Randomness In Droplet Collisions In Numerical Cloud Models

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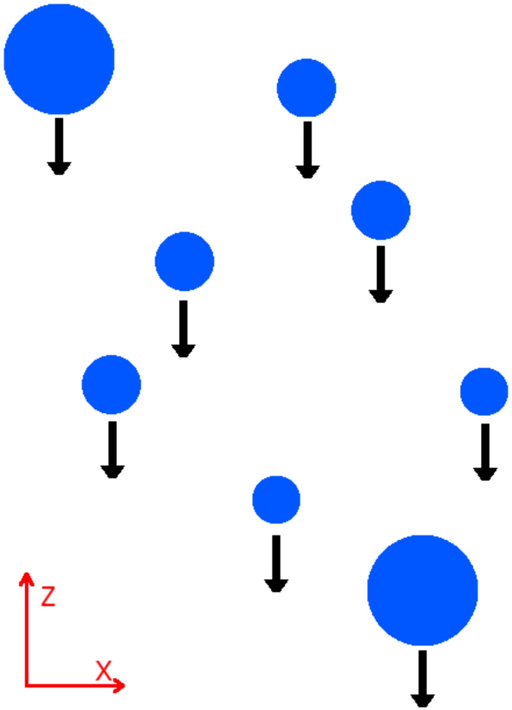
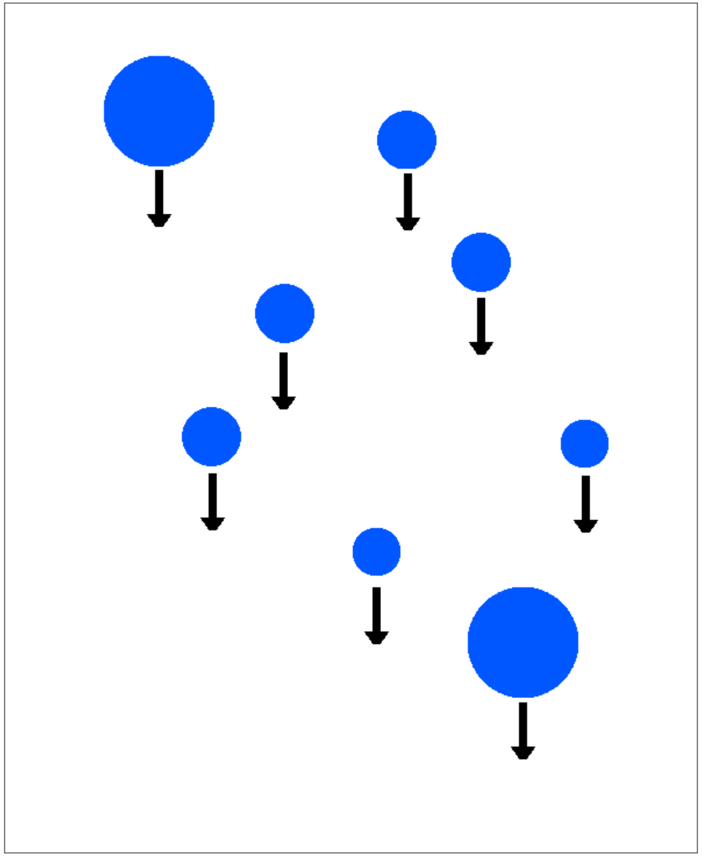
Models of collision-coalescence in a single cell

Microscopic model



- Resolved positions and velocities of all droplets
- Collisions are deterministic
- Unfeasible in almost all cases

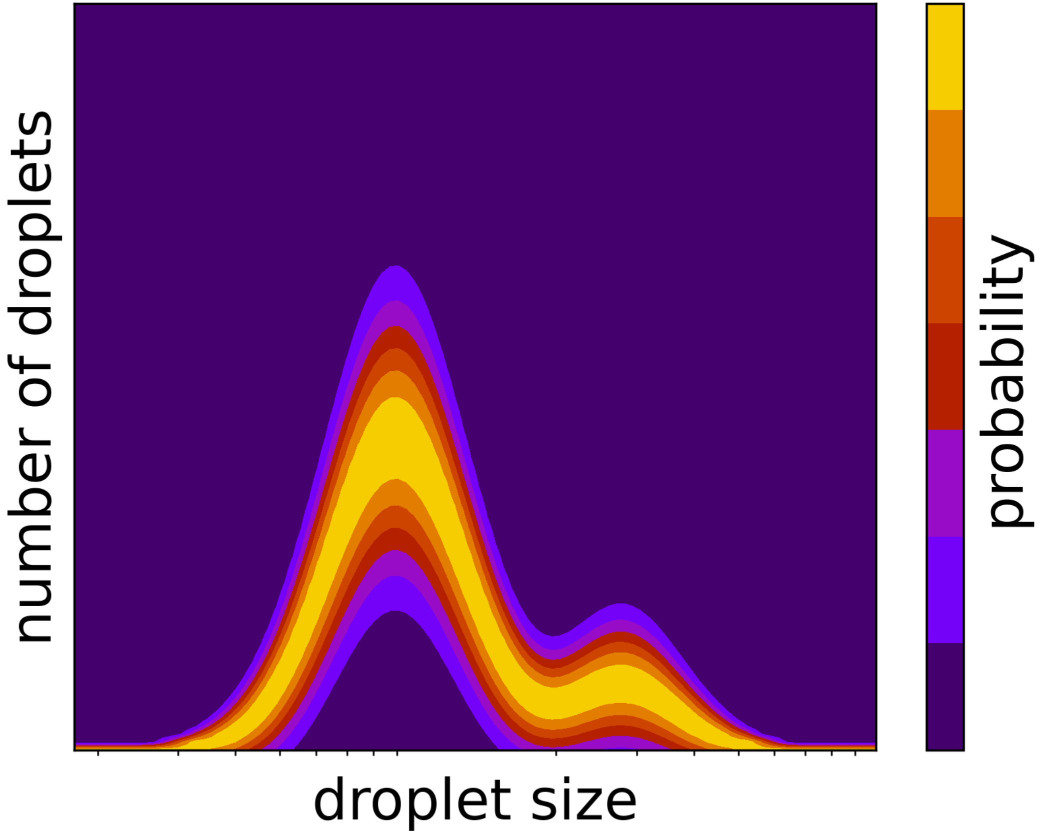
Stochastic model



- Consider collisions within some volume (cell)
- Neglect droplet positions within a cell
- Define collision probability (coalescence kernel)

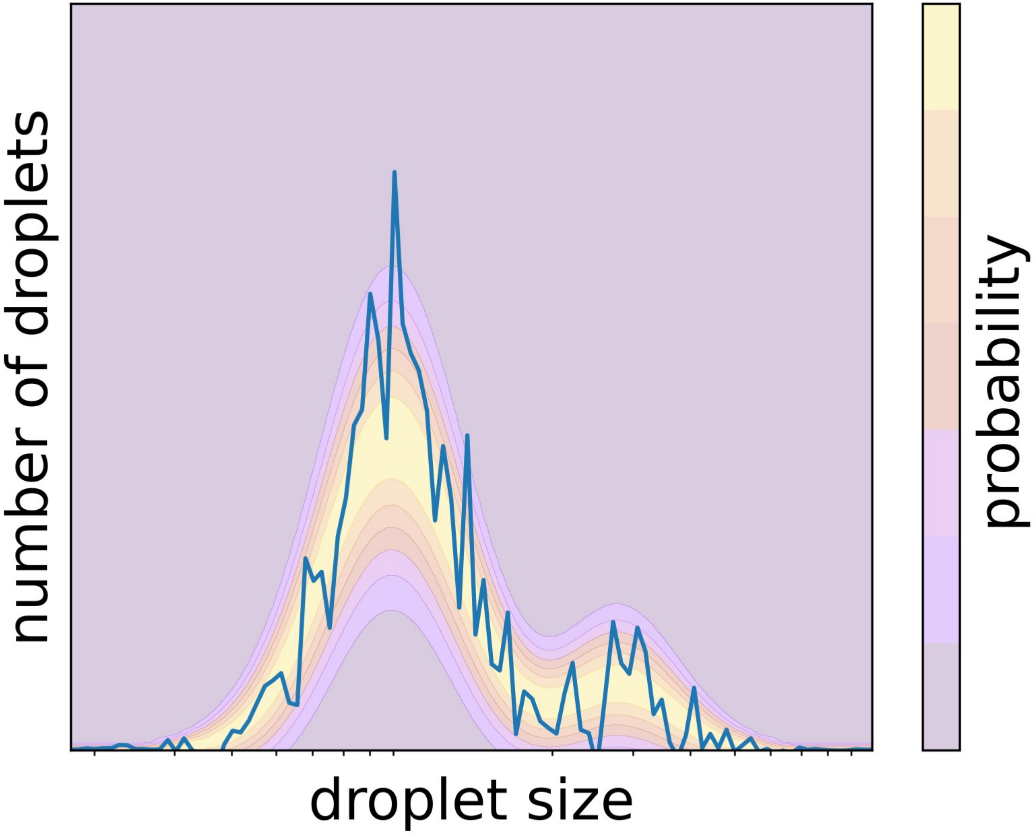
Stochastic model

- Size distribution described by P(N,r,t) – probability of finding N droplets of size r at time t



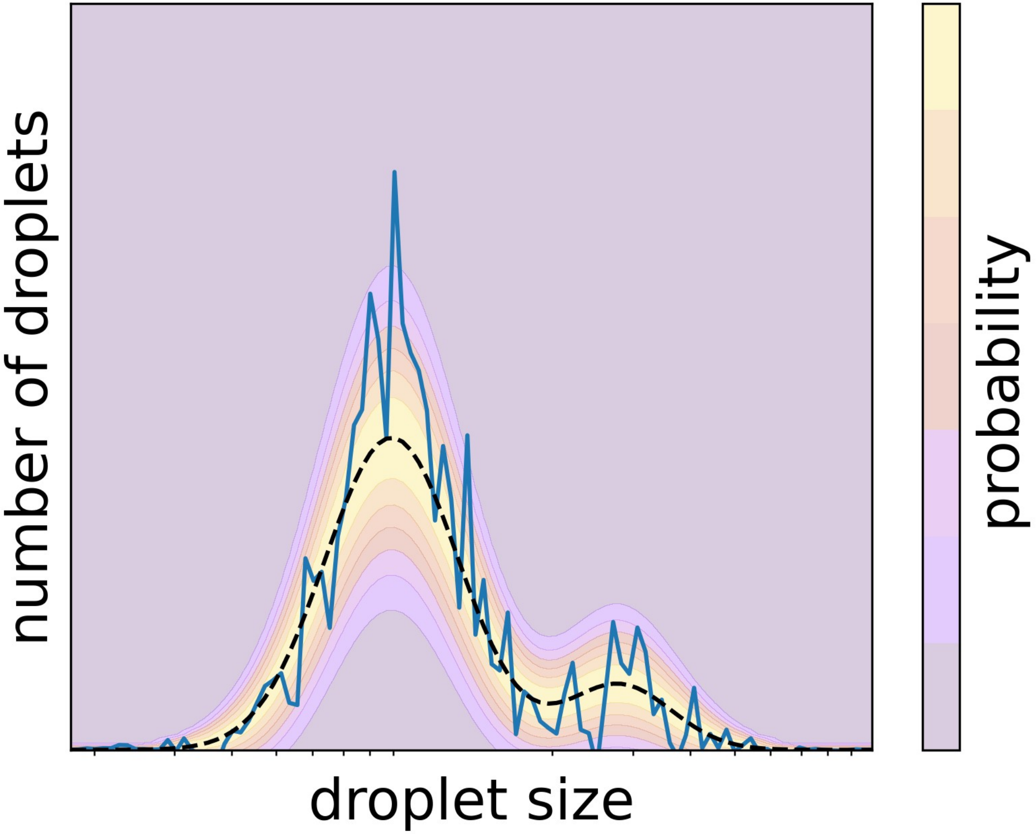
Stochastic model - realizations

- Size distribution described by P(N,r,t) – probability of finding N droplets of size r at time t
- Random realizations – e.g. blue line



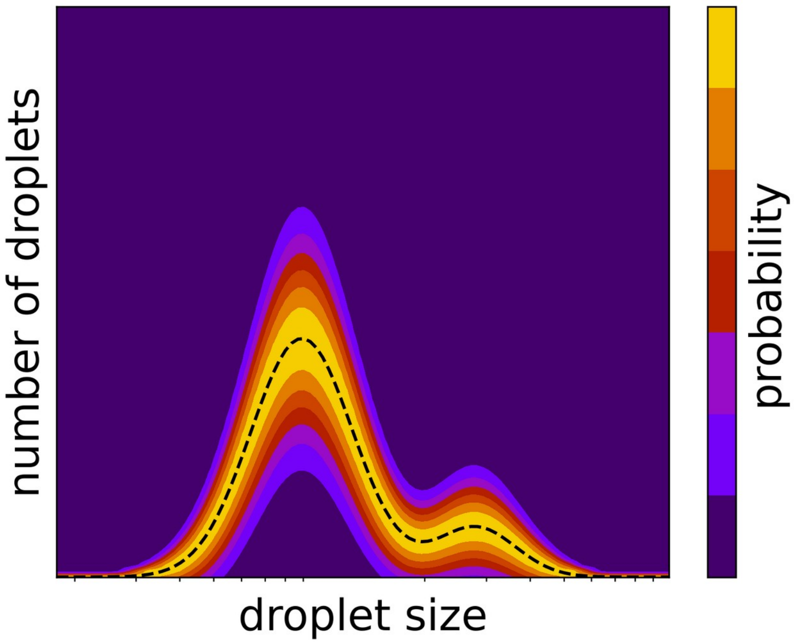
Stochastic model – expected value

- Size distribution described by P(N,r,t) – probability of finding N droplets of size r at time t
- Random realizations – e.g. blue line
- Expected value E(N) – black line

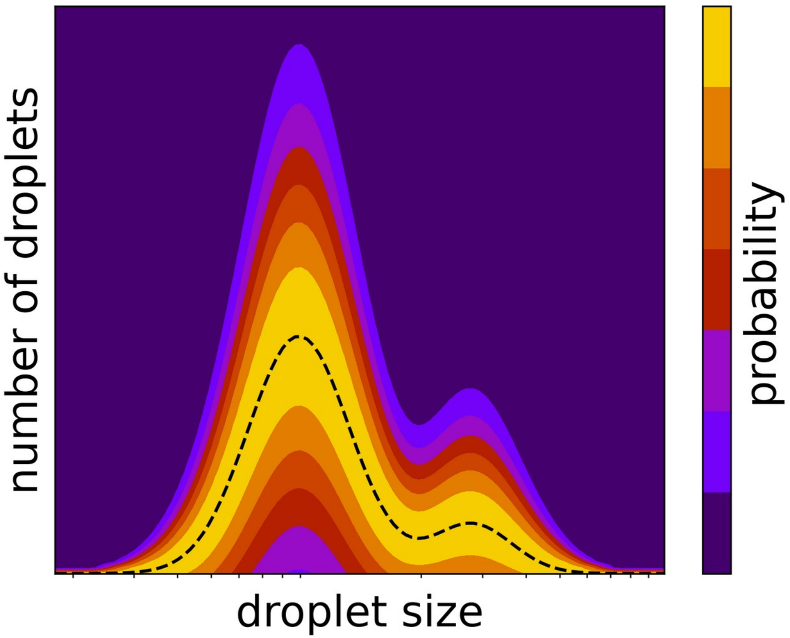


Stochastic model - variance

Large population – low variance



Small population – high variance

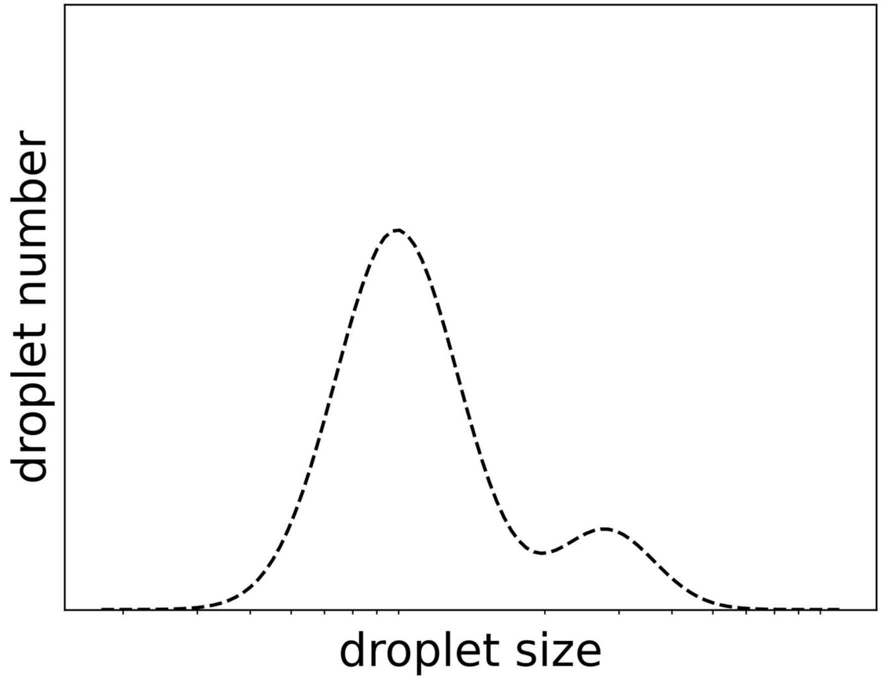


Stochastic model - limitations

- Probability distribution can be modeled only in idealized cases
- Realizations can be modeled only up to single cubic meters

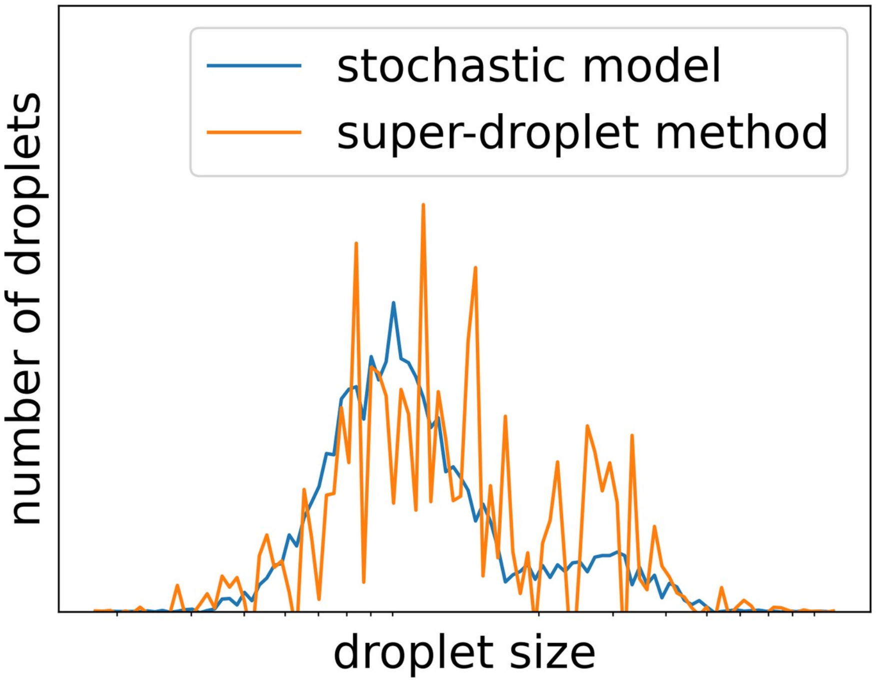
Stochastic coalescence equation (SCE)

- Number of droplets equal to the expected value E(N)
- Deterministic time evolution
- Zero variance (but it can be estimated with var(N)=E(N))
- Valid for populations greater than 10^7 droplets

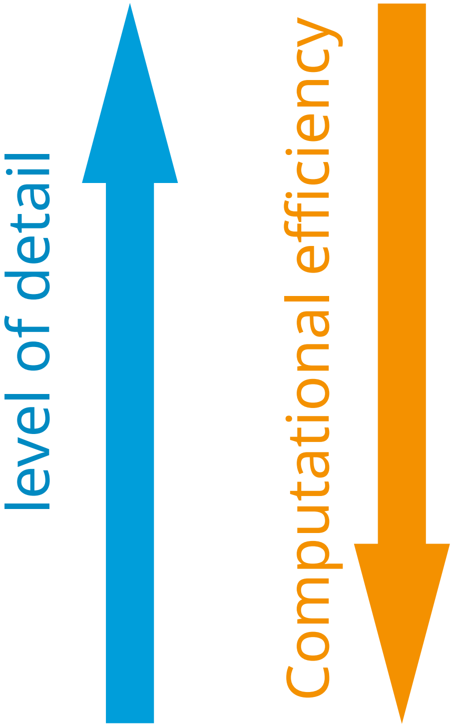


Super-droplet method (SDM)

- Produces random realizations
- Correct expected value
- Variance proportional to the number of superdroplets, not the number of droplets → greatly increased variance in most cases



Single cell – summary



1. Microscopic model

2. Stochastic model

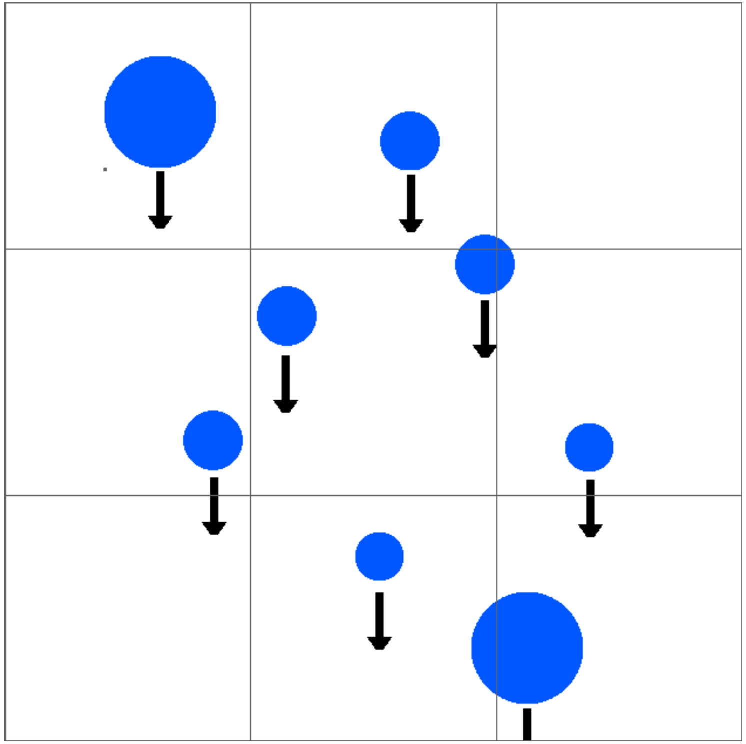
3. SDM
- Correct E(N)
- Too large var(N)

3. SCE
- Correct E(N)*
- var(N)=0

*for large cells

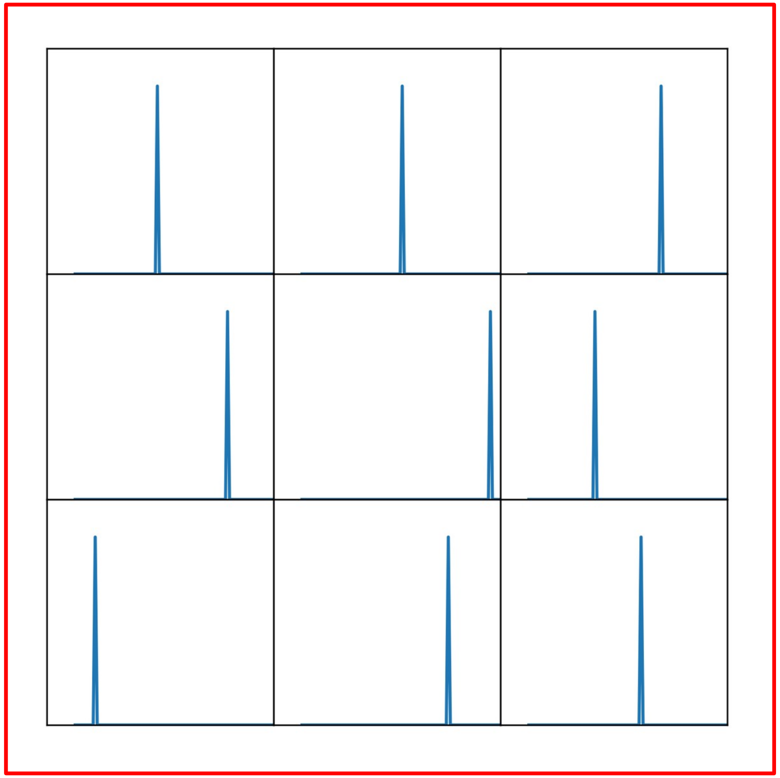
Models of collision-coalescence in multiple cells

Multiple cells – stochastic model



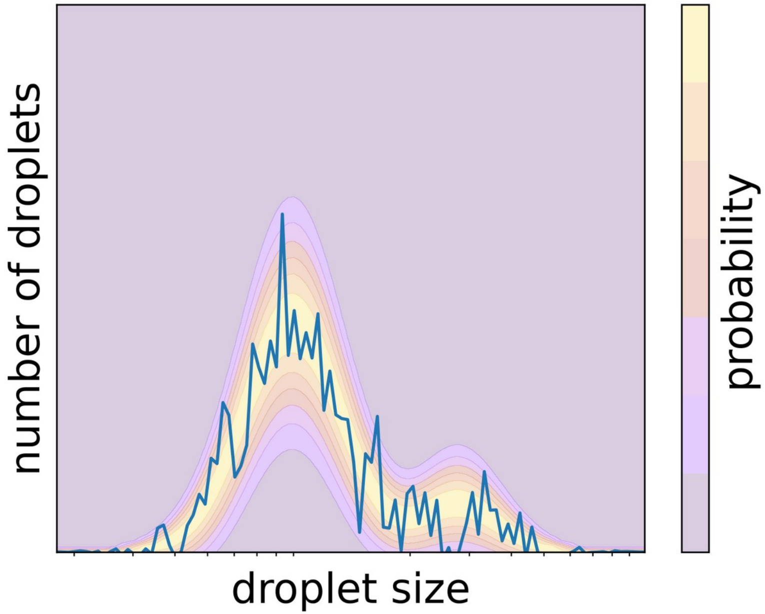
- One droplet per cell on average
- Cell ~2 mm, domain ~1m
- Inter-cell mixing (sedimentation, turbulence)

Multiple cells – stochastic model



average

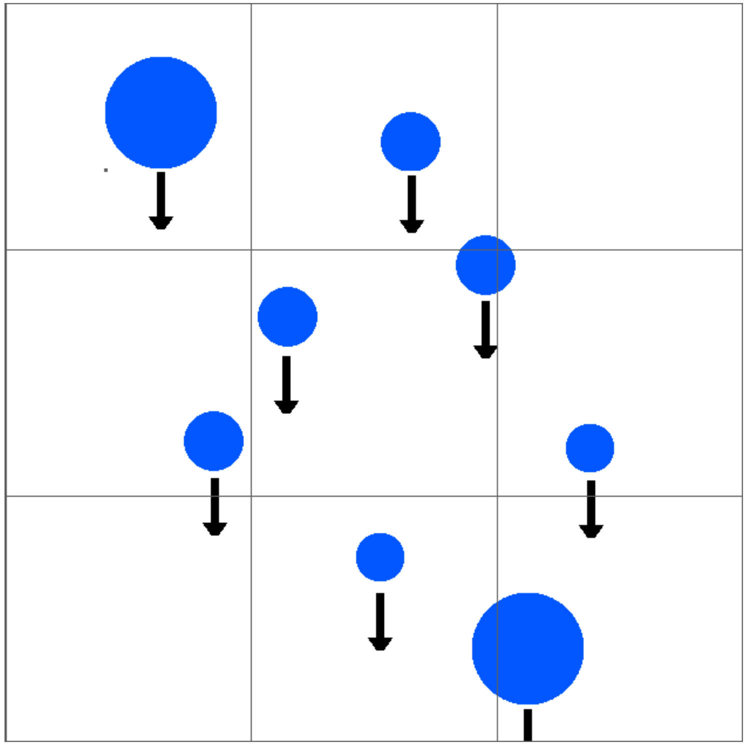
=



Multiple cells – stochastic model

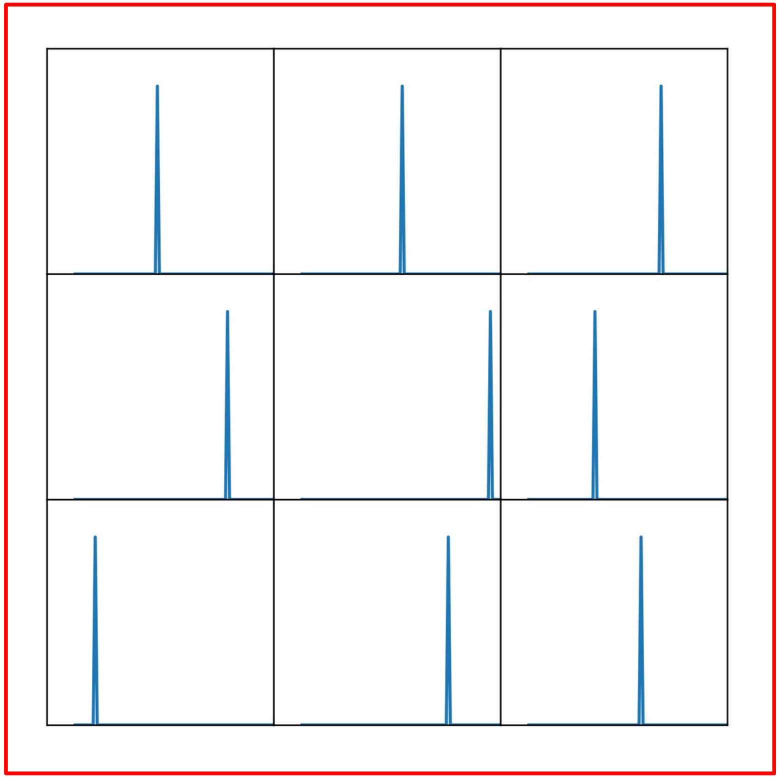
- Modeling the domain as a single cell gives the same domain-wide statistics as dividing the domain into cells
- Shows that the the domain is “well-mixed”, i.e. time scale of mixing (~1 ms) is shorter than time scale of collisions (~100 ms)
- No error associated with using large cells

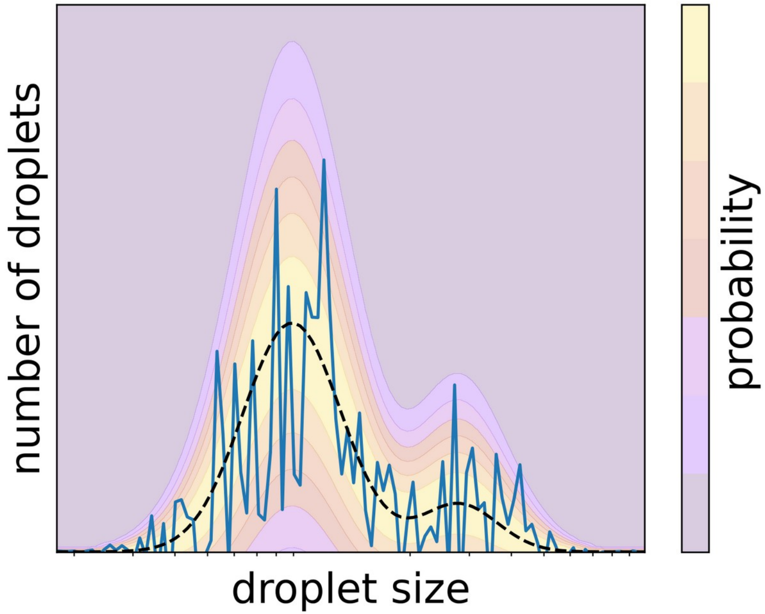
Multiple cells – SDM



- Cell ~10 cm, domain ~1m
- 1000 superdroplets in the domain
- One superdroplet per cell on average
- Inter-cell mixing (sedimentation, turbulence)

Multiple cells – SDM





Multiple cells – SDM

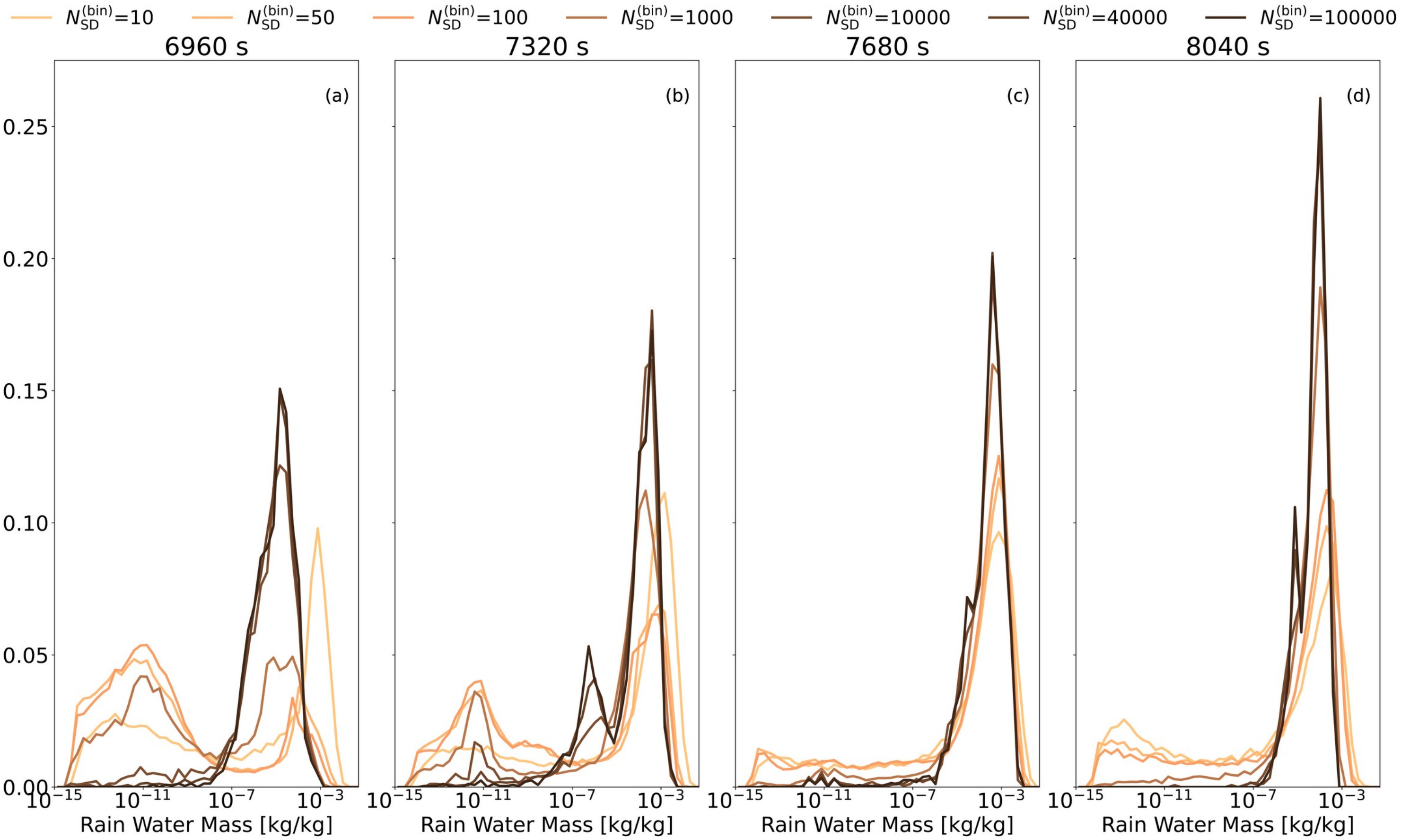
- Dividing the domain into smaller cells causes errors
- Different than in the stochastic model, because in SDM cells are larger, so the time scale of mixing (~1 ms) is longer than the time scale of collisions (~100 ms)
- Better to use large cell with many superdroplets

Randomness in collision-coalescence in LES

Randomness in collision-coalecence in LES

- Sensitivity of rain production to randomness in collision-coalescence can be studied using SDM, because variance scales with the number of superdroplets
- Ensembles of cumulus congestus simulations with:
  - the same flow field
  - the same initialization
  - different number of superdroplets

LES – spatial distribution of rain



LES – tentative conculsions

- Rain mass distribution converges for 10^4 superdroplets per cell, more than needed in LES without collision-coalescence and more than needed in simulations of pure collision-coalescence
- Randomness in collisions is important for rain formation once other processes (e.g. condensational growth) are also modeled?

Conclusions

- Pure collision-coalescence simulations show that it is correct to use large cells for collision-coalescence → SCE is valid & randomness in collision-coalescence can be neglected

  but:

- Processes other than collision-coalescence can create spatial differences in the DSD
- Some evidence that rain formation is sensitive to randomness in collision-coalescence when other processes (e.g. condensation) are included