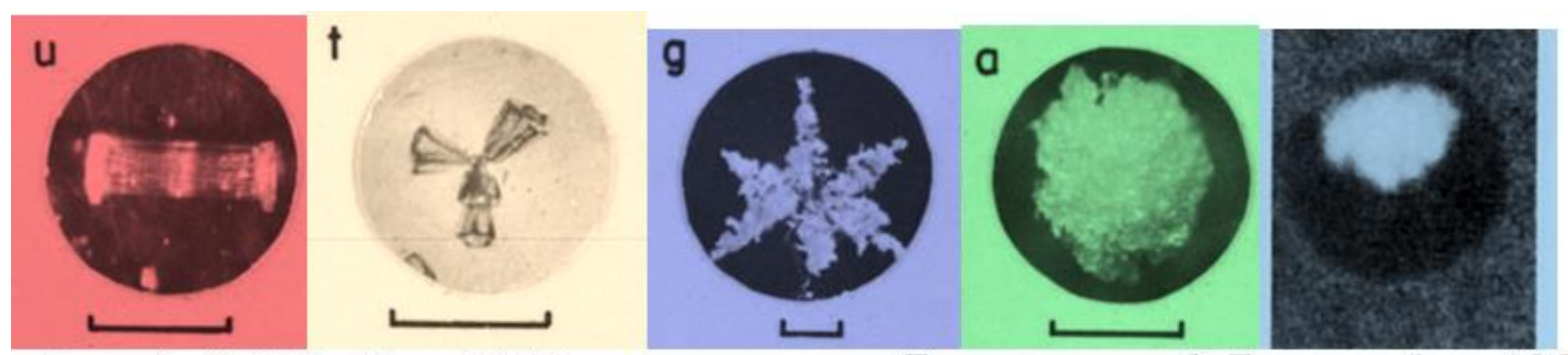
HD(CP)²
High definition clouds and precipitation
for advancing climate prediction

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

McSnow: Particle-based microphysics model in ICON

Christoph Siewert , Axel Seifert, GB Forschung und Entwicklung (FE14), Deutscher Wetterdienst

Cloud and precipitation (CP) processes constitute one of the largest uncertainties in current weather and climate prediction models. Hence, this project within the HD(CP)^2 aims to improve current ice microphysics parameterizations. In these parametrizations the ice phase is typically partitioned into several hydrometeor categories, e.g. ice, snow, graupel, and hail, to account for the very different characteristics of ice particles during their evolution (fig. 1).



Locatelli & Hobbs 1974 Rasmussen & Pruppacher 1982

Fig. 1: Monomer (red), aggregate (yellow), rimed aggregate (purple), graupel (green), partially melted (i.e. liquid) (blue)

However, the modeling of the transition between these artificial categories is a source of uncertainties. To avoid these categories, it is necessary to individually compute the prognostic variables such as the ice mass m_i, the number of monomers in an aggregate N_m, the rime mass m_r and density ρ_r, and liquid mass due to melting m_w. In the novel particle-based Monte-Carlo ice microphysics model (McSnow) [1] these prognostic variables are modified by processes such as nucleation, vapor diffusion, melting, shedding, collisions, ice multiplication, sedimentation, and break-up. Hence, with our new model it is possible to study, how monomers are converted to aggregates, rimed aggregates, and then graupel, while they fall through the cloud (see fig. 2 to the right).

[1] S. Brdar and A. Seifert 2017, *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, 10.1002/2017MS001167

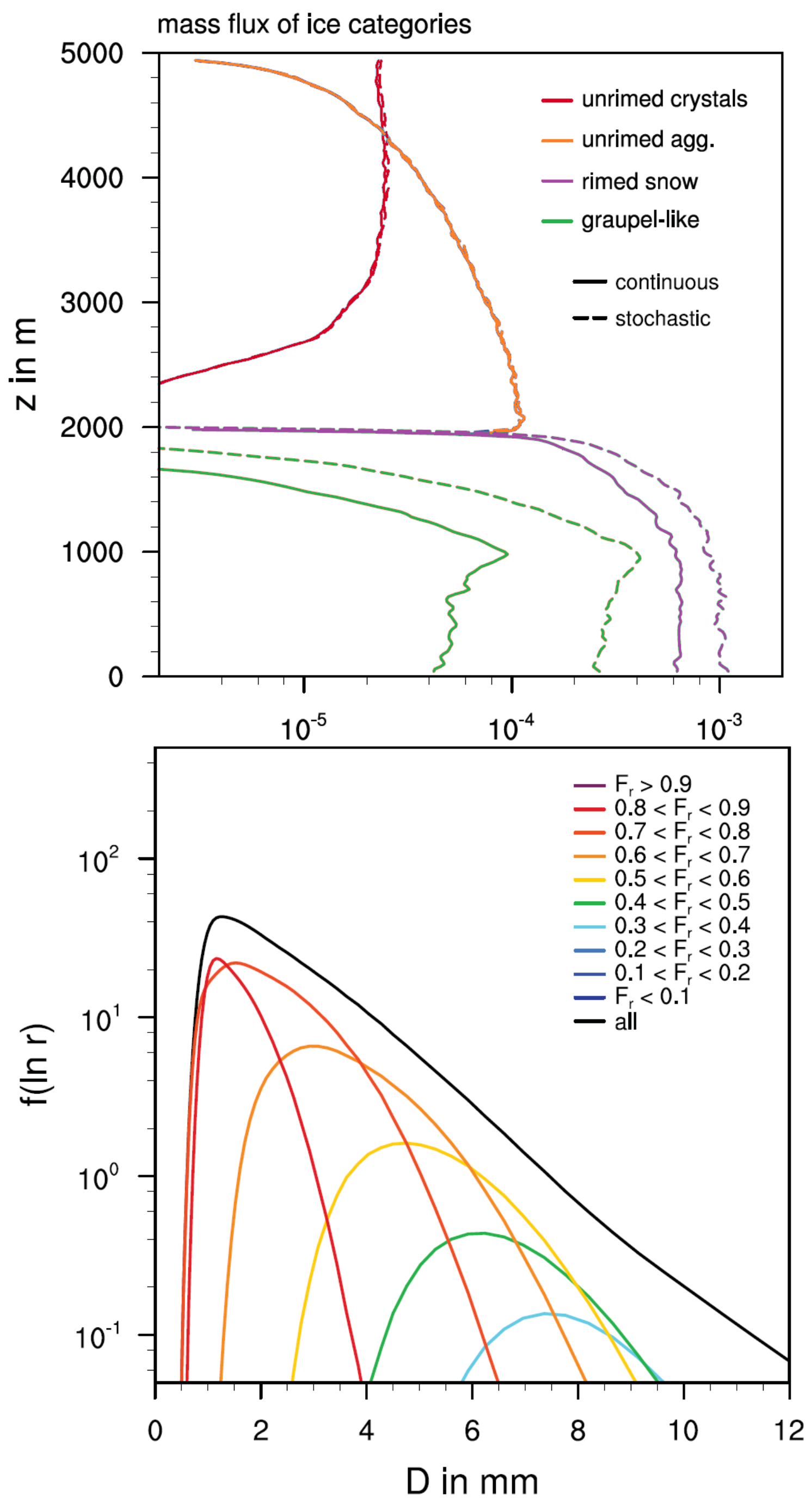


Fig. 2: 1D model run results for the prognostic variables m_i, N_m, m_r, ρ_r, and z [1]. Exemplarily: Mass flux density [kg m^{-2} s^{-1}] over height z [m] (top) and the size spectra with rime fraction $F_r = m_r/m_{tot}$ as parameter (bottom).

ICON storm resolving simulations

Within HD(CP)^2 the ICON model was extended such that it can be run in a high-resolution large eddy mode (ICON-LEM). Hindcast simulations in an unprecedented horizontal resolution of 156 m are performed over very diverse regions, such as Germany and the Tropical Atlantic.

Need for improved microphysics

These storm resolving simulations possess lower uncertainties as they resolve several physical processes that need to be parametrized otherwise, for instance convection. However, the remaining parametrized small-scale processes such as turbulence and cloud microphysics then become more important, e.g. for correctly predicting convective events. To improve microphysical parametrizations as accurate as possible simulations of the particle spectra evolution are needed.

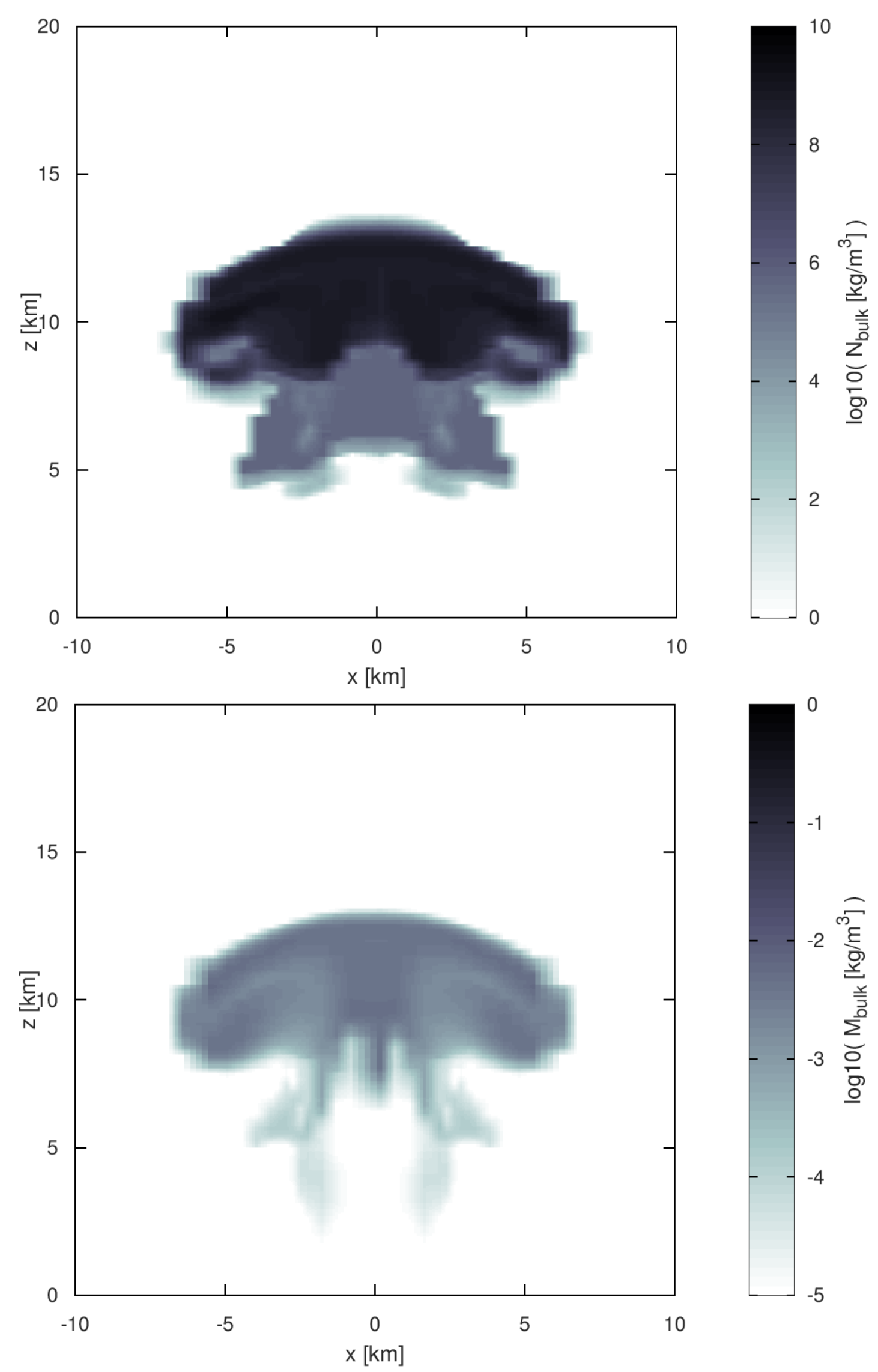
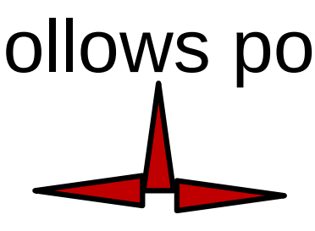


Fig. 3: Total ice number density (top) and total ice mass density (bottom) in a slice through a warm bubble

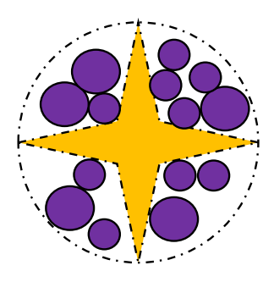
Super-particle method

Recently developed super-particle models are computationally more efficient than bin models for high-dimensional problems. They model the physical processes of single particles. In McSnow the particle geometry:

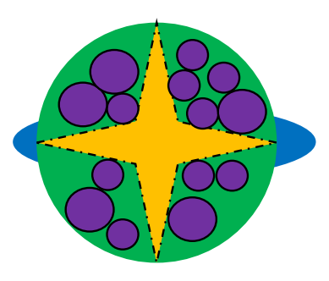
- Follows power-laws for aggregates



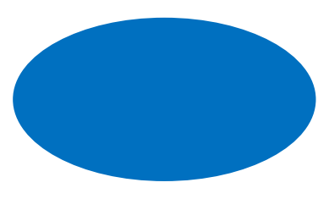
- Fills in riming supercooled droplets



- Builds up a water torus if melting



- Flattens out for large water drops



The settling velocity can be computed based on the particle geometry and on the particle mass (m_i, m_r, m_w).

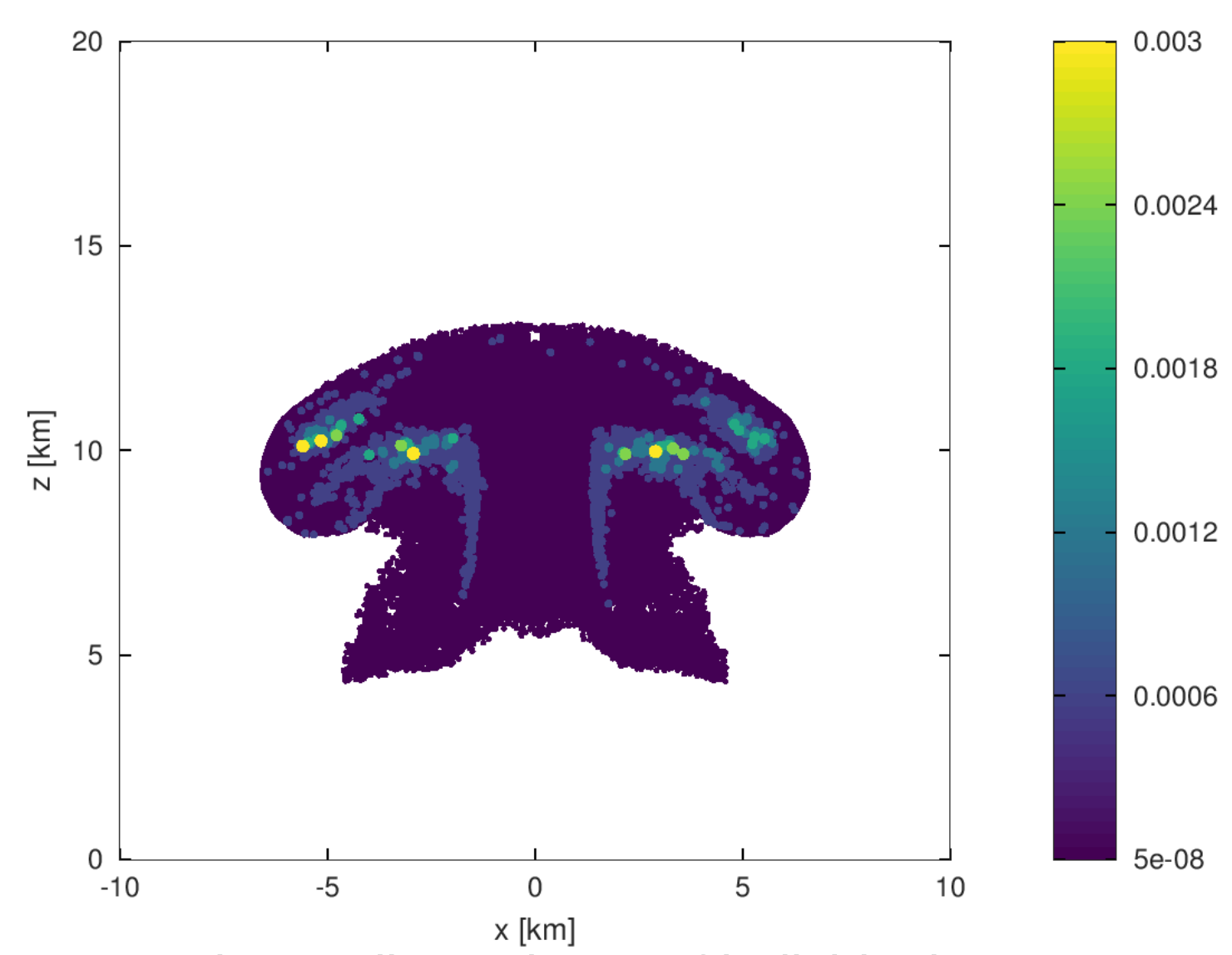


Fig. 4: Maximum dimension D of individual super-particles based on the McSnow geometric model

For computational feasibility, each super-particle stands for several similar real particles. Then, the collisional interaction has to be modeled in a stochastic sense. This approach allows to implement very detailed particle-based microphysical processes. Thus enables to look at the growth history of individual ice particles, helping to develop an in-depth understanding of the ice phase evolution.

McSnow in ICON

Currently, the McSnow model [1] is transferred from a 1D rainshaft framework to the ICON_LEM extending LaMETTA (Lagrangian MESSy Tool for Trajectory Analysis, Bastian Kern, Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen). This allows to show what trajectories and pathways individual snowflakes and graupel particles take in a dynamic, three-dimensional convective cloud.

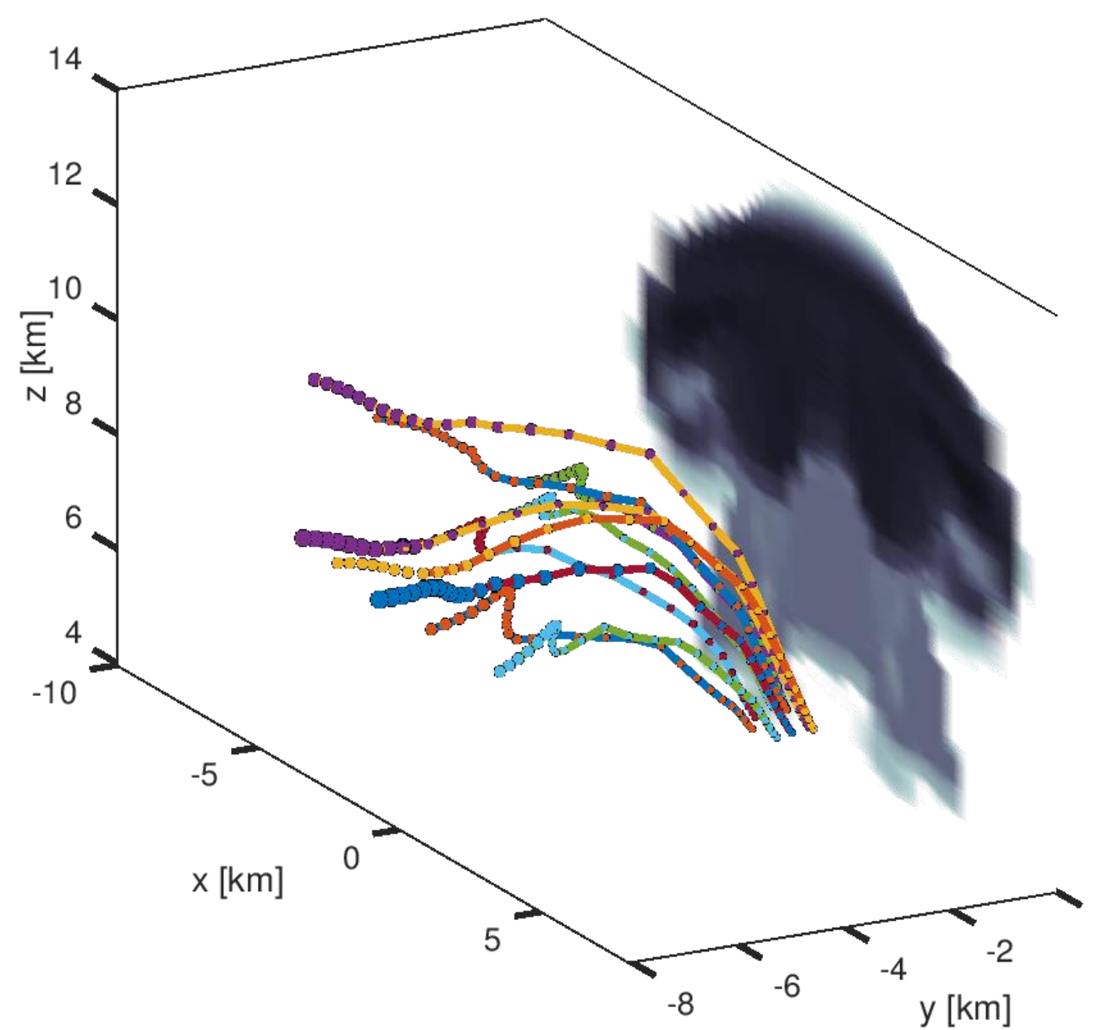


Fig. 5:Three dimensional trajectories of super-particles

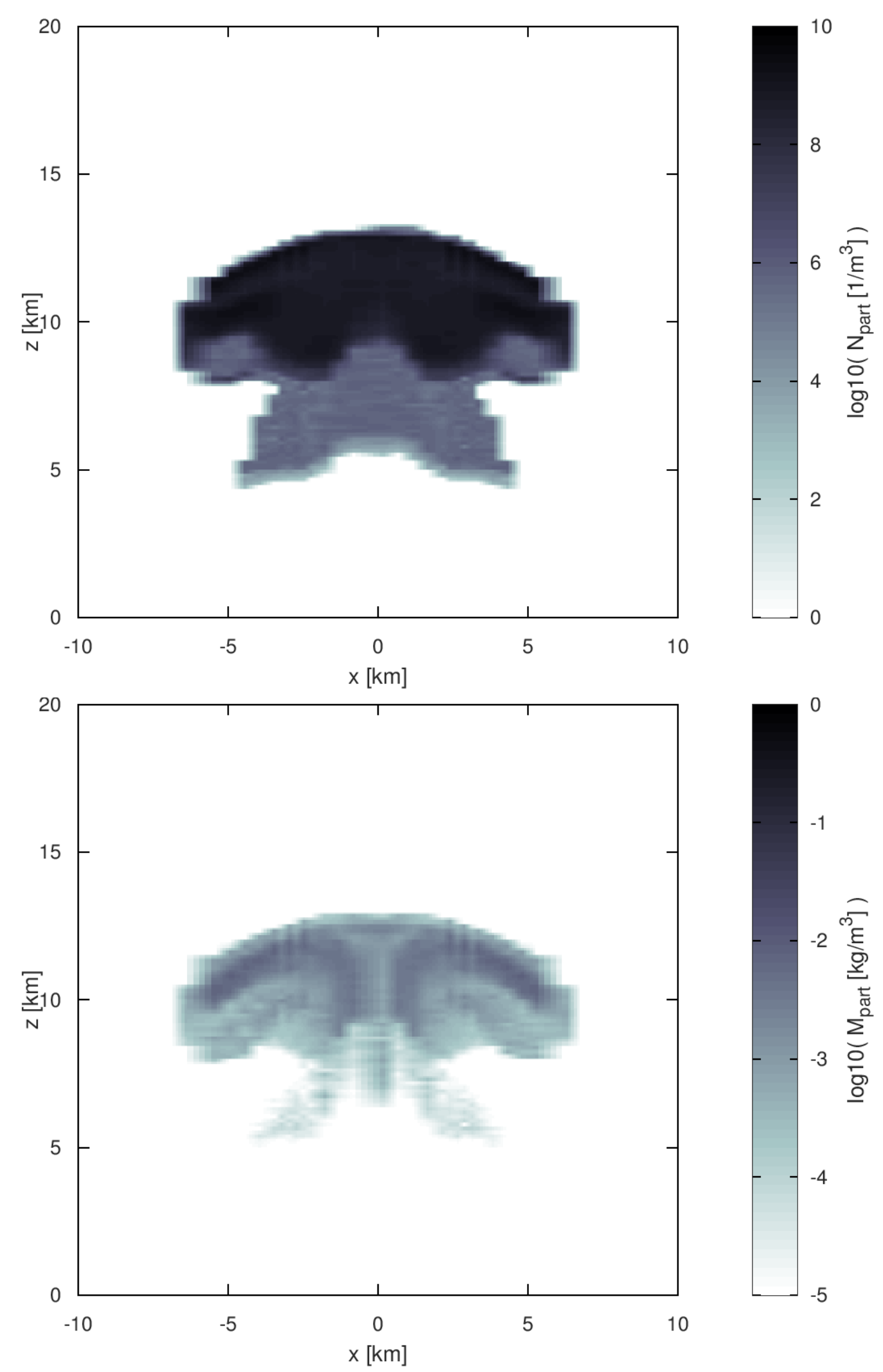


Fig. 6: Ice number density (top) and ice mass density (bottom) coarse-grained from 150 Mio. super-particles

Outlook

We will focus on the formation, evolution and growth of ice particles in deep convective clouds and the formation of convectively-generated cirrus and mid-level stratiform clouds. It then can be explicitly shown what makes one snowflake different from another and explain why some end up in the anvil, some in mid-levels, and some reach the ground as precipitation. We hope to understand how to better parameterize these processes in large-scale models used for numerical weather prediction.

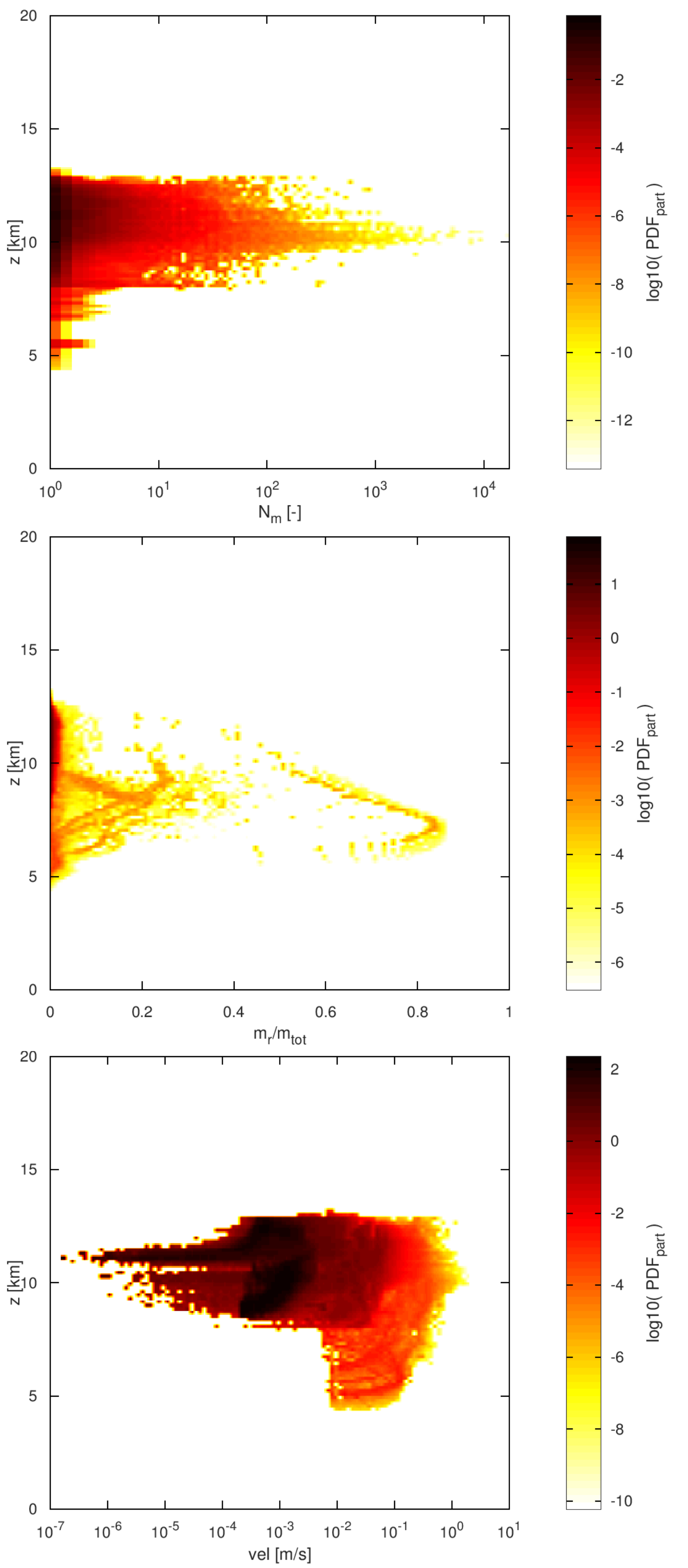


Fig. 7: Number of monomers (top), rime fraction (middle) and settling velocity (bottom) PDFs over height

Christoph.Siewert@dwd.de