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Interactive comment on "Improving Collisional Growth in Lagrangian Cloud Models: Development and Verification of a New Splitting Algorithm" *by* Johannes Schwenkel et al.

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1 Introduction

The authors introduce a new extension of the lagrangian microphysics schemes - the splitting and merging algorithm. The splitting part of the algorithm increases the resolution of the lagrangian microphysics scheme for big droplets. This is especially important for correctly representing the collisions between droplets and the resulting onset of precipitation. The merging part of the algorithm decreases slightly the computational cost of the splitting algorithm. Both developments are described and tested. The paper is well written and interesting for the GMD community. It should be published after some corrections and additional tests.

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Discussion paper

2 Major comments

- A lagrangian microphysics scheme can represent collisions in different ways and can be initialized in different ways. Both choices have big impact on the accuracy of the scheme, Unterstrasser et al. (2017). Here the authors in their implementation of the lagrangian microphysics scheme use the most accurate way to represent collisions (the all-or-nothing algorithm Shima et al. (2009)). This is great. However, they initialize the droplet size distribution with constant weighting factors. This is the worst initialization strategy for representing collisions, see Figure 1 in Unterstrasser et al. (2017). It cannot be said that this is the standard way to initialize lagrangian microphysics schemes. Other groups initialize their schemes in different ways, see for example Unterstrasser and Sölch (2014), Arabas et al. (2015). Because this work focuses on improving the representation of collisions between droplets, such a bad-for-collisions initialization choice is not justifiable.

  The authors should also test their splitting and merging algorithm with a better initialization way (any of the singleSIP, multiSIP or ν_{random} from Unterstrasser et al. (2017) would suffice). Redoing the single cloud and cloud field simulations might be to expensive and unnecessary for the purpose of testing. However, it would be very interesting to see the single and multi-box tests done again with a different initialization choice. Does the splitting and merging algorithm improve the results as much for a different initialization choice? Are the multi-box simulations really necessary if the droplet size distribution is initialized correctly? How does the estimate given in line 25 on page 15 change with a better initialization?

- page 6 line 3: What is more important in counterbalancing the increase in super-droplet number due splitting algorithm? - Is it the limiting number of super-droplet per grid-box $N_{P,max}$ or merging algorithm? What is the impact of merging on the possible future activation of merged super-droplets to cloud droplets? What is the resulting resolution of the scheme for aerosol particles after merging? Is

merging more accurate than using super-droplets just for representing clouds and precipitation and parameterizing activation process, as it is done in Grabowski et al. (2018)?

- page 6 line 16-19: The mass conservation is a necessary constraint. But it is not enough to determine the super-droplet properties after merging. For the purpose of this study it's probably not important to have a more detailed strategy for determining super-droplet properties after merging. However it might be important for aerosol processing or secondary activation of aerosol particles to cloud droplets. Having that in mind, what would be the best way to determine the super-droplet properties after merging? For example: The current one assumes that the super-droplet radius after merging is equal to the radius of the super-droplet with the bigger weighting factor. An alternative could be to assume that the weighting factors are summed and to calculate the new radius from the mass conservation?

- page 7 line 11: Are all the boxes in the multi-box simulation homogeneous and there is no droplet sedimentation? If yes, what is the difference between the introduced here multi-box approach and a single-box simulation that would use a better way to initialize the droplet size distribution (with a better initial representation of the tail of the distribution) and use the same total number of super-droplets as the multi-box simulation? What is the total volume simulated in the multi-box approach vs the single-box? Is multi-box approach increasing the simulated volume only to introduce different realizations of the initial condition to counter the problems introduced by the constant weighting factor initialization?

- Both the high super-droplet concentration simulations (Fig 5) and the splitting simulations (Fig 7) overestimate the biggest droplet sizes. Why? Would using even more super-droplets allow to reach better agreement with the bin reference simulation for the biggest droplet sizes?

- page 11 line 14: What is the benefit of using a 3-dimensional simulation setup if the initial condition is 2-dimensional? Using a 2-dimensional setup (with cyclic boundary condition in the missing dimension) would reduce the computational cost by two orders of magnitude. This in turn would allow to test the performance, accuracy and convergence of the scheme for two orders of magnitude higher super-droplet concentrations.

- Figure 11: I agree that eliminating the fluctuations in the size distribution of big droplets is a good result. However, the box model tests (Fig 5 and 7) show that the lagrangian scheme overestimates the sizes in the large tail of he droplet distribution. Therefore the fact that the biggest drop size for the simulation with splitting is 350μm bigger might not necessarily be an improvement?

- Figure 11 and 12: Is there any change in the behavior for the small droplet sizes at t=3000s (end of the simulation) that is caused by merging?

- Figure 13 c, d, f: Why is the simulation with the biggest initial concentration of super-droplets (N=186) the biggest outlier? Out of the simulations without splitting and merging I would expect the one with initial N=15 to perform the worst and not the best. If the resolution for big droplets is important for collisions then the N=186 simulation should be better than N=15? Would running an ensemble average help? Or is this behavior consistent for even higher initial super-droplet concentrations?

- page 14 line 6: What is the computational cost and storage demand increase due to splitting algorithm?

- page 15 line 13: The work by Dziekan and Pawlowska (2017) shows that when used in high-enough resolution the lagrangian methods truly do resolve the collisions between droplets. The tests presented in Unterstrasser et al. (2017) also

suggest that when initialized correctly and when using a good algorithm for representing collisions the lagrangian microphysics schemes can represent collisions for coarser resolution settings (i.e low initial super-droplet concentration). The splitting and merging algorithm presented here is a valid improvement. It is especially important for large eddy simulation applications when by necessity the lagrangian schemes have to be used with low super-droplet concentrations. Nevertheless in my opinion, saying that in general the lagrangian methods are known to insufficiently represent collisions is not justified.

3 Minor comments

- The Lagrangian particles used to represent droplets are named differently by different modeling groups: super-droplets, simulation particles, etc. The original term super-droplet was introduced by Shima et al. (2009). Instead of using another notation $superdroplet$ it would be better to follow the notation that is already used by others.
- page 1 line 16: Are the references meant to be chronologically or alphabetically ordered?
- page 1 line 16: A couple more references to lagrangian microphysics applications: Lee et al. (2014), Arabas et al. (2015), Sardina et al. (2018)
- page 1 line 23: Which of the previously cited works use all-or-nothing algorithm?
- page 2 line 3: What is a large weighting factor and a large number of super droplets? Could you provide an order of magnitude estimate of those for a typical large eddy simulation grid box?

- page 2 line 30: Is it more correct to say that it is a probability that super droplet *m* will collect super droplet *n*?
- page 2 line 30: An alternative is to consider for collisions only the non-overlapping pairs and scale the probability - see section 5.1.3 in Shima et al. (2009) or section 5.1.4 in Arabas et al. (2015). This allows for the collision algorithm to scale linearly and not quadratically with the number of super-droplets. Maybe it should be mentioned?
- page 6 line 14: Are the super-droplets sorted with regard to their size in memory? Or in other words are the super-droplets merged with the most similar super-droplet in a given grid-box?
- page 6 line 26: Is diffusional growth allowed in the box model simulations? If yes, what is the assumed saturation? It is confusing with regard to line 15 on page 12. - Saying that collisions dominate the droplet growth in the box simulations suggests that there are other processes considered.
- page 6 line 30 (and onward): It's a bit confusing to talk about grid boxes when using a single box model setup. There is no real computational grid here.
- page 6 line 30: Where does the assumption that the box dimensions are $\Delta x = \Delta y = \Delta z = 20$m matter for the lagrangian scheme? Is it enough to say that the box volume is $8 * 10^3$m^3?
- page 7 line 1: How many boxes are used? How are the boxes in multi-box approach located with regard to each other? What are the boundary conditions?
- page 7 line 6: As stated in my first major comment - I don't agree that the initialization with constant weighting factors is a standard. Because it is such a bad initialization for representing collisions the new splitting algorithm should also be tested with a better initialization.

- Figure 2b: Why is the LCM1000 behaves like a step function after 2500s?
- Figure 3: The plotting colors and patterns should be kept the same between Figs. 3,and 7 to allow easier comparison.
- page 10 line 25: Is the initial super-droplet concentration again 87 per box?
- Figure 13a and 15c: The notation N_{SIP} was never used before. The authors choose to refer to the lagrangian particles as super-droplets and not simulation particles.
- page 14 line 15: When it is not possible? What happens then?
- page 15 line 24: Dziekan and Pawlowska (2017) would be a valid reference here.
- page 15 line 27: Figure 10 suggests that the maximum number of super-droplets $N_{P,max}$ is as important as the splitting radius r_{spl}?
- page 16 line 13: The code of the Large Eddy Simulation model along with the new splitting and merging algorithm is available online and therefore fulfills the GMD requirements. It would have been great if the simple box model tests were available as a stand alone and easy to download and compile project. It would enable easy testing of the algorithm by others, for example this reviewer. It is by far too much coding to ask to do this now. I would just like to leave this comment as an idea for future development and testing.

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