Development of an effective field theory for mixed-phase clouds

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Clouds are important players in the Earth-Atmosphere system, since they control major parts of the energy budget of the system as well as the hydrological cycle (e.g. precipitation). However, the representation of clouds and their governing processes is quite difficult. Clouds are composed by a huge number of water particles (liquid droplets or ice crystals), which can interact via different processes, e.g. via collision or diffusion of water vapour. For the temperature range 235K ≤ T ≤ 273K, the liquid and the solid phase can coexist, although in this range liquid water is metastable (see fig. 1). Clouds in this range consisting of supercooled liquid droplets and (stable) ice crystals are called mixed- phase clouds. These clouds are of high interest since probably most of precipitation is formed in these clouds. For the treatment of the statistical ensemble cloud in cloud physics often evolution equations of statistical distributions are used; here, usually we assume a spatially homogeneous distribution of cloud particles. However, due to measurements this assumption is especially in mixed-phase clouds violated. In contrast, direct simulations of ice crystals surrounded by water droplets show that the particles show very different behaviour due to their spatial inhomogeneous distribution. For a general treatment of these effects a kind of field theory for cloud particles would be necessary.

The aim of the project is to develop a prototype of an effective field theory for clouds, which can be used for deriving consistent parameterizations for reduced order models.

We will proceed in two steps. In the first step, we will derive a particle-based model for spatially inhomogeneous clouds, where each particles represents a droplets. Particles have internal degrees of freedom, such as size,

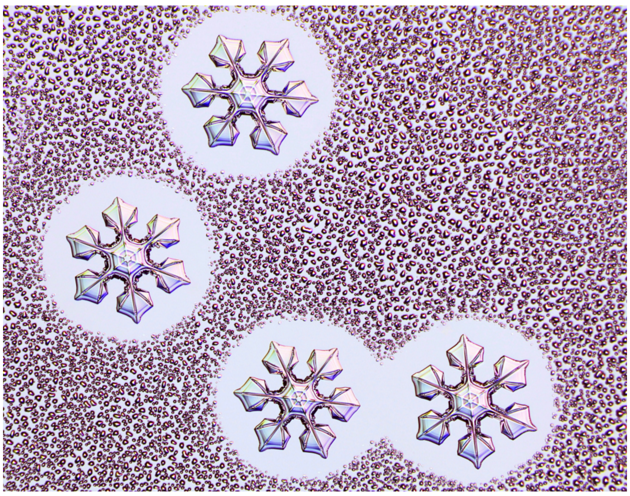

Figure 1: Coexistence of ice crystals and water droplets in a laboratory experiment (Libbrecht, 2005).

temperature, and they may or may not contain an ice nucleus. Particles undergo convective motion and they interact by exchanging material through the surrounding water vapour, or by coalescing. In a first step, we will mostly investigate the growth of water particles due to water vapour diffusion and phase transition. For a single droplet, the governing equations are available and steady state solutions can be derived (Baumgartner and Spichtinger, 2017, 2018). Due to the similarities between the steady-state diffusion equation and the Poisson equation, multidroplet systems can presumably be mapped onto the electrostatic problem of a system of conducting particles.

In the second step, we will use the particle model to derive an effective field theory of mixed-phase clouds, using techniques from statistical physics and electrodynamics in matter. This field theory can be used to model spatially inhomogeneous clouds and might also serve as a basis for deriving much simpler models that include the dominant effects of local interactions of water particles.

References

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