Application of the Super-Droplet Method to Mixed-Phase Clouds Based on the Porous Spheroid Approximation of Ice Particles

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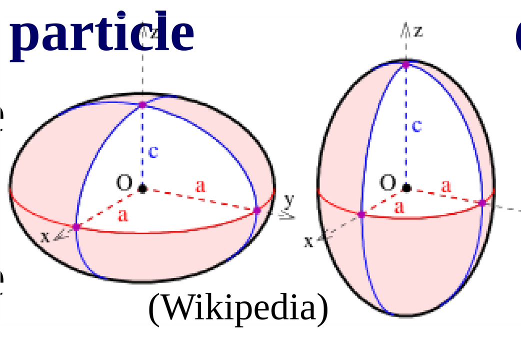
The super-droplet method (SDM) is a particle-based and probabilistic numerical scheme, which enables accurate simulations of cloud microphysics with less demand on computation (Shima et al. 2009). In this study, the SDM is applied to mixed-phase cloud microphysics. Following Chen and Lamb (1994), ice particles are represented by porous spheroids. The model is evaluated through a 2D LES simulation of an isolated cumulonimbus. It is confirmed that the result is in reasonable agreement with the known mass-dimension relationships of ice particles. (to be submitted to GMDD)

Application of SDM to Mixed-Phase Cloud Microphsics

Attribute variables of a particle

- Equatorial radius of ice
- Polar radius of ice
- Apparent density of ice
- Rime mass
- Number of monomers (primary ice crystals)
- Freezing temperature of particle
- Equivalent radius of droplet
- Mass of soluble materials



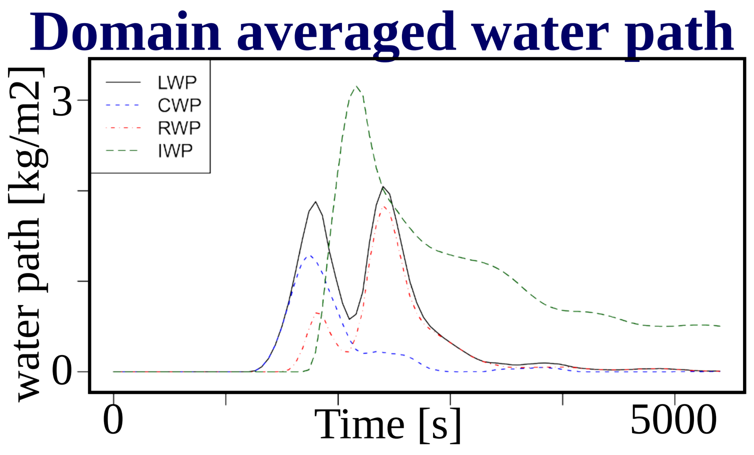
Cloud microphysical processes

- Ice formation (condensation/immersion/ homogeneous freezing)
- Melting
- Deposition/sublimation
- Condensation/evaporation (incl. CCN act.)
- Sedimentation of ice/droplets
- Droplet-ice coalescence (riming)
- Ice-ice coalescence (aggregation)
- Droplet-droplet coalescence
- (Breakup is ignored)

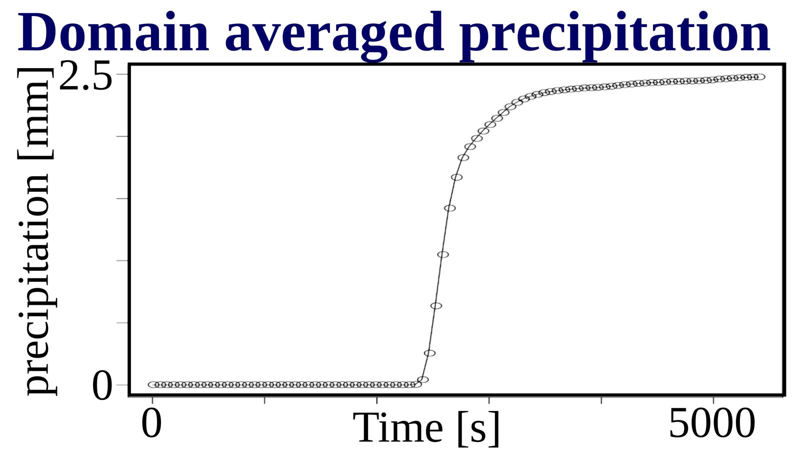
Numerical Setup

Sounding	Khain et al., Part I, JAS (2004)
Aerosol	Pure $(NH_4)_2SO_4$: 105/cc Mineral dust internally mixed with $(NH_4)_2SO_4$: d=1μm, 10/cc
Grid size	Δx=Δy=Δz=125m
Cloud microphysics	SDM (256SD/grid)
LES solver	SCALE (Nishizawa et al. 2015; Sato et al. 2015)

Domain averaged water path

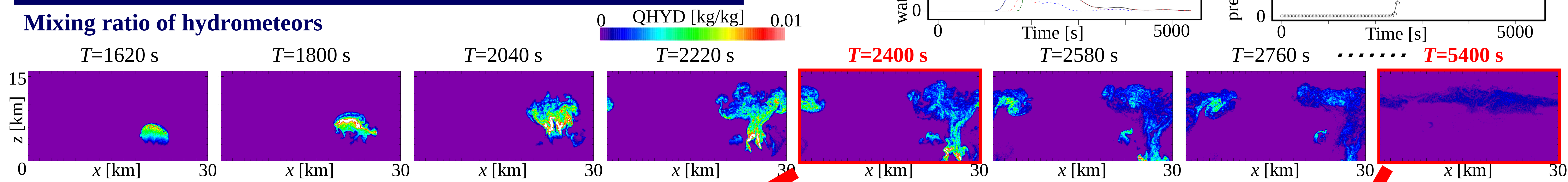


Domain averaged precipitation

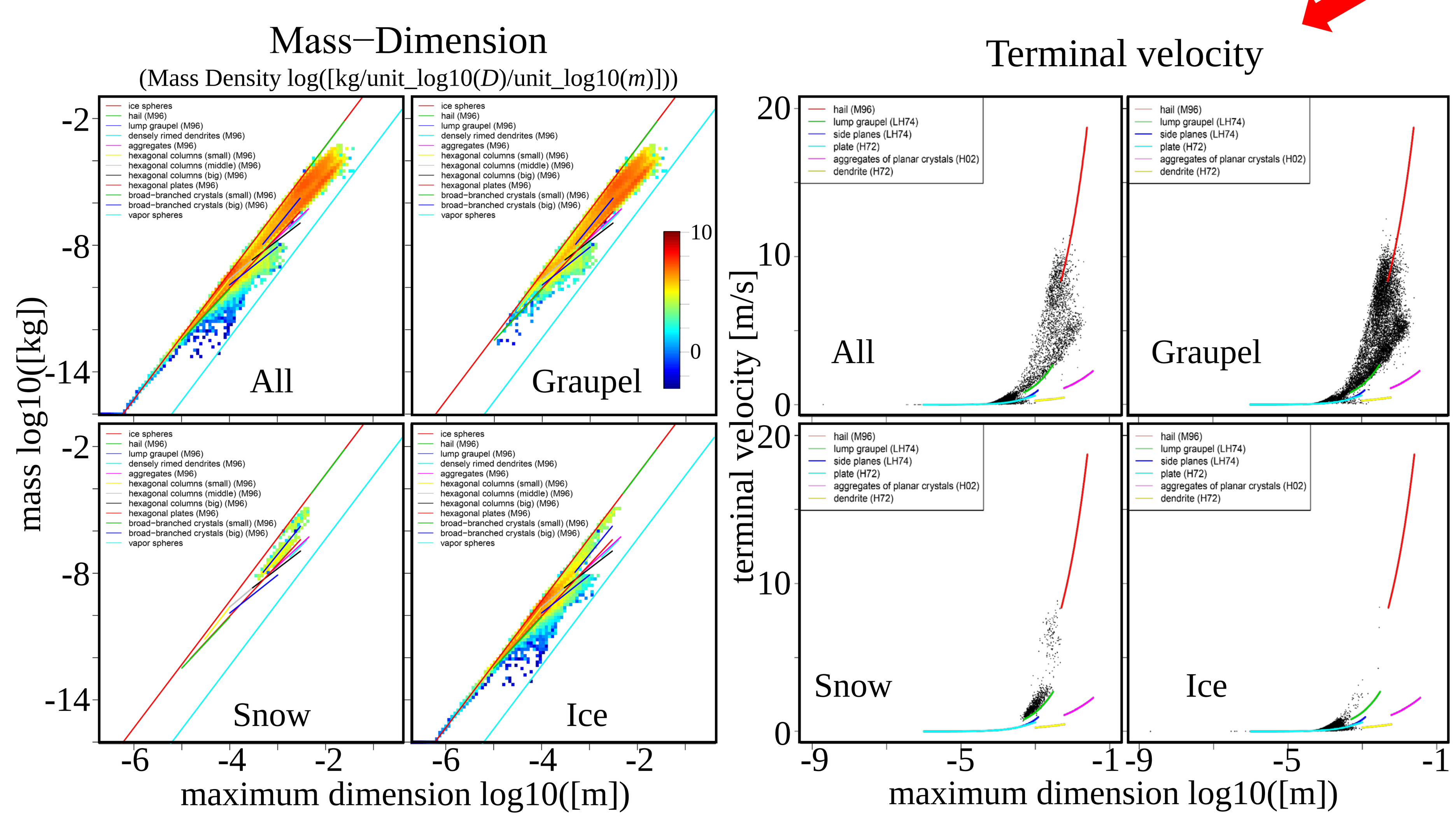


Results of 2D LES simulation of an isolated cumulonimbus

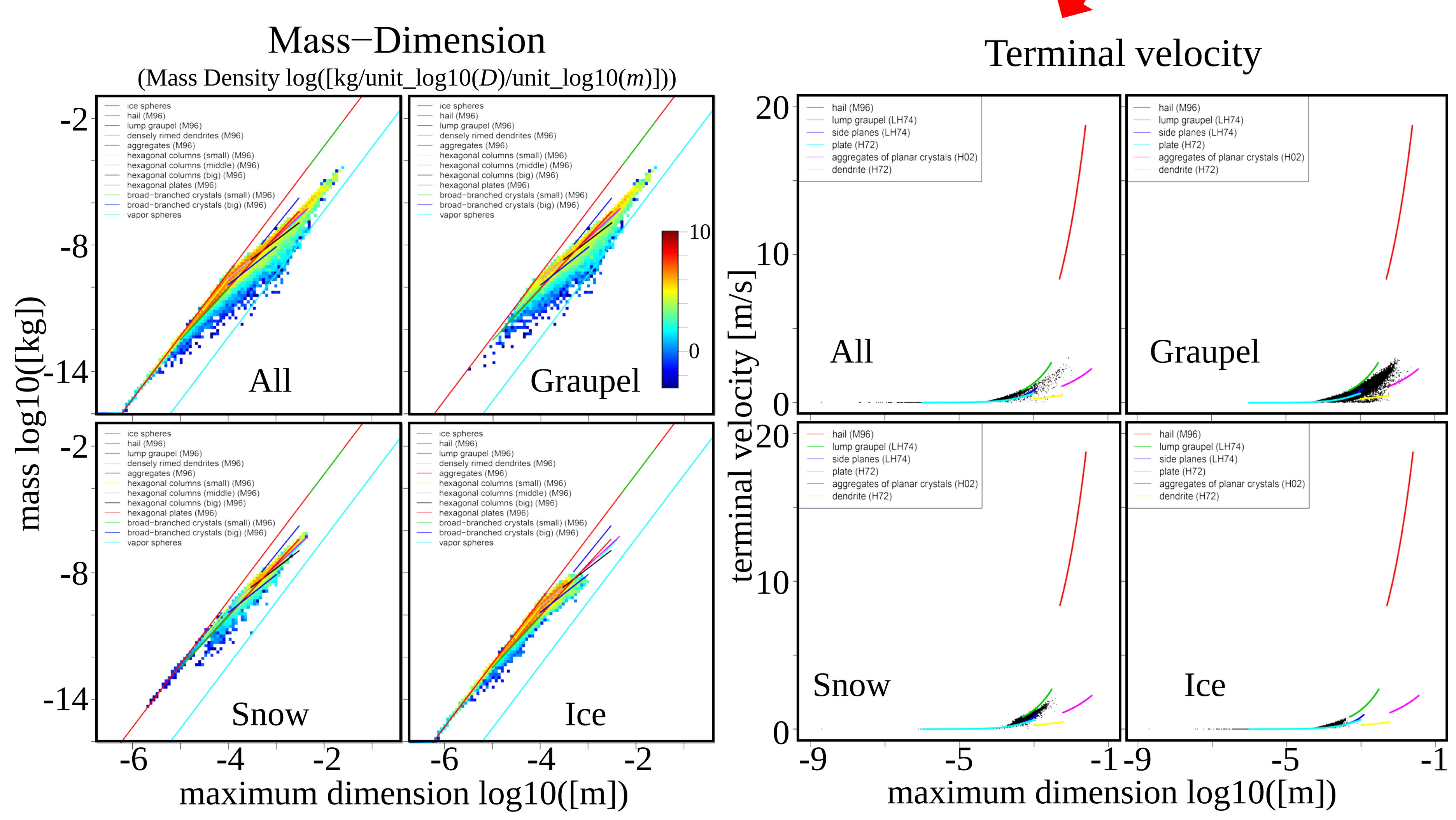
Mixing ratio of hydrometeors

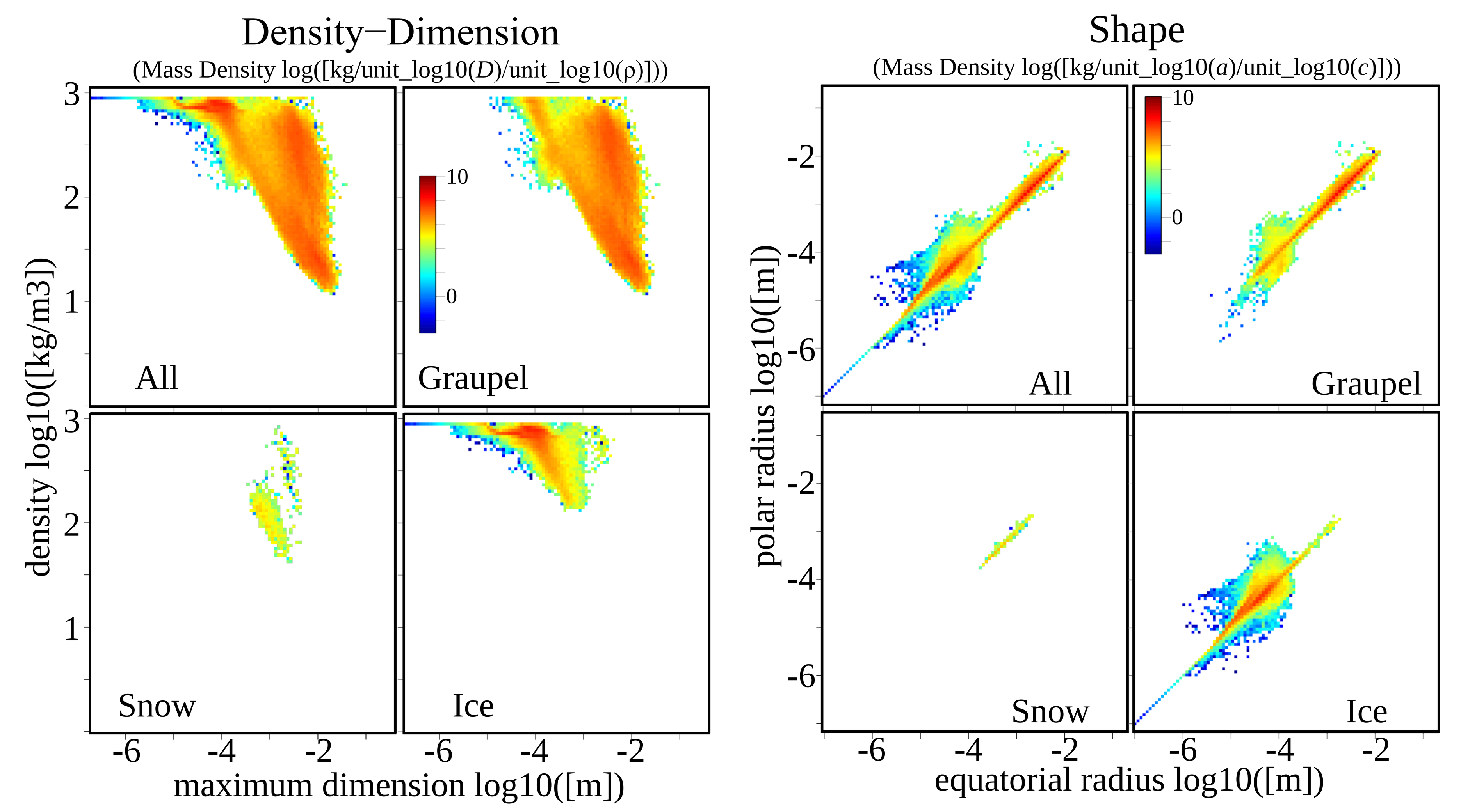


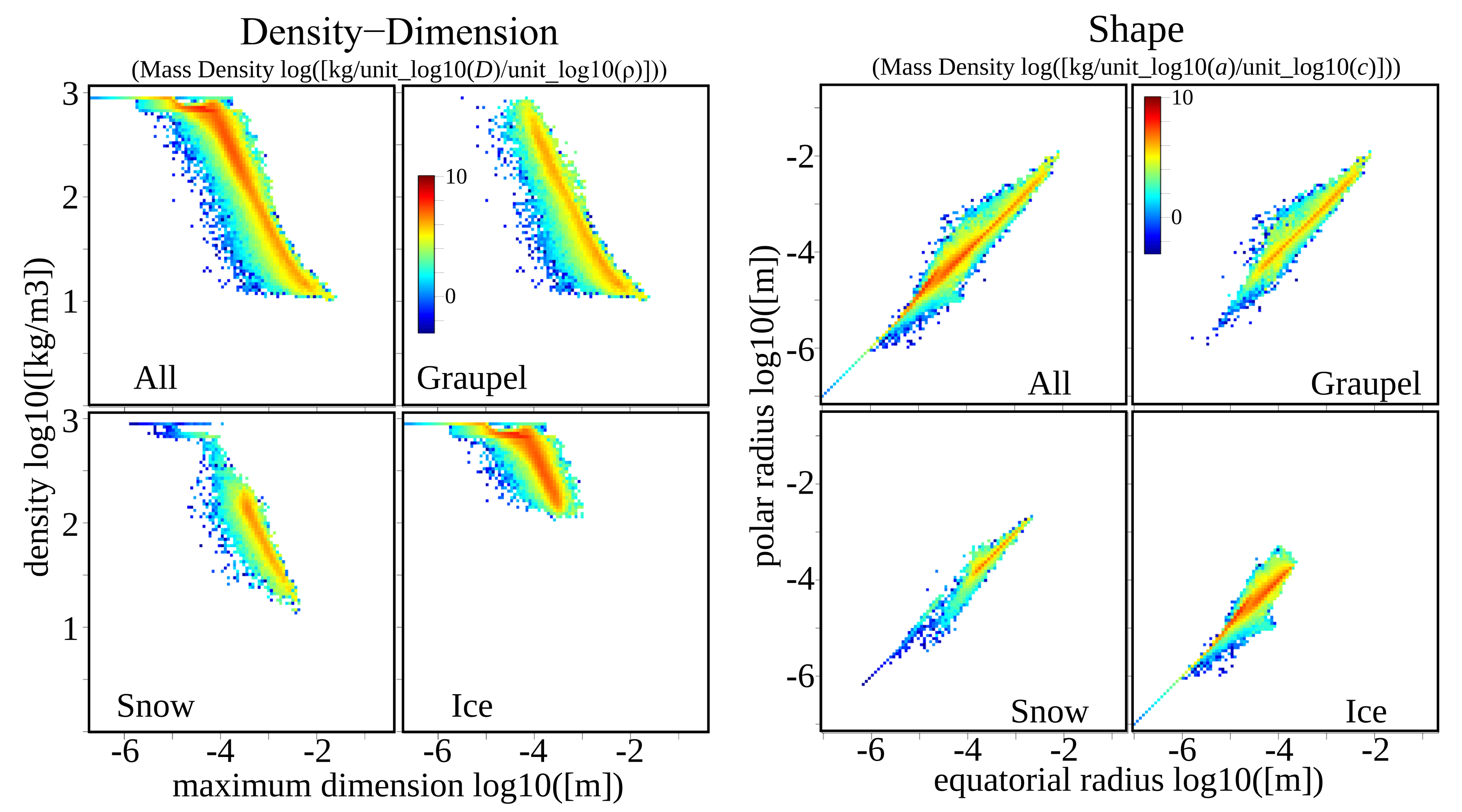
Shape and structure of ice particles (T=2400 s)



Shape and structure of ice particles (T=5400 s)







Conclusion

- SDM was applied to mixed-phase cloud microphysics
- 2D LES simulation of a cumulonimbus was carried out for model evaluation
- The model reproduced mass-dimension relationships reasonably well
- More detailed validation and sophistication of the model is needed:
  - Reliable aggregation efficiency and outcome; Breakup (spontaneous, collisional, rime splintering); Partial melting and shedding

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Supplement: Polluted Case (105/cc → 10500/cc)

Numerical Setup

Sounding	Khain et al., Part I, JAS (2004)
Aerosol	Pure $(NH_4)_2SO_4$: 105/cc → **10500/cc** Mineral dust internally mixed with $(NH_4)_2SO_4$: d=1μm, 10/cc
Grid size	$\Delta x=\Delta y=\Delta z$=125m
Cloud microphyiscs	SDM (256SD/grid)
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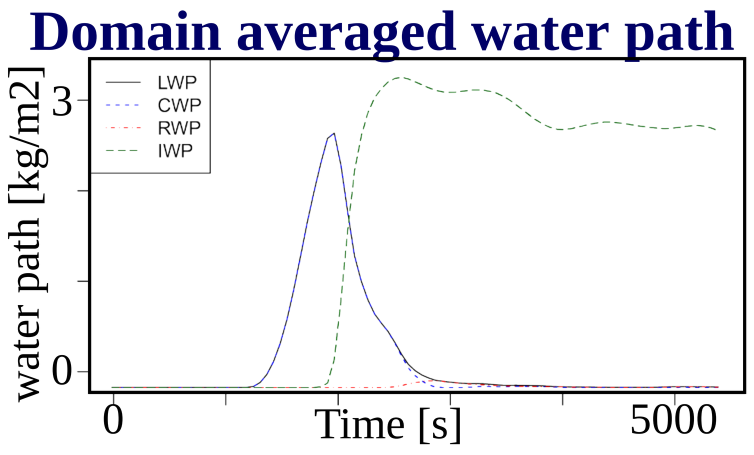
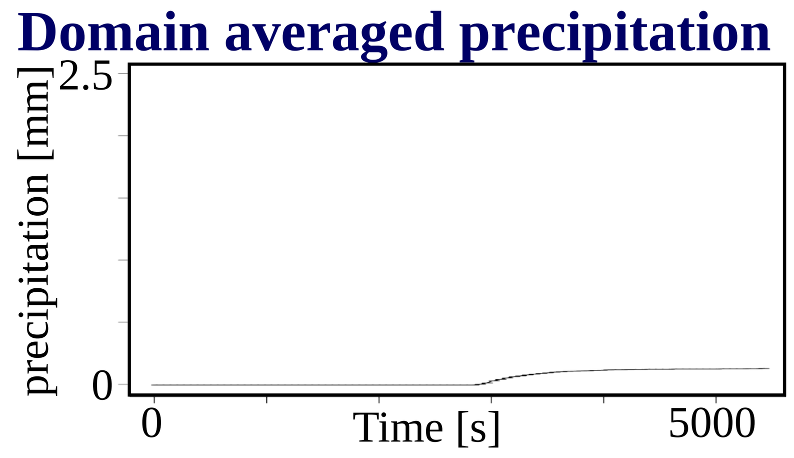
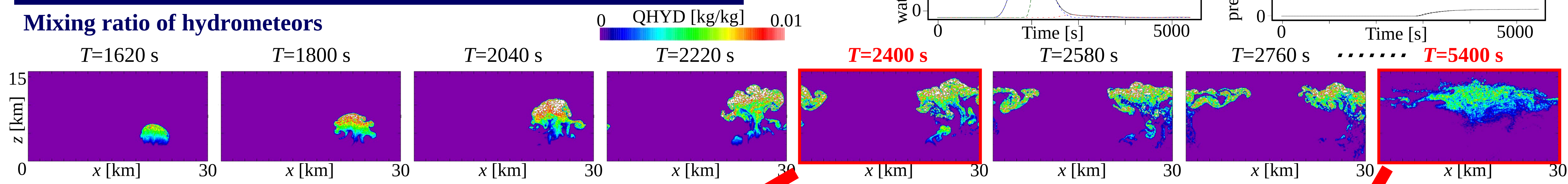


Domain averaged precipitation

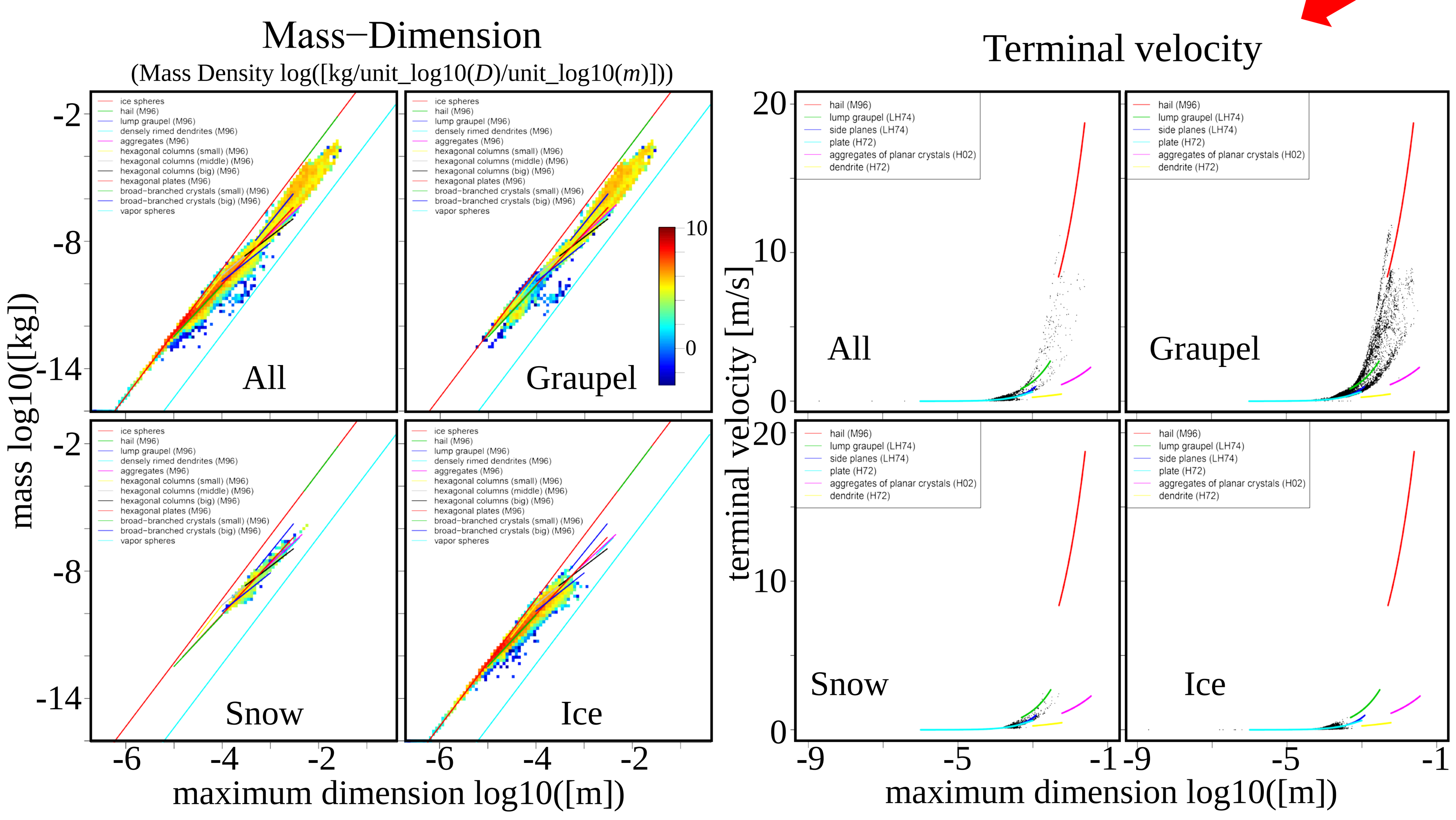


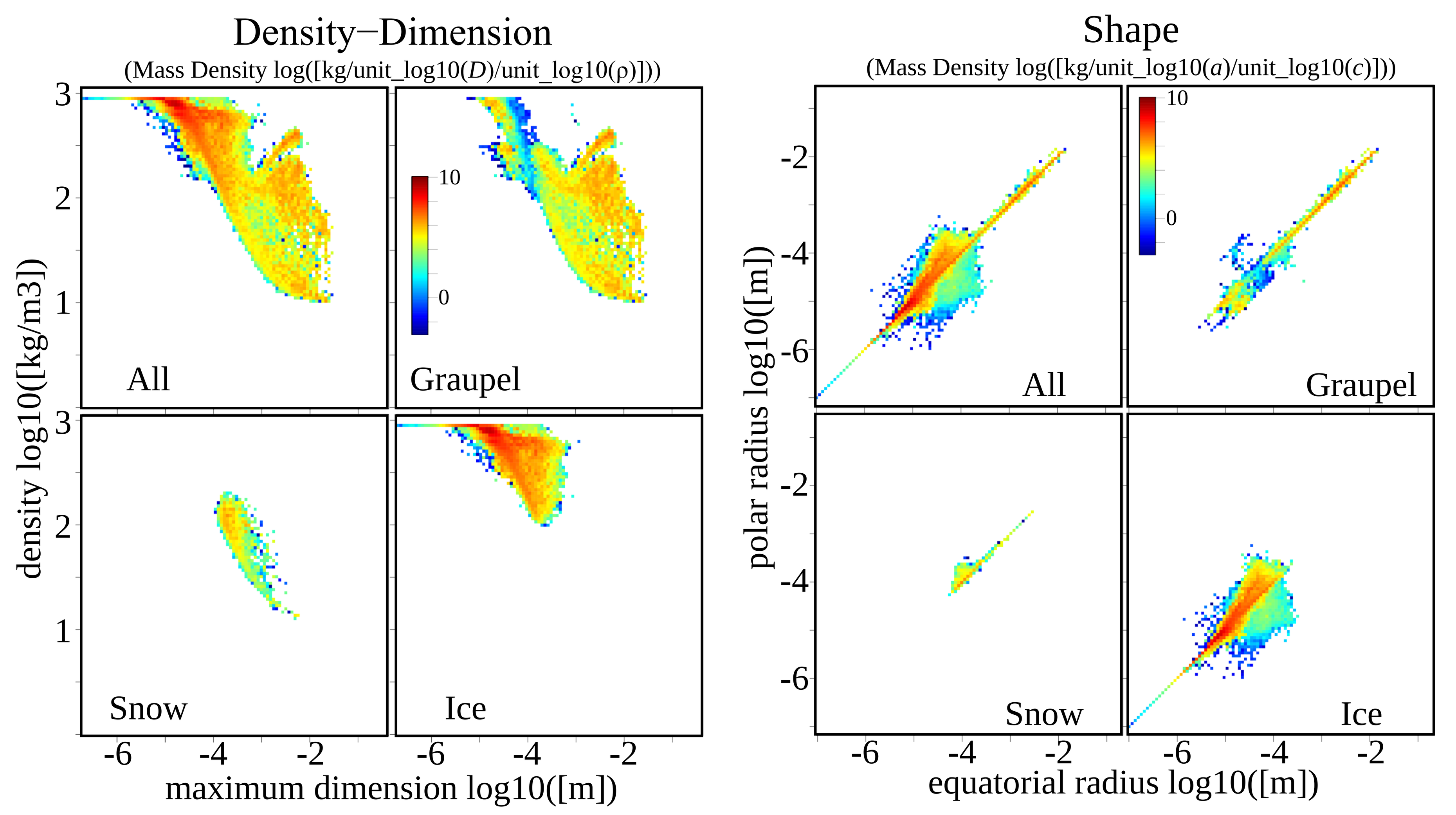
Results of 2D LES simulation of an isolated cumulonimbus

Mixing ratio of hydrometeors



Shape and structure of ice particles (T=2400 s)





Shape and structure of ice particles (T=5400 s)