig. 3c) highlights this contrast. It can also be observed in Fig. 3c, that the BRATIO case has a greater number of very small cloud clusters of less than 1 km and few large clusters ranging from 1 to 4 km, while the negative tail at large diameters reflect the presence of domain-scale cloud cluster in the AERO case."

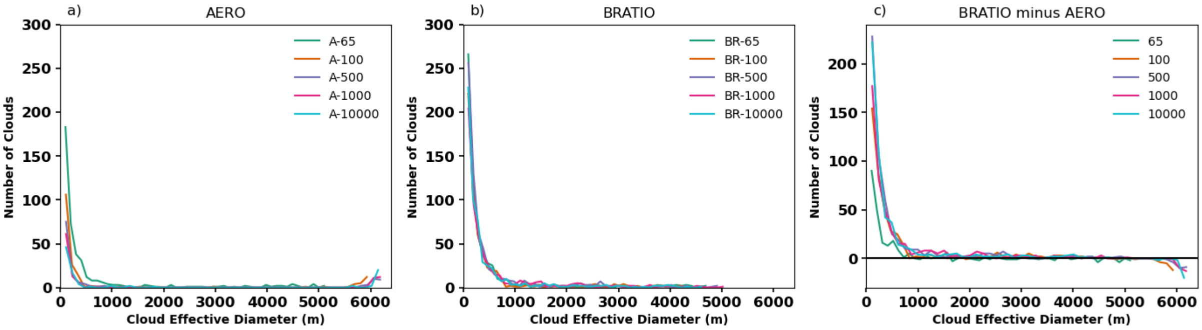

Figure 3: Distribution of Cloud cluster effective diameter, in m, for the a) AERO, b) BRATIO and c) difference BRATIO minus AERO simulations.

3. Discussions in lines 288-318 are very misleading. I agree that cloud droplet number and updraft velocity do seem to have a positive correlation in each experiment. But if we compare all the AERO experiments, from A-65 to A-10000, it is seen that cloud droplet number increases significantly (Figure 4c), but updraft velocity does not change very much (Figure 4d). The updraft velocity may increase a little due to enhanced evaporation and turbulence when aerosol concentration is higher, but the increase is not significant. The writing of lines 288-290 may also need to be revised. Here "the coupling (between aerosols and updraft velocity)" is used. This could be confused with the "interplay between aerosol and updraft velocity" as described in the title. I believe "coupling" and "interplay" in this manuscript means completely different issues. But because these two words have similar meanings, I strongly suggest revising the writing in lines 288-290.

Response: Yes, cloud droplet number and updraft show a positive correlation and that is consistent with the parcel model and Abdul-Razzak and Ghan (2000) activation parametrization. We agree that as the aerosol concentration is increased, we do not observe the comparative increase in updraft velocity, except in the A-65 simulation. The simulations are performed with a prescribed large-scale domain-wide divergence of $3.75 \times 10^{-6}\ s^{-1}$, representative of marine stratocumulus conditions, which constrains the magnitude of vertical velocity unless stronger surface forcing is applied. As a result, increases in updraft velocity with aerosol concentration are weak and secondary compared to the direct aerosol effect on cloud droplet number. We agree that coupling was the wrong word and we have updated lines 288-318 in previous manuscript to lines 372-415 in the revised manuscript to clearly address this issue as stated in the major comments of Reviewer 1 above.

4. Figure 8 and Figure 9, what is the unit of density? Please explain why the clouds with high cloud base have high number concentration at low updraft. It is also not very easy to understand why some clouds would have high cloud base in a stratocumulus cloud case. I would imagine the cloud base is more uniform. Are these clouds with high cloud base related to open cells?

Response: In Figures 9 and 10 (previously Figure 8 and 9), the color shading represents $\log_{10}$(count), i.e., the number of samples in each bin of the joint distribution; this has now been clarified in the figure captions of the revised manuscript.

We have now clearly stated and explained the reason for the second branch at which we observe high concentration with low updraft, in reply to Major comments of Reviewer 1 and updated the text from line 372-415 of revised manuscript. Please see above.

5. The title of 3.1 should be changed to "transition from aerosol-limited regime to updraft-limited regime", because the transition is discussed in this section.

Response: As suggested, we have now changed the title of Section 3.1 from "Updraft limited regime" to "Transition from aerosol limited to updraft limited regime"

6. Panels in Figure 4 better use same horizontal scales as panels in Figure 6.

Response: As suggested, we have now used the same horizontal scales for Figure 4 and Figure 6.

7. Lines 194-196, "attributed to enhanced radiative cooling near cloud top", please provide evidence for this or provide a reference for this conclusion.

Response: We thank the Reviewer for pointing that out. As suggested, we have provided the reference to the conclusion. (Christensen, M. W. et al. (2024). Aerosol-induced closure of marine cloud cells: enhanced effects in the presence of precipitation. https://doi.org/10.5194/acp-24-6455-2024)

8. Line 212. "The strength of updrafts within an air parcel", better be changed to "the strength of updrafts of an air parcel", because an air parcel moves with an updraft.

Response: As suggested, we have now changed "The strength of updrafts within an air parcel" to "*The strength of updrafts of an air parcel*".