

Summary

Weather forecast and climate models suffer from the difficulty to make accurate predictions because many of the interconnected physical and chemical processes over the diverse scales of atmospheric clouds are not yet well understood and parameterized. Such limitations exist, for example, in our knowledge on broadening of droplet size for rain initiation or with respect to the collisional effectiveness of the droplets or with respect to the processes that produce new cloud particles. This PhD thesis elaborates the numerical investigation on two such topics, namely 1) cloud droplet size broadening and the effect of collision in the cloud edge mixing, and 2) aerosol activation in the wake of large precipitating cloud hydrometeors.

Atmospheric clouds and clear air interfaces create a turbulent mixing, which plays an important role in the life of a cloud. The entrainment and detrainment of the clear air and cloud volume leads to a turbulent mixing at the interface, which results in broadening of the cloud droplet spectrum. In the first part of this thesis (Chapter 2), the transient broadening of three initial mono-disperse cloud droplet populations is studied in a turbulent cloud top interface. The numerical code uses the pseudo-spectral direct numerical simulation (DNS) method along with the Lagrangian droplet equations, and also a model for the collision and coalescence of the droplets. These simulations are initial value problems without the presence of any turbulent forcing model. Therefore, the evolution of in-cloud turbulent kinetic energy (TKE), temperature and the density of water vapor are of transient nature which exhibit a transient decay in their turbulent mixing intensities. The clear air and the cloudy volume mixing through the interface is observed to produce turbulent fluctuations in the fields of the density of water vapor and temperature. These turbulent fluctuations in the transported scalar quantities result in supersaturation fluctuations, which influence the locally the cloud droplet population. The small scale turbulence and the resulting local supersaturation conditions, along with the gravitational forces influence the droplet population at different weights depending on their sizes. This study finds that the larger droplet populations, with the simulated initial 25 and 18 μm radii, show a significant growth as a result of droplet-droplet collision and a higher rate of gravitational sedimentation as a result of comparatively larger size and a higher mass content. However, the simulated

smaller droplet population, with initial $6 \mu\text{m}$ radius, does not show any droplet-droplet collision. However, a large size distribution broadening is observed in this population due to the differential condensation/evaporation induced by the supersaturation fluctuations and turbulent mixing across the interface, and this droplet population was not influenced by the gravity significantly.

On the other hand, the activation of aerosols inside clouds is still an open scientific question which has significant influence in our understanding about the life cycle of the clouds, their radiative properties and hydrological fluxes. Aerosol activation produces new cloud particles which also contribute to the broadening of particle size through condensation/collisions. Therefore, a detailed understanding on the potentiality of any aerosol activation process is necessary for reliable weather modeling and climate prediction. Recent laboratory experiments have demonstrated that aerosols can potentially be activated in the wake of the precipitating hydrometeors, such as, rain drops, hails etc, because supersaturation can be produced in the wake. However, many of the quantitative aspects of this wake-induced activation of the aerosols in the wake-induced supersaturation of the precipitating hydrometeors remain unclear. In the second part of this thesis, a detailed numerical investigation is conducted in Chapter 3 to understand the evolution of fluid and the transported scalar populations in the wake of such precipitating spherical objects, which is later used in the Chapter 4 for a detailed quantification on the parameter space for the wake-induced supersaturation and its impact on the activation of the cloud aerosols that entrain inside the hydrometeor wake. It is estimated by using the Lagrangian tracking of aerosols that a significant fraction of aerosols are activated in the supersaturated wake. These ‘lucky aerosols’ are indeed entrained in the vortices of the hydrometeor wake when the hydrometeor produces oblique wake and therefore, these aerosols can reside in this supersaturated wake environment for sufficiently long duration which is necessary for the aerosol activation. This presented study shows that the wake-induced activation of aerosols can produce some significant concentration of new cloud particles that is similar to the other well known secondary particle production processes.