Response to RC2 of manuscript egusphere-2023-2507 submitted to Geosci. Model. Dev.

Apr, 2024

## 1. General Response:

The ‘Preliminary evaluation of the effect of electro-coalescence with conducting sphere approximation on the formation of warm cumulus clouds using SCALE-SDM version 0.2.5-2.3.0’ focuses on numerical modelling of particle coagulation in a Cumulus cloud typical of fair-weather convection. The focus is on studying the effects of droplet charges on the effectiveness of coagulation, and the resultant changes in rainfall properties. The study employs a two-dimensional idealised fluid dynamics setup resolved on a grid with 50m spacing, with no subgrid-scale dynamics representation. The particulate phase is represented with simulation point particles, each representing a sample of modelled droplets. The simulation particles undergo collisions (only with other simulation particles, not within the subpopulation represented by each of them), and the resultant coagulation efficiency is parameterised taking into account theoretical considerations for the enhancement of collisions probability due to the particles being charged. The simulations do not involve tracking particle charges - these are a priori determined as a function of the droplet size. Particle collisions are treated employing coagulation kernel approach, without assessing the inter-particle distances. Besides collisions, the particles are subject to condensational growth and evaporation, sedimentation and advection with the flow. The representation of collisions and the initial sampling of the simulation particle population is probabilistic, and the study analyses 50-member ensembles for each setup.
Unfortunately, it is hard not to begin with pointing out that the lax approach to text and figure composition, reference consistency and equation typesetting distracts from the paper’s content and tarnishes overall impression. The manuscript was submitted prematurely and calls for a major revision.
We greatly appreciate the invaluable and constructive feedback provided by Reviewer #2. We have acted upon all the points raised. We believe the current manuscript is greatly improved through addressing the review comments and further elaborating the methods and results.

## 2. Detailed Responses:

### Overall impression and suggestion of a major revision

Thank you for your comments, we will answer these comments and explain my revision point by point.

- **The choice of the particle-resolved method is not explained - what are the benefits, tradeoffs, limitations as compared to other modelling techniques, in the very context of modelling charged-particle interactions?**
  We appreciate this observation and have revised the explain the advantages and shortcomings of particle-base method compare to bin method and bulk method at the beginning of section **2. Description of the cloud model** (page: 3, line: 97-101) as follow:
  The particle-based microphysics method, which calculates the electro collision-coalescence kernel in real time, offers more detailed insights into droplet behavior influenced by electrostatic forces, surpassing the bin method that relies on lookup tables (Khain et al., 2004), while also demanding less computational resources.
- **What are the implications of one of the key assumptions, namely that the drop charge is merely parameterized as a function if its size?**

Thank you for pointing out this issue. Based on the formulas for the voltage near a charged spherical particle and the breakup voltage in air, we have expanded section **2.4 Collision-coalescence and the Electric Effect** (p7, l227-239), to include a detailed derivation of how the charge amount can be parameterized as a function of droplet radius:

The voltage near a charged spherical particle is described by $U = q / 4\pi\varepsilon_0 r^2$ (Bleaney and Bleaney 1993), here $\varepsilon_0 = 8.854\times10^{-12}$ is the dielectric permittivity of free space. The maximum charge that cloud droplets can carry is determined by the air breakdown voltage $U_b \sim 3\times10^6$ $\mathrm{Vm^{-1}}$ (Meek and Craggs 1953). Consequently, the maximum charge that droplets can carry is as follows:

$$q_{\max} = 4\pi U_b \varepsilon_0 r^2 \quad (17)$$

To simulate droplets in weakly electric field, we following Andronache (2004), described the mean charges on the larger droplet and smaller droplet in a pair of droplets as a function of the droplet radii as follows:

$$Q_R = 4\alpha AR^2,\ q_r = 4\alpha Ar^2 \quad (18)$$

Here $A = \pi \times U_b \times \varepsilon_0 \times 10^{-2} = 0.83\times10^{-6}$ is two orders of magnitude smaller than the maximum particle charge, representing weakly charge condition, and the charging rate $\alpha$ is an empirical parameter ($\alpha$ is referred to herein as the droplet charging rate, equal to ratio of particle charge amount and maximum possible charge) that varies between 0, which represents neutral particles, and 7, which represents highly electrified clouds associated with thunderstorms (Andronache, 2004).

- **Unlike the velocity-differential driven gravitational coagulation, the Brownian mode applies to same-sized particles, and thus should occur also within particles represented by a single simulation particle, which IIUC is not the case in the model?**

Thank you for your comment. Brownian motion would not significantly affect the coalescence or collision of droplets of similar sizes. Brownian motion primarily influences the movement of very small particles, such as aerosols or dust smaller than 0.1 micrometers, rather than the larger droplets commonly found in clouds. Particles larger than 1 micrometer are predominantly governed by gravitational effects and fluid dynamics.

For droplets of same size, the impact of Brownian motion is negligible. These droplets possess enough mass to render the random molecular collisions characteristic of Brownian motion inconsequential. Instead, their movement and interactions are more likely to be driven by factors like fluid dynamics, gravitational settling, and potentially electrical charges, rather than by Brownian motion.

It's also worth noting that particles within the 0.1 to 1 micrometer range typically exhibit lower concentrations, a phenomenon known as the Greenfield gap. A key focus of our study is on how the electro-coalescence effect enhances the collision-coalescence kernel within this size range that increases rain in the warm cumulus cloud.

- **Despite the whole paper focuses on fair-weather convective cloud simulation, and only the**

**very last sentence of the Discussion section relates to fog, the Conclusions section puts forward a hypothesis that "Electro-coalescence has a larger impact on highly polluted warm clouds or fog" - are there grounds for this statement**
**in this study?**

Thank you for your observation. We removed the part that involved fog elimination in the **Discussion** and **Conclusion** section.

- **More background on electro-coalescence would help to cater to readers not acquainted with the earlier works of the authors, and to highlight the importance of the results by explaining a broader perspective on the challenges in this domain, from measurement, theoretical and numerical modelling perspectives.**

Thank you for your comment. We have revised the **Introduction** to highlight previous contributions from authors more prominently. Additionally, we introduce the measurement of the electric field within an actual cloud and include the progress of previous work on the parameterization of electro-coalescence modeling:

In weakly electrified clouds, the accumulation of space charges on droplets is controlled by the diffusion of atmospheric ions produced by the cosmic ray flux, and the concentration is dependent on the ratio of attachment and recombination and the downward ionosphere-earth current density (Jz). When the Jz penetrates the cloud, the gradients of the electric field at the cloud boundary could generate net positively charged droplets at the upper cloud boundary and net negatively charged droplets at the lower boundary (Zhou and Tinsley, 2007; Nicoll and Harrison, 2016). The observations of Beard et al. (2004) revealed that with a Jz of 1-6 pAm-2 in stratocumulus and altostratus clouds, a cloud droplet with radius of 10 microns can accept approximately 100 elemental charges, which is consistent with the theoretical calculations by Zhou and Tinsley (2007). In the cumulus, with vertical convection, the charged droplets at the boundaries can be mixed, droplets with opposite sign charged affect by electro-coalescence. The maximum charge on the droplets is determined by the air breakdown voltage for corona discharge (Meek and Carggs, 1953) and is a quadratic function of the droplet radius (Khain et al., 2004; Andronache, 2004).

Numerous studies have focused on parameterizing the microphysics of the electro-coalescence of particles, the challenge is to approximate calculate the electrostatic force between charged droplets. In the 1970s, the collision efficiency of oppositely charged droplets evaluated with a centered Coulomb force indicated that only in strongly electrified clouds can the charge on droplets significantly affect cloud droplet coagulation (Wang et al., 1978). The series of trajectory simulation work by Tinsley et al. (2001, 2006), Zhou et al., (2009) and Tripathi et al., (2006) revealed that in a weakly electrified cloud, when taking into account the image charge force, the collision rate coefficient between the charged droplets could be different. Even with droplet charges of the same sign, the collision rate coefficient could be enhanced as a function of the charge on the particles with radii ranging from 0.1 microns to 10 microns (Zhou et al., 2009). Then, with a sufficiently large charge on the droplets, the so-called Greenfield gap (Greenfield, 1957) could be closed. Simulation results showed that for particles with radii smaller than 0.1 microns, when the particles obtain a large charge due to the evaporation of highly charged droplets, the collision rate coefficient is significantly decreased due to the repulsive electric force of droplets with charges of the same sign and is increased for charges of the opposite sign (Tinsley and Leddon, 2013). The updated simulation by Zhou et al. (2009) with an exact electric force treatment with the conducting sphere (CS) method indicated that the collision efficiency is a factor of two higher in the Greenfield

Gap than that from the results of single image charge (IM) treatment. A few laboratory experiment results were consistent with these theoretical simulations (Ardon-Dryer et al., 2015). These findings highlight the need to represent coagulation due to droplet and aerosol charges in the cloud model. Khain et al. (2004) (hereafter Khain04) conducted a 0-dimension simulation to study the effect of seeding charged droplets on a cumulus cloud using the spectral bin cloud model with a 4-dimensional (mass and charge rate of two droplets) collision efficiency lookup table based on the static electric force between charged droplets. The results showed a significant response in the evolution of clouds due to charged droplets. 5% of maximum charge amounts of natural droplets, which is 2.5 times larger than the results from Zhou et al. (2007), was used in Khain04 to investigate their influence on rain enhancement and fog elimination. Andronache (2004) and Wang et al. (2015) claimed that charged droplets significantly contribute to below cloud scavenging according to the analytical formula suggested by Davenport and Peters (1978), where the minimum amount of charge on droplets is 7% of the maximum limit. However, only Coulomb force (CB) treatment was used in Andronache's and Wang's simulation.

**Detail comments**

**Abstract:**

- **the first sentence of the abstract does not seem to apply to this paper - the analytic expression is not established here, it is used here? (if not, please clarify in the text)**

  Thank you for your comments, we apply the analytic expression of conducting sphere method to approximate the electrostatic force in this paper.
- **the abstract should clearly state what kind of simulations are done (2D, flow-coupled, capturing aerosol microphysics, warm rain, no subgrid dynamics, ...)**
- **it should be indicated that despite employment of a particle-resolved microphysics representation, the particle charges are not among the particle attributes**
- **similarly, worth clarifying that despite calculating drop trajectories, collisions are modelled assuming well-mixed coalescence volume assumption**
- **worth iterating the considered options of assumptions regarding charge treatment (e.g., charge polarity always opposite, ...)**

  Thank you for the comment, we clarified the simulation detail setup in the abstract as follow.

  This study employs 2D simulation in flow-coupled model that captures aerosol microphysics in warm cumulus case without relying on subgrid dynamics process, we assume droplets are always with opposite charge and well mixed in the cloud and charge is not a particle attribute in the simulation.
- **provision of numbers with 3 significant digits in the abstract (e.g., 5.42% higher) seems overzealous**

  Thank you for your comment. In response, we have simplified the abstract by removing three significant digits to more clearly present the conclusion.
- **it is worth to highlight the probabilistic nature of the simulations and the number of realisations employed in the study**

  Thank you for your comment. We have clarified in the abstract that each case involves 50 random runs for simulation realization as follows:

  To assess fluctuation effects, we conducted 50 simulations with varying pseudo-random number sequences for each electro-coalescence treatment.

- **usage of the word "treatment" in the abstract suggests that CS is an alternative to super-droplet method (line 17)**

  Thank you for your observation, modified word "particle treatment" to "particle-based method" in abstract.

- **according to the GMD guidelines (https://www.geoscientific-model-development.net/submission.html#manuscriptcomposition), references should not be included in the abstract unless urgently required - suggest removing the reference to Khain 2004 (retaining the rest of the sentence)**

  Thank you for pointing out this issue. We have removed the reference from the abstract and apologize for the oversight in meeting the specifications.

**Code and data availability**

We agree with the comments of code and data availability, we have update the Zenodo code and data in https://zenodo.org/records/11058066.

- **the Zenodo archive contains four 9GB tar files without any annotation or metadata, with two-letter file names – one can guess that these contain simulation output, but provision of a description that can be accessed prior to downloading it would be helpful;**

  **Thank you for your kind comment,**

  Thanks for suggestions, we added description of the files in the Zenodo website:

  Ruyizhang2333/SCALE-SDM-electro-coalescence: SCALE-SDM-electro-coalescence-v0.3

  Ruyi Zhang

  The release used for Zhang et al. (2023).

  - Simulation codes and data analysis programs are provided in 'SCALE-SDM-electro-coalescence-v0.3.zip';
  - Package 'nc.tar' represents the simulation result of the 'No charge' setting;
  - Package 'cb.tar' represents the simulation result of the 'Columnb force' setting;
  - Package 'im.tar' represents the simulation result of the 'Image charge' setting;
  - Package 'cs.tar' represents the simulation result of the 'Conducting Sphere' setting;

  The user guide of SCALE-SDM please refers to 'README.md' within 'SCALE-SDM-electro-coalescence-v0.3.zip'

- **the referenced source code archive on Zenodo contains spurious non-portable compiler output (*.o, *.a, and *.mod files) which should be removed**

  Thank you for the comment, we removed the compiler output files and update the release of model.

- **the title mentions v0.2.5-2.3.0 but the README.md file gives v0.0-2.2.2 - please make it consistent and add to Zenodo metadata**

  Thank you for the comment, we modified the model version within README.md file and update in Zenodo.

- **the "The data ... are available from the corresponding author upon request" statement is not in line with the journal policies - the statement implies lack of anonymous and persistent access to the data and should be removed, while clarification on what is included in the multi-gigabyte datafiles on Zenodo provided**

  Thanks for comment, we removed this sentence in the manuscript.

- **Trying to understand the contents of the provided contrib/SDM/sdm_coalescence.f90 file, I became puzzled with why all the electro-coalescence efficiency calculation lines (824, 825, 828, 830 and 834) are commented out, only to realise that the README.md file hints that such code blocks need to be manually uncommented if trying to reproduce the simulation results -**

**it seems to be quite an obscure way to provide the code. Please provide the source code in a way that no manual alterations are needed to reproduce the results and that the version identifier provided matches the unmodified code used for simulations.**

Thank you for your important comment and suggestion, in the latest version, we use two namelist var "sdm_elecol" and "sdm_elerate" to setup electro-coalescence scheme and charge rate in run script. After this modification, users could select electro-coalescence scheme and set charge rate in the run script without recompiling the model. We didn't modify the subroutine program of the electro-coalescence scheme and made a test run to make sure the simulation output was inconsistence with the previous version.

**Figures**

Thanks for the important comment and suggestion, we have modified the figures following all the comments.

- **Fig 1: the kernel dimensionality should be volume over time, not volume over inverse-time**
- **the "*10-12" multiplication factor for Y axis in Fig. 1 is awkward given the 10-4 – 102 axis range – please avoid using scaling factors in labels**

Thank you for the comment, we modified the unit of x axis of fig1.

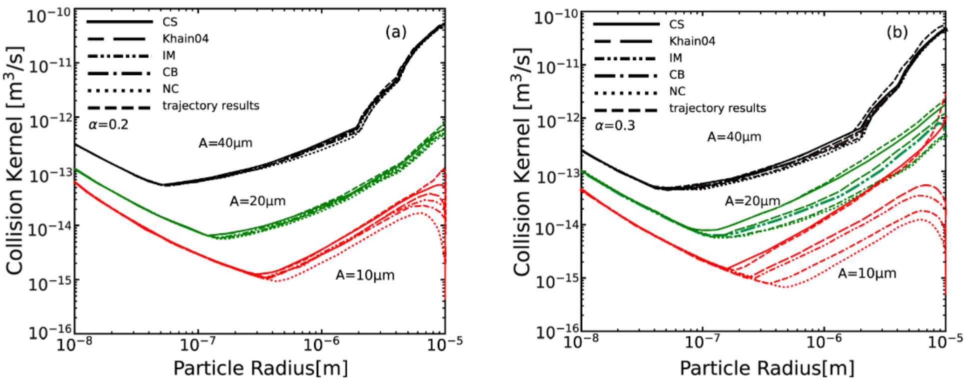


Figure 1: Comparison of the effect of electric charge on the collision kernel for droplets sized 40 μm, 20 μm and 10 μm with small droplet radii between 10-2 μm and 10 μm. The charging rate α is 0.2 for panel (a) and 0.3 for panel (b). The solid line represents the results where the collision kernel is calculated by the analytical expression and treats the charged droplets as CS setting. The long-dashed line represents the results calculated by the analytical expression and treats the charge droplets as Khain04 setting. The dashed-dotted-dotted line represents the results calculated by the analytical expression and treats the electrostatic electric force by the IM setting. The dashed-dotted line represents the results calculated by the analytical expression and treats the electrostatic electric force by the CB setting. The dotted line shows the results with NC setting. The dashed line represents the results of the trajectory simulation according to Zhou et al. (2009).

- **typo in Fig 3b and 5d: "Liquid" not "Liquit"**

Sorry for the misspell, modified fig3 x axis labels.

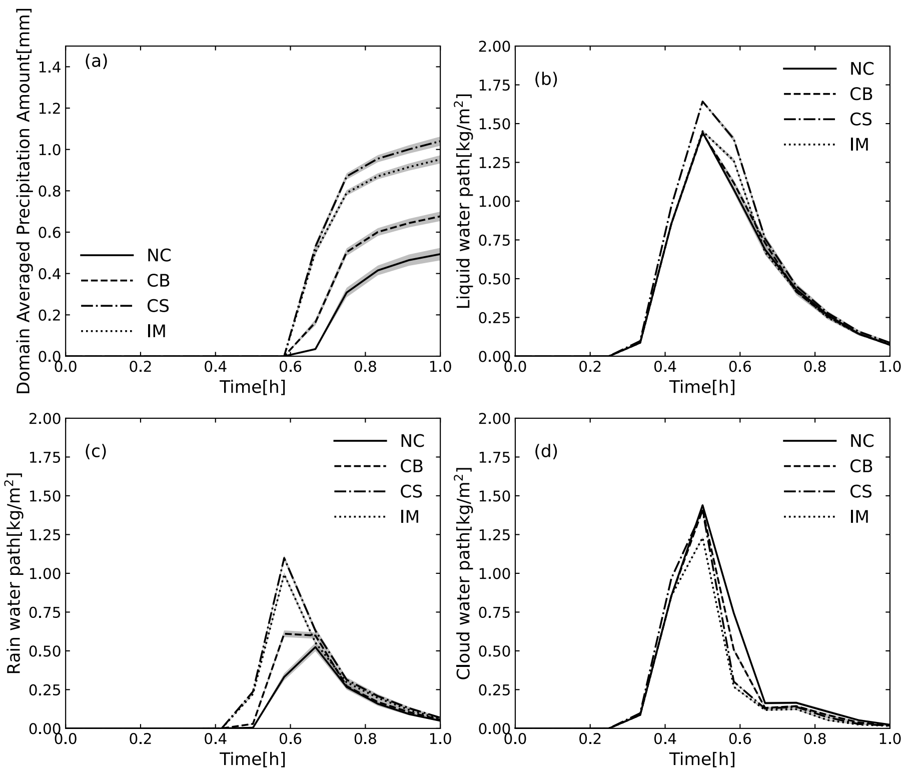


Figure 3: The time evolution of the domain-averaged precipitation amount (a) and the domain-averaged water path of the liquid water path (b), rainwater path (c) and cloud water path (d), which is consistent with Figure 2. The solid line represents NC setting, the dashed line represents CB setting, and the dashed-dotted line represents CS setting. The grey shade indicates the standard deviation calculated from 50 members of the random ensemble.

- **font sizes in the figure labels (incl. axis tick labels) should match text size, and be uniform, currently these span all sizes from unreadable small (Fig. 2!) to unreasonably large**

  Thank you for your comment, we replot the fig2 and make the title front size looks readable.

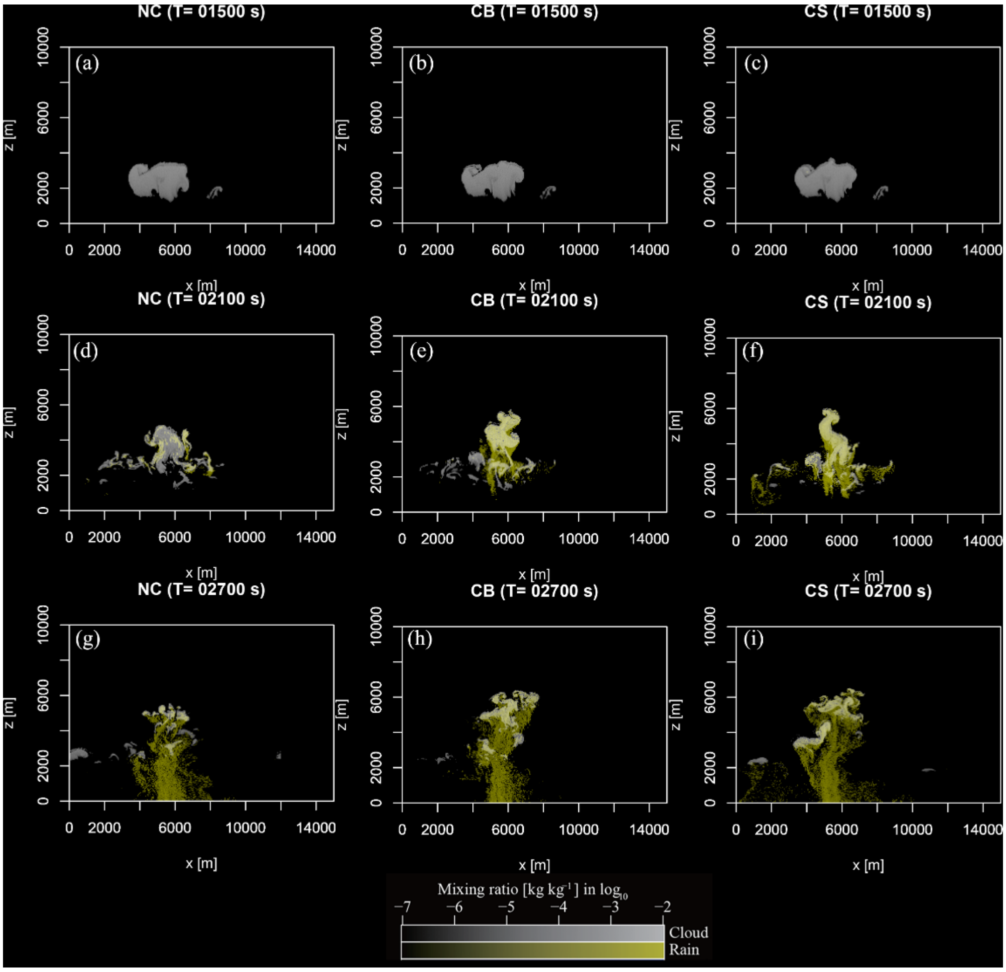


Figure 2: A comparison of the spatial structure of the mixing ratio of hydrometeors of the cumulus with NC setting, the electric force evaluated by CB setting and the electrostatic electric force evaluated by CS setting at times of 1500s, 2100s and 2700s. The charging rate α is 0.3.

- **the employment of a multiplication factor given above Y axis in figs 3a and 6-8 is misleading, non-standard and hard to notice, please use intuitive units instead**
- **labels are missing spaces between quantity name and unit parentheses, parentheses are sometimes ”()”, sometimes ”[]”**
- **the choice of X and Y axis ranges in figs 3a, 6-8 seems awkward (vast majority of the plot area is left blank for no good reason)**
- **some units are typeset in italics, some in normal font**
- **X axis in figs 6-8 would be more intuitive if presented in minutes/hours, while Y axis in mm**
- **figure quality is poor due to choice of inadequate raster graphics format, please use vector graphics**

  Thank you for your careful and important comments and suggestions, we replot all figures as vector graphics, used intuitive units and axis range for fig3a and 6-8, made unit parentheses consistent and typeset in normal font, and made X axis in fig6-8 in hour and Y axis in mm.

**Equations**

- **eq. 27 - split into two equations - the comma is hard to interpret**

Thank you for your comment, we split eq.27 to two equations as follow.

$$\xi(a,x) = n(a,x,t=0)/(N_s(0)p) \quad (28)$$

$$p(a,x) = p = \text{constant} \quad (29)$$

- **parentheses in equations are typeset with misleading sizes (small parens surrounding large parens)**

  Thank you for pointing out this issue, e retyped all equations using the equation application 'MathType' to make the equations more specification.

- **using almost identical "a" and "α" right next to each other is very misleading (e.g., eq. 17)**

  Thank you for your comment, we modified 'a' to 'A' of eq.17 to make it more readable.

$$Q_R = 4\alpha AR^2,\ q_r = 4\alpha Ar^2 \quad (18)$$

- **suggest avoiding defining parameters with their units, e.g.: "α (cm-2)" and mentioning unitless values in the text – it is clearer to write "rate α ... with a range of 0.1 – 0.6 cm-2 ..."**

  Thank you for your comment, α is empirical parameter don't have unit, we remove this $cm^{-2}$ in the text.

**Text comments**

- **line 26: "electrostatics on charged droplets" seems awkward - please rephrase**

  Thanks for comment, we rephrase this sentence as follow:

  It is found that the electro-coalescence effect could affect cloud formation even when the droplet charge is lower charge limit.

- **line 37: cite Rayleigh 1879 (https://www.jstor.org/stable/113853)?**
- **line 114: likely worth referencing Montero-Mart´ınez et al. 2009 (https://doi.org/10.1029/2008GL037111)**

  Thanks for comment, we added cite Rayleigh 1879 and Montero-Mart´ınez et al. 2009 in the text.

- **line 62: suggest replacing well-known with so-called**

  Thanks for comment, we replaced 'well-known' with 'so-called'

- **line 72: 0-dimension but 4-dimensional**

  Thanks for your comment, this sentence is misleading, we rephrase this sentence as follow:

  Khain et al. (2004) (hereafter Khain04) conducted a 0-dimension simulation to study the effect of seeding charged droplets on a cumulus cloud using the spectral bin cloud model with a 4-dimensional (mass and charge rate of two droplets) collision efficiency lookup table based on the static electric force between charged droplets.

- **line 91: remove "accurate"?**

  Thanks for comment, we removed "accurate"

- **line 100: why the radius is "equivalent"? (+unintentional "::" at line end?)**

  Thank you for your comment, the use of an equivalent radius in the Super-Droplet Method (SDM), is fundamentally about simplifying the complex interactions and transformations of water droplets in clouds while maintaining accuracy in simulations. We removed the '::' at the line end.

- **line 104: replace "floating in the atmosphere" with "in the domain"?**
- **line 109: "sediments" -> "sedimentation"**
- **line 126: "heat conditions" -> "latent heat release"**

Thanks for comments, we replace these words as suggestions in the text.

- **line 131: mixing coefficients, units and functional dependencies in one expression leads to ambiguities - e.g., what does K means here - thermal conductivity (should be in italics) or Kelvin (all units should not be in italics, but with upright font)**

  Thanks for the comment, we rephase this sentence to make units in upright font.
- **line 134: the water density was already defined in line 111**

  Thanks for the comment, removed the repeat definition.
- **line 143: parenthesis in eq. (5) suggest at first sight that $\pi$ is a function and E is a constant, while the opposite holds - please try to format the equations intuitively**

  Thanks for the comment, we format the equation 5 as follow:

$$K = \pi E\left(\left(R+r\right)^2 \left|v_R^\infty - v_r^\infty\right|\right) + K_B \tag{5}$$

- **line 146: the single-particle size is given along with "mean" charge of particles - how the mean is defined, why isn't it a mean size as well? Should it be characteristic instead of mean? - please elaborate on the assumptions needed to define the notion of the kernel in four dimensional attribute space**

  Thanks for the comment, we call it 'mean charge' following Andronache 2004 (https://doi.org/10.1016/j.jaerosci.2004.07.005 ), 'mean charge' represent the statistically averaged representation of the charges carried by particles as a function of radius.
- **line 175: eq. (16) is referenced before being given**

  Thanks for the comment, removed eq (16) in line 175.
- **line 183: different symbol used for terminal velocity than before**

  Thanks for the comment, modified the symbol of terminal velocity to keep consistency.
- **line 184: collision -> colliding**
- **line 185: Fes -> Fes**
- **line 236: element -> elemental (also in lines 418 & 437)**

  Thanks for the comment, replace these words as suggestions.
- **line 257: "the interception effect" was never mentioned before**

  Thanks for the comment, we added explanation of the interception effect in line 272-274 as follow:

  The interception effect in particle collision coalescence refers to the process where smaller particles are captured by a larger droplet's boundary layer and swept into it, even without direct contact, due to the aerodynamic airflow around the falling droplet.
- **line 302: please rephrase "number and size distribution are made"**

  Thanks for comment, we rephase this sentence as follow:

  The aerosol number concentration and size distribution were adjusted to 3, 6 or 9 times from that given in Van Zanten et al. (2011) for RICO intercomparison case.
- **line 304: the composition was already given in line 301**

  Thanks for comment, removed repeat composition.
- **lines 305-307: subscripts, units with upright font; also: worth mentioning that these parameters are actually altered across simulations (section 3.3)**

  Thanks for comment, we modified units to upright font and note the aerosol parameter were altered in the simulation as follow:

  The aerosol number concentration and size distribution is given by a bimodal log-normal distribution: The particle number concentrations of the two modes are $N_1 = 90\ \mathrm{cm^{-3}}$ and

$N_2 = 15$ cm$^{-3}$, respectively. Note that aerosol concentrations are multiplied by factors of 3, 6, or 9, depending on the aerosol background conditions.

- **line 310: it would be worth to clarify that Shima et al. (2009) includes warm-rain algorithm definition, while the 2020 paper includes mixed-phase extension (not used here) and coupling with SCALE (used here)**

  Thanks for comment, we pointed out we are running warm-rain simulation base on SCALE-SDM latest version as follow (line 332-335):

  This study concentrates on warm-rain microphysics. We developed a numerical simulation using the latest version of SCALE-SDM, specifically employing the SDM warm rain algorithm from Shima et al. (2009), rather than the SDM mixed-phase extension presented by Shima et al. (2020).

- **line 312: IIUC, the employed/developed SDM code is not available at the provided riken.jp URL – worth clarifying**

  Thanks for comment, we clarified the SDM code is not available in the riken url.

  Shima et al. (2009, 2020) constructed a particle-based cloud model SCALE-SDM by implementing the SDM into SCALE, which is a library of weather and climate models of the Earth and other planets (Nishizawa et al., 2015; Sato et al., 2015; https://scale.riken.jp). The SDM code is not accessible through this site.

- **line 313: provide reference for the lower cost mention**

  Thanks for comment, we added the reference mention lower computation cost (Shima et al., 2009).

- **line 330: this reads as if the fluid dynamics were not influenced by the latent heat budget of the particles, but surely are - should there be a third step defined?**

  Thanks for comment, we added third step as follow:

  The order of calculation in the model is as follows: 1) calculate the fluid dynamics without the coupling terms from the particles to moist air, and update the moist air; 2) update the super-droplets $\{\{\zeta_i, x_i, a_i\}\}$ from $t$ to $t+\Delta t$ . 3) We integrate one cloud microphysics process one time step forward and then moves on to the next process.

- **line 333: I fail to understand the "Process lags in time is calculated preferentially" statement**

  Sorry for unclear statement, we rephrase this sentence as follow:

  Lagging processes are prioritized in computational priorities to ensure their synchronization and accurately describe their subsequent impact, consistent with overall system dynamics.

- **line 340: refer to Lu & Shaw 2015 (DNS study, https://doi.org/10.1063/1.4922645) and elaborate on the implications of lack of small-scale turbulence representation**

  Thanks for important suggestion, we added reference and elaborate on the implications of lack of small-scale turbulence representation as follow:

  We are employing a subgrid-scale (SGS) turbulence model for dynamic processes, but not for cloud microphysics processes such as collision-coalescence enhancement, velocity fluctuations, and supersaturation fluctuations. This approach may lead to an underestimation of the collision rate of charged droplets (Lu & Shaw 2015). The simulations conducted are based on the Large Eddy Simulation (LES) methodology.

- **line 351: please underline that this is just one of 50 realisations simulated, and given that and the fact that these plots are hardly distinguishable, are the conclusions really supported by this figure?**

Thanks for the comment, we clarified that fig2 from the single run and replot it, I agree that the first row plots (1500s) look similar, but as the rain develops, three setups are distinguishable and support the conclusions.

- **line 363: should be ”standard deviation”, not ”standard deviation error”, right?**

  Sorry for the mistake, we plotted “standard error” here, modified all “standard deviation error” with ‘standard error’.
- **lines 365-366: are three significant digits for a percentage increase meaningful here?**

  Thanks for the comment, we think these three percentages better quantify the precipitation differences between the three methods.
- **line 388: is it both domain- and ensemble-averaged? (same remark for lines 397, 405, 410, 421, 471, captions of Figs 3, 5, 6, 7 & 8)**

  Thanks for your comment, we modified all “domain averaged” with “domain and ensemble averaged” in the text.
- **line 389: ”droplets with higher charging rate” suggests that within one simulation, different droplets have different charging rate, which is not the case, right?**

  Sorry for the unclear statement, we rephase this sentence as follow:

  However, cloud elimination is faster in higher charging rate condition, at 2700s, a lower charging rate condition results in a higher droplet mass density at a peak of approximately 1000 μm, which indicates that a higher charging rate results in a shorter lifetime of the cumulus cloud.
- **lines 406-407: four significant digits for percentage change grossly contrasts with the idealised setup of the simulations, with relatively small ensemble size, and with the (chaotic) nature of the modelled system**

  Thank you for your comment. We conducted 50 ensemble simulations across three aerosol backgrounds, and the results support the notion that electro-coalescence increases precipitation in warm cumulus clouds. We believe these findings are convincing.
- **line 494: check sentence grammar**

  Thanks for comment, we rephase this sentence as follow:

  The electro-coalescence effect on a weakly electrified warm cumulus was revisited. Assuming droplets with opposite signs are charged instantaneously by $J_z$, the amount of charge is determined by the size of the droplets.
- **caption of Fig. 5: should be ”water path”, not ”water precipitation” (three times)**

  Thanks for the comment, we corrected the caption of fig5.

**References**

- **Forbes & Clark is cited but not listed in references**
- **Zhang et al. 2019 cited in line 38 but not listed in references (likely meant to be Zhang et al. 2018 which is listed but not referenced in the text)**
- **Frederick et al. 2018 should be Frederick and Tinsley 2018 in line 42**
- **Beard (2004) should be Beard et al. (2004) in line 48**
- **Tripathi et al. (2006) is cited (in line 58) but not listed**
- **Andronache et al. (2004) should likely be Andronache (2004) in line 77**
- **K¨ohler et al. 1936 should be K¨ohler 1936 in line 122**
- **Bott 1998 is cited in line 152 but not listed in the references**
- **Seeßlberg should be Seeßelberg in line 152**

- **Seinfeld and Pandis is cited in line 155 but not listed in references**
- **Fuchs 1964 is cited in line 156 but not listed in references**
- **Shima et al. 2014 is missing a permalink: http://hdl.handle.net/2115/55063 (it would also be worth indicating that it is in Japanese)**
- **Davis 1964a and Davis 1964b are cited but not included in the references (lines 208 and 210)**
- **"Zhang,2023" reference given in line 507 is not listed in the references**
- **Rogers & Yau is cited but Yau & Rogers is listed**
- **Pruppacher & Klett is cited but Pruppacher, Klett and Springer is listed (BTW, the DOI is 10.1007/978-0-306-48100-0, please also double check the year)**
- **Sato et al. 2017, 2018 and VanZanten et al. 2011 have doubled journal names in the reference list**
- **Sate et al. references are not listed in chronological order**
- **VanZanten vs. van Zanten**
- **Lasher-Trapp vs. Lasher-trapp**
- **Tinsley & Zhou 2006 is listed but not cited**
- **some journal names are abbreviated, some are not**
- **some surnames are in ALL-CAPS, some not**
- **some journal names are ALL-CAPS**
- **some titles are typeset with All Words in Caps, some with just the first word capitalised**
- **if citing a work with parentheses, avoid double "))" - lines: 86, 213, 500**

  Thank you for your detailed technical feedback on the references part. We have carefully reviewed and addressed each point you listed, ensuring that all corrections and modifications have been implemented to meet the required standards. We appreciate your important review, which has undoubtedly enhanced the quality and accuracy of our manuscript.