# A case study of particle accumulation in rain drops and immersion freezing

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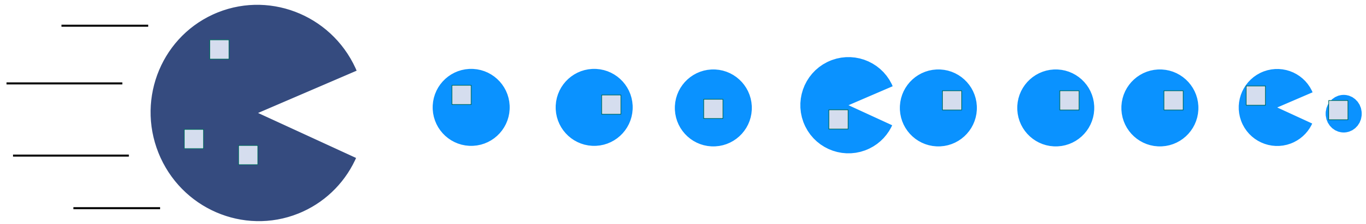


# „How do ice nuclei (IN) influence precipitation?“

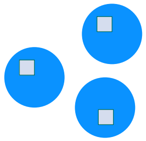
- **rain drop properties determine formation & growth of precipitating ice**

  surface rain formation originates from graupel/hail melting

  but: graupel & hail properties are determined by rain properties in the convective core

  most important here  primary formation of graupel & hail
  vs. efficiency of liquid water depletion
  vs. growth of graupel & hail by riming

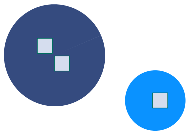
- **aerosol-dependent immersion freezing in bulk microphysics**
  - general assumption:
    every activated particle (IN) is incorporated in one cloud droplet



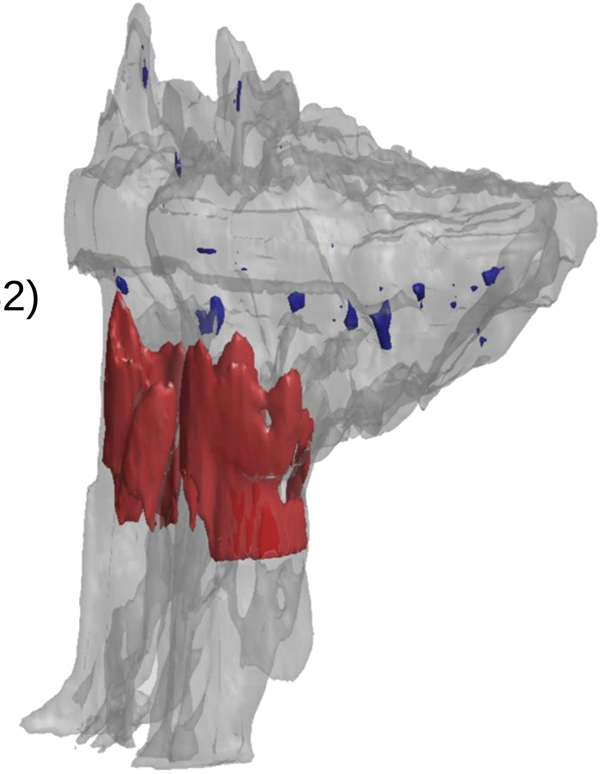
  - rain freezes independent of IN, function of drop mass (Bigg, 1953)
    based on the idea of a stochastic freezing process
    → less (!) rain freezing with more IN by indirect rain mass depletion


- **here: what if we let IN influence rain drops?**

  problem: particle content depends on the microphysical history



CONSORTIUM FOR SMALL SCALE MODELING
COSMO



- **idealized setup**
  - deep convection, based on Weisman and Klemp (1982)
  - $\Delta x \approx 500m$, some hours simulation time

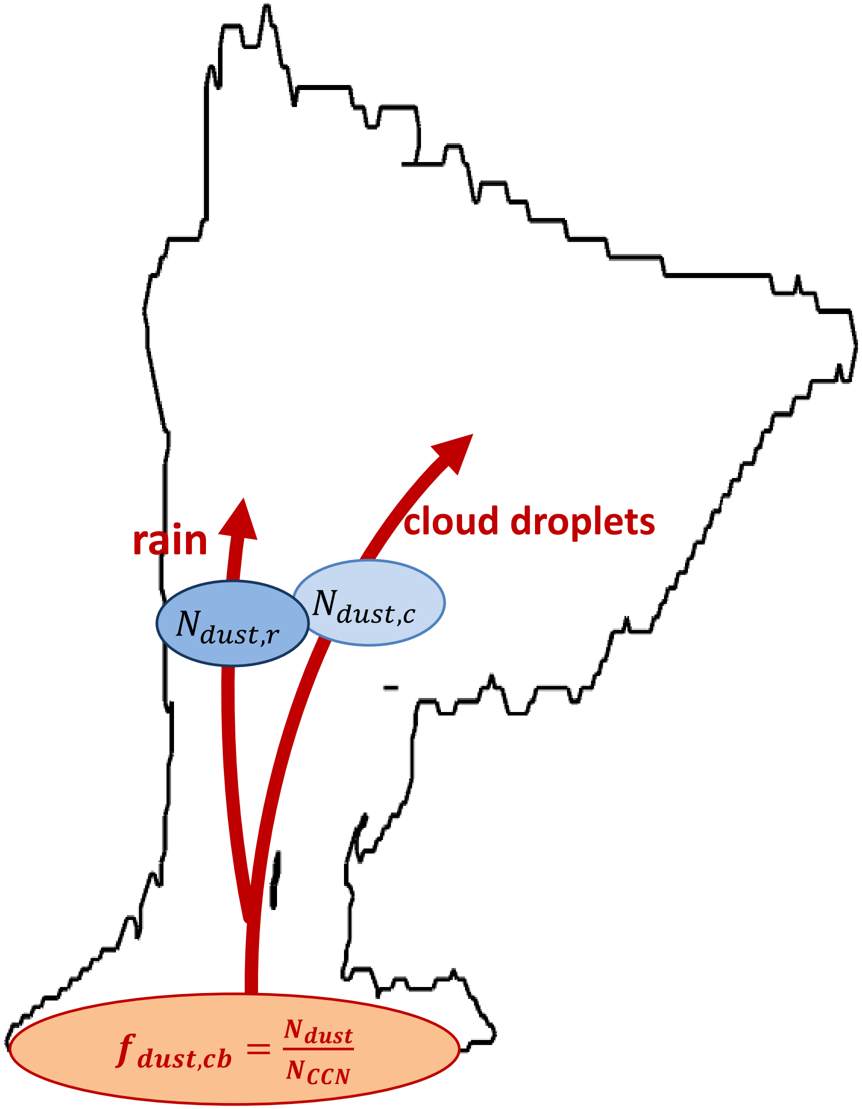
- **COSMO-ART** (Vogel et al., 2009)
  pollen module used for tracers

- **two-moment scheme** (Seifert and Beheng 2006)

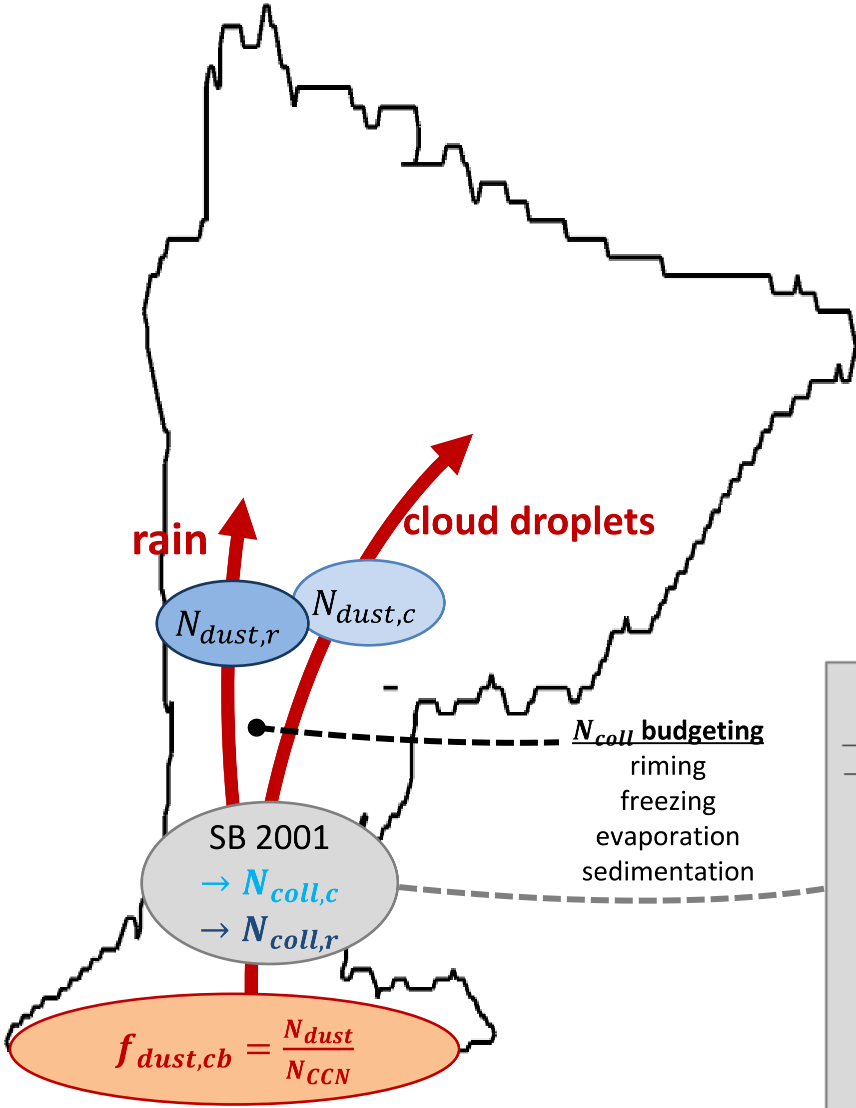
  aerosol-dependent ice formation
  immersion freezing (Niemand et al., 2012)
  deposition nucleation (Ullrich et al., subm.)
  ice nuclei depletion (Paukert and Hoose, 2014)

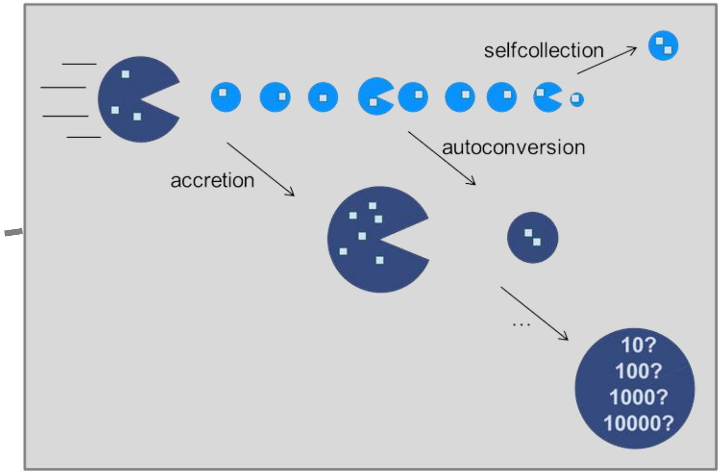
- **“perturbed microphysics”**
  multiple sets of microphysics are calculated within one simulation,
  i.e., each perturbed cloud is based on the same atmospheric dynamics

# Redistribution of mineral dust



# Redistribution of mineral dust



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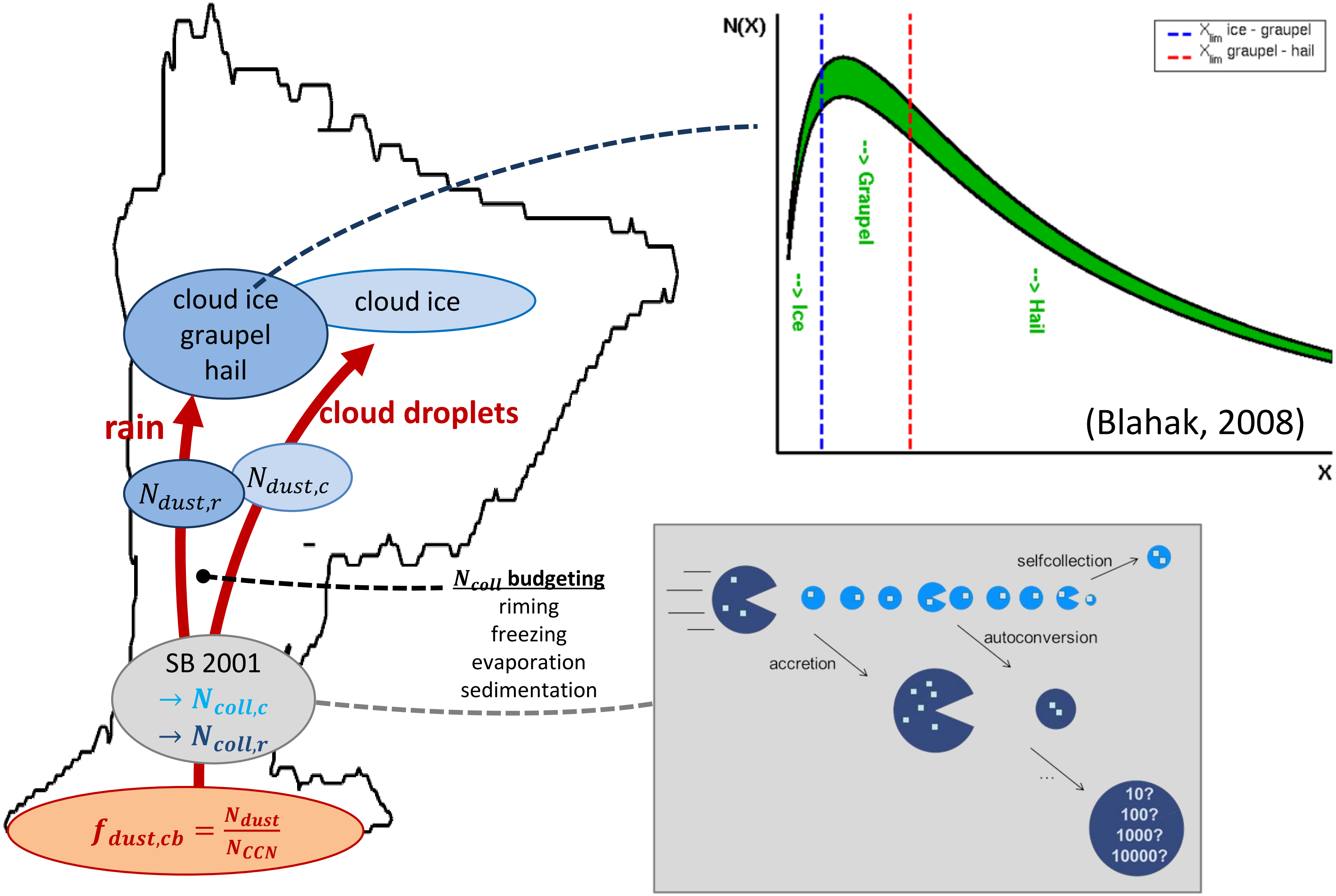
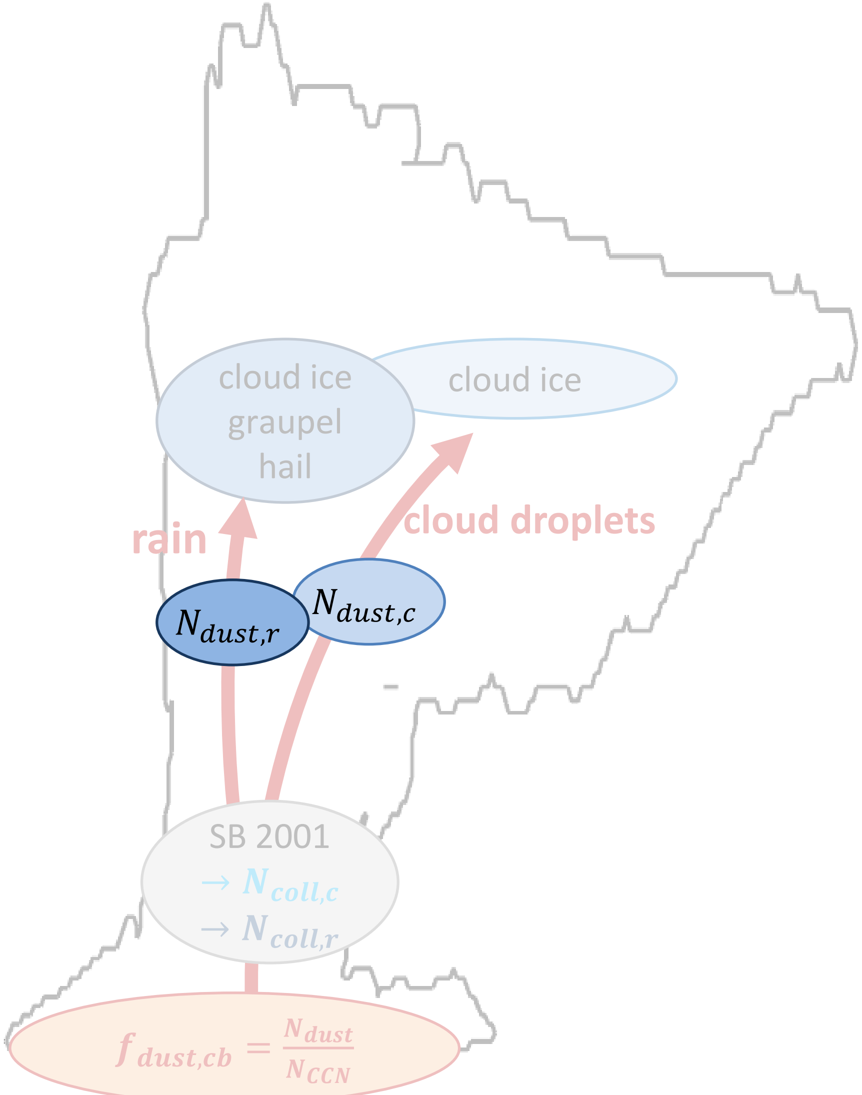
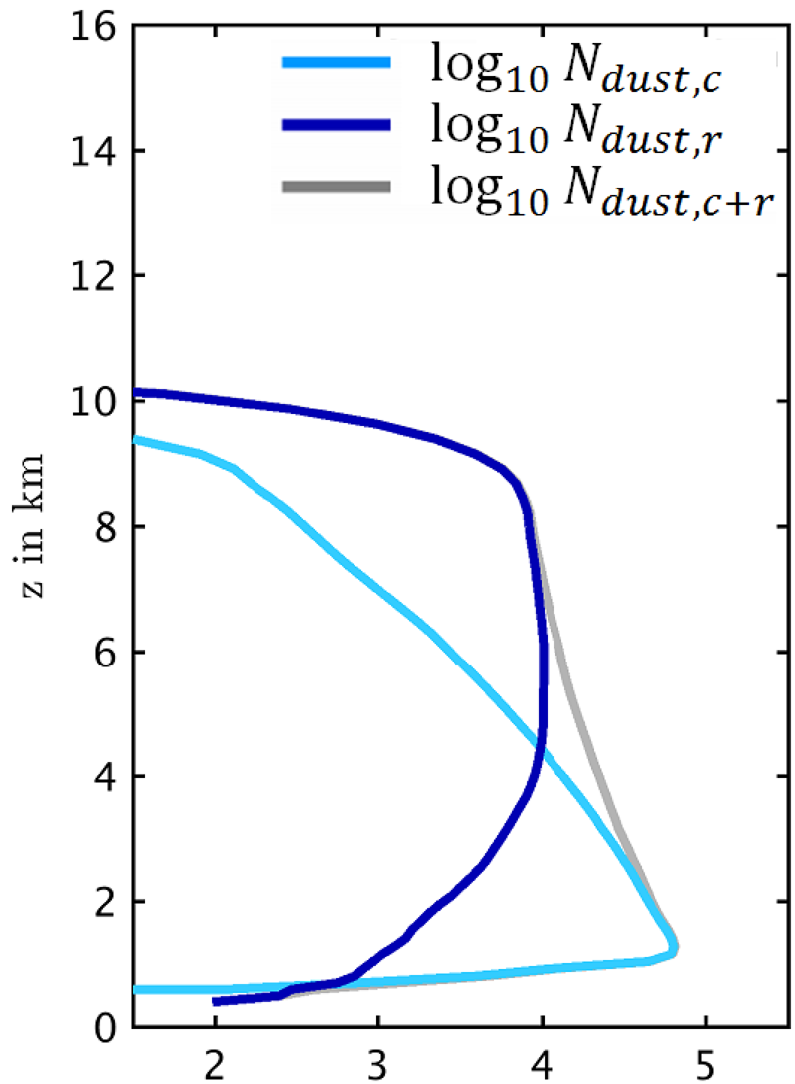


# Redistribution of mineral dust



# just another freezing parameterization…

activated sites per dust surface area

total activated particles in rain

$$N_{IN,r} = \int n_{dust,r}(D)\, e^{-n_s(T)\pi D^2} dD_{dust}$$

for mono-disperse rain

mean IN per rain drop

$$\lambda_{IN} = \frac{N_{IN,r}}{N_r}$$

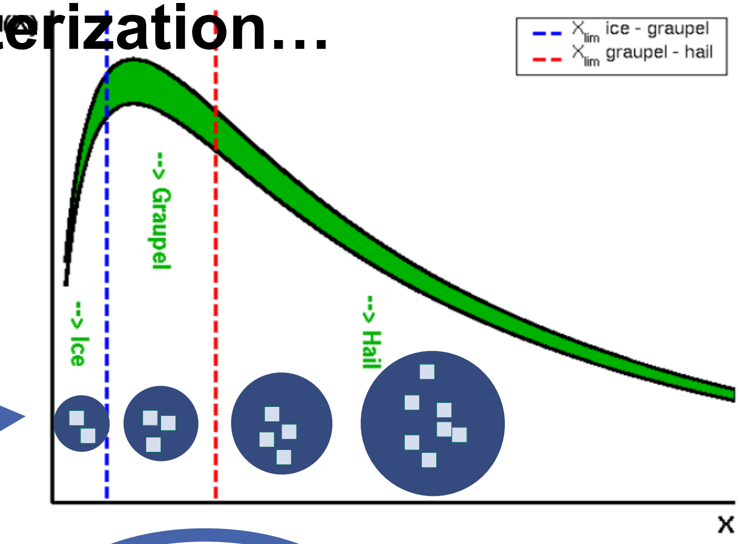
frozen rain drops
with Poisson-distributed IN

$$N_{ice} = N_r \cdot \left(1 - e^{-\lambda_{IN}}\right)$$

freezing rate
fct(drop cooling rate)

$$\frac{\partial N}{\partial t} = -e^{-\lambda_{IN}} n_s a_{N12} (w - v_{sed}) \frac{\partial T}{\partial z} \cdot \int \pi D^2\, n_{dust,r}(D)\, e^{-n_s \pi D^2} dD$$

# just another freezing parameterization…




solved for 8 rain „bins“

for mono-disperse rain

- mean IN per rain drop

$$\lambda_{IN} = \frac{N_{IN,r}}{N_r} = fct(x_{rain})$$

- frozen rain drops with Poisson-distributed IN

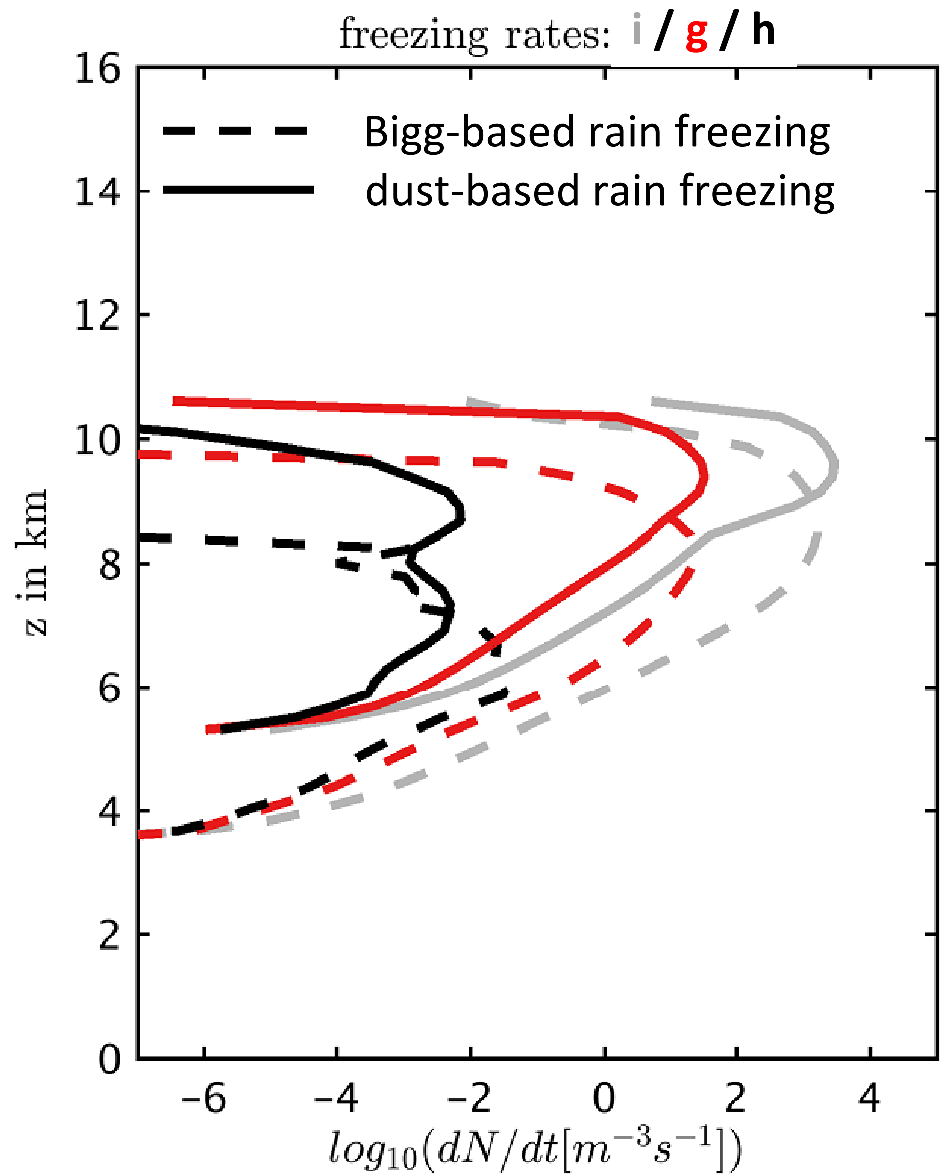
$$N_{ice} = N_r \cdot \left(1 - e^{-\lambda_{IN}}\right)$$

- freezing rate fct(drop cooling rate)

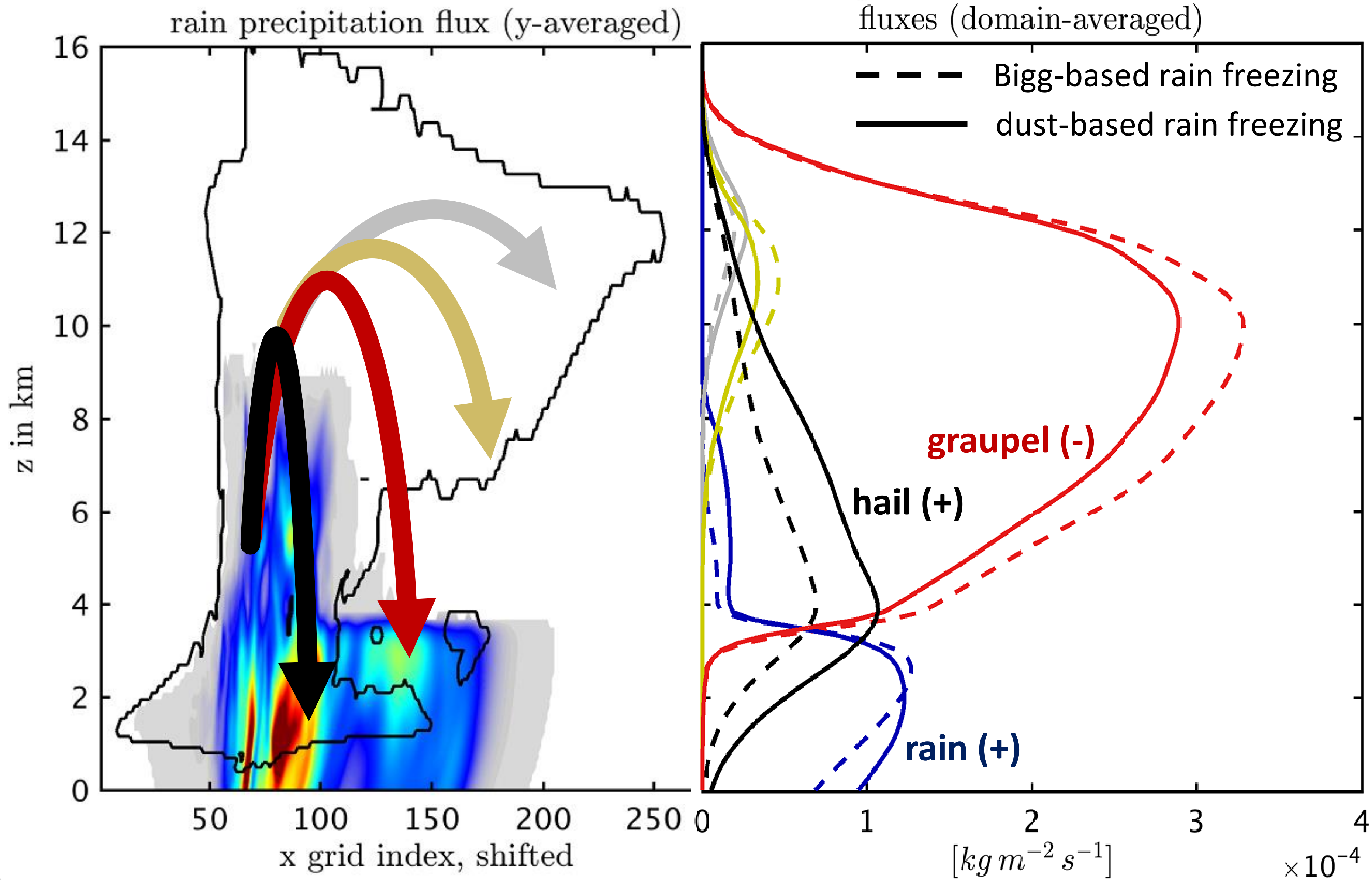
$$\frac{\partial N}{\partial t} = -e^{-\lambda_{IN}} n_s a_{N12} (w - v_{sed}) \frac{\partial T}{\partial z} \cdot \int \pi D^2 \, n_{dust,r}(D) \, e^{-n_s \pi D^2} dD$$

# Dust-dependent rain freezing rates

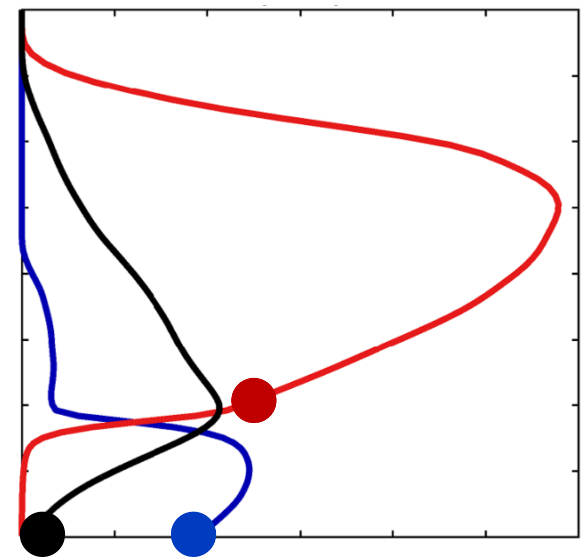
- here: $N_{dust} = 10^5 m^{-3}$
- dust-induced freezing rates are (much) smaller than Bigg-rates
- homogeneous freezing becomes dominant at z>9km
  (now parameterized explicitly)
- more liquid mass survives (z<9km)
  riming of g/h…
  sedimentation fluxes…
  melting / rain formation…



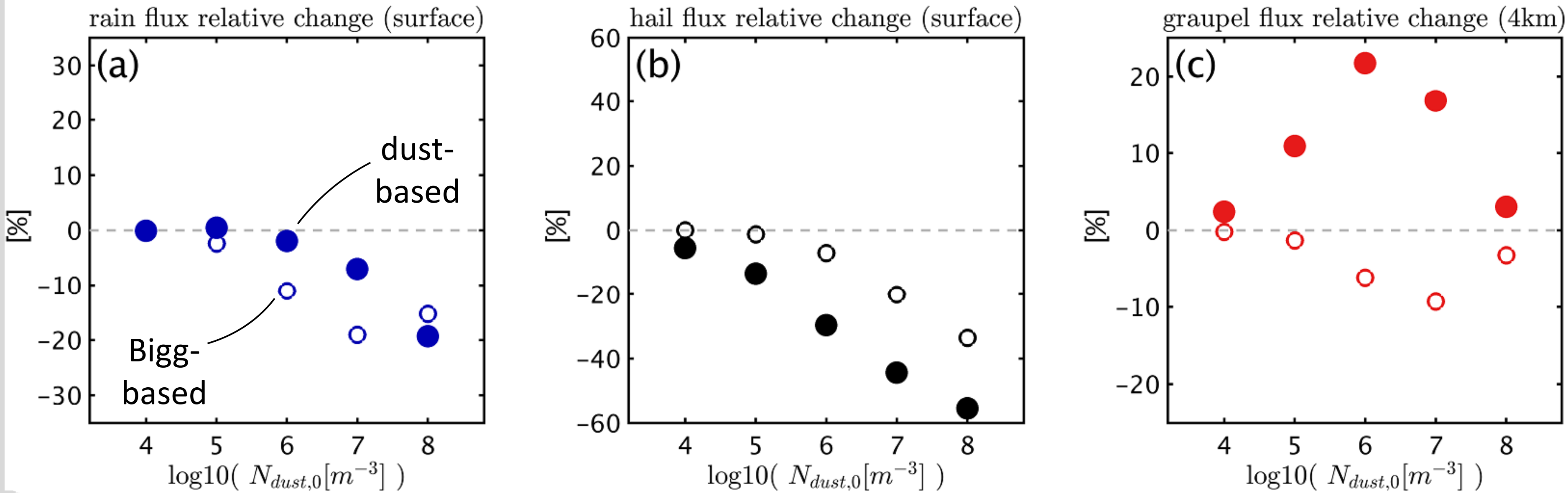
# Precipitation



# Precipitation sensitivity: Bigg- vs. dust-based



- dust perturbation: $N_{dust,0} \pm 90\%$ (factor of 19)
- „strong“ convection
  w>50m/s
- **surface rain** change dominated by **hail**
- technical note: „ice_typ=2“






Marco Paukert and Corinna Hoose - Rain Drop Freezing

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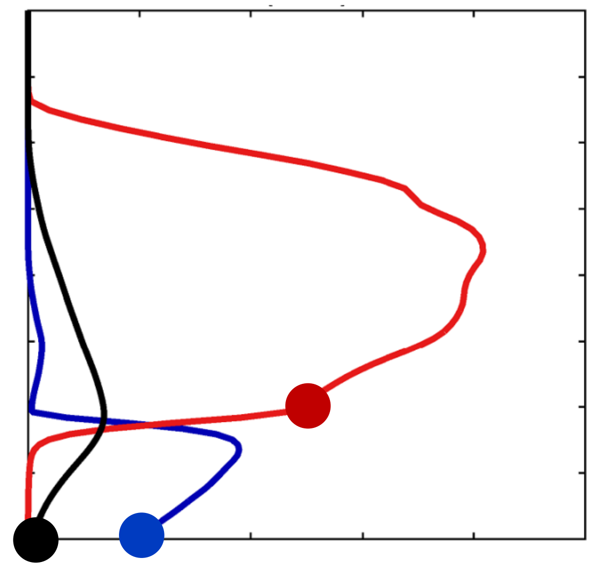
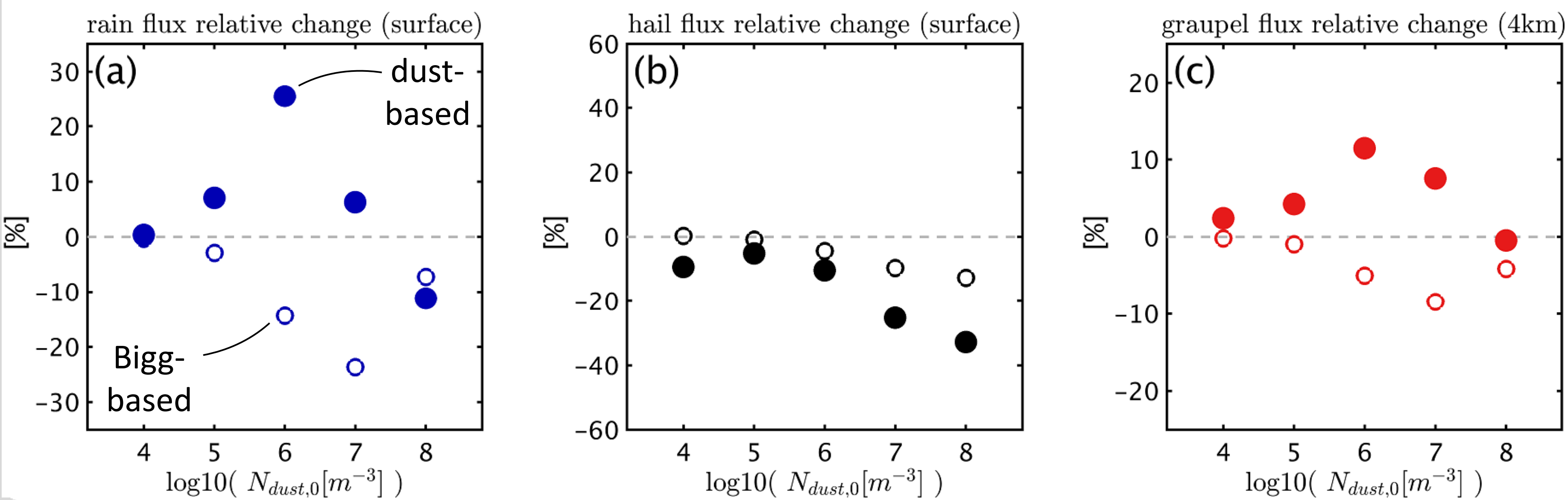
# Precipitation sensitivity: Bigg- vs. dust-based

- dust perturbation: $N_{dust,0} \pm 90\%$ (factor of 19)
- „weak" convection
  - w~10m/s
  - dissipates after ~1.5 hours
  - graupel dominates the surface rain formation

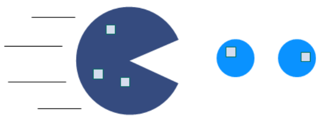


- **surface rain** change dominated by **graupel**

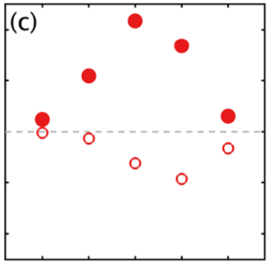


# Summary

- in the freezing regimes, most of the particles are immersed in rain



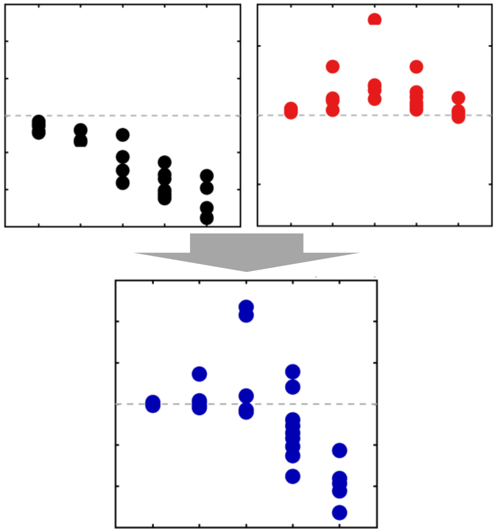
- dust-based rain freezing is less efficient than the Bigg-based freezing



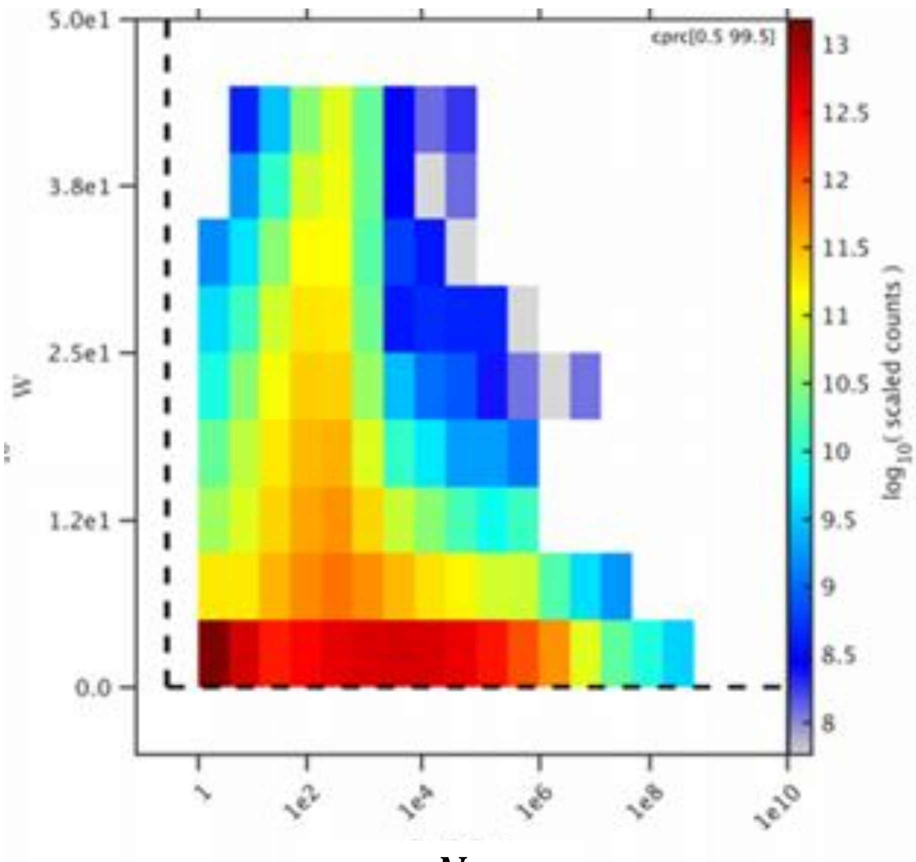

- Bigg-based rain freezing cannot reproduce the sign of graupel flux changes

- with a perturbed dust immersion freezing, we find
  - **graupel** / **hail** antagonism:
    more vs. less efficient riming growth
  - **rain flux change** depends on the relative importances of graupel and hail fluxes, determined by

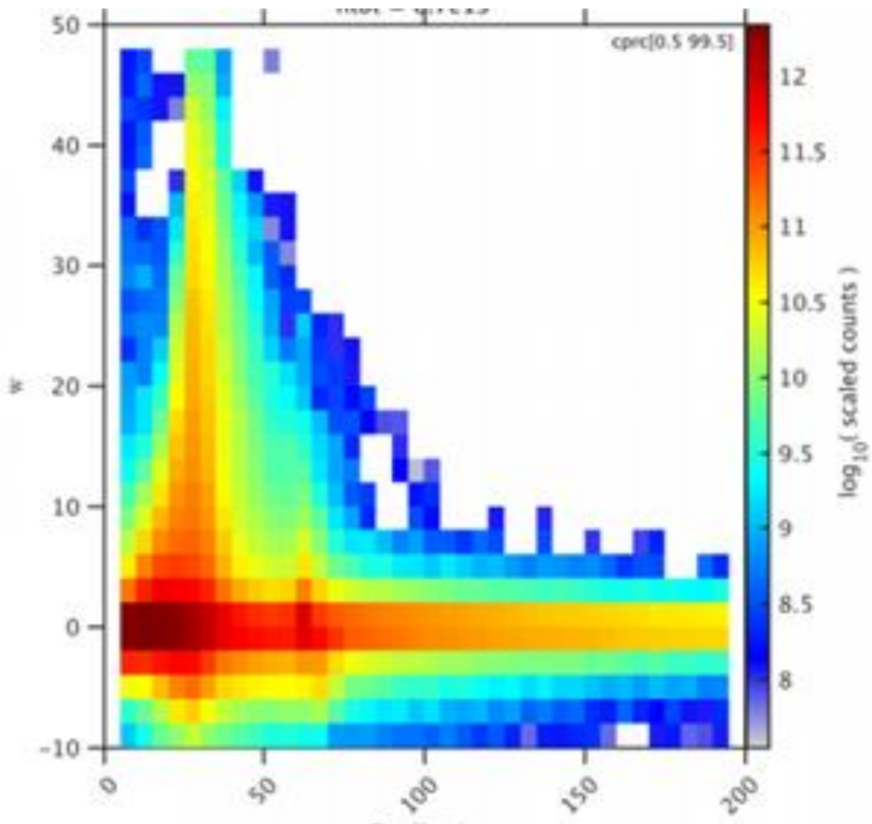
    → convection strength
    → „ice_typ“ (particle conversion during riming)
    → riming? Seifert 2014 update may make a difference



# some backups…




$$\lambda_r = \frac{N_{coll,r}}{N_r}$$




$D_{coll}$