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Cloud Droplet Activation and Cloud Processing in a Simplified Sectional Model

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Introduction

For many atmospheric model applications, dynamic treatment of cloud droplet activation and cloud processing of aerosol particles is computationally too demanding. However, accurate description of the effect of clouds on the aerosol population – and vice versa – is vital in order to understand the indirect climate effects of atmospheric particles.

In this study, we investigate how to formulate a simplified and computationally fast, yet accurate cloud scheme for sectional aerosol models. Several ways to treat the activation and cloud processing of particles are explored with regard to their ability to reproduce the CCN concentrations and out-of-cloud aerosol distributions obtained with a detailed adiabatic cloud model.

Methods

The simplified aerosol scheme was run with 20 size sections, a resolution typical to computationally fast aerosol modules, which were spaced logarithmically on the basis of their dry size. The cloud scheme in this model required prescribed values for the maximum supersaturation reached inside the cloud, the time the air parcel spends in the cloud as well as the average cloud liquid water content. Based on this information, the model can calculate from the initial particle size distribution the number of activated particles. When we make a further, albeit fairly realistic, assumption that all the activated particles reach the same wet size inside the cloud, the model can be used to simulate the heterogeneous chemical reactions producing sulphate in the cloud droplets.

The prescribed cloud properties mentioned above were taken from a simulation with the detailed adiabatic model. Besides these properties, the two models were run independently of each other with the same input data. The detailed model solves explicitly for the saturation and liquid water content profiles inside the cloud and treats the condensation of water onto the cloud droplets dynamically. In our simulations, we ran the model with 500 moving size sections in order to minimize numerical errors.

Results and conclusions

An ideal description of the particle activation and cloud processing should reproduce the results of the detailed model in three respects: Firstly, the number of activated particles should be accurately solved for in cases with identical initial distributions. Secondly, the cloud processing of the particles should yield a dry particle distribution that agrees with the one obtained from the dynamic model. This is to ensure that the simplified model gives an accurate particle distribution when the air parcel exits the cloud. Thirdly, the simplified scheme should reproduce the particle distribution after several successive cloud cycles with different saturation conditions.

Based on these criteria, our results suggest that the number of activated particles can best be reproduced by assuming a particle profile inside the size sections. Of the profiles studied, a sloped profile conserving number and mass within the section and a profile shaped according to the surrounding sections were slightly more accurate than a flat profile. Furthermore, when considering the activation of particles, no vital errors are made if the particle mass is not exactly conserved. This is due to the fact that production of sulphate mass in the cloud droplets overdrives the mass inconsistencies introduced at the activation stage. Our results also suggest that reproducing the particle distribution with the simplified model after one and especially after several successive cloud cycles is challenging. However, with a careful choice of the simplified cloud scheme relatively accurate results can be obtained.