Simulation of CCN Distributions on the Regional Scale and their Impact on Clouds and Warm Precipitation

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Abstract. The impact of the aerosol on the state of the atmosphere, especially on clouds and precipitation, is investigated in this study for the regional scale. The CCN distributions are simulated on the base of anthropogenic and natural emissions of aerosol particles and their gaseous precursors with a comprehensive online coupled model system. Therefore the simulations comprise the temporal and spatial variation of aerosol particles in the atmosphere and show their impact on clouds and precipitation.

Key Words: Aerosol cloud interaction, CCN, Modelling (regional), Tropospheric aerosols, Clouds

Introduction

Recent modeling studies followed a variety of approaches to improve the understanding of aerosol-cloud interactions responsible for the largest uncertainties in understanding the climate change[7)]. Studies with temporal and spatial high resolved models showed the response of individual clouds on changes in the aerosol load[4),11), 20)]. Global climate models investigated the impact of aerosols on large scales in space and time[12),15)]. Although the distribution of clouds and aerosol particles are mesoscale features only a few studies focused on this scale until now[9),14)]. The variations in the distribution of aerosol particles caused by the spatial and temporal variation of the emissions and the ongoing physical and chemical processes are not considered yet in these mesoscale studies.

Model System

Studying the interaction of the aerosol and the atmosphere with a numerical model at a specific scale requires the treatment of the relevant physical, chemical, and aerosol dynamical processes at a comparable level of complexity. To fulfill these requirements we developed the model system COSMO-ART for the regional to continental scale. COSMO-ART is based on the non-hydrostatic weather forecast model COSMO

(**Co**nsortium for **S**mall-scale **Mo**deling) of the German Weather Service (DWD) and is online coupled with comprehensive modules for gas phase chemistry and aerosol dynamics. ART stands for **A**erosols and **R**eactive **T**race gases. COSMO-ART includes complex photochemistry to calculate the temporal and spatial distribution of the gaseous precursors of the secondary aerosol particles. MADEsoot[2),17)] represents the aerosol population within COSMO-ART by several overlapping log-normal distributions. For submicron particles five modes are used. Two modes represent secondary, internally mixed particles consisting of sulphate, ammonium, nitrate, secondary organic compounds, and water, one mode represents pure soot and two more modes represent aged soot particles consisting of sulphate, ammonium, nitrate, organic compounds, water and soot in an internal mixture. All modes are subject to condensation and coagulation. The emissions of natural NO_x and VOC emissions, sea salt, and mineral dust are parameterized in terms of the land-use and the meteorological conditions. Anthropogenic emissions of SO_2, CO, NO_x, NH_3, and VOC are prescribed at each grid point with an hourly resolution. A detailed description of the model formulation can be found in [21)].

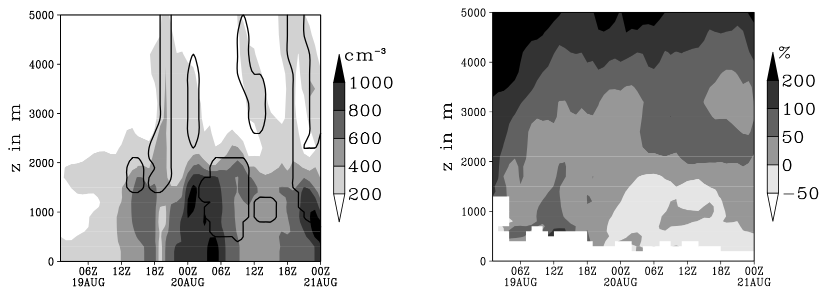
Activation and Cloud Scheme

The number of activated particles is calculated by integration of the size distribution of the individual modes. The critical radius for the integration is determined with Köhler theory[10)]. For the calculation of the maximum supersaturation a parameterized solution of the supersaturation balance equation for an ascending cloud parcel is used[1)] considering the cloud-base vertical velocity[13)], the aerosol size distribution, and the chemical composition of the individual modes. The cloud scheme is an extended version of the operational scheme used for operational weather forecast with the COSMO model[5)]. Prognostic equations for cloud liquid water content, cloud droplet number density, rain water content, ice water content, and snow water content are solved. For the representation of autoconversion, accretion and selfcollection of cloud drops a double-moment parameterization[19)] is used. Nucleation of droplets occurs only at cloud base[8)] with respect to grid scale vertical advection and turbulent diffusion.

Results

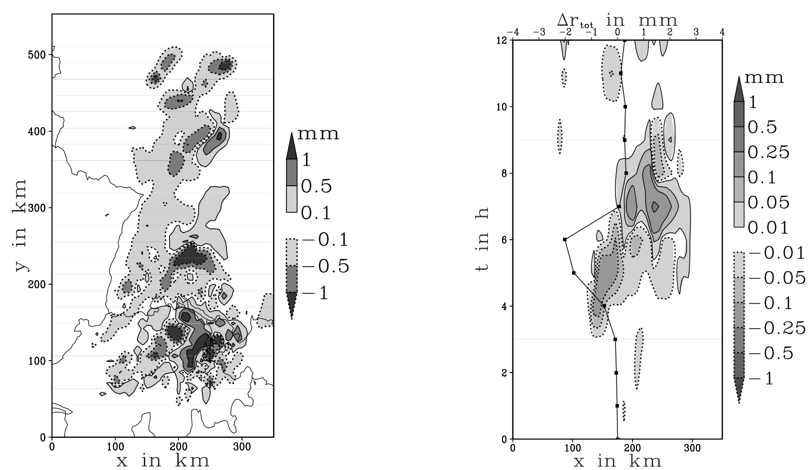
Several simulations were performed for Central Europe with a spatial resolution of 7 km and 40 vertical levels. The results show changes in CCN number density of several hundred percent within a few hours and kilometers (figure 1a). Beside the number density of the aerosol particles the considered size distribution and chemical composition of the particles are important factors for the distribution of the CCN. The simulations indicate that in the area of a forming cloud the availability of CCN is higher than in the surrounding area (figure 1b). Possible reasons are the intensified vertical transport of aerosol in these areas and the influence of the high humidity on the chemical composition of the particles. Therefore the distribution of CCN number density and clouds is related to each other. The enhancement of CCN in areas of cloud formation is currently not considered in global models.

Compared with a simulation that was performed with a fixed homogenous aerosol distribution (II) the simulations allowing variable aerosol distributions (I) lead to changes in cloud droplet number density. Consequently, this has an influence on the warm rain process. The changes in precipitation are mostly below 1 mm/h i.e. they are caused by drizzle events. High CCN-concentrations weaken the initial formation of rain and tend to delay the rain formation in warm clouds (figure 2a). Depending on the lifetime of the cloud system the net precipitation amount can remain the same, but with temporal and spatial shifts in the distribution of precipitation (figure 2a, 2b).



a) **b)**

Figure 1 **a)** CCN for 1% supersaturation (greyscale) and cloud contours at Würzburg **b)** Relation of CCN for 1% supersaturation from cloudy to cloud-free grid points.



a) **b)**

Figure 2 **a)** Difference (I-II) in rain amount from 0 UTC to 12 UTC, **b)** Differences (I-II) in the hourly precipitation amount (greyscale) and in the total precipitation amount (line) for a 7km wide band at y=280km.

SUMMARY

The interaction of CCN and clouds has been simulated with the online coupled model-system COSMO-ART. The aerosol is simulated on the base of gaseous and particulate emissions and therefore no prescribed aerosol concentrations are necessary. The simulations show that the distribution of CCN and the distribution of clouds are related to each other because of first principles like vertical advection. The strong variability of the aerosol and its properties causes temporal and spatial shifts of the precipitation. Because the changes are in the order of 1mm/h the impact is most significant for drizzle events.

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