A study of aerosol production at the cloud edge with direct numerical simulations

N. Babkovskaia[1], M. Boy[1], S. Smolander[1], S. Romakkaniemi[2], M. Kulmala[1]

[1]Department of Physics, University of Helsinki, PO Box 48, Erik Palmenin aukio, 1, 00014, Finland
[2]Department of Applied Physics, University of Eastern Finland, P.O. Box 1627, 70211 Kuopio, Finland
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Presenting author email: NBabkovskaia@gmail.com

Introduction

Aerosol clouds are dynamic systems with spatially and temporally varying properties. More cloud droplets may form due to in-cloud activation or due to entrainment of air from cloud edges that might lead to formation of fresh cloud droplets. On the other hand, cloud droplets may be evaporated because of mixing at cloud boundaries or in-cloud dynamics causing part of droplets to evaporate. The latter of these can be important in stratus type clouds with long in-cloud residence time of air parcel. The mixing at cloud boundaries takes place in all clouds, and the type of mixing is dependent on the conditions and mixing time scales.

Methods

To study the structure of the cloud edge area we use the direct numerical simulation (DNS) high-order public domain finite-difference PENCIL Code for compressible hydrodynamic flows. The PENCIL Code is a powerful tool for studying the aerosol dynamics in a turbulent medium with complicated chemical composition (PENCIL Code, 2001; Babkovskaia et al., 2011). The scientific goals for the construction of the new model are to investigate the spatial distribution of aerosol particles, turbulent mixing of clouds with the environment and the influence of turbulence on aerosol dynamics (and vice versa).

Results

We study the activation process at the cloud edge. We consider the flux of aerosol particles, which goes through the boundary between the dry and wet air. For a test purpose we start from a zero-dimentional problem. Following by Andrejczuk et al. (2004), we take into account the condensation and evaporation of the aerosol particles covered by liquid water. Next, we consider a one dimensional problem to study a motion and evolution of the front between the dry and wet air. This approach allows us to analyze the effect of the fluid mechanics on the aerosol dynamics (and vice versa) in a laminar regime. Finally, we make two- and three-dimentional simulation with a more complicated velocity field at the cloud edge. We assume that the dry air flux is coming into the computational domain in its middle part and coming out near its boundaries. Wet air is moving in horizontal direction with velocity $U_x = 50 - 100$ cm/s. The third velocity component initially equals to zero, $U_z = 0$ cm/s. We study the effect of air mixing, comparing the results of simulation with zero, $U_{in} = 0$ cm/s, and non-zero, $U_{in} = 20$ cm/s, inlet velocity. We find that for $U_{in} = 0$ cm/s (no mixing) the most efficient growing of particles due to condensation occurs inside the front. In a case of $U_{in} = 20$ cm/s the intensive mixing of air results to evaporation and increasing of the supersaturation in the front area. Additionally, comparing the results of simulation for such two cases (with $U_{in} = 0$ cm/s and $U_{in} = 20$ cm/s) we conclude that the air mixing leads to increase of the number of activated particles (with the size larger than 5 μm). It happens because of extending of the front area where the most efficient growing of particles occurs. Also, we compare the results of 2D and 3D simulations and of the 3D simulations with different grid sizes and analyze how such approaches are valid for the correct description of aerosol production at the cloud edge.

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