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Interactive Comment

Interactive comment on "Modelling sea salt aerosol and its direct and indirect effects on climate" *by* X. Ma et al.

X. Ma et al.

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We would like to thank the referee for the thoughtful and constructive comments.

1. The sea salt aerosol distribution is prescribed using a single mode with fixed mean size and width. The number concentration of the mode is allowed to depend only on the wind speed. The authors state that this involves less uncertainties and approximations than a flux-based approach (without giving any arguments for this), but they do not mention all the drawbacks of their treatment. First, the empirical approach is based on a limited data set and as such, may not represent the global variation of the sea salt aerosol (for example, it remains unclear why model has problems in predicting sea salt concentrations in tropics). Second, the representation does not link the sea

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salt aerosol distributions with their production and removal mechanisms and therefore the model may fail to capture some important dynamical feedbacks. Third, the current parameterization neglects smaller sea salt particles (Figure 8) which may cause problems when diagnosing cloud droplet concentrations (CDNC) from the aerosol size distribution.

As indicated in the manuscript, the approach of sea salt production used for this study is based on the parameterization that was proposed by Lewis and Schwartz (2004). This parameterization is based on a compilation of a large number of in-situ measurements which took place in various locations around the world. So the approach should in principle be applicable to different geographic locations. In contrast, flux-based approaches used in other models are typically based only on a limited number of observations which may not be representative of more general conditions over the ocean. For example, as pointed out by Smith et al. (1993) and Gong et al. (1997), the laboratory-based flux estimates given by Monahan et al. (1986) tend to be excessive for spume droplets if compared to other observations. Similar, there are generally large differences between different flux-based parameterizations that are based on different field data.

Model results for sea salt are subject to considerable uncertainty in the tropics. Unfortunately, other global model studies typically do not specifically address the validity of model results for tropical regions. Owing to qualitative agreements of simulated sea salt concentration patterns for our and other models, it is possible that similar differences may also exist for other models.

Sea salt production not only depends on wind speed, as is usually assumed in models. Other factors, such as wave activity, temperature, and composition of the sea water, are probably very important for sea salt production. Additional fundamental experimental and theoretical work on sea salt generation mechanisms would be required to reduce the substantial uncertainties that are currently associated with the representation of

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sea salt production on global scales.

Sea salt removal processes, including dry and wet deposition, are indeed considered in the study (see section 3). Therefore, the model captures basic feedbacks between sea salt and atmospheric dynamics via radiative and microphysical processes.

We agree that the omission of smaller particles could be a potential weakness of the sea salt parameterization that was proposed by Lewis and Schwartz (2004). In order to address this concern, we included results from a second parameterization Clarke et al. (2006) in the paper. This parameterization produces much higher concentrations of small sea salt particles.

An empirical parameterization of cloud droplet number concentrations (CDNC) is used in the GCM based on aerosol mass concentrations. Owing to relatively small contributions of small particles to total aerosol mass concentrations, small particles tend to have only relatively weak impacts on the representation of aerosol indirect effects in the model. The low sensitivity of the parameterized CDNC to concentrations of small particles is a general feature of all currently available mass-based empirical parameterizations. In the future, we will test the empirical approach by doing comparisons using a first principle-based treatment for aerosol activation (see also next comment).

2. The model calculates CDNC (eq. 14, P. 14950) as a function of the sulphate and sea salt concentrations. Such a highly parameterized empirical approach suffers from the same drawbacks as the treatment of the sea salt aerosol distributions. The authors should discuss the uncertainties that are associated with the combination of a simplified cloud droplet activation scheme and a simplified sea salt representation (see also the first comment above).

We are currently working on a new first principle-based aerosol activation approach

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(vonSalzen et al., 2007). In the future we will use this new approach to quantify the uncertainties of the empirical relationship. Uncertainties in the empirical parameterization for CDNC are related to various causes, including omission of the effects of variable size distributions, varying chemical composition, and differences in cloud dynamical processes for different types of clouds. However, empirical relationships between CDNC and aerosol mass concentrations are still widely used in global models. First-principle based parameterizations, if combined with an accurate treatment of the aerosol size distribution, can be used to quantify some of the uncertainties that currently exist for simulations of global aerosol indirect effects on climate.

Minor comments:

1. In page 14944, the authors state that 'The parameterization is limited to the particle diameters greater than 0.1 um as there are few observations for smaller particles and concentrations are generally expected to be small'. The latter argument should be contrasted with the results of Clarke et al.,2006.

The results of Clarke et al. (2006) became available only recently. The data sets used by Lewis and Schwartz (2004) are for earlier observations for which probably only few observations were available for small particles. The corresponding text was modified accordingly for the revised version of the manuscript.

2. Section 3.2. Given that sea salt particles having a diameter $<$0.1 um are not considered, the Kelvin effect does not affect the water activity significantly. The authors may want to mention this.

The text was changed as suggested.

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3. Second paragraph of the section 4. The authors do not cite any experimental studies on the aerosol activation.

The text was changed as suggested.

4. Section 4. Mechanistic activation parameterizations have been implemented to GCMs recently, see e.g. Penner et al.: 'Model intercomparison of indirect aerosol effects' (ACP,6, 3391-3405, 2006). The authors should cite these works.

The text was changed as suggested.

5. Page 14951, line 15. The author state earlier (section 2) that both the sea salt mass and number are included as new traces in the model (four new tracers in total). Therefore this seems to be an inconsistent statement.

Thanks for bringing this to our attention. In this paper, only sea salt mass and number concentrations are included as new tracers. Other types of aerosol, including sulphate, are still treated based on total mass. O'Dowd's parameterization of CDNC is a function of the number concentrations of sulphate and sea salt. We changed the text to 'It should be noted that sulphate aerosol number concentrations are not available'.

6. Section 6.3. How the sea salt aerosol distributions are calculated in the model when the sea salt flux parameterization of Clarke et al. is used?

We added a description of the approach to the paper.

The parameterization of Clarke et al. (2006) provides sea salt fluxes as function of dry

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particle size and wind speed. For applications in the GCM, the fluxes were integrated over the corresponding particle size sections that are used for the PLA scheme. The resulting fluxes for sea salt aerosol mass and number concentrations are applied in the first model layer above the ocean surface for each individual size section. Similar to the application of the parameterization of Lewis and Schwartz (2004), sea salt concentrations above the first model layer are predicted based on simulated transport, gravitational settling, and wet removal processes. However, in contrast to simulations based on the parameterization by Lewis and Schwartz (2004), the same processes are now also applied in the first model layer.

Technical comments

1. Page 14940, line 25,'And', not 'at'.
2. Page 14941, line 27. 'Seinfeld'.
3. Page 14947, line 16. 'constants'.
4. Equation 13. Are the units for the terms in the right-hand side correct?
5. Page 14951, line 19. No reference is given for Lohmann et al., 1999.
6. Page 14952, line 2. No reference given for Khairoutdinov and Kogan, 2006.

All changes were made.

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