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super-droplets make breakups easier

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Community comment on "Breakups are complicated: an efficient representation of collisional breakup in the superdroplet method" by Emily de Jong et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-1243-CC1, 2022

Dear colleagues,

Thanks for this very interesting manuscript. I appreciate the effort to find a breakup implementation that is appropriate for super-droplets. Having worked on collisional breakup myself, I take the liberty to make some subjective comments. This is not a formal review, just an opportunity for scientific discussion.

1. Filament breakup:

Low and List write about filament breakup that 'the original two drops usually reappeared in some fashion as recognizable remnants of the colliding drops' (LL82b, page 1609). In Figure 11 of LL82a the fragment distribution functions for filament breakup show three distinct peaks corresponding to the remnants of the two original drops and the small satellites. Hence, for filament breakup of two drops with masses A and B, the remnants of the original drops have masses A' and B' and in addition, we find a certain number of small satellite drops of mass C'. All three masses are distinctly different in case of filament breakup. I don't see how it is possible to describe the outcome of such a breakup event with only 2 super-droplets. Of course, you can assume that A'=B', but this is not what the laboratory experiments show. You can assume B'=C', but also this is inconsistent with drop physics. You may assume that there already exists a super-droplet with a mass similar to C', but this is an additional assumption. In my opinion, is it simply impossible for filament breakup to conserve the number of super-droplet and at the same time have an accurate description of drop physics seen in laboratory experiments.

2. Super-droplet breakup based on individual mass conservation

If you allow yourself to create (at least temporarily) new super-droplets, the implementation of collisional breakup in a super-droplet code is actually quite straightforward. The super-droplet approach has the great advantage that we can make use of individual mass conservation, which greatly simplifies the implementation of collisional breakup. Much of the complication of traditional breakup parameterizations arises from the fact that the size distribution of fragments has to conserve mass. In a super-droplet model, this mass conservation comes naturally. This makes super-droplets, in my opinion, the method of choice for collisional breakup and more accurate than the oldfashioned bin microphysics. Bin microphysics has only integral mass conservation and therefore needs additional closure assumptions to describe collisional breakup. This is described in the Appendix of

Bringi, V., Seifert, A., Wu, W., Thurai, M., Huang, G. J., & Siewert, C. (2020). Hurricane Dorian outer rain band observations and 1D particle model simulations: A case study. Atmosphere, 11(8), 879.

Sorry, that we did not bother to write a dedicated paper on this super-droplet breakup algorithm, but the implementation is really straightforward. For us, the focus was on understanding the physics of the raindrop size distribution in the observations using super-droplets as a tool to do so.
In this algorithm, it is eventually necessary to limit the number of super-droplets by merging similar-sized drops (the satellites of filament breakup). For droplets, which have only a one-dimensional particle distribution, this merging step is not difficult. In my opinion, it is also cleaner from a conceptual point of view to have an accurate description of the drop physics and a separate merging afterward. The latter is only necessary to achieve computational efficiency in 2d or 3d simulations. Separating physics from numerics is usually a good thing and also for Lagrangian particle methods we should strive to do so.

3. Straub et al. fragment distribution function

A note of caution on the Straub et al. fragment distribution. Based on more recent laboratory experiments of

Szakall, M., & Urbich, I. (2018). Wind tunnel study on the size distribution of droplets after collision-induced breakup of levitating water drops. Atmospheric Research, 213, 51-56.

the McFarquhar (2004) or the original Low and List (1982) fragment distribution functions should be preferred over the one published by Straub et al. (2010). The filament mode of Straub et al. seems to be too narrow and does not compare favorably with the new laboratory data of Szakall and Urbich (2018). In my opinion, this issue is caused by some simplifications in the DNS simulation that are the empirical basis for the Straub et al. parameterization. As far as I remember, the raindrops were not oscillating in the initial condition of the DNS of Schlottke et al. (2010). Unfortunately, we were also not able to perform a large number of simulations for the same collision parameters back then. Doing all these DNS runs to sample the parameter space was challenging enough, especially since DNS needs to explicitly sample the eccentricity of the collision. This may explain the bias, especially in the width of fragment distribution of the satellites in filament mode.

4. Stochastic sampling of the fragment distribution

The existing parameterization of the fragment distribution (Low and List 1982, McFarquhar 2004, Straub et al. 2010) are a super-position of lognormal and Gaussian distributions. Hence, it is possible to sample directly from these analytic distributions. I don't see the need for the approach suggested in Appendix A. To apply these parameterizations, it is only necessary to first decide which breakup mode (filament, disc, sheet) occurs for the collision event, then the fragments can be sampled directly from the lognormal or Gaussian fragment distribution functions. At least, that's how my super-droplet implementation of collisional breakup works.

5. Limiter

I think the limiter equation (A2) is not consistent with the physics of collisional breakup. It is possible and consistent with lab measurements that the larger of the original droplets grows during the collision event, i.e. A' > A is possible. The limiter (A2) would suppress this behavior because is limits A' to max(A,B).

6. A methodological suggestion

As mentioned above, I would suggest developing a reference model that captures all the essential and known physics in detail. The beauty of the super-droplet approach is that it allows to do this very naturally. Based on this reference model, it is then possible to systematically investigate approximations and simplifications to improve computational efficiency. Especially in cloud physics, where validation with observations can be a challenge by itself, such a two-step approach is strongly recommended.

Thanks again for your nice work. I like the conceptual and idealized way of thinking. This helps to understand the interaction between the various processes.

Best regards, Axel