Impacts of Collision-induced Drop Breakup on Droplet Size Distributions

Contact email: *pujaroy@ucar.edu*

Puja Roy[1,2], Kamal Kant Chandrakar[3], Hugh Morrison[3], Lulin Xue[1], Sarah Tessendorf[1], Wojciech W. Grabowski[3]

[1]Research Applications Laboratory [2]Advanced Study Program [3]Mesoscale and Microscale Meteorology, NSF NCAR, CO

Motivation

- **Collision-induced drop breakup** modify raindrop size spectra, inhibiting formation of very large raindrops, thus *playing an important role in warm rain cloud microphysics*
- Scientific understanding of drop collisional breakup is **still largely incomplete**, introducing significant uncertainties in parameterization schemes and **inadequate representation** of warm rain cloud microphysics in numerical models
- Microphysical processes affecting cloud dynamics are impacted by **how drop size distributions (DSDs) are represented** in cloud models

<u>Goal:</u> Utilizing Lagrangian super-particle-based approach, implement collision-induced drop breakup in an idealized box model, and conduct sensitivity analyses of DSD evolution to model parameters

Methodology

(Barros et al, 2008)

Three different modes of drop breakup – **filament, sheet, disk** - were implemented in the box model along with all-or nothing stochastic collision-coalescence based on Lagrangian approach using superdroplets (SDs) *(Morrison et al, 2024)*

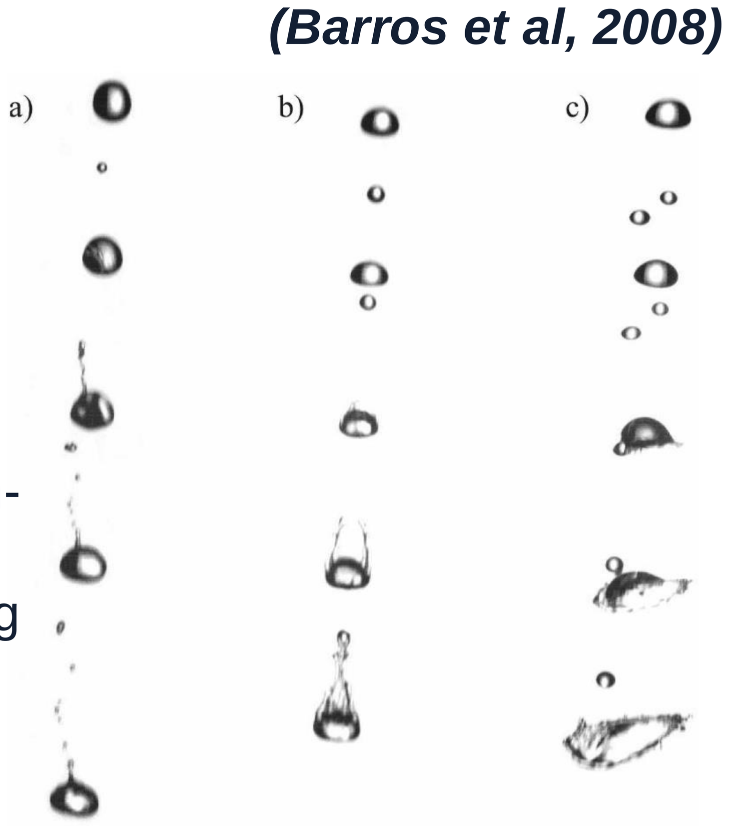


Fig. 1: Different breakup modes

- **Probability of coalescence and breakup:** Coalescence efficiency parameterization (*Straub et al., 2010*) => Ec = exp(-1.15 We) (We = Weber number)
- **Probability of breakup type** as a function of We and Collision kinetic energy (CKE) (*Low and List, 1982*)
- **Number of fragments** - function of sizes, CKE, surface energy (*Low and List, 1982*)
- **Fragment size sampling** (*McFarquhar, 2003)*

Results and Key Findings

Filament Break up

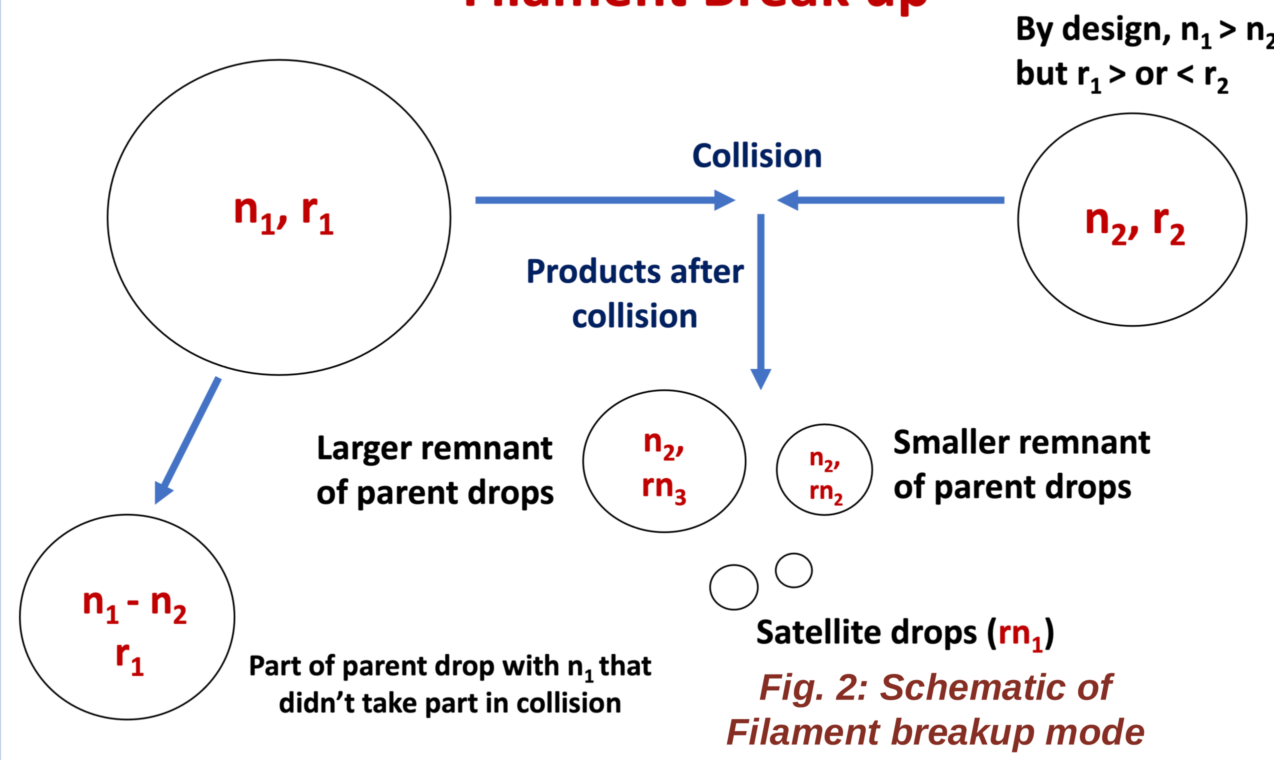
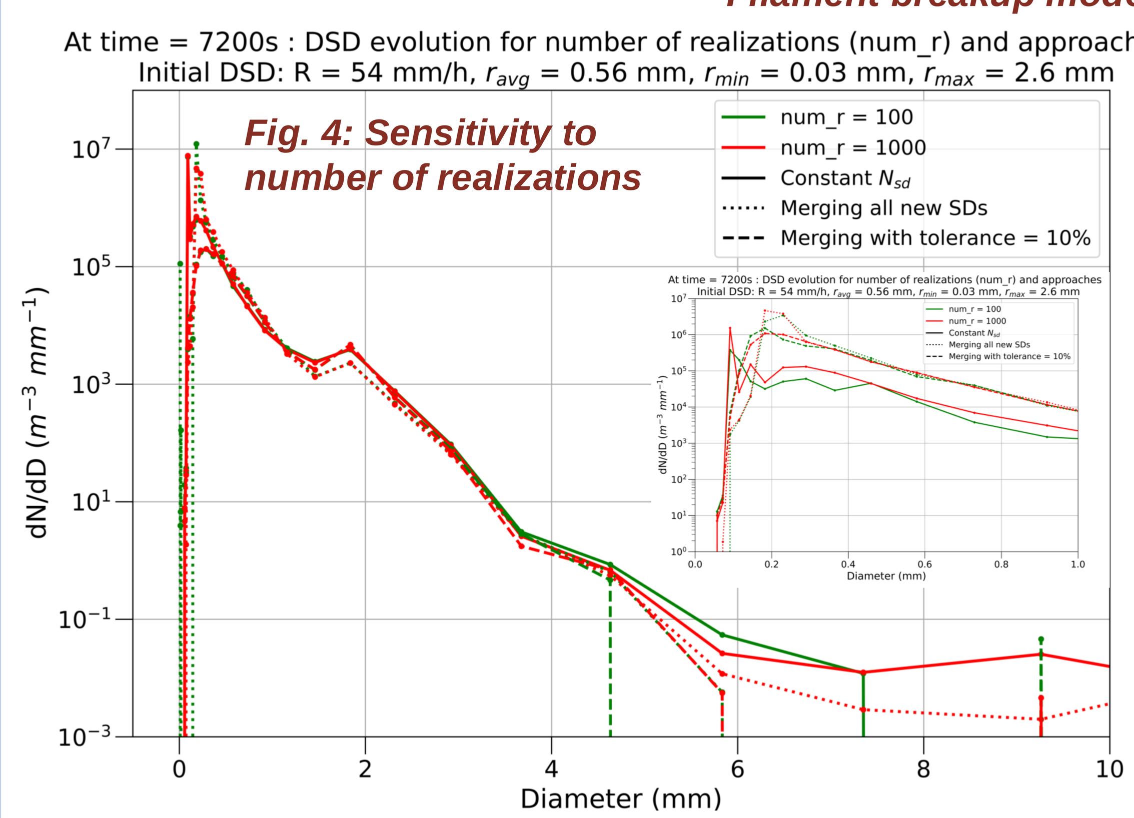
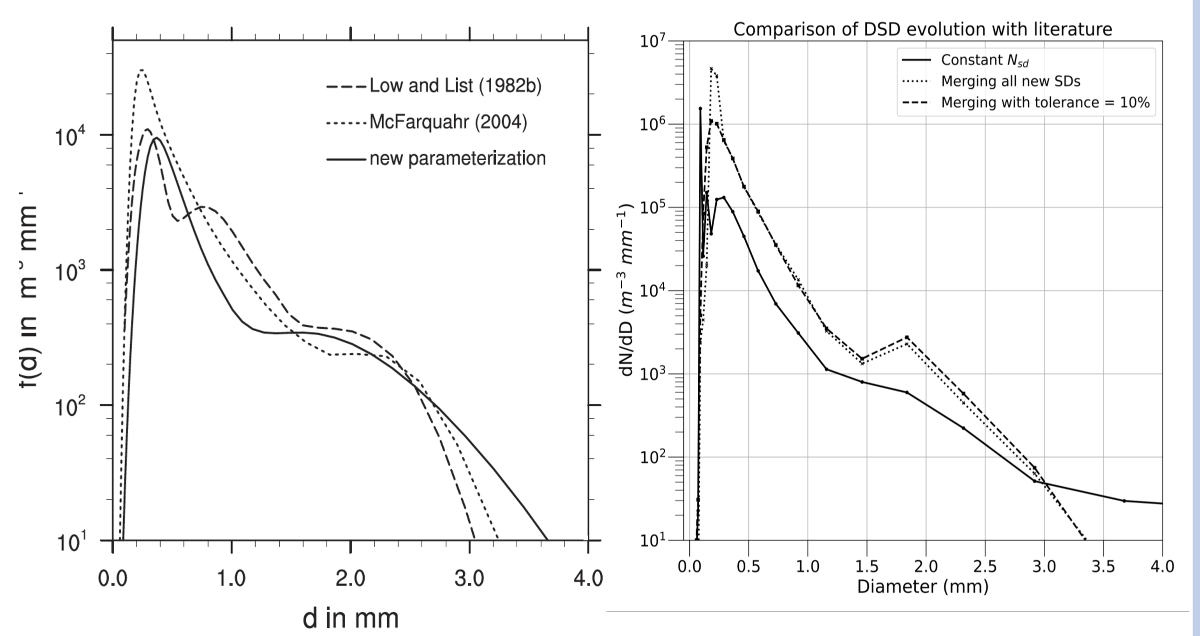


Fig. 2: Schematic of Filament breakup mode

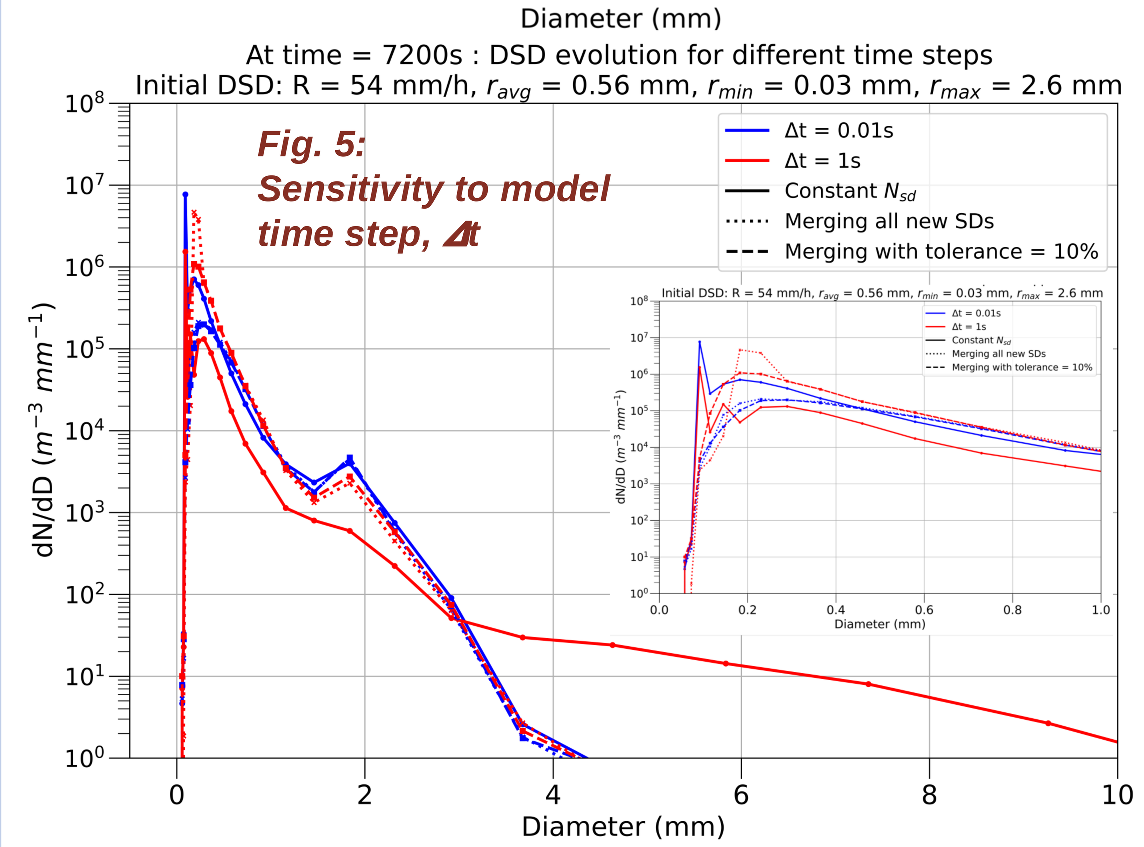
How does drop breakup impact droplet size distributions?

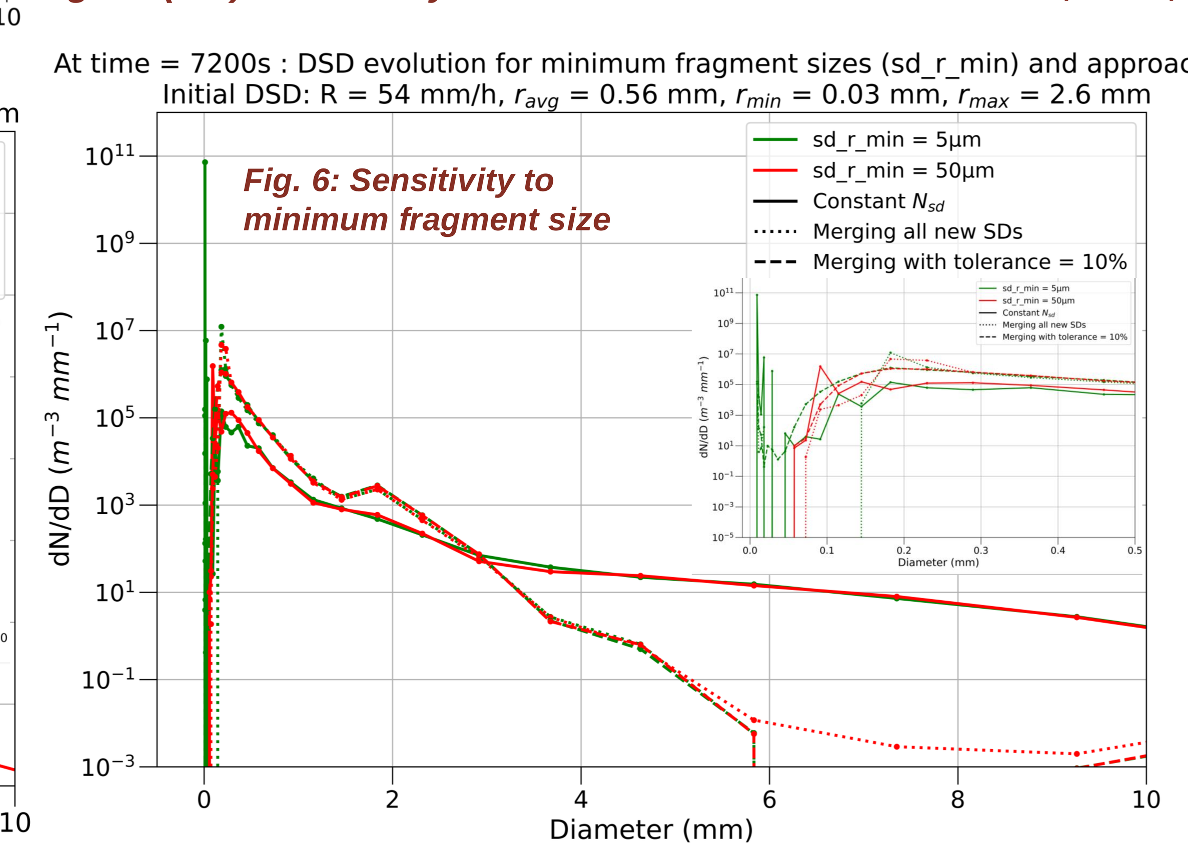
For an initial larger droplet size distribution, drop breakup creates smaller droplets and intermediate sized droplets, which can further impact the collision-coalescence and other microphysical processes.



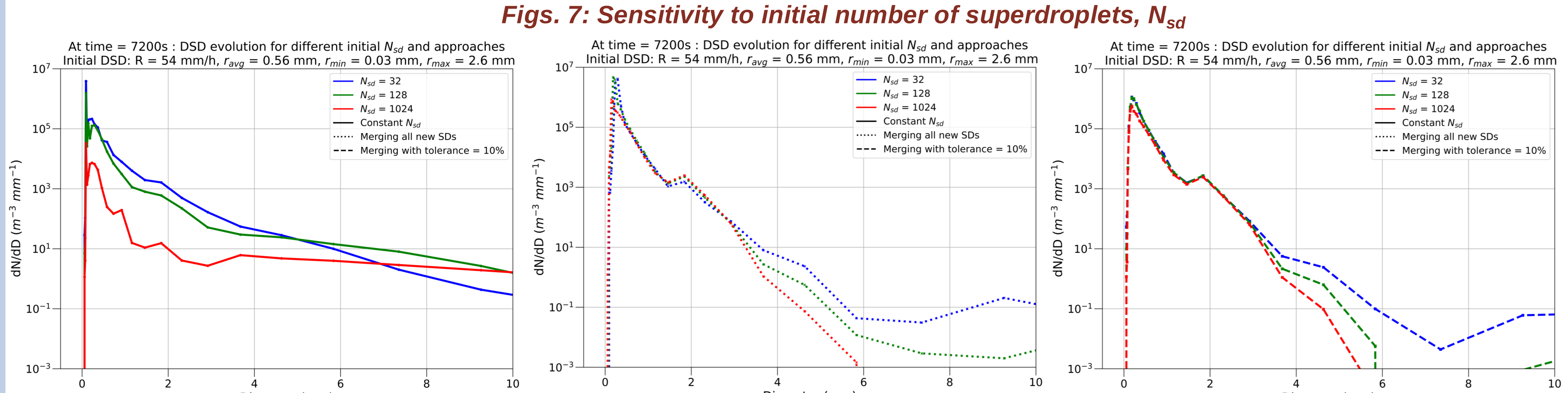


Figs. 3 (left): Stationary size distribution from Straub et al., 2010;





Figs. 7: Sensitivity to initial number of superdroplets, N_{sd}



Discussion

- These preliminary results involve three different approaches to treating drop breakup – 1. constant total number of SDs (**Constant N_{sd}**), 2. forming new SDs and merging all of them (**Merging all new SDs**), 3. forming new SDs and merging some of them based on a threshold (**Merging with tolerance = 10%**).
- All methods tend to produce similar size distributions as previous studies, with some differences in peak sizes and concentrations. Including droplet breakup produces smaller and intermediate sized droplets - similar to past studies, but with typically higher number concentrations). At time, t = 7200s, the DSDs approximately reach equilibrium, with the highest peak at ~ 0.2 mm diameter, followed by the second peak at ~1.8 mm (Figs. 3).
- Sensitivity analyses of droplet size distribution (DSD) evolution with different approaches of implementing drop break up to different model parameters such as number of realizations, model time steps, minimum size of fragments, number of superdroplets (N_{sd}), and so on were conducted.
- DSDs mostly converge for number of realizations ≥ 100 and are mostly insensitive to collision efficiencies used (not shown here). Increasing minimum size of fragments eliminates the production of very small droplets. Increasing initial N_{sd} leads to lowering smaller droplet concentration for constant N_{sd} approach, while increasing the larger drop peak radii for all approaches.

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