Review of "Modeling Collision-Coalescence in Particle Microphysics: Numerical Convergence of Mean and Variance of Precipitation in Cloud Simulations Using University of Warsaw Lagrangian Cloud Model (UWLCM) 2.1" by Zmijewski et al. (gmd-2023-44)

The presented study investigates the numerical convergence of cumulus congestus simulations with a Lagrangian (or particle-based) cloud microphysics scheme. The authors find that the convergence requires much more computational particles than previously assumed. In fact, the authors suggest that convergence is only possible using computational particle numbers that exceed any realistically feasible value. While I am convinced that the general subject of the study is very important and that the study very well suits the journal Geoscientific Model Development, I am not (yet) convinced that the author's results are correct. In the following, I will suggest additional analyses required to accept this study for publication.

Major Comments

Condensation-coalescence bottleneck. Similar to the study by Hill et al. (2023), I believe that the high susceptibility to the number of computational particles is the very narrow droplet size distribution (DSD) caused by condensation, from which it is very hard to initiate collision-coalescence. For such distribution, producing sufficiently large precipitation embryos to start the collision-coalescence process is very important, and depends heavily on the number of computational particles to sample the tails of the DSD correctly. I suspect condensation narrowing is much more prominent in the kinematic simulations, in which condensation does not interact with the dynamics. Accordingly, the convergence in the kinematic simulations is much slower than in the dynamic simulation (Figs. 8 and 9). If this is true, the slow convergence cannot be seen as an inherent defect of Lagrangian cloud microphysical schemes, but must be considered a result of the artificially narrow DSD. To address this issue, additional analyses on the development of the SD width before the onset of collision-coalescence are highly recommended. Are there differences in the DSD width between the dynamic and kinematic simulations before collision-coalescence onset? How does the DSD width before collision-coalescence onset change with the computational particle number? If there are substantial differences between the dynamic and kinematic simulations, I highly recommend adding stochastic supersaturation fluctuations to the condensational growth [e.g., the approach by Grabowski and Abade (2017)] to obtain a realistic DSD width.

More quantities. The number of analyzed quantities to determine convergence is relatively low. While I understand the choice for the surface precipitation rate as the main subject, I recommend also checking the cloud base precipitation rate. Differences in the convergence of surface and cloud-base precipitation rates could indicate differences in the evaporation below cloud base. Furthermore, I miss deeper analyses of the convergence of the liquid water path (LPW) and rain water path (RWP), as well as the cloud droplet concentration. As all these parameters determine the surface precipitation rate, a comprehensive convergence on precipitation study should not negate them.

Cloud-type dependence. This study makes a strong statement on how many computational particles must be used in Lagrangian cloud microphysics schemes. However, these results are only obtained for one specific cloud type, a single cumulus congestus cloud. First, cumulus congestus are not a singularity. If a first cloud does not rain sufficiently, preconditioning might allow a second cloud to rain more, and vice versa. Thus, the convergence rate of an individual cloud has limited meaning. Thus, I recommend adding simulations of a cloud field. As I see that simulating several cumulus congestus can be cumbersome, I suggest simulating a standard shallow cumulus case (BOMEX, RICO). Furthermore, the convergence of drizzling stratocumulus can be a worthwhile extension (DYCOMS-II, RF02), primarily since they can easily be represented in a two-dimensional framework.

Minor Comments

L. 96: Is there a reference to support this statement?

L. 99: Give an equation for $P_{i,j}$.

Ll. 124 – 125: From what are the mean and standard deviation calculated? I assume the ensemble of simulations, but this should be stated clearly.

Ll. 139 – 140: How large is the ensemble?

Ll. 146 – 150: Where do we see this?

Ll. 160 – 162: How can one estimate the standard deviation from the SCE by taking the square root of the number of droplets? I think this approach can be correct, but the authors must elaborate.

Fig. 3, ll. 165 – 173: This analysis is distracting. I suggest removing it.

Ll. 203 – 206: If small differences result in differences in rain formation, they should be visible in the moments that are most susceptible to rain, e.g., the 6th moment of the DSD or the radar reflectivity, which is analyzed in Unterstrasser et al. (2017, 2020).

Eq. 3: What is "n"?

Fig. 5: Does the ordinate show "the number of simulations with P within a bin"? The resultant number of simulations seems to be very high.

L. 337: Stating that more than 1000 computational particles per grid box are necessary to simulate condensation correctly, needs to be supported by data.

Sec. 4.7: The initialization method might strongly impact how the aerosol size distribution is represented, and hence droplet activation. Thus, there might be differences in the droplet concentration and, commensurately, the rain rate.

Ll. 404 – 420: Can the approach by Schwenkel et al. (2018) help to accelerate convergence?

Technical Comments

The text is understandable, but there is a large number of spelling and grammatical errors that need to be taken care of.

L. 79: Write about "bin edges" already here. "Edges" without context is confusing.

Ll. 116 – 117, ff.: When narrative citations (\citet{…}) are used, a semicolon should not separate the individual references, but a comma or an "and".

References

Grabowski, W.W. and Abade, G.C., 2017. Broadening of cloud droplet spectra through eddy hopping: Turbulent adiabatic parcel simulations. *Journal of the Atmospheric Sciences*, *74*(5), pp.1485-1493.

Hill, A.A., Lebo, Z.J., Andrejczuk, M., Arabas, S., Dziekan, P., Field, P., Gettelman, A., Hoffmann, F., Pawlowska, H., Onishi, R. and Vié, B., 2023. Toward a numerical benchmark for warm rain processes. *Journal of the Atmospheric Sciences*.

Schwenkel, J., Hoffmann, F. and Raasch, S., 2018. Improving collisional growth in Lagrangian cloud models: development and verification of a new splitting algorithm. *Geoscientific Model Development*, *11*(9), pp.3929-3944.

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