A similarity model of partially rimed snowflakes and its application in Lagrangian super-particle simulations

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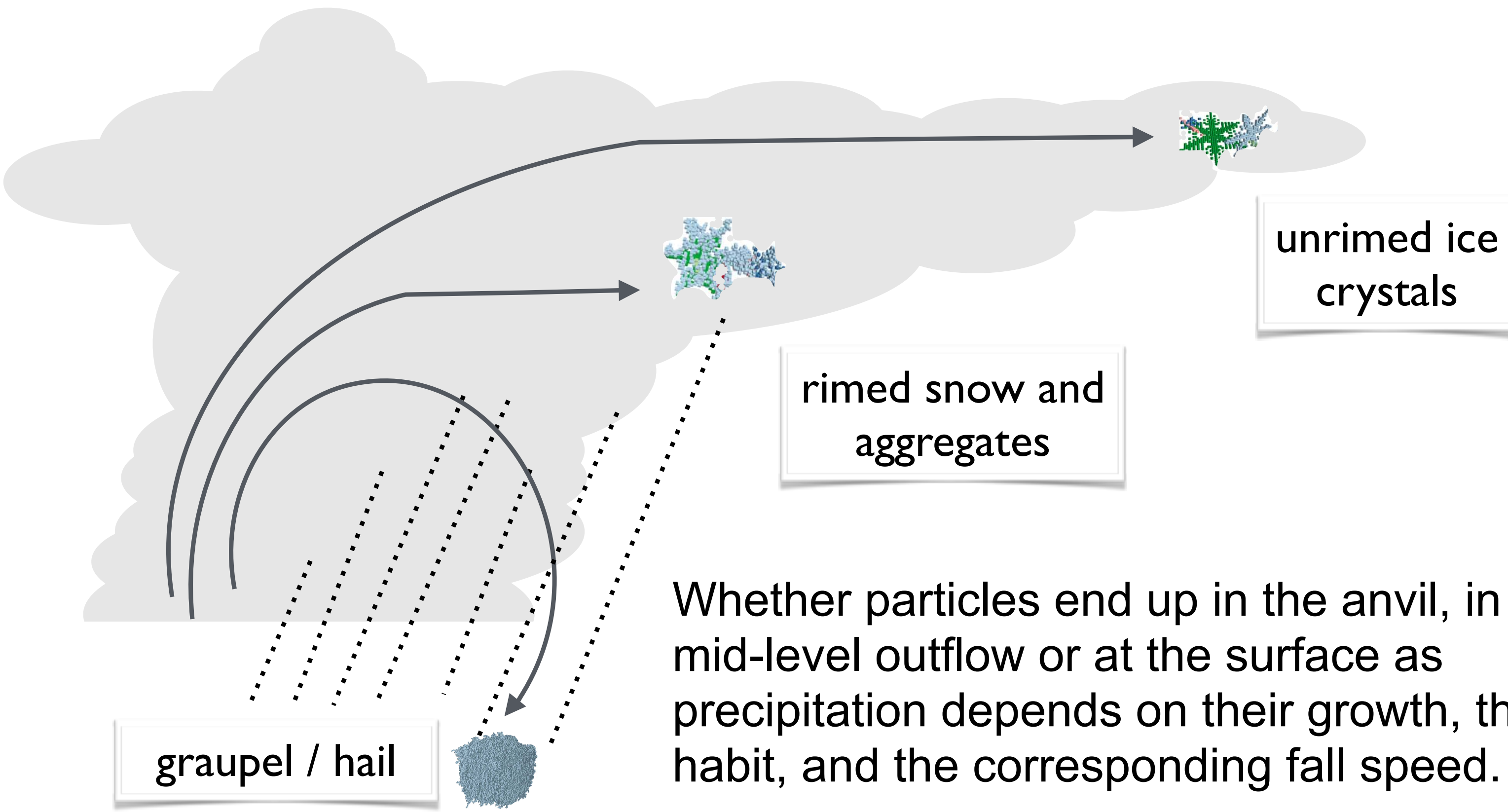
Motivation: Vertical structure of deep convection



Whether particles end up in the anvil, in the mid-level outflow or at the surface as precipitation depends on their growth, their habit, and the corresponding fall speed.

How good are our models in describing this change in particle habit?

How can we determine the geometry of rimed snow?

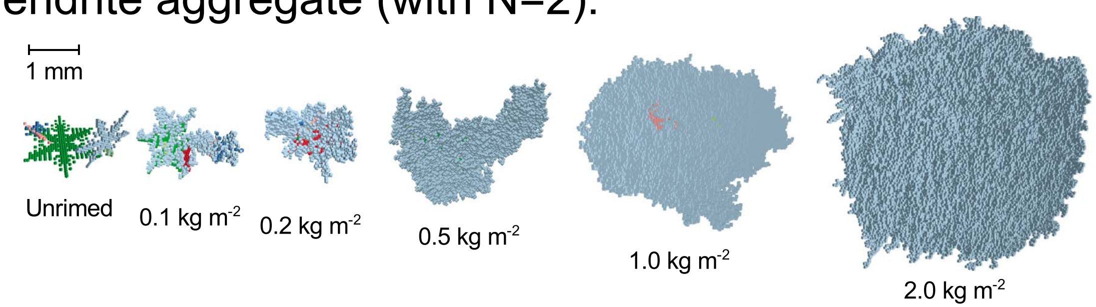
- Field measurements
- Lab experiments
- Modeling of individual particles

} difficulties to measure the degree of riming

Here we use the aggregation and riming model of Leinonen and Szyrmer (2015)

- Statistical geometrical model.
- Simulates aggregation of ice monomers and subsequent riming.
- No flow solver, no collision efficiency, etc.
- Droplets „freeze“ at first contact with ice structure.

Example of the riming of a dendrite aggregate (with N=2):

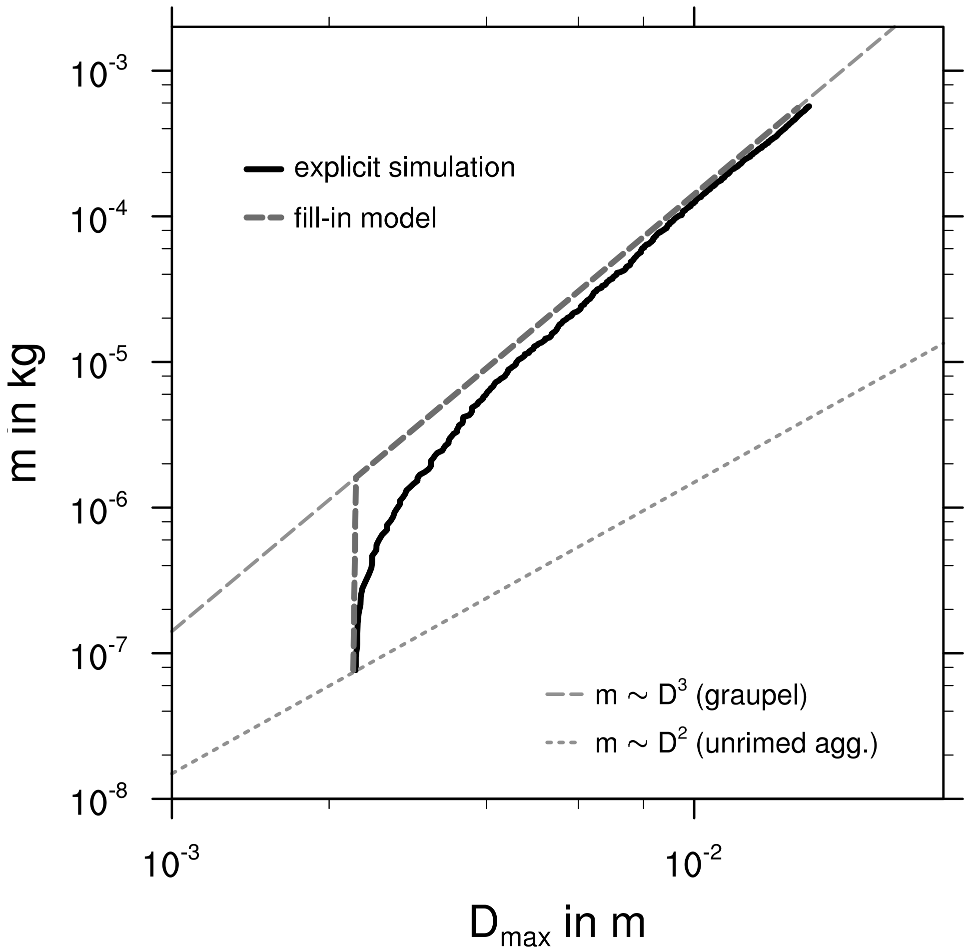


Transition from snow to graupel in m-D space

We want to parameterize the conversion from snow to graupel in a continuous way.

Using the explicit aggregation and riming model of Leinonen and Szyrmer (2015) we can simulate individual aggregates and rimed snowflakes.

This gives us access to the full information regarding their geometry, especially their mass-size relation.



Parameterization using normalized variables

To parameterize the geometry of partially rimed snowflake we introduce two dimensionless quantities.

$$\mathcal{M} = \frac{m_{\mathrm{rime}}}{m_g} \quad \text{with} \quad m_g = \frac{\pi}{6}\rho_{\mathrm{rime}} D_{\mathrm{max}}^3$$

$$\mathcal{D} = \frac{D_{\mathrm{max}}}{D_{\mathrm{agg}}}$$

Given the rime mass and the size of the original aggregate (or the ice mass in McSnow), we want to calculate the maximum dimension.

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$\mathcal{D}$ is the size relative to the unrimed snowflake. It is 1 for unrimed snowflakes and becomes large for graupel.

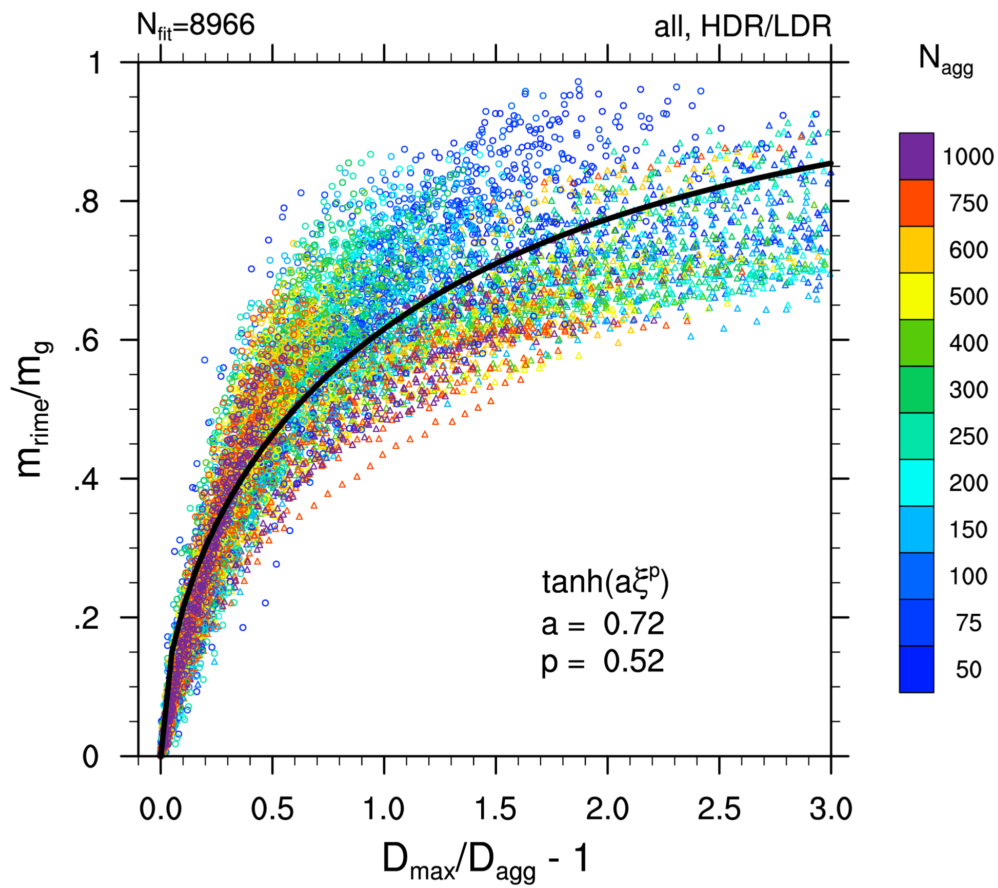
Given the rime mass and the size of the original aggregate (or the ice mass in McSnow), we want to calculate the maximum dimension.

Result for the aggregation-riming model

Quite large scatter, but this is not unexpected for snowflakes.

This already includes

1. Different crystal habits.
2. Two different rime densities.
3. Aggregates of different size or monomer number N.



Result for the aggregation-riming model

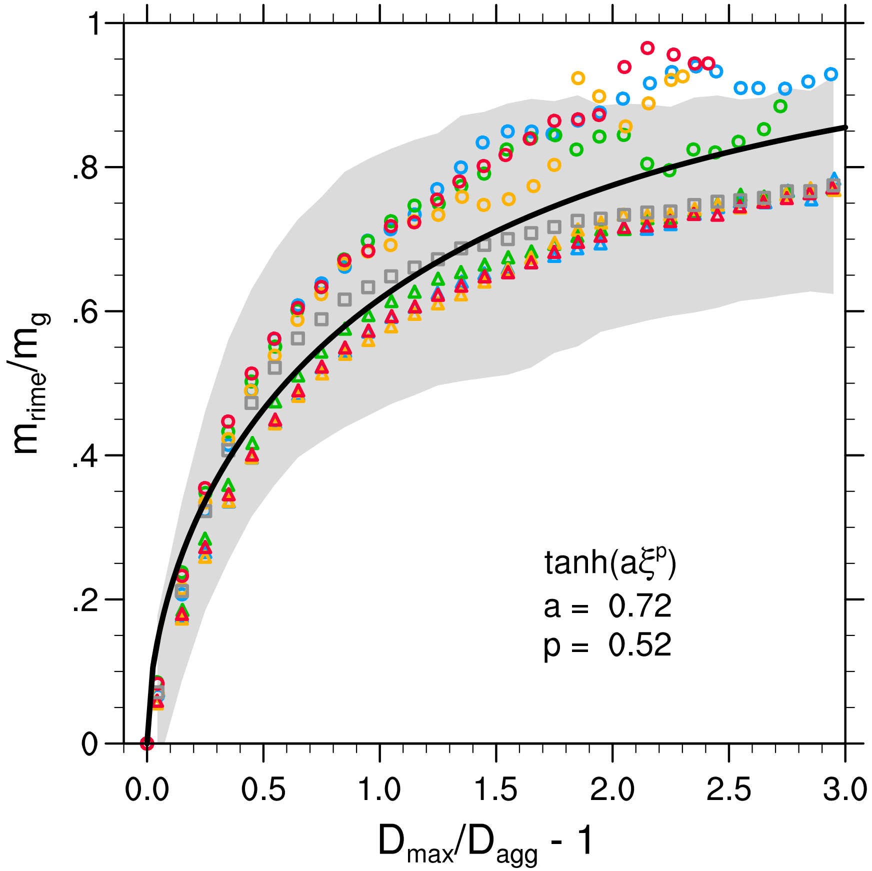
Same data, different plot.

Now the different colors are different habits: aggregates of dendrites, needles, rosettes, and plates.

Circles are low density rime and triangles are high density rime.

Grey area shows two standard deviations around the mean.

Not perfect, but probably good enough.

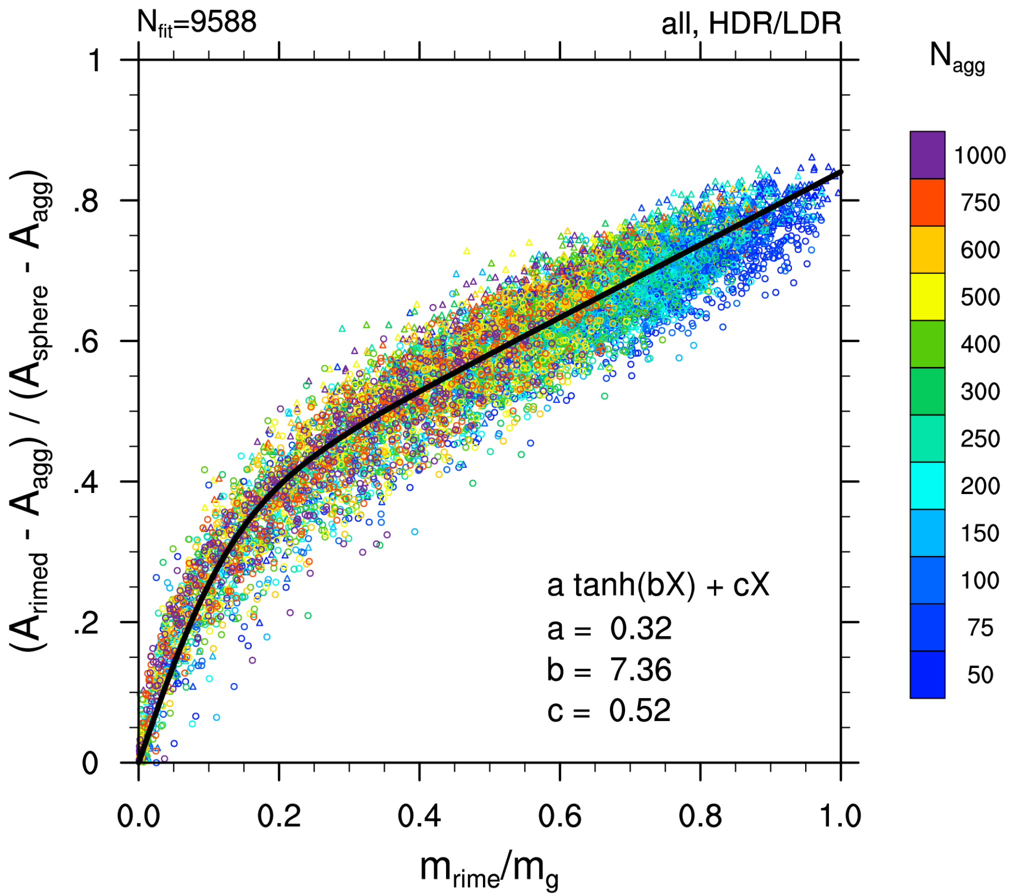


The result for the cross-sectional area

Two different regimes:

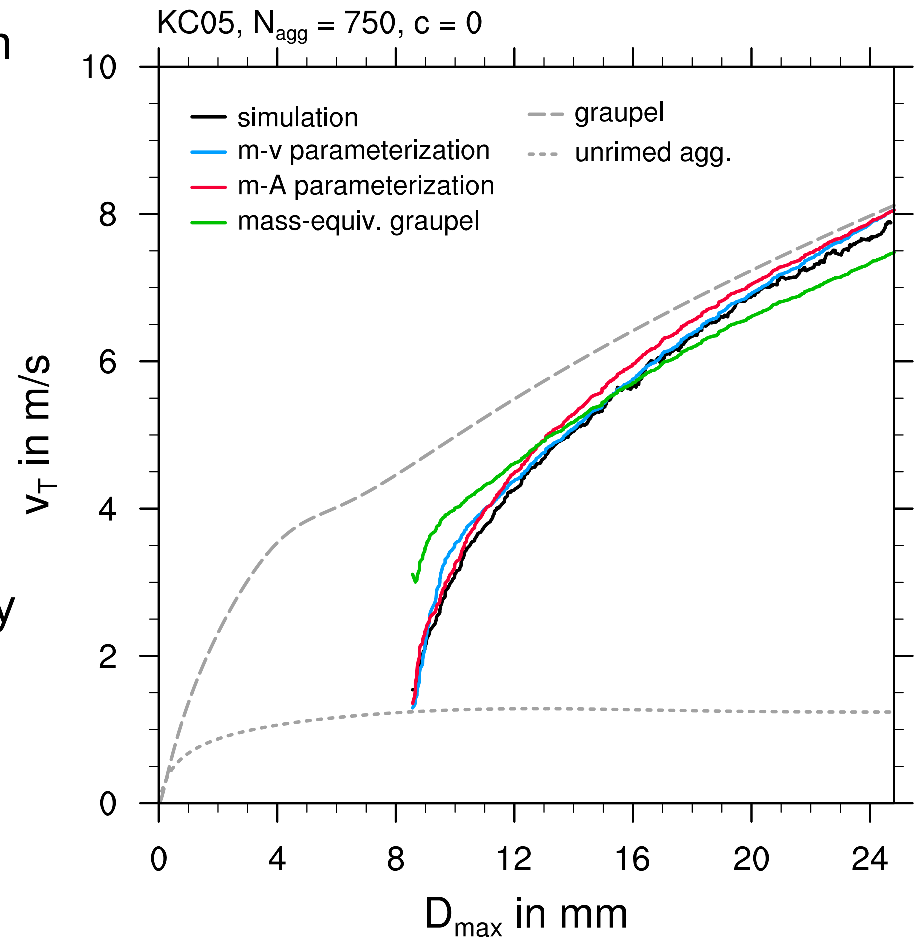
1. A fill-in regime in which interstitial spaces are filled with rime
2. A linear growth regime in which the change of the maximum dimension dominates the area growth.

Having m-D and m-A relations provides us also with the terminal fall velocity.



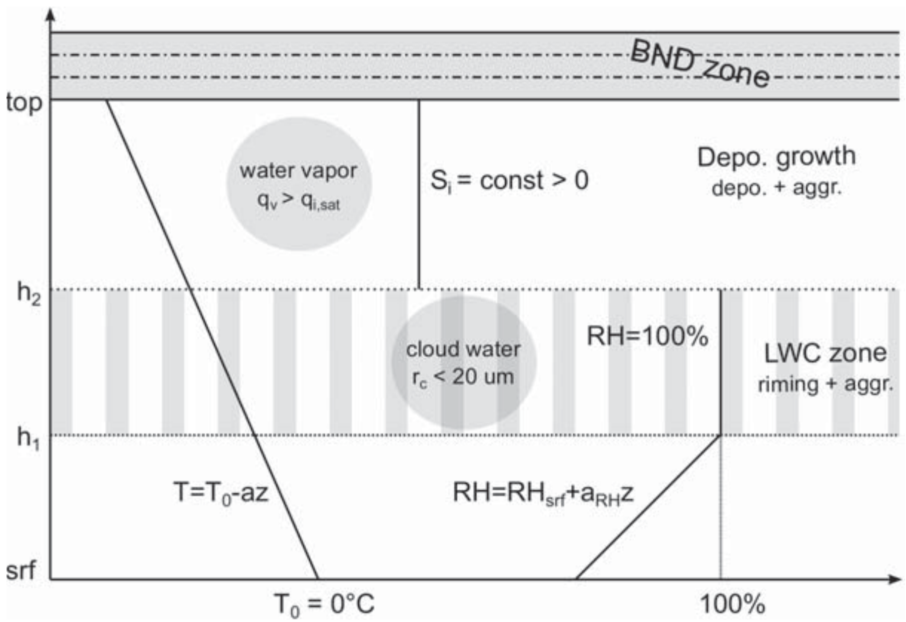
Fall speed during rime growth

- Individual large snowflake of 8 mm
- Pure rime growth
- Fall speed slowly approaches that of graupel
- Grey lines are size-equivalent reference particles
- All colored lines are mass-equivalent particles
- Transitioning to graupel too quickly would lead to a large overestimation of the fall speed (green line)



1D simulations with McSnow

- Ice crystals falling through an atmosphere at rest and growing by depositional growth, aggregation and riming.
- Model setup as in Brdar and Seifert (2018), but here we set h1=srf. Hence, no evaporation.

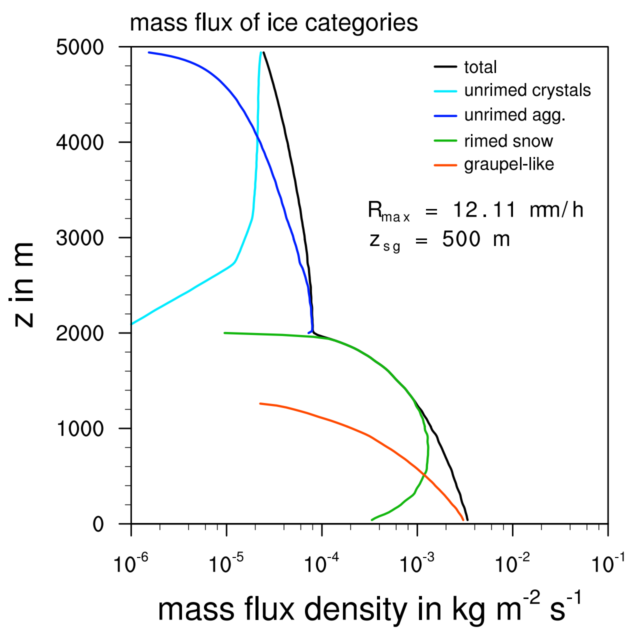


Citation: Slavko Brdar and Axel Seifert (2018). McSnow: A Monte-Carlo particle model for riming and aggregation of ice particles in a multidimensional microphysical phase space. Journal of Advances in Modeling Earth Systems, 10, 187–206.

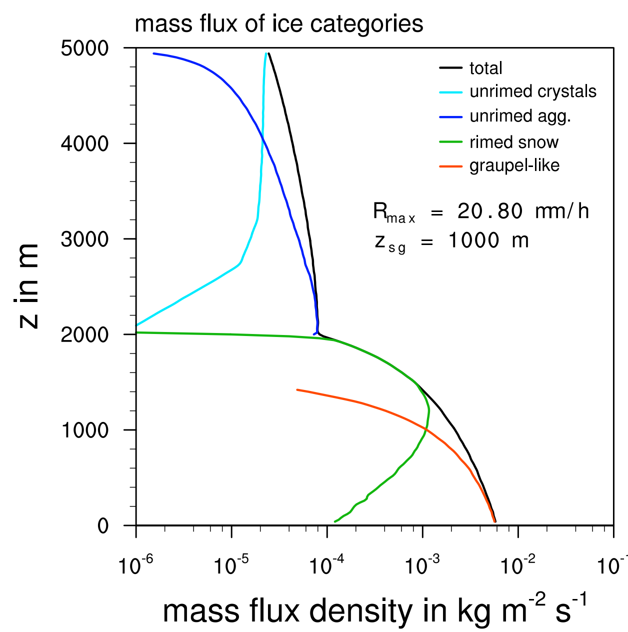
Application in McSnow

Simple idealized 1d simulations of aggregates falling into a liquid layer

a) fill-in model



b) similarity model



Quite dramatic increase in the precipitation rate due to increased riming!

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Simple idealized 1d simulations of aggregates falling into a liquid layer

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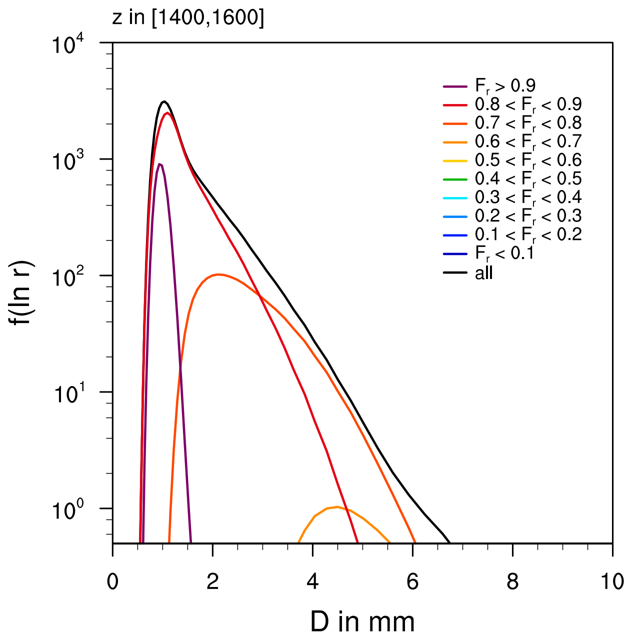
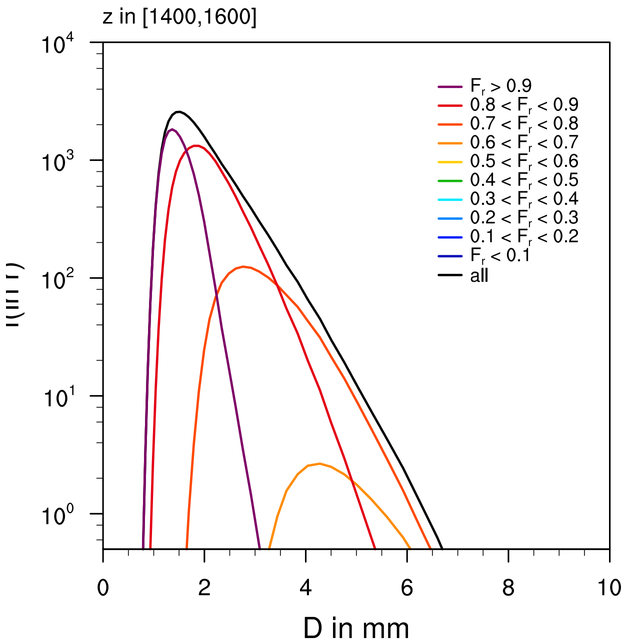


b) similarity model



More large particles and no artificial modes for similarity model.

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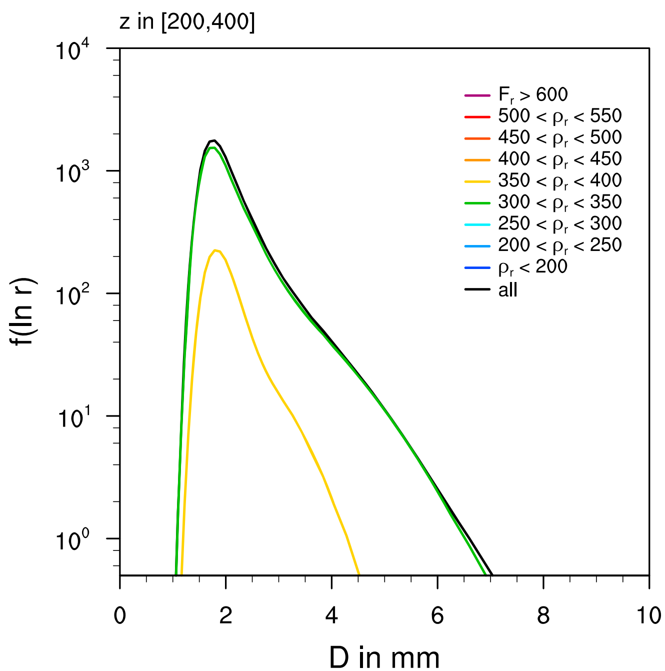
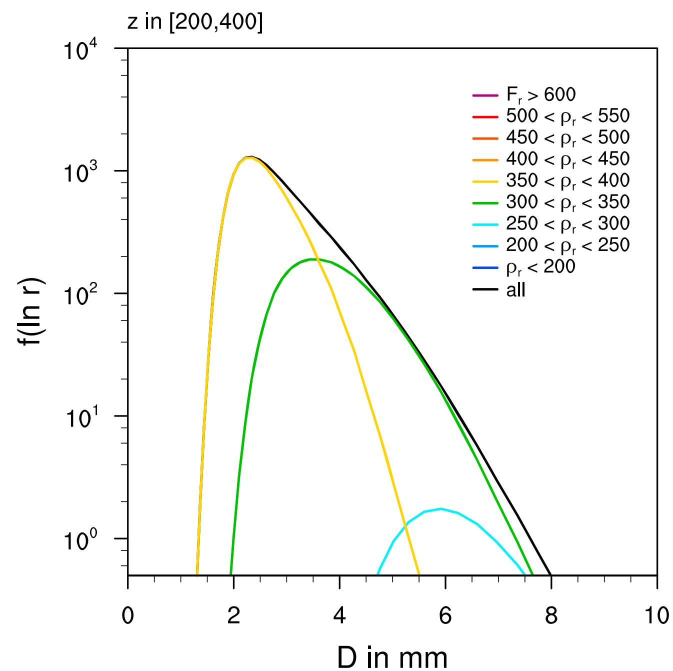


b) similarity model



The rime density changes due to the different fall speed.

Conclusions

- We developed a new parameterization for the geometry of rimed snowflakes based on explicit simulations using an aggregation-and-riming model.
- The parameterization is an alternative to the classic fill-in model, which describes the graupel formation as a two-stage process.
- Application of the new snow geometry in a Lagrangian particle model leads to a quite dramatic increase in the precipitation rate.
- This is because the riming rate has a nonlinear dependency on the size of the particle. Hence, size growth increases riming increases size growth etc.
- Note that our treatment of the snowflake habit can hardly be applied in bulk or spectral bin models, because it requires the knowledge of the size of the unrimed crystal inside of each individual partially rimed snowflake.
- Hence, Lagrangian particle models provide completely new opportunities for understanding cloud processes.