The effects of anthropogenic aerosol particles on the cloud life-cycle

Blending of theory, modeling, and fieldwork

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In Short

- To quantify the effects of thermodynamics, aerosol size distribution, and aerosol number concentrations on the formation of cloud condensation nuclei.
- To investigate effects of turbulent supersaturation fluctuation on the process of aerosol activation.
- To suggest a modified parameterization of the Twomey equation considering the effects of supersaturation fluctuations.

The effect of aerosols on clouds has been identified as crucial to estimate the radiative properties of clouds, their role in the hydrological cycle, and accordingly in their influence on the climate system (e.g., [1]). Therefore, process-level understanding of the interaction of clouds and aerosols is a key element for our understanding of the global climate ([2]). However, the consideration of these processes in climate prediction models is challenging because they involve a wide range of spatial and temporal scales which are usually unresolved, starting from entire, but shallow, cloud systems, individual clouds, their micrometer-sized droplets and the even smaller aerosols. Accordingly, the impact of these scales needs to be parameterized in climate models, and recent studies have pointed out that it is crucially important to represent these small-scale aerosol-cloud interactions in global climate prediction models for an accurate representation of the Earth's climate ([3], [4]). These parameterizations are usually developed and validated by utilizing other numerical models, which are designed to cover the unresolved scales and accordingly provide detailed information on the unknown processes in large-scale climate models ([5], [6], [7]).

In the context of aerosol-cloud interactions, one of the most fundamental and widely applied parameterizations is the so-called Twomey (1959) equation [8], which is used to determine the number of aerosols that activate to cloud condensation nuclei (CCN), i.e., the particles from which future cloud droplets grow:

$$N_c = N_0 S^k.$$

which depends on the water vapor supersaturation S, and two parameters N_0 nd k resulting from the specific distribution of aerosols. The implications of the Twomey equation are simple to understand: as soon as S increases to a new maximum, new aerosols are turned into CCN increasing the number of cloud droplets. This process of aerosol activation is in the primary focus of the proposed project.

Although the Twomey equation is widely applied, it has one distinct limitation from which several shortcomings arise. The Twomey equation represents activation as an instantaneous process. In fact, activation is not instantaneous, and the associated timescale can become sufficiently long to be of physical relevance for the determination of the number of CCN (e.g., [9], [10]). By neglecting this timescale, i.e., applying the Twomey equation, the interaction of aerosol activation with high frequency, small-scale phenomena like turbulent supersaturation fluctuations might inherently result in a false determination of the number of CCN and accordingly a wrong estimate of the role of clouds in the climate system. The most reliable ways to explicitly resolve the activation process are so-called Lagrangian cloud models (LCMs; [11], [12], [13]). In these models, individually simulated particles represent aerosols, whose activation is represented without parameterizations. Accordingly, this novel approach for simulating clouds is the method of choice to validate and derive additions to the Twomey equation to consider effects arising from its inherent limitations. Coupled with an underlying Large Eddy Simulation (LES) model for representing the motions of air as well as the transport of heat and moisture, the LCM based on LES approach used within this project enables new insights on the small-scale processes unresolved in

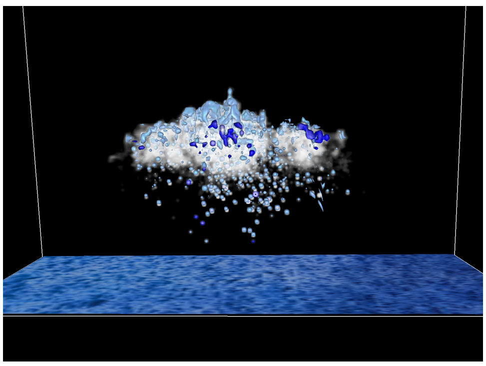

***Figure 1:** Snapshot of the simulation of a cloud with embedded the LCM in PALM model by VAPOR.*

large-scale climate models and their parameterizations.

Figure 1 shows the snapshot of the simulation of a cloud with the LCM. In this project, an embedded the Lagrangian cloud model in the A **PA**rallelized **L**arge-Eddy Simulation **M**odel (PALM) will be used. It is a novel method for better understanding of the many small-scale processes and their non-linear interactions between aerosol particles and clouds[13]. Therefore, various simulations shall be conducted which investigate aerosol activation under various thermodynamic conditions and for diverse aerosol concentrations (i.e., pristine and polluted scenarios). Comparing the results to the established Twomey equation will highlight under conditions in which the parameterization fails.

But, even the high-resolution LES is not well suited for the consideration of the small-scale supersaturation fluctuations. The range of spatial scale in the LES is too broad to resolve correctly. It has been claimed that the turbulent supersaturation fluctuations around Kolmogorov microscale can affect droplet activation. The size of entrainment and detrainment is typically ranging from a few centimeters to meters. However, even high-resolution simulations of the LES cannot resolve the small-scale processes, but only the Direct Numerical Simulation (DNS) can resolve adequately. Accordingly, it is necessary to represent unresolved scale fluctuation process in the LES framework. One of the candidates, referred to as the eddy hopping[14], clearly showed a broader droplet spectrum in idealized adiabatic parcel model simulations. We implemented the supersaturation fluctuation parameterization by [14]. With the help of Eddy hopping mechanism, the cloud model can incorporate the variety of chemical compositions to act as CCN. Together with the project earlier, it will suggest a new Twomey-type CCN size distribution used in the current NWP models.

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http://palm.muk.uni-hannover.de/

More Information

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