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Geoscientific Model Development Discussions
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# *Interactive comment on* "In-cloud scavenging scheme for aerosol modules" *by* Eemeli Holopainen et al.

**Anonymous Referee #1**

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In this manuscript, a revised size-segregated in-cloud aerosol wet removal scheme is implemented in the Sectional Model for Large Scale Application (SALSA). The revised wet removal scheme determines the fraction of aerosol that is contained in cloud hydrometeors based on cloud droplet activation and ice nucleation rates, and also includes size-dependent in-cloud impaction scavenging. This scheme is compared to another scheme that uses fixed scavenging coefficients. The authors also examine sensitivity studies with varying assumptions about the size of black carbon emissions and hygroscopicity. Model output for the various simulations is compared with aircraft observations from the ATom campaigns.

The manuscript addresses parameterizations that are of key importance but are notoriously challenging for global models that simulate aerosol concentrations. The pre-



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sented results are scientifically interesting and contribute towards development of wet removal parameterizations for aerosol modules. The manuscript should be suitable for publication in GMD provided that the following concerns can be satisfactorily addressed. Certain aspects of the model description and discussion lack clarity as noted in the specific comments below. Please consider revisions to improve the clarity of the presentation with careful attention to details. As well, to put the study in context of previous work, please consider including discussion about how these results compare to other studies that have introduced similar wet removal schemes, while identifying the aspects of this scheme that are novel. A clearer presentation of main recommendations for the global modelling community could also be of benefit to the manuscript.

Specific Comments

1) An identification of the model used in the study would be of help to readers of the abstract.

2) Line 10-11: Please clarify what sizes are meant by 'small particles'. As well, the number of these particles could be influenced by changes in the rate of new particle formation. As a result, it is not clear that this decrease in number concentration indicates that impaction scavenging is increased relative to the fixed coefficient scheme.

3) Lines 15-16: Why was the simulation baserun_old excluded from the comparisons with observations? Please consider including this simulation in comparisons with the observations.

4) Line 61: 'new in-cloud scheme' - Please consider clearly identifying the main aspects of the scheme that are new relative to previous studies. The word 'new' is used 5 times in this paragraph and repeatedly throughout the manuscript. It could be helpful to the readers to provide information that assists with understanding the developments made here relative to earlier work.

5) Eq. 1 – Are certain of these variables in-cloud versus grid-box mean?

6) Line 107: Is the aerosol diameter wet or dry for this calculation?

7) Line 113: What aerosols are ice nuclei in the model?

8) Line 133-135: Is there a model version number? Please clarify what you mean by 'its sensitivity'.

9) Line 149: 'refine the entire scavenging scheme'. Is below-cloud scavenging also modified? Are both convective and stratiform wet removal modified? Please provide clarification about the wet removal treatment for the stratiform versus convective clouds. Are there differences between these two? How is the cloud fraction parameterized for each for the purposes of wet removal? Are there differences in the assumed updrafts for cloud droplet activation for stratiform and convective clouds?

10) Line 154-155: What size is meant by 'large particles'? What size is meant by 'fairly small'? Did you conduct any test simulations for dust without the modified activation scheme but with the revised wet removal?

11) Eq. 5-7: Please clarify if this is wet aerosol radius.

12) Line 165: 'assume each size class is a lognormal mode' – for consistency is this same assumption also made for the nucleation scavenging? In that case, are separate scavenging coefficients calculated for mass versus number?

13) Eq. 7 and Eq. 8: Are there specific references for the collision efficiencies, terminal velocity and ice crystal radius used here?

14) Section 2.4: Please clarify if the SALSA module is coupled to ECHAM6.3-HAM2.3-MOZ1.0 for all simulations.

15) Section 2.3-2.5: Please consider adding a description about the treatment of aerosol aging in the baserun_old and baserun_new. Is there any exchange between the soluble and insoluble classes in the baserun simulations? Also consider adding brief discussion about the treatment for OA emissions, sulfate emissions and chem-





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istry. As well, do the simulated particles grow by aqueous phase sulfate production? What is the treatment for removal of gas-phase particle precursors? Consider mentioning here that the model does not include secondary organic aerosol.

16) What is the treatment of below-cloud wet removal in these simulations? In the subsequent discussions, consider addressing how these parameterizations impact your conclusions. Likewise, what is the treatment of dry deposition and how does that affect your conclusions?

17) Please consider referring to Fig. 1 at the start of Section 2.5 to help the reader to better follow the details presented.

18) Table 1: The color and line style for baserun_old and BC_soluble are very similar. Please consider revising.

19) Line 213-214: Does the model also include biofuel emissions?

20) Line 232-234: Are the baserun_old and baserun_new simulations not coupled to ECHAM-HAMMOZ but the sensitivity simulations are coupled and why? The text did not appear clear on the related description. Are the cloud microphysics parameterizations that are relevant for the wet removal different between the baserun simulations and the sensitivity simulations?

21) Section 2.7: What are the size ranges for the SP2 and HR-AMS? Do you extract mass concentrations from the model with consideration to similar size ranges?

22) Line 245: What is the size range for the total number concentration?

23) Line 268: 'model accumulated BC' – why does this occur, over how many years, would the model eventually reach a steady state?

24) Line 279: 'impaction scavenging is faster' – how can this be determined? If impaction scavenging is implicit in the prescribed coefficients scheme, then impaction rates cannot be directly compared between the two schemes - and as well other pro-

cesses such as new particle formation can affect the number concentration. A similar question arises regarding the statement at line 273 since nucleation scavenging rates cannot be directly compared if both nucleation and impaction are implicitly represented by the fixed coefficients.

25) Figure 2: Please consider using the same scale for the relative differences for all panels.

26) Figure 3: What is the size range for Ntot?

27) Figure 4: Do these plots include both stratiform and convective wet deposition?

28) Line 294: Are there observation-based lifetimes available from previous studies for OA and sulfate, in addition to the lifetimes for BC from Lund et al., 2018?

29) Line 305: Do you mean the global mean BC 'lifetimes' are spurious? The previous section did not show vertical profiles.

30) Figure 5: Please consider if it would be instructive to include baserun_old in this figure.

31) Line 335: How sensitive are the results to the assumed supersaturation?

32) Line 344: What is meant by 'simplified sulfate chemistry'?

33) Line 370: 'same aerosol size distribution' – please consider if this information should be in the methods – is this assumption used for all simulations?

34) Lines 392: Some of this discussion was confusing – '3 times larger than in baserun_new' – where is baserun_new shown in Fig. 7?

35) Line 419: Please consider presenting what are the new developments made with this wet deposition scheme relative to previous studies. As well, consider putting the study in context of previous work by presenting how the main findings of this study compare to previous similar model developments.

36) Line 425: Perhaps the following could be clarified in the methods – for all simulations does SALSA run with an on-line coupling to a certain version of ECHAM-HAM-MOZ model and are the outputs used for the wet removal from the cloud droplet activation scheme and ice nucleation scheme from the same ECHAM-HAM-MOZ?

37) Line 428: What are the main adaptations needed for this wet removal scheme relative to the Croft et al. (2010) scheme?

38) Line 437: Please clarify how you know that '..impaction scavenging in the new scheme was faster'. If impaction was implicit in the prescribed coefficients scheme and new particle formation also influences particle number concentrations as noted in the text – how can this statement be justified?

39) Line 460-462: The implementation of insoluble to soluble transfer is dismissed as being unsuitable. However, this aging process is commonly included with various parameterizations in global models. Are the authors able to clarify why the particular parameterization used in this study was chosen? Are there certain aspects of the parameterization that could be improved with future work to enable a representation of aging from the insoluble to soluble classes? Why did the chosen parameterization for aging perform so poorly for dust in these simulations? What are the emitted dust sizes?

40) Line 466: 'failed to reproduce global aerosol fields adequately. . .'. This statement is quite general. Please clarify. Does this statement refer to all aerosols – or it is specifically for BC? For example, at line 413, OC is excluded as a skill indicator.

41) Please consider including the main recommendations for future model development based on the findings of this study.

Technical corrections

1) Line 5: 'aerosol size' - please clarify if this is wet or dry aerosol radius

2) Line 33: 'no or small amount' – consider removal of 'no'

3) Line 95-96: Check order of citations

4) Line 48: Please check this citation as Ladino et al., 2011 appears to focus on impaction as opposed to nucleation scavenging.

5) Line 125: 'amount of nucleated ice particles' – do you mean number nucleated?

6) Figure 1: 'N' on vertical axis is not defined

7) Line 259 'are lowest' – do you mean relative to other latitudes?

8) Line 283: 'modest change' – consider quantifying

9) Line 286: 'small shift' – consider quantifying

10) Line 288: 'more moderate' – consider quantifying

11) Line 294: consider referring to Table 2 here

12) Figure 5: are these mean or median values?

13) Line 355: 'good correlation' – consider quantifying

14) Line 363: 'fairly similar', 'modest differences' – consider quantifying

15) Line 365, 368: 'fairly well', good agreement' – consider quantifying

16) Line 394: 'moved to insoluble' – do you mean moved to soluble?

17) Line 434: 'large particle concentrations' – do you mean number concentrations, what size range?

18) Line 468: a word seems to be missing before the words 'model produces'

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