Geosci. Model Dev. Discuss.,
doi:10.5194/gmd-2016-271-RC2, 2017

Geoscientific Model Development Discussions

Interactive comment on "Collection/aggregation algorithms in Lagrangian cloud microphysical models: Rigorous evaluation in box model simulations" *by* Simon Unterstrasser et al.

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Received and published: 13 January 2017

The Authors evaluate three algorithms for representing collisions in Lagrangian cloud microphysics schemes that are available in the literature. The design and some implementation details are discussed. The accuracy of the three collision algorithms is compared against the analytical solution of Golovin kernel and bin solutions of Long and Hall kernels. A very wide parameter space is investigated. The manuscript also tests three different initialization techniques for the Lagrangian cloud microphysics schemes.

The work presented here is very useful. Lagrangian schemes offer very detailed

representation of microphysical processes in clouds. Yet, because the Lagrangian methods are new, they have not been sufficiently tested in cases relevant for numerical simulations of clouds. The topic of the presented work is therefore very interesting and fits well into the scope of the GMD journal.

General comments

The presentation of the design of the three different collision algorithms is done very well. Figure 2, combined with the detailed description of collision algorithms and the "hypothetical algorithm", clearly shows the differences in treatment of collisions inherent to these three algorithms. Also, the presentation of the three different initialization procedures is done well.

The Authors did an immense job at testing different algorithm options and simulation parameters. The Authors have tested 3 different algorithms ("remapping" (RMA), "average impact" (AIM) and "all-or-nothing" (AON) algorithms), used 3 different test cases (Golovin, Long and Hall kernels), 3 different initialization procedures and many different collision algorithm options and simulation parameters. The Authors have tested a big parameter space and it is a big achievement of the presented work. However, the presentation of the results from this set of tests could be improved. In my opinion the big number of figures showing results from many combinations of simulation options makes the manuscript difficult to read and pinpoint the interesting and beneficial parameter combinations. Instead of providing a report from many test simulations that were made, a more concise summary of obtained results would be more beneficial and easier to comprehend for the reader, in my opinion. In general, the quality of many figures in the manuscript is poor and sometimes makes them impossible for me to comprehend.

The final analysis of the accuracy of the three tested collision algorithms is very critical, witch is a good aspect of the manuscript. The Lagrangian schemes are free of many numerical limitations of the bin schemes, but they do introduce new numerical challenges that need to be addressed. The big number of tests performed by the Authors allows a detailed analysis of accuracy. The final discussion of the collision algorithms could also underline some advantages of the Lagrangian schemes.

Overall, the manuscript discusses an interesting topic and provides a wide variety of tests. The corrections suggested in the following part of my review are minor and focus mostly on improving the figures.

Specific comments

1. "Too many" figures

As stated before I think that the Authors did a tremendous job implementing the three algorithms and then testing them in such a large variety of simulations. Nevertheless, in my opinion, some parts of the presentation could be improved by removing figures and providing instead a summary of the obtained results. Below I'm including some suggestions on how it might be done.

For the sake of completeness and some potential future comparisons with other algorithms I would suggest moving some figures to electronic supplement. Such supplement could contain all figures, data needed to plot them and (if the Authors are willing) the scripts used for plotting. This would enable other Lagrangian scheme

users to test their own implementations and then easily plot their own results against the tests performed by the Authors. A good example of such electronic supplement is in the Lauritzen 2014 GMD paper (doi: `10.5194/gmd-7-105-2014`). Note, that such supplement does not demand publishing the actual code of the three algorithms but only simulation results. This is easier to do and to document.

List of figures that could be moved to supplement:

- **6, 9, 15:** Both AIM and AON algorithms do not change the number of SIPs (N_{SIP}). Maybe stating in the legend what was the number of SIPs used is enough and the first row of plots could be redundant. For the RMA algorithm it would be more beneficial for me to provide the actual number of the additional SIPs needed (for example as a % of the initial number of SIPs). For the size distribution moments it would be more beneficial for me to introduce some measure of error and then report the error value for different combinations of parameters that are tested. – In most of the plots the lines are on top of each other and are therefore not readable. A table of error values would be easier to read.
- **11, 19, 22 - top row and the last or second to last row:** Similar to the previous comment, the N_{SIP} is constant and therefore a clear legend instead of the first row of plots would be enough in my opinion. The behavior of the second and the third moment is very similar and I think that one row of panels could be omitted. The behavior could be only described in text. Again, introducing some error measure and reporting its value would be more informative for me. It would help to summarize all the results and enhance the comparison between different options and algorithms.
- **13:** The behavior for Hall kernel is similar to Long kernel (Fig. 11) Perhaps stating that in text could be sufficient?

- **17:** Similar to Fig. 11 and 19, maybe just two size distribution moments are sufficient? Again, some error measure would be useful.

2. Comments on figures

All the figures presented in the manuscript are too small for me to read easily. Also the font size and the line thickness is too small.

The color-coding and plot styles of some of the figures make them difficult to read for me. Below I'm including a list of such figures with some ideas on how they could be improved:

- **2 – RMA algorithm:** The gray font color used for text regarding contribution k is not readable. Maybe just for text a darker color could be used?
- **3, 4 – top panel:** The number of points and the chaotic color-coding makes it impossible for me to easily see what is happening in the left part of the plot. Reducing the number of SIPs shown, especially for the small drop sizes, would help. I would also suggest choosing line colors basing on the initial drop size rather than at random – for example http://stackoverflow.com/questions/13972287/having-line-color-vary-with-data-index-for-line-graph-in-matplotlib
- **5, 7, 8, 10, 12, 14, 16, 18:** Similar to the previous case I would suggest choosing line colors basing on the simulation time rather than at random. Especially for later figures showing oscillations for RMA or less smooth solutions for AON it would make it easier to compare different lines.
- **11, 13, 19, 20, 22:** Similar to the previous case, consider choosing colors basing on the number of SIPs used. It would make the first row of plots unnecessary and allow easier comparison.

- **16:** In my opinion showing just one realisation and the average over 50 realisations could be enough. It's obvious that any realisation from AON will be burdened with irregular scatter. It's also obvious that averaging over even bigger ensemble will further smooth the solution and it could be just stated in text. Gained space could be then used to increase the size of the plots. The symbols *, + and - in the last two panels are not readable in a plot of this size and obscure the lines representing the actual size distribution.
- **17:** The red and green colors overlay each other and make it difficult to read the figure. I'd suggest omitting one size distribution moment and using the space to significantly increase the size of the plot as well as the size of points and line thickness.

3. Pseudo-code listings

Please consider providing an additional caption explaining the conventions used in the listing. What lines are marked as comments and what lines are the actual pseudo-code? What does it mean if a line is written in italics, bold or in capital letters?

4. Discussion for Long kernel

The bin scheme solves the Smoluchowski equation for the number concentration function and by default should provide a smooth solution. However, the Smoluchowski equation is strictly true for infinite systems. For cases of big population of similar drops (i.e. a population of rain drops from a fully formed precipitation event) solving the Smoluchowski equation provides a good representation of the drop size distribution. In contrast, the onset of precipitation (or the "transition phase" for the Long kernel in 30-40 minutes of simulation time) might be governed by the behavior of just a few big "lucky" drops. See for instance the discussion in Lushnikov 2004 (doi: `10.1103/PhysRevLett.93.198302`) and Bayewitz et. al. 1974 (doi: 10.1175/1520-0469(1974)031<1604:TEOCIA>2.0.CO;2) The bin solutions are commonly considered a true solutions during comparison studies. However it is not clear to me what volume should be used in order to ensure that solving the Smoluchowski equation is a good method for all precipitation phases. A discussion of issues related to this topic is definitely out of the scope of this manuscript. However, could you consider adding a small warning or comment on this aspect?

In the summary of box model tests, could you outline in text how the difficulties encountered in the transition phase of the Long kernel actually affect the final solution at t=60 for RMA, AIM and AON for the best combination of the algorithm options? Do the oscillations in RMA and scatter in AON preclude a good final solution? How accurate is the final stable and smooth solution from AIM in comparison? Is the location and value of the final maximum easily captured in AIM and AON?

5. Other comments

- line 221 - Could you comment on what techniques do you recommend when fighting numerical cancellation errors? What procedure was used in the current implementation?
- line 252-253 - Could you comment on why the described behavior is considered advantageous?
- line 273 - Maybe consider stating what initialization will be used as default in the later box model tests?
- Pseudocode for RMA, line 30 - is $N_{SIP} = ii$ or should it be i?

- Figure 3 and 4 bottom panel - normalizing once with regard to the initial condition and once with regard to the final state is confusing
- line 488 - Another alternative could be to assign the product of collision to just one SIP and use the remaining SIP to split the biggest weighting factor between two SIPs. See the third to last paragraph in sec. 5.4.1 in Arabas 2015
- line 535 - In my opinion performing collisions only for selected random pairs and scaling the probability is a very useful feature. It changes the asymptotic behavior of the scheme with regard to the number of SIPs from quadratic to linear. It allows to perform simulations with a bigger number of SIPs, which increases the resolution of the obtained results. Could you consider underlying those benefits? If some further tests are planned for the future, I would suggest adding this option to the AON implementation. On a side note, we use AON with collisions for random pairs and singleSIP init by default in our Lagrangian simulations. Out of curiosity, we ran the Long and Hall tests described in the manuscript using our default parameters. The results are similar to those presented by the Authors for AON box model tests.
- Figures 5, 6, 7 are not averaged over 50 realisations. In contrast, the corresponding figures for AIM and AON are. Could you comment on why? Does the design of RMA algorithm guarantee no need for ensemble runs? Could the ensemble runs be obtained using one of the random initialization procedures? For Golovin kernel RMA produces good results for a single realisation, which should be underlined. If for Long and Hall kernels ensemble average does not help, it should also be underlined. Could you comment on how an ensemble average for RMA for high SIP number (for example $\kappa = 200$) for Long kernel would look? In general it was unclear for me if RMA (i) becomes unstable and does not provide a solution for Long test or (ii) is stable but generates cumbersome oscillations and wrong final solution.

- Is it necessary to average over an ensemble for AIM?
- line 796 - For the sake of summarizing the box model simulations, could you discuss in text what was a minimum number of SIPs and a maximum timestep needed to obtain satisfactory results for the best combination of options for RMA, AIM and AON? Was the computational cost of all algorithms similar? Does it scale in the same way when increasing SIP number? Could you summarize in text how sensitive the three algorithms are to timestep?
- line 814 - For me, the total number of SIPs is a more intuitive parameter than κ. Could you also state what is the total number of SIPs for $\kappa = 20$ and $\kappa = 100$?
- line 838 - Could you comment on why the RMA is excluded in this part of the study? Are the oscillations as prominent as in the Long test scenario? Does it again fail to reproduce the bin model results at the final stage?
- line 895 - Since the Authors state in line 858 that it is not clear which findings of the performed tests are most relevant for simulations of clouds, I would suggest somewhat weakening the statements about the RMA algorithm in the conclusions.

Technical corrections

- line 142 - k! should be the factorial not faculty?
- caption of Fig. 1 - λ_3 is missing
- Pseudocode for RMA, line 34 - should be "can be easily incorporated in ..."
- line 435 - should be Figure 3?

- line 560 - space missing after “per construction”.
- Figure 14 is missing the third column that should depict a version of AON without self collections.
- line 834 - Could you rephrase the part “where the abundance of droplets larger than 10 um drops strongly”