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Interactive comment on "CCN activation and cloud processing in simplified sectional aerosolmodels with low size resolution" *by* H. Korhonen et al.

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REPLY TO REVIEWERS' COMMENTS

We would like to thank the three anonymous referees for their valuable questions and suggestions. Point-by-point answers to the comments are presented below.

Referee 1

Major comments

1. General:

Some of the terminology used in the manuscript seems to have been confusing. The simulations presented have been made with two models: (1) The detailed reference

model bases the description of cloud microphysics on first principles and represents the aerosol size distribution with 500 moving sections (high resolution). (2) The simplified model describes the cloud with three prescribed parameters and uses only 10 sections to represent the particle distribution (low resolution).

The simplified model closely resembles typical large scale models both in complexity of aerosol-cloud interactions and in size resolution. Thus the idea behind the comparison of the two models was to examine how well the simplified approach used in large scale modeling can reproduce the results of a detailed cloud model.

For clarity, we no longer use 'simplified scheme' as a synonym for 'simplified model'. Instead, the two models are now called 'reference model' and 'simplified model' throughout the manuscript.

In section 2 (Model description) the following further changes were made:
Page 4874, line 14: "was extended with a simplified cloud scheme" -> "was extended with a cloud scheme that resembles in complexity those used in large scale models"
Page 4875, lines 8: "reference dynamic cloud model" -> "reference dynamic cloud model described below."
Page 4876, the beginning of the last paragraph of section 2 now reads: "In summary, the simplified cloud model described above represents the cloud with three prescribed parameters and the aerosol particle size distribution with only 10 size sections. The results from the this model were compared against a dynamic adiabatic cloud model (used as a reference model in this study) which solves explicitly —"

We have also modified the title of the manuscript accordingly to 'CCN activation and cloud processing in sectional aerosol models with low size resolution'.

These clarifications and modifications should answer the reviewer's questions and comments regarding points ii), iii) and iv).

i) In our simplified model, the cloud is described with three parameters: maximum

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supersaturation, average liquid water content and time the particles spend inside the cloud. The choice of these parameters and their link to quantities typically available in large scale models is now explained in more detail in the first full paragraph on page 4875:
"The three prescribed parameters, namely S_{max}, LWC and t_{cloud}, were in this study taken from reference model simulations in order to facilitate the comparison between the simplified model and a reference dynamic cloud model described below. In large scale models, the liquid water content, and the time the activated and interstitial particles are influenced by the cloud are typically available in one form or another but the maximum supersaturation needs to be calculated from other variables. Several parameterizations (e.g. Nenes and Seinfeld, 2003;Abdul-Razzak and Ghan, 2002) have been developed to link S_{max} to the particle distribution, cloud updraft velocity and other relevant model quantities. Any of these parameterizations could be easily incorporated into our simplified cloud model."

2. The reviewer recommends including simulations with a log-normal model, which is an approach used in many large scale modeling frameworks. However, the manuscript at hand focuses specifically on sectional approach. The logic behind sectional and log-normal approaches is very different and therefore the techniques presented in this work cannot be extended to log-normal models in a meaningful way.

We have, however, added the following new paragraph discussing the cloud activation in log-normal models on page 4876 of the manuscript.
"One should also note that many large scale models apply modal (typically log-normal) rather than sectional representation of the particle size distribution. Due to the different philosophy behind these two representations, the activation approaches and sulphate formation in the aqueous phase used in this study cannot be generalized to modal models in a straightforward way. However, several activation concepts have been suggested for modal models in earlier work, ranging from detailed parameterizations (e.g. Fountoukis and Nenes, 2005;Abdul-Razzak et al., 1998) to simple treatment of cloud

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processing only for water-soluble accumulation and coarse mode particles (Stier et al., 2005)."

3. See reply to major comment 1.

4. The simulations focus on convective boundary layer clouds, or cumulus clouds. The numerical values presented in the study are naturally dependent on the cloud type and formation mechanism. However, the cloud type and the formation mechanism do not affect the conclusions concerning the main research questions of this study: 1) What is the optimal way, regarding activation to cloud droplets, to describe the particle size distribution in a low resolution model? 2) Can a simplified model (resembling large scale models both in size resolution and complexity of cloud description) predict cloud droplet concentration and cloud processing of aerosols to a reasonable accuracy?

Minor comments

1 and 2: See reply to major comment 1.

3: The last sentences of the abstract and the conclusions have been modified according to reviewer's suggestion. E.g. in conclusions:
"– a simplified low-resolution cloud model is in general suited for large scale modelling purposes. It can, however, show uncertainties in areas with strong pollution from anthropogenic sources."

4: Addition suggested by the reviewer has been made.

5: 'Dynamically' has been replaced with 'from first principles'

6-9: Text modified according to reviewer's suggestions.

10: 'Standard simulations' has been replaced by 'most of the simulations'. For the second part of the comment, see reply to major comment 1.

11-13: See reply to major comment 1.

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14: Modified according to reviewer's suggestion.

15: We have added references to the gas phase concentrations used in the simulations and changed the units of OH concentration as suggested by the reviewer.

16: See reply to major comment 1.

17: A reference to Hoppel et al. (1994) has been added.

18 and 19: See reply to major comment 1.

Referee 2

The reviewer recommends including simulations with a log-normal model. Please see reply to Referee 1, major comment 2.

Referee 3

Comments on the philosophy of the approach

As the reviewer points out there are several other simple equations that could be used to describe aerosol distribution within a model size section. We do not believe, however, that using a non-linear profile would change the conclusions of this study. This is because the three tested distributions were fairly different from each other; yet the accuracy of the model results was insensitive to the shape of the assumed distribution in almost all cases.

It is true that the cloud activation approach is not the only - or even the most severe - source of uncertainty in a large scale model simulations of aerosol-cloud interactions. The short discussion of this in the third paragraph of the introduction has now been extended to include subgrid scale processes:
"One of the major difficulties in large scale models is that important subgrid processes need to be neglected or parameterized. Furthermore, most large scale cannot afford to —"

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The activation approaches discussed in this study will help to reduce only uncertainty related to the activated fraction of particles of a certain composition, not the uncertainty related to e.g. subgrid processes and organic effects.

Specific comments

1. More detailed explanation of the simulation of cloud downdraft is now included in Section 3 on page 4877.
"In all the simulations presented below, the model runs begun close to the ground with initial relative humidity and temperature of 63.5

2. We now discuss on page 4877, end of second full paragraph, that the results concerning sulphate formation in cloud droplets should be considered relative to the model framework:
"— using different initial composition or more detailed condensation and sulphate formation mechanisms would not change the main conclusions of the study. It could, however, affect the magnitude of the results at least to some extent and thus the results should be considered relative to the reference model."

3. Including entrainment and turbulence would change the results of individual simulations through aqueous phase sulphate formation in a broader cloud droplet spectrum. This could in turn affect the number of activated cloud droplets in the following cloud cycles. These effects would not, however, be so large that they would change the main conclusions of the study.

Minor corrections

1. The figure was modified according to reviewer's suggestions.

2. The figure has been prepared according to ACP instructions and should be clearer in the final manuscript.

3-5: The manuscript has been modified according to reviewer's suggestions.

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6: We have done our best to proofread the manuscript again.

Interactive comment on Atmos. Chem. Phys. Discuss., 5, 4871, 2005.